University of South Australia

Public open space 'greenness' in urban residential environments

Prospective associations with mental health and potential psychosocial explanatory mechanisms

Submitted for the award of Doctor of Philosophy

Stine Bordier Høj
BCom, MBus (Research)

School of Health Sciences
Division of Health Sciences
University of South Australia

Supervisory team
Dr Catherine Paquet
Professor Mark Daniel
Associate Professor Jean Caron

July 2016

I declare that this thesis presents work carried out by myself and does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, are clearly acknowledged.

…….

Abstract

This thesis explores prospective associations between the level of vegetation in residential public open space (POS) and individual trajectories of mental health, evaluating three distinct mechanisms by which protective effects might accrue: (i) POS 'greenness' could buffer against the psychological harm of acute stressful life events (SLE); (ii) POS 'greenness' could exert a main salutogenic effect independently of exposure to SLE; and (iii) POS 'greenness' could influence mental health indirectly by augmenting the availability of psychosocial resources that support healthful outcomes.

The thesis presents a secondary analysis of three waves (approximately four years) of data collected from 929 adults residing within a psychiatric epidemiological catchment area of southwest Montréal, Canada. Self-reported person-level data on mental health, SLE, and psychosocial resources were linked via residential location to objectively measured POS 'greenness' within 500m/1000m of the home, using satellite imagery collected during the first wave of interviews.

Two measures of mental health – psychological distress and life satisfaction – were collected at each wave and analysed separately. Linear change in each outcome was modelled using a novel growth mixture method that statistically distinguished individuals following a healthful trajectory of good, stable mental health (class 1) from those following a worsening (class 2) or chronically poor (class 3) trajectory. Proposed explanatory mechanisms were then assessed through relationships with the odds of membership in the adverse trajectory classes (2 and 3), relative to the healthful class. Analyses were adjusted for POS availability and size, physical health, length of residence and socio-demographic factors.

In Study 1, SLE reported after the first measurement occasion increased the likelihood of membership in the adverse trajectory classes of both psychological distress and life satisfaction. Living among greener POS attenuated the association between SLE and the worsening distress class ($p<0.05$) but not the chronic high-distress class. POS 'greenness' also did not moderate associations between SLE and either of the adverse life satisfaction classes.

In Study 2, POS 'greenness' was again protective against membership in the worsening distress class ($p<0.05$), this time through a main effect mechanism. POS 'greenness' was not associated cross-sectionally with perceived coping ability, social support, neighbouring

behaviour, or community participation, but was associated with greater perceived local social cohesion. Social cohesion, in turn, decreased the odds of membership in the worsening and chronic high-distress classes as well as the chronic low-satisfaction class. Asymmetric 95% confidence intervals for corresponding indirect effects did not include the null, indicating the transmission of protective effects via social cohesion. There was, however, no evidence for an indirect effect on membership in the worsening life satisfaction class.

In summary, POS 'greenness' appeared to relate to perceptions of trust and unity in urban neighbourhoods and was protective against psychological distress, particularly among individuals facing heightened exposure to acute stressors. There was, however, little evidence to support analogous effects in relation to life satisfaction. Findings indicate the potential importance of POS 'greenness' as an urban health resource, but also possible limits to its effectiveness. Further research is required to establish the causal basis of the observed associations and clarify their sensitivity to individual or contextual conditions.

Table of Contents

Abstract iii
Index of Figures ix
Index of Tables xi
Index of Abbreviations xv
Acknowledgements xvii

Chapter 1: Introduction 1

1 Place, mental health, and the importance of nature in urban environments 2
2 Research aims 5
3 Overview of study design 7
4 Structure of the thesis 8
4.1 Outline of the thesis 10
4.1.1 Chapter 1: Introduction 10
4.1.2 Chapter 2: Literature review and conceptual framework 10
4.1.3 Chapter 3: Methodology 10
4.1.4 Chapter 4: Growth mixture modelling to describe inter-individual variation in trajectories of mental health 10
4.1.5 Chapter 5: Public open space 'greenness' as a buffer against the psychological harm of stressful life events (Study 1) 11
4.1.6 Chapter 6: Main effects of public open space 'greenness' on mental health and mediation by psychosocial resources (Study 2) 11
4.1.7 Chapter 7: Discussion and conclusion 11

Chapter 2: Literature review and conceptual framework 13

1 Introduction 14
2 Stress, restoration and mental health in urban environments 14
2.1 A spatio-temporal framework for adaptive stress processes 17
2.1.1 Stress: a complex system across multiple levels of organisation 17
2.1.2 A sociological perspective on stress 19
2.1.3 Stress and restoration in the residential milieu 21
2.1.4 Conscious and non-conscious pathways linking residential context to restoration and mental health 24
2.2 The two-continua model of mental health and thriving as a process independent of reactions to environmental stressors 25
2.3 Biophilia and the psychosocial benefits of access to nature 27
2.3.1 Nature promotes restoration from stress and cognitive fatigue 29
2.3.2 Nature supports positive social cognitions and behaviours 32

2.3.3 Beyond biophilia: natural settings as therapeutic landscapes 33
3 Facilitating access to the psychosocial benefits of nature in urban environments . 34
3.1 POS may enhance restoration from stress and psychological coping ability 34
3.2 POS may influence neighbourhood social integration..... 37
3.3 POS may augment support from social networks 39
3.4 POS may especially buffer the effects of acute or repeated acute stressors 40
3.5 POS may influence other components of the stress process..... 40
3.6 Is all POS created equal? The importance of 'greenness' 40
3.7 Conscious and non-conscious pathways linking POS 'greenness' to restoration and mental health 44
4 Overview of associations between public open space and mental health, with attention to hypothesised psychosocial mechanisms 45
4.1 Associations between residential POS and mental health..... 46
4.1.1 Cross-sectional evidence..... 46
4.1.2 Longitudinal evidence..... 54
4.2 Psychosocial resources in the relation between POS and mental health..... 61
4.2.1 Limitations to causal inference in cross-sectional analyses of mediation 64
4.3 POS as a buffer against the detrimental effects of stressful events 65
4.4 Key limitations and research opportunities..... 66
4.4.1 Preponderance of cross-sectional designs 67
4.4.2 Limited evidence regarding POS 'greenness'..... 67
4.4.3 Limited evidence regarding positive dimensions of mental health 69
4.4.4 Explanatory pathways: scope of measures and constructs..... 69
5 Research aims and analytic models 71
5.1 Analytic model: Study 1..... 72
5.2 Analytic model: Study 2..... 74
6 Summary 75

Chapter 3: Methodology.....77

1 Introduction 78
2 Setting and Context 78
3 Sampling, recruitment, and the final sample..... 81
3.1 Sampling frame..... 81
3.2 Stratified sampling plan 83
3.3 Recruitment to baseline (T1) interview..... 83
3.4 Follow-up to second (T2) and third (T3) interviews 86
3.5 Post hoc exclusion of residentially mobile participants 88
3.5.1 Exclusion criterion (a): residential relocation within the zone 89
3.5.2 Exclusion criterion (b): insufficient residential tenure at baseline..... 89
3.6 Final sample composition and representativeness 90
4 Potential selection biases in recruitment, attrition and sample exclusion..... 93
4.1 Area-level factors associated with baseline recruitment..... 93
4.2 Predictors of attrition and exclusion..... 94
4.2.1 Summary of factors associated with attrition or exclusion 101
5 Data collection and data sources..... 102

5.1 Seasonal influences on data collection 103
6 Measures 105
6.1 Exposure variables: public open space 105
6.1.1 Defining the local residential area 107
6.1.2 'Greenness' of POS in the local residential area (POS greenness) 111
6.1.3 Total availability of POS in the local residential area (POS availability) 114
6.1.4 Size of POS in the local residential area (POS size) 114
6.2 Dependent variables: mental health 117
6.2.1 Life satisfaction 117
6.2.2 Psychological distress 119
6.3 Mediating variables: neighbourhood social integration 122
6.3.1 Social cohesion 122
6.3.2 Neighbouring behaviour 124
6.3.3 Community participation 125
6.4 Mediating variables: network-based social support & coping 126
6.4.1 Network-based social support 126
6.4.2 Coping 129
6.5 Stressful life events 131
6.6 Covariates 134
6.6.1 Individual-level covariates 134
6.6.2 Area-level covariates 137
7 Missing data and imputation strategy 139
8 Temporal design 140
9 Analytic approach 142
10 Summary 145

Chapter 4: Growth mixture modelling to describe inter-individual variation in trajectories of mental health 146

1 Introduction 147
1.1 Longitudinal structural equation modelling: assessing 'true' change 147
1.2 The latent variable approach to growth modelling 149
1.2.1 The growth mixture model 152
2 Statistical analysis 156
2.1 Modelling trajectories of psychological distress and life satisfaction: selecting the optimal unconditional GMMs 158
2.1.1 Model fit and parsimony 160
2.1.2 Substantive utility 161
2.1.3 Classification quality 161
2.2 Estimating associations of socio-demographic covariates with trajectories of psychological distress and life satisfaction: specifying the conditional GMMs 162
3 Results 164
3.1 Specification of unconditional GMMs 164
3.1.1 Psychological distress 165
3.1.2 Life satisfaction 170

3.1.3 Interpreting trajectory classes: the influence of regression to the mean 175
3.2 Covariate associations with mental health trajectories..... 177
3.2.1 Psychological distress 181
3.2.2 Life satisfaction 183
3.3 Cross-classification agreement between models of psychological distress and life satisfaction..... 187
4 Summary of results 189

Chapter 5: Public open space 'greenness' as a buffer against the psychological harm of stressful life events (Study 1).....192

1 Research aims and conceptual model 193
2 Data analysis 196
3 Results 198
3.1 Associations between stressful life events and trajectories of psychological distress and life satisfaction..... 198
3.2 POS greenness as a moderator of the association between stressful life events and mental health..... 200
4 Summary of results 204

Chapter 6: Main effects of public open space 'greenness' on mental health and mediation by psychosocial resources (Study 2) 205

1 Research aims and conceptual model 206
2 Data analysis 210
3 Results 213
3.1 Associations between POS greenness and psychosocial resources (*path a)* 213
3.2 Associations between POS greenness, social cohesion and psychological distress (*paths b, c, c')* 216
3.3 Associations between POS greenness, social cohesion and life satisfaction (*paths b, c, c')* 218
3.4 Indirect effects of POS greenness on psychological distress and life satisfaction via social cohesion 220
4 Summary of results 221

Chapter 7: Discussion and conclusion.....223

1 Introduction 224
2 Key findings in relation to the research aims 224
2.1 Research Aim 1: To evaluate whether POS 'greenness' exerts a protective 'stress-buffering' effect against the potential psychological harm of acutely stressful life events 225
2.2 Research Aim 2: To evaluate whether POS 'greenness' exerts a 'main' salutogenic effect independently of exposure to acutely stressful life events... 226

2.3 Research Aim 3: To evaluate the intermediary role of psychosocial factors at three levels – within the individual, within the neighbourhood social environment, and within broader social networks – in explaining prospective associations between POS 'greenness' and mental health 226
2.4 Research Aim 4: To explore whether findings differ according to the dimensionality (positive or negative) of the mental health outcome under consideration 227
3 Interpretation and discussion 231
3.1 An innovative approach to modelling trajectories of change in psychological distress and life satisfaction 231
3.1.1 Empirical evidence to support validity of the latent classes 232
3.1.2 Cross-classification and the two-continua model of mental health..... 234
3.2 Research Aims 1 and 2: Stress-buffering and main salutogenic effects of POS 'greenness' 235
3.2.1 Evidence for a 'stress-buffering' effect 235
3.2.2 Evidence for a 'main' salutogenic effect 239
3.2.3 Summary of findings: stress-buffering and main salutogenic effects 241
3.2.4 Interpretation of null findings: non-conscious (direct-contextual) mechanisms 242
3.2.5 Interpretation of null findings: conscious (indirect-cognitive) mechanisms 245
3.2.6 Summary 254
3.3 Research Aim 3: Assessing the indirect effects of POS greenness on mental health, via psychosocial resources 254
3.3.1 Evidence for cross-sectional associations with psychosocial resources 255
3.3.2 Indirect effects of POS greenness via social cohesion 259
3.3.3 Relevance of cognitive vs. behavioural dimensions of social integration... 260
3.3.4 Limitations attributable to a (half) cross-sectional mediation design 266
3.4 Effects of POS 'greenness' on positive versus negative dimensions of mental health 267
4 Threats to validity 270
4.1 Construct validity 270
4.1.1 Latent trajectory classes of psychological distress and life satisfaction 270
4.1.2 Measurement of residential POS 'greenness' 274
4.1.3 Measurement of stress and psychosocial resources 279
4.2 Internal validity 282
4.2.1 Ambiguous temporal precedence 282
4.2.2 Further limitations in temporal design 284
4.2.3 Confounding 286
4.2.4 Selection bias 289
4.2.5 Regression to the mean 294
4.3 Statistical conclusion validity 294
4.3.1 Possibility of type I error 294
4.3.2 Possibility of type II error (statistical power) 296
4.4 External validity 297
4.4.1 Generalisability to the source population 297

4.4.2 Generalisability to other contexts ... *299*
4.4.3 Generalisability to the candidate's home country of Australia ... *300*
5 Relevance, timeliness and contribution ... **302**
6 Implications for public health practice ... **307**
6.1 Interventions targeting the environment ... 309
6.1.1 Interventions targeting the physical environment ... *309*
6.1.2 Interventions targeting the social environment ... *312*
6.2 Interventions targeting the individual ... 315
6.2.1 Interventions in primary healthcare settings ... *315*
7 Directions for future research ... **317**
7.1 Pursuing innovation in the measurement of stress arousal ... 317
7.2 Pursuing innovation in the measurement of POS exposure ... 318
7.3 Distinguishing between conscious and non-conscious pathways ... 319
7.4 Moving beyond cross-sectional associations between the physical and social attributes of places ... 320
7.4.1 Addressing the influence of individual life course ... *321*
7.4.2 Addressing the social evolution of a neighbourhood ... *322*
7.4.3 The utility of natural experiments ... *323*
7.5 Increasing the number and length of observations in longitudinal research ... 324
7.6 Widening the scope of investigations into psychosocial resources ... 324
8 Conclusion ... **326**

References ... 329

Appendix 3.1 Ethical approval ... 376

Appendix 3.2 Validation of public open space data sources ... 380

1 Preface ... **381**
2 Definition of public open space ... **381**
3 POS boundaries ... **382**

Appendix 3.3 Approaches to defining the 'residential area' ... 385

1 Preface ... **386**
2 Predefined spatial units ... **386**
3 Egocentric buffers ... **387**

Appendix 3.4 Missing data and imputation strategy ... 389

1 Preface ... **390**
2 The problem of missing data ... **390**
2.1 Missing data mechanisms ... 391
2.1.1 Missing completely at random ... *392*
2.1.2 Missing at random ... *392*
2.1.3 Missing not at random ... *393*

2.1.4 Diagnosing the missing data mechanism ... *393*
3 Missing responses to items within multiple-item scales ... **394**
3.1 Prevalence of item missingness within scales ... 395
3.2 Person-mean imputation of missing item responses ... 397
3.2.1 Person-mean imputation of items missing by design ... *399*
4 Missing scale totals and covariates ... **399**
4.1 Prevalence of missingness on scale totals and covariates ... 400
4.2 Missing data mechanisms: scale totals and covariates ... 401
4.2.1 Missing data mechanism: coping ... *401*
4.2.2 Missing data mechanism: household income ... *401*
4.3 Multiple imputation of scale totals and covariates ... 404
4.3.2 Addressing the key assumptions of multiple imputation ... *405*
4.3.3 The imputation model ... *406*

Appendix 4.1 GMM and LGCM with individually-varying versus fixed time scores ... 409

1 Preface ... **410**
2 Psychological distress ... **410**
3 Life satisfaction ... **412**
4 Summary ... **414**

Appendix 4.2 Criteria for assessing the quality of growth mixture solutions ... 415

1 Preface ... **416**
2 Model fit and parsimony ... **416**
2.1 BIC, SSABIC and approximate Bayes factors ... 419
2.2 Scaled likelihood ratio test ... 420
2.3 Wald test ... 421
3 Classification quality ... **421**
3.1 Entropy ... 422
3.2 Average Posterior Probability and Odds of Correct Classification ... 423
4 Substantive utility: class size and interpretability ... **424**

Appendix 4.3 Single-step versus three-step approaches to latent class regression ... 425

1 Preface ... **426**
2 Single-step approach ... **426**
3 Three-step approach ... **427**
4 Choice of single-step over three-step approach ... **428**

Appendix 4.4 Assessing the influence of regression to the mean on latent class trajectories ... 430

1 Preface **431**
2 Regression to the mean **431**
3 Graphical assessment of RTM **434**
4 Statistical assessment of RTM **438**

Appendix 6.1 Sensitivity analysis: POS 'greenness' and psychosocial resources 442

1 Preface **443**
2 Manipulations to the outcome variables **444**

Index of Figures

Figure 1: Structure of the thesis 9

Figure 2: Theoretical framework describing sources of inter-individual variation in mental health, with attention to: (a) the translation of adverse experiences into longer-term mental health outcomes via short-term stress reactions within a dynamic stress process; (b) the socio-spatial ecology of risk, protective and salutogenic factors that shape outcomes of the stress process as well as opportunities for thriving independently of stress and adversity; (c) the bi-directional relationship of those factors as both amenable to, and supported by, short-term temporal cycles of stress arousal and restoration; and (d) the cumulative long-term consequences of inadequate restoration over time. 16

Figure 3: Analytic model to be tested in Study 1, depicting the proposed 'stress-buffering' effect of public open space 'greenness' in relation to the effects of stressful life events on positive and negative dimensions of mental health (arising from the conceptual framework presented on page 16). 73

Figure 4: Analytic model to be tested in Study 2, depicting the proposed 'main' effect of residential public open space 'greenness' on positive and negative dimensions of mental health, operating independently exposure to acute stressors and mediated through the social environment and intra-personal resources, over time (arising from the conceptual framework presented on page 16). 76

Figure 5: The Zone d'Épidémiologie Psychiatrique du Sud-Ouest de Montréal (ZEPSOM) .. 79

Figure 6: Public open spaces within the ZEPSOM Epidemiological Catchment Area (the 'study region') and immediate surrounds 82

Figure 7: Recruitment of the ZEPSOM wave one sample 84

Figure 8: Final sample size and sources of sample loss arising from attrition and exclusion criteria 87

Figure 9: Number of years between first, second and third interviews among final participants (n=929) 88

Figure 10: Sample losses and final sample participation throughout the study area 99

Figure 11: Completed interviews by month of the year (final sample, n=929) 104

Figure 12: 500m (blue) and 1000m buffers (pink) for final sample participants 109

Figure 13: Intersection of Public Open Spaces with a 500m road network buffer 110

Figure 14: Clipped (left) and unclipped (right) parcels of POS, shaded in purple 111

Figure 15: Landsat 7 satellite imagery indicating NDVI across the ZEPSOM region in Summer, 2008 113

Figure 16: Graphical depiction of temporal design, indicating occasions of measurement and applicable time spans for key measures in the thesis 140

Figure 17: Summary of data analysis procedure as distributed across Chapters 4 to 6 143

Figure 18: Latent growth curve model for *t* time points with intercept (η_0) and linear slope (η_1) (left) and extension to GMM through the addition of a latent class variable (C) (right) 151

Figure 19: Procedure for selecting the optimal unconditional GMM t (Steps 1-4) and estimating associations with sociodemographic covariates (Steps 5-6) 159
Figure 20: Elbow plots of BIC and SSABIC for GMMs of psychological distress with an increasing number of classes 167
Figure 21: Elbow plots of BIC and SSABIC for GMMs of life satisfaction with an increasing number of classes 172
Figure 22: Covariate-adjusted mean trajectories of psychological distress (with 95% CI) from GMM E 176
Figure 23: Covariate-adjusted mean trajectories of life satisfaction (with 95% CI) from GMM E 176
Figure 24: Analytic model to be tested in Study 1, depicting the proposed 'stress-buffering' effect of public open space 'greenness' in relation to the effects of stressful life events on positive and negative dimensions of mental health (arising from the conceptual framework presented in Chapter 2) 194
Figure 25: Causal model in which Z moderates the effect of X on Y 195
Figure 26: Relative odds of membership in the worsening psychological distress class with increasing numbers of stressful life events at high (1SD above mean) versus low (1SD below mean) levels of POS greenness within 1000m and 500m of the home 203
Figure 27: Analytic model to be tested in Study 2, depicting the proposed 'main' effect of residential public open space 'greenness' on positive and negative dimensions of mental health, operating independently of exposure to acute stressors and mediated through the social environment and intra-personal resources, over time (arising from the conceptual framework presented in Chapter 2) 207
Figure 28: Causal model in which M mediates the effect of X on Y 208
Figure 29: Summary of relationships between POS 'greenness' within 1000m (top row) and 500m (bottom row) and psychological distress via stress-buffering, main effect and indirect effect mechanisms (±95% CI) 228
Figure 30: Summary of relationships between POS 'greenness' within 1000m (top row) and 500m (bottom row) and life satisfaction via stress-buffering, main effect and indirect effect mechanisms (±95% CI) 229
Figure 31: Summary of cross-sectional associations (±95% CI) between POS 'greenness' within 1000m (top row) or 500m (bottom row) of the home and psychosocial resources 230
Figure 32: Circular (red) and road network (black) buffers within high and low density road networks 387
Figure 33: Paired, log-transformed measurements of psychological distress (panels a, c) and life satisfaction (panels b, d) illustrating the relationship between baseline scores (x axis) and observed change from baseline to final follow-up (y axis) 436

Index of Tables

Table 1: Research aims 6
Table 2: Research aims 71
Table 3: Socioeconomic characteristics of the study area population and characteristics of T1, T2 and T3 samples (unweighted data, all participants in each wave) 92
Table 4: Mean cooperation rates (% completed interviews among people who were contacted and eligible to participate) in relation to quartiles of Dissemination Area profiles (n=465) 95
Table 5: Mean absence rates (% doors knocked with no response) in relation to quartiles of Dissemination Area profiles (n=465) 95
Table 6: Variable blocks entered as predictors of attrition or exclusion within a multilevel model..... 97
Table 7: Multilevel associations of individual and area-level characteristics at T1 with attrition or exclusion of participants from the final sample..... 98
Table 8: Prevalence of sample losses (attrition or exclusion) in relation to quartiles of public open space accessibility and quality characteristics in participant-centred residential environments at T1 (n=2433) 100
Table 9: Descriptive statistics for continuous measures of local area POS characteristics (final sample, n=929)..... 116
Table 10: Descriptive statistics for categorical measures of local area POS characteristics (final sample, n=929)..... 116
Table 11: Satisfaction with Life Domains scale. Items and Cronbach alphas for scale and subscales (final sample, n=929)..... 118
Table 12: Reduced Satisfaction with Life Domains scale (17 items). Descriptive statistics (final sample, n=929)..... 119
Table 13: K10 psychological distress scale. Items and Cronbach alphas (final sample, n=929) 121
Table 14: K10 psychological distress scale. Descriptive statistics (final sample, n=929) 121
Table 15: Social cohesion, neighbouring behaviour, and community participation scales: items and Cronbach alphas (final sample, n=929) 123
Table 16: Social cohesion, neighbouring behaviour, and community participation scales. Descriptive statistics (final sample, n=929)..... 124
Table 17: Social support scale. Descriptive statistics (final sample, n=929) 127
Table 18: Social support scale. Items and Cronbach alphas for scale and subscales (final sample, n=929)..... 128
Table 19: Coping scale. Descriptive statistics (final sample, n=929)..... 130
Table 20: Stressful life events inventory. List of items (reference period: 12 months preceding interview)..... 132
Table 21: Stressful life events inventory: weighted total scores. Descriptive statistics (final sample, n=929)..... 133

Table 22: Descriptive statistics for individual-level covariates (baseline and time-varying). 137
Table 23: Model fit, class size and classification quality statistics for GMMs of psychological distress with an increasing number of classes..... 166
Table 24: Parameter estimates from the final unconditional psychological distress GMM and unconditional latent growth curve model 169
Table 25: Model fit, class size and classification quality statistics for GMMs of life satisfaction with an increasing number of classes 171
Table 26: Parameter estimates from the final unconditional life satisfaction GMM and unconditional latent growth curve model 174
Table 27: Socio-demographic predictors of trajectories of psychological distress under GMM (class membership and within-class variation) and LGCM (variation about single population means) (1 of 3)..... 178
Table 28: Socio-demographic predictors of trajectories of psychological distress under GMM (class membership and within-class variation) and LGCM (variation about single population means) (2 of 3)..... 179
Table 29: Socio-demographic predictors of trajectories of psychological distress under GMM (class membership and within-class variation) and LGCM (variation about single population means) (3 of 3)..... 180
Table 30: Socio-demographic predictors of trajectories of life satisfaction under GMM (class membership and within-class variation) and LGCM (variation about single population means) (1 of 3)..... 184
Table 31: Socio-demographic predictors of trajectories of life satisfaction under GMM (class membership and within-class variation) and LGCM (variation about single population means) (2 of 3)..... 185
Table 32: Socio-demographic predictors of trajectories of life satisfaction under GMM (class membership and within-class variation) and LGCM (variation about single population means) (3 of 3)..... 186
Table 33: Row-wise conditional probabilities of membership in each psychological distress trajectory class (columns) given membership in a particular life satisfaction trajectory class (rows). 188
Table 34: Associations between stressful life events (SLE) and trajectories of psychological distress and life satisfaction, accounting for socio-demographic characteristics 199
Table 35: Main and interactive effects of stressful life events and public open space greenness on trajectories of psychological distress and life satisfaction: estimated odds ratios of membership in the adverse mental health classes (relative to the healthful class) adjusted for physical health, socio-demographic covariates, POS availability and POS size 202
Table 36: Cross-sectional associations between *POS greenness* in a 500m and 1000m buffer and psychosocial resources measured at T1, adjusted for physical health, length of residence and socio-demographic covariates..... 214
Table 37: Standardised regression coefficients for the association between *POS greenness* and social cohesion..... 215
Table 38: Main salutogenic effects of POS greenness on trajectories of psychological distress, adjusted for physical health, socio-demographic covariates, SLE, POS availability and

size (Model 1); and direct (aka residual) effects after further adjustment for social cohesion (Model 2) 217
Table 39: Main salutogenic effects of POS greenness on trajectories of life satisfaction, adjusted for socio-demographic covariates, stressful life events, POS availability and POS size (Model 1); and direct (aka residual) effects after further adjustment for social cohesion (Model 2) 219
Table 40: 95% confidence intervals for the indirect effects of public open space 'greenness' on trajectory class membership, via social cohesion 220
Table 41: Summary of thesis results. Odds ratios for membership in a given class, relative to the healthful class for that outcome, with a one-unit change in POS greenness 225
Table 42: Prevalence of mental disorders and sociodemographic characteristics by psychological distress class membership 233
Table 43: Mean weighted stressful life event scores by psychological distress class membership 233
Table 44: Selected demographic characteristics of Montréal, Canada and Melbourne, Australia 301
Table 45: Proportion of scale items missing per participant at each time point (final sample, n=929) 396
Table 46: Proportion of participants missing data on scale totals and covariates at each time point following person-mean imputation of missing item responses (final sample, n=929) 400
Table 47: Results of Generalised Estimating Equation (GEE) models (adjusted for the clustering of individuals within census tracts) for testing associations between household income missingness and sociodemographic factors. Final sample (n=929) 403
Table 48: Variables included in the multiple imputation model 408
Table 49: Parameter estimates from final unconditional GMM and LGCM of psychological distress with fixed versus individually-varying timing scores 411
Table 50: Correspondence in modal class assignments between final unconditional psychological distress GMM with fixed versus individually-varying timing scores 411
Table 51: Parameter estimates from the final unconditional three-class GMM and single-population LGCM of life satisfaction (SLDS) with fixed versus individually-varying timing scores 413
Table 52: Correspondence in modal (most likely) class assignments between final unconditional life satisfaction (SLDS) growth mixture model estimated with fixed versus individually-varying timing scores 413
Table 53: Interpretation of the magnitude of Bayes factors in both the original and -2*log scales 420
Table 54: Distribution of outcome scores at T1; baseline cut-points used to approximate class membership; and observed correlations between paired observations of outcomes at T1 and T3 433
Table 55: Baseline cut-points used to approximate class membership and observed correlations between paired observations of outcomes at T1 and T3 440

Table 56: Sensitivity analyses pertaining to cross-sectional associations between POS greenness within 1000m of the home and coping, social support, neighbouring behaviour, and community participation 445
Table 57: Sensitivity analyses pertaining to cross-sectional associations between POS greenness within 500m of the home and coping, social support, neighbouring behaviour, and community participation 446

Index of Abbreviations

APP	Average posterior probability
ART	Attention Restoration Theory
BIC	Bayesian information criterion
BLRT	Bootstrap likelihood ratio test
CI	Confidence interval
CT	Census tract
DA	Census dissemination area
DCS	Diploma of college studies
GMM	Growth mixture model or growth mixture modelling
HPA axis	Hypothalamic-Pituitary-Adrenal axis
K10	Kessler K10 psychological distress scale
LCGA	Latent class growth analysis
LGCM	Latent growth curve model
LMRT	Lo-Mendell-Rubin test
MAR	Missing at random
MCAR	Missing completely at random
MNAR	Missing not at random
NDVI	Normalised Difference Vegetation Index
OCC	Odds of correct classification
POS	Public open space(s)
RPSF	Risk, protective & salutogenic factors
RTM	Regression to the mean
SEM	Structural equation modelling
SED	Socioeconomic deprivation

SES	Socioeconomic status
SLDS	Satisfaction with Life Domains Scale
SLE	Stressful life events
SRT	Stress Reduction Theory
SSABIC	Sample Size Adjusted Bayesian Information Criterion
ZEPSOM	Zone d'Épidémiologie Psychiatrique du Sud-Ouest de Montréal (Epidemiological Catchment Area of South-West Montreal)

Acknowledgements

I would like to take this opportunity to sincerely thank the many people who have contributed to the completion of this thesis. To my supervisors, Catherine and Mark, thank you for introducing me to spatial epidemiology with such openness and providing me the latitude and support to learn and grow as a scientist. Your generosity of knowledge, time and encouragement has made this a truly fulfilling and enjoyable experience. To Jean, thank you for your valued insights into this research and for generously granting such significant access to the ZEPSOM data in order to realise its aims.

The ZEPSOM epidemiological catchment area study was funded by a Canadian Institutes of Health Research (CIHR) team grant in 2006 (#154150) and a CIHR operating grant in 2011 (#245417). I would like to thank the investigators on those grants – Serge Beaulieu, Thomas Brown, Alain Brunet, Jean Caron, Margaret Cargo, Anne Crocker, Mark Daniel, Marie-Josée Fleury, Yan Kestens, Vasavan Nair, Catherine Paquet, Duncan Pederson, Michel Perreault, Jens Pruessner, Norbert Schmitz, Michel Tousignant, Jacques Tremblay, Gustavo Turecki, and Robert Whitley – for their efforts in establishing and continuing this valuable study.

I would also like to thank the geomatics technicians – Karine Léger, Pier-Olivier Tremblay, Jean-Bernard Gariépy, and Jean-Gabriel Hasbani – who did the work of compiling, structuring and extracting a large quantity of geospatial data into the MEGAPHONE GIS used in this research. In a similar vein, I must sincerely thank Yan Kestens and his team at the University of Montréal Spatial Health Research Lab for hosting and assisting me in the validation and extraction of public open space data for this project. In particular, my thanks go out to Benoît Thierry, who so patiently and kindly guided me through this process.

To my friends and colleagues in the Spatial Epidemiology and Evaluation Research Group, thank you for being such a kind and supportive group of people to arrive to each morning. I would like to especially thank my office 'neighbour' Peter Lekkas for listening to, and helping with, so many of the issues encountered in the preparation of this thesis.

Finally, to my family and friends – who are always there when I need them – thank you for everything that you do to make my life so special. This achievement would not have been possible, in particular, without the support of my incredible parents. To Peter Høj and Mandy Thomas, and in loving memory of Robyn van Heeswijck, I dedicate this thesis.

CHAPTER 1
Introduction

1 Place, mental health, and the importance of nature in urban environments

Globally, it is estimated that more than 25% of people will experience a mental or behavioural disorder during their lifetime, with approximately 10% of the adult population affected at any given time (World Health Organisation, 2001). Characterised by onset early in life (Kessler et al., 2007a, Kessler et al., 2007b), and with potentially high chronicity (Keller et al., 1992, Judd et al., 1998, Kessler and Greenberg, 2002), mental disorders can have long term implications for wellbeing and are a leading contributor to global non-fatal disease burden. In 2010, mental and substance use disorders accounted for 23% of total years lived with disability (YLD) worldwide (Whiteford et al., 2013). Yet, even in Australia, a country with a universal public health insurance program, only four in 10 people with a mental disorder utilise mental health services (Groom et al., 2003). This highlights the importance of primary prevention efforts in this area. Good mental health underpins a productive and inclusive society, whereas mental illness has substantial personal, social, and economic consequences. Most notably, individuals with mental disorders suffer distressing symptoms and face lost opportunities in work, social relations, and leisure as a result of functional impairment and/or discrimination (Kessler and Greenberg, 2002, Kessler et al., 2009). Their illness also negatively affects quality of life for family and friends, who must often provide physical, financial and emotional support and may be restricted in their own ability to pursue social and employment interests (World Health Organisation, 2001). In Australia, for instance, the full economic burden of mental illness – including the cost of mental health and community service outlays, lost productivity and decreased workforce participation – has been estimated at approximately $A20 billion (Council of Australian Governments, 2006).

Yet, mental health is widely considered as more than just the absence of mental illness, for example: "a state of well-being in which every individual realises his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community" (World Health Organisation, 2010). The continuum between wellbeing and illness is graded, where a person's mental state might be 'better' or 'worse' rather than simply good ('healthy') or bad ('ill') (Antonovsky, 1996, Mirowsky and Ross, 2003). Moreover, it appears that mental health and mental illness are not opposite ends of a single continuum, but two distinct (yet related) continua (Keyes, 2002). Thus, the absence

of mental illness does not imply the presence of mental health, and vice versa (Keyes, 2007). This conceptualisation of mental health highlights the importance of promoting positive dimensions of mental health (e.g. overall life satisfaction) as well as preventing diminishments in cognitive, emotional, or social faculties that are not severe enough to meet clinical definitions of disorder (Commonwealth of Australia, 2009, Galea, 2011). Symptoms of psychological distress, such as feeling worthless, unable to concentrate, or unable to enjoy day-to-day activities, can still result in considerable disablement despite failing to reach levels for formal diagnoses of anxiety or depression (Korten and Henderson, 2000). The aims of health promotion initiatives have expanded, accordingly, from a focus on preventing specific disorders to include the promotion of mental health and wellbeing more generally (Reiss and Price, 1996, Durlak and Wells, 1997).

Mental health and wellbeing are determined by complex interactions among a broad range of biological, psychological, and social influences and ultimately result from a balance between the risk factors to which an individual is exposed, and the protective factors at their disposal (World Health Organisation, 2001). Risk factors, such as stress, increase the likelihood that a disorder will develop and can exacerbate the burden of existing disorders. Protective or salutogenic factors contribute to people's resilience in the face of adversity and increase the possibility of psychological growth and positive wellbeing (Durlak and Wells, 1997, Victorian Government Department of Health, 2010). In this thesis, stress is regarded as a commonly experienced process in which the experience of demanding strains, events or perceptions stimulates a range of short term reactions to re-establish homeostasis, which may, in certain circumstances, lead to longer term consequences for the health of the individual. The nature of the translation of demanding stressors into stress reactions and consequences is contingent upon a number of factors, primary among which is the availability of protective psychosocial resources, such as coping abilities and social support.

These resources, mobilised in order to alter the stressful circumstances facing the individual or to inhibit the arousal of detrimental reactions and consequences, are depleted during this process and require restoration in order to permit their remobilisation in response to future stressors. By maintaining a reserve of psychosocial resources and restoring the baseline adaptive state of the individual, effective restoration might prevent the development of psychopathology over time. Moreover, this reserve of personal and environmental resources serves to promote mental health independently of exposure to stressors by shaping and

supporting the pursuit of opportunities for personal growth and development. Each aspect of this process takes place within a broader sociological and geographic context that conditions and constrains the likelihood of exposure to stressors and accessibility of health promoting resources.

As a result, mental health is inextricably linked to the individual's environment (World Health Organisation, 2001). It has long been noted that urban dwellers face a greater risk of mood, anxiety and psychotic disorders than their rural counterparts (Peen et al., 2010), while a health gradient is also frequently observable across the strata of neighbourhood disadvantage within urban environments (Truong and Ma, 2006, Kim, 2008, Mair et al., 2008, Blair et al., 2014). These trends are only partially explained by compositional differences in the populations under study, indicating that contextual features of geographically distinct residential environments might influence the mental health of individuals. In other words, because neighbourhoods regulate access and exposure to health-related risks, resources and opportunities, variable configurations of these shared circumstances might lead to discrepant population health outcomes and a spatial patterning of health inequalities (Bernard et al., 2007). At the level of individuals, the physical, social, and service accessibility conditions of places influence vulnerability to poor health among those exposed to them, such that ongoing person-place interactions shape health trajectories over time (Galea et al., 2005, Daniel et al., 2008, Kim, 2008). Features of urban neighbourhoods are thus liable to act as risk or protective factors for entire populations, and present an enormous opportunity for interventions seeking to shift the population distributions of mental health and disorder (Cutrona et al., 2006, Galea, 2011).

Identifying the design characteristics that transform urban landscapes into "good places" for health is a question of global concern, with projections that two-thirds of the world's population will live reside in urban areas by 2050 (United Nations, 2014). In this respect, easily accessible natural settings are frequently cited among the most important features for health promotion (Jackson, 2003, Abraham et al., 2010), particularly with respect to mental health (Sugiyama et al., 2008, Maas et al., 2009c, Groenewegen et al., 2012). Evolutionary theories describe an innate predilection of human beings for natural environments, with a variety of experimental studies indicating that forced exposure to a natural setting can have 'restorative effects' for cognitive capacity, emotional states, and both self-reported and physiological measures of stress, in the short term (Abraham et al., 2010, Bowler et al., 2010,

Bratman et al., 2012). Natural settings are also thought to elicit a sense of belonging and mutual understanding that may be conducive to cooperative behaviour and the development of supportive interpersonal relationships (Kellert, 1997, Terhaar, 2009). Consequently, it is hypothesised that the effects of intermittent or repeated exposure to nature in daily life might accumulate into longer-term mental health benefits. In the modern urban milieu, ready access to nature is often severely lacking but may be facilitated through the provision of 'green' public open space (POS). Consequently, the past decade has seen growing interest in the possibility that residential POS might protect or promote mental health in urban populations.

Distribution of this resource, as with other aspects of the physical environment, is regulated by proximity; individuals residing closer to POS, or surrounded by more POS, will more easily and readily access its benefits (Corti et al., 1996, Grahn and Stigsdotter, 2003, Nielsen and Hansen, 2007, Bernard et al., 2007). Indeed, evidence is increasingly mounting to support the hypothesised relationship between accessibility or availability of green POS and mental health (e.g. White et al., 2013, Alcock et al., 2014, Gariepy et al., 2015, Krekel et al., 2016). But proximity to POS is unlikely to be the sole determinant of its salutogenic potential; the quality of these spaces is also likely to be important (Francis et al., 2012b). For example, qualitative research indicates that the therapeutic potential of open spaces may be enhanced in the presence of expansive, varied, and attractive natural scenery (particularly featuring mature trees and bodies of water) and the potential for a sense of solitude and escape from everyday demands (e.g. Palka, 1999, Windhorst and Williams, 2015). However, large-scale quantitative research has largely failed to assess the translation of such attributes into benefits for mental health at the population level. Despite the frequently espoused role of 'nature experience' as a theoretical foundation for interest in POS, this research has typically treated green POS as a homogenous resource irrespective of whether it comprises monotonous lawn or urban forest (Richardson et al., 2012). Scant empirical attention has been paid to the importance of the density and health of vegetation within these spaces, referred to hereafter as POS 'greenness'. That is the gap addressed by this thesis.

2 Research aims

This thesis explores the notion that the provision of 'green' public open spaces (POS) in urban neighbourhoods, by virtue of enabling relatively frequent or incidental access to nature,

may help to create an environment that is supportive of good mental health. More specifically, it assesses whether relative 'greenness' is a causally relevant feature of POS by investigating variation in prospective mental health outcomes among individuals with 'greener' or 'less green' POS in the local residential environment. Additional to this broader question, the thesis tests a number of mechanisms by which the salutary benefits of POS greenness might accrue. The research aims are addressed across two key studies, as summarised in Table 1 below, which differ in terms of the generic form of the salutary mechanism being tested.

Table 1: Research aims

Research aims		Key study	Key chapter(s)
1	To evaluate whether POS 'greenness' exerts a protective 'stress-buffering' effect against the potential psychological harm of acutely stressful life events	1	5
2	To evaluate whether POS 'greenness' exerts a 'main' salutogenic effect independently of exposure to acutely stressful life events	2	6
3	To evaluate the mediating role of psychosocial resources at three levels – within the individual, within the neighbourhood social environment, and within broader social networks – in explaining prospective associations between POS 'greenness' and mental health	2	6
4	To explore whether these findings differ according to the dimensionality (positive or negative) of the mental health outcome under consideration	1, 2	5, 6

Study 1 evaluates a *stress-buffering* model, which suggests that the primary salutogenic function of personal and environmental resources is to enable the individual to cope with hardship and *protect* against the damaging consequences of stress arousal (Cohen, 2004). Here, the thesis seeks to determine whether POS 'greenness' buffers against the psychological harm of stressful life events, situating the salutary benefits of this resource specifically within a stress process framework as a potential moderator of short-term stress reactions and longer-term consequences for mental health. Study 2 evaluates a more general *main-effect* model, which posits that personal and environmental resources *promote* mental health by shaping and

supporting the pursuit of opportunities for personal growth and development (Cohen, 2004). In this respect, the thesis investigates evidence for a salutogenic effect of POS 'greenness' that operates independently of exposure to stressors[1]. It also aims to evaluate evidence for a number of psychosocial mechanisms by which such an effect might accrue, including through the enhancement of the individual's cognitive and behavioural integration into the local community; the level of social support derived explicitly from their personal social networks; and/or their perceived ability to cope with daily hassles or unexpected events. Finally, across both studies, the thesis seeks to explore distinctions in the salutary benefits of POS greenness in relation to the manifestation of negative (psychological distress) versus positive (life satisfaction) dimensions of mental health and wellbeing by addressing each of the questions just outlined in relation to both potential outcomes.

3 Overview of study design

This observational prospective cohort study capitalises on a unique opportunity to assess longitudinal relationships between the 'greenness' of residential public open spaces and mental health outcomes among a geographically defined sample of adults living within a metropolitan psychiatric epidemiological catchment area (ECA) in the Southwest region of Montréal, Canada. The *Zone d'Épidémiologie Psychiatrique du Sud-Ouest de Montréal* (ZEPSOM) comprises four of 19 boroughs on the Island of Montréal and is home to approximately 15% of its population. This thesis analyses data collected from a sample of 929 adult residents of the catchment area who were each interviewed on three occasions between 2007 and 2013. The 'greenness' of POS in the local residential area was summarised at the individual level using an objective indicator, derived at two spatial scales within a geographic information system. This was treated as a time-invariant baseline exposure and analysed against contemporaneous measures of psychosocial resources, incident stressful life events, and prospective trajectories of mental health across the ensuing four-year period. Individual-level data on positive and negative dimensions of mental health (life satisfaction and

[1] The term 'main effect' is employed in the tradition of literature on stress, coping, and social support, to distinguish a salutogenic mechanism that operates independently of the experience of stress (main effect) from a mechanism that operates primarily by augmenting the ability to cope with socio-environmental stressors (stress-buffering effect). It is not intended to suggest, as may be implied by use of the term in mediation analysis, that there are no intervening variables on the causal pathway between POS 'greenness' and mental health.

psychological distress); psychosocial resources including neighbourhood social integration (social cohesion, neighbouring behaviour, and community participation), perceived availability of network-based social support, and perceived ability to cope with stress; and the experience of stressful life events, were measured using validated self-report instruments during the aforementioned interviews.

The thesis adopts a latent trajectory approach to longitudinal analysis with a focus on intra-individual change in mental health outcomes and the prediction of inter-individual differences in these change processes. Specifically, it employs a growth mixture modelling framework to empirically identify multiple subpopulations characterised by unique patterns of change over time, and predict membership in these latent classes based on the exposures of substantive interest. This is a relatively novel statistical approach that remains to be widely adopted in the epidemiological literature outside studies of child and adolescent development, ageing (in the later stages of life), and other transitional contexts such as among populations that have experienced trauma, mental or physical illness, or the birth of children.

4 Structure of the thesis

This thesis is structured into chapters according to a fairly conventional model comprising an introduction, literature review, statement of methodology, presentation of results, and discussion. Whereas the introduction (Chapter 1) and literature review (Chapter 2) are presented in self-contained chapters, the descriptions of both methodology and results are spread across multiple chapters. This is for two reasons. First, the complexity of the statistical analysis employed in the thesis demands a particular focus on the derivation of longitudinal models of change in mental health, which serve as the focal outcomes of interest in addressing each of the substantive research aims described previously. For this reason, a bridging chapter is employed to detail the primary method of data analysis and present results pertaining to the extraction of latent statistical constructs summarising inter-individual variation in longitudinal trajectories of mental health (Chapter 4). This chapter presents the derivation of base analytic models to which exposures of primary substantive interest are subsequently added, effectively linking the general statement of methodology (Chapter 3) to the results of two studies that specifically address the research aims of this thesis (Chapters 5, 6). This is illustrated in Figure 1, on the following page, which depicts the contributions of Chapter 4 to both methodology

and results. The further division of results across the Chapters 5 and 6 reflects a conceptual distinction between research aims seeking to evaluate stress-buffering (Chapter 5) versus main effects (Chapter 6) of POS greenness, as described earlier. Throughout the thesis, discussion of results is reserved for the final chapter (Chapter 7), which also describes possible threats to validity, implications for public health practice, and recommendations for future research arising from the thesis as a whole. This section concludes with a brief outline of the contents of each of these chapters.

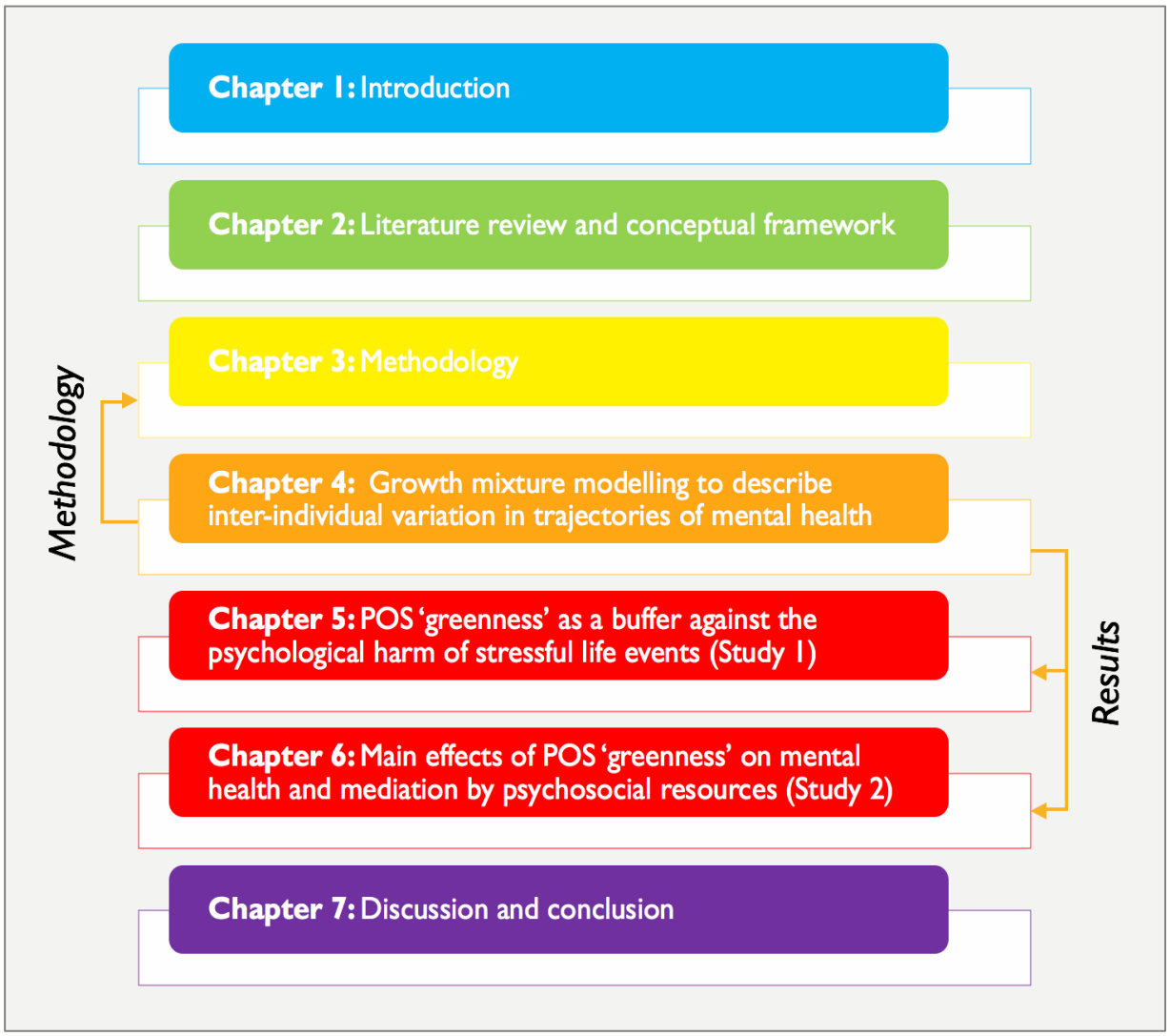


Figure 1: Structure of the thesis

4.1 Outline of the thesis

4.1.1 Chapter 1: Introduction

This chapter will briefly contextualise the research problem within current understandings of the societal burden of mental health problems and their possible intersection with the accessibility of nature in urban environments. It has stated the aims of the original research presented in this thesis, providing an overview of the research design and the thesis structure.

4.1.2 Chapter 2: Literature review and conceptual framework

Chapter 2 presents a narrative review of theoretical and empirical literature pertinent to a possible relationship between public open space (POS) and mental health, with a particular focus on the salutogenic contribution of natural stimuli to this relationship. Existing theories of stress, psychosocial restoration, and biophilia in humans are integrated into a conceptual framework for this research, from which specific research aims and analytic models are derived based on a critical review of limitations in the existing evidence base linking POS to mental health.

4.1.3 Chapter 3: Methodology

Chapter 3 details the thesis methodology, describing and outlining the basis for selection of the data sources, measures, and analytic approach employed to achieve the research aims. This chapter also presents a selection of analyses that provide insight into potential threats to the validity of the research findings, particularly due to selective participant recruitment or attrition as well as missing data within completed questionnaires. In relation to the analytic approach, Chapter 3 presents a broad overview intended to illustrate the manner in which the substantive research aims of Study 1 (Chapter 5) and Study 2 (Chapter 6) are achieved through an extension of a preliminary analysis reported in Chapter 4. Due to the complexity of the analysis, specific details pertaining to the statistical methods employed are explored more fully in subsequent chapters.

4.1.4 Chapter 4: Growth mixture modelling to describe inter-individual variation in trajectories of mental health

Chapter 4 details the statistical foundations of growth mixture modelling (GMM) and outlines the rationale behind its use as the framework for statistical analysis in this thesis. It then presents the analysis procedure and results of two exploratory linear GMM analyses performed to enumerate and describe latent classes (subpopulations) of study participants

based on intra-individual trajectories of change in positive (life satisfaction) and negative (psychological distress) dimensions of mental health throughout roughly a four-year period. Finally, this chapter illustrates the manner in which auxiliary variables are used to predict the likelihood of membership in classes characterised by distinct trajectory shapes, through the analysis of associations with a range of individual and residential-area covariates. These models form the basis of further analyses in Chapters 5 and 6.

4.1.5 Chapter 5: Public open space 'greenness' as a buffer against the psychological harm of stressful life events (Study 1)

Chapter 5 presents findings from the first of two studies addressing the substantive research aims of this thesis. Study 1 addresses Research Aims 1 and 4. Specifically, it assesses whether residential public open space 'greenness' buffers the psychological impact of stressful life events in relation to both positive (life satisfaction) and negative (psychological distress) dimensions of mental health outcomes. The analyses extend upon those described in Chapter 4, so that Chapter 5 outlines only supplementary details of the analytic method specific to Study 1. Discussion of results is reserved for the final chapter of the thesis.

4.1.6 Chapter 6: Main effects of public open space 'greenness' on mental health and mediation by psychosocial resources (Study 2)

Chapter 6 presents findings from the second of two studies addressing the substantive research aims of this thesis. Study 2 addresses Research Aims 2, 3 and 4. Specifically, it assesses whether residential public open space 'greenness' exerts a main effect on mental health independently of exposure to stressful life events. It also assesses whether psychosocial resources at various levels of organisation – within the individual, within the neighbourhood social environment, and within broader social networks – comprise part of an indirect causal sequence between POS 'greenness' and mental health. Once again, these questions are addressed in relation to both positive (life satisfaction) and negative (psychological distress) dimensions of mental health outcomes. The analyses again extend upon those described in Chapter 4, so that Chapter 6 outlines only supplementary details of the analytic method specific to Study 2. Discussion of results is reserved for the final chapter of the thesis.

4.1.7 Chapter 7: Discussion and conclusion

The final chapter in this thesis presents a summary, interpretation and discussion of findings from the original empirical research reported in Chapters 4 through 6. This chapter

outlines the relevance and contribution of the research, including its implications for public health policy and practice. It also details potential threats to validity of the research findings and suggests avenues for future research. The chapter then concludes the thesis.

CHAPTER 2
Literature review and conceptual framework

1 Introduction

This chapter presents a narrative review of theoretical and empirical literature pertinent to a possible relationship between public open space (POS) and mental health, with a particular focus on the salutogenic contribution of natural stimuli to this relationship. The chapter proceeds in three key stages. First, existing theories of stress, restoration and biophilia are integrated to present a framework that describes how features of urban residential environments might influence the mental health of individuals. The following section focuses the lens of this theoretical perspective on public open space, highlighting a selection of mechanisms by which this particular aspect of the physical environment might influence downstream psychosocial resources, nested within the socio-spatial ecology of risk, protective, and salutogenic factors (RPSF), and introducing the need to consider public open space quality as well as accessibility. Existing research in this domain is then critically reviewed in order to identify key limitations in the existing knowledge base regarding causal effects and mechanisms linking public open space to mental health. The chapter ends with the statement of research aims and presentation of the analytic models that underpin the two key studies undertaken in this thesis.

2 Stress, restoration and mental health in urban environments

In recent years, there has been growing interest in identifying which features of the urban environment influence the mental health of individuals, and the causal mechanisms that explain these relationships (Galea, 2011). Because residence in urban areas may be characterised by enduring exposure to a variety of socio-environmental stressors, such as high population density, criminality, social isolation, air pollution, and noise, a focus on stress responses presents a promising starting point in the identification of modifiable causal mechanisms linking residential contexts to mental health (Cutrona et al., 2006, Berry, 2008, Galea, 2011, Blair et al., 2014).

In this context, **stress** refers to an adaptive process of responding to changing or demanding circumstances that are appraised, consciously or not, to pose a potential threat to wellbeing (Lazarus and Folkman, 1984). These circumstances disturb the natural equilibrium of internal

and external forces acting on the individual, triggering a variety of functional perturbations (physiological, psychological and behavioural) intended to restore balance and stability in the face of change. The struggle for readjustment can be wearing and exhausting, and the accumulation of stress reactions may increase the individual's vulnerability to deleterious physical and psychological consequences (Pearlin et al., 1981, Turner, 2010). In this sense, stress represents the mechanism by which demands that are discernable in the socio-physical environment 'get under the skin' to cause observable health consequences. Importantly, the arousal of stress does not reflect "unusual people doing unusual things and having unusual experiences" (Pearlin p.396) but occurs frequently as a product of everyday pursuits and the performance of a variety of social roles within a broader ecology of normative values, commitments and expectations[2].

This section begins by describing a broad, integrative framework of the stress process (Elliott and Eisdorfer, 1982), within which a social ecological model of stress and restoration tailored specifically to the residential context (Hartig et al., 2003b) is embedded to derive the conceptual framework for this thesis. Accordingly, these early stages of the chapter focus on elaborating a theoretical exposition of the role that risk, protective and salutogenic factors (RPSF) play in determining mental health outcomes, and the manner in which residential environments could condition and constrain exposure and access to these factors. In relation to these issues, the section ends with a discussion of the evolutionary legacy of human adaptation to natural environments, describing the important salutogenic role that our innate predilection for nature might play in promoting psychosocial fulfilment and mental health.

2 These roles, including employment, marriage, parenthood, and financial management, occupy an enduring and important place within the lives of individuals, often demanding navigation of complex activities and interpersonal relationships, and carry the impetus of meeting socially constructed expectations associated with their enactment (Pearlin, 1999). The mental burden of meeting this "hidden curriculum" has a special potential to expose the individual to chronic or repeated strains that may be threatening to the psyche (Kegan, 1994), and even the act of planning, coordinating and executing otherwise enjoyable activities places demands on the individual when situated within the broader activity cycles (Hartig et al., 2003b).

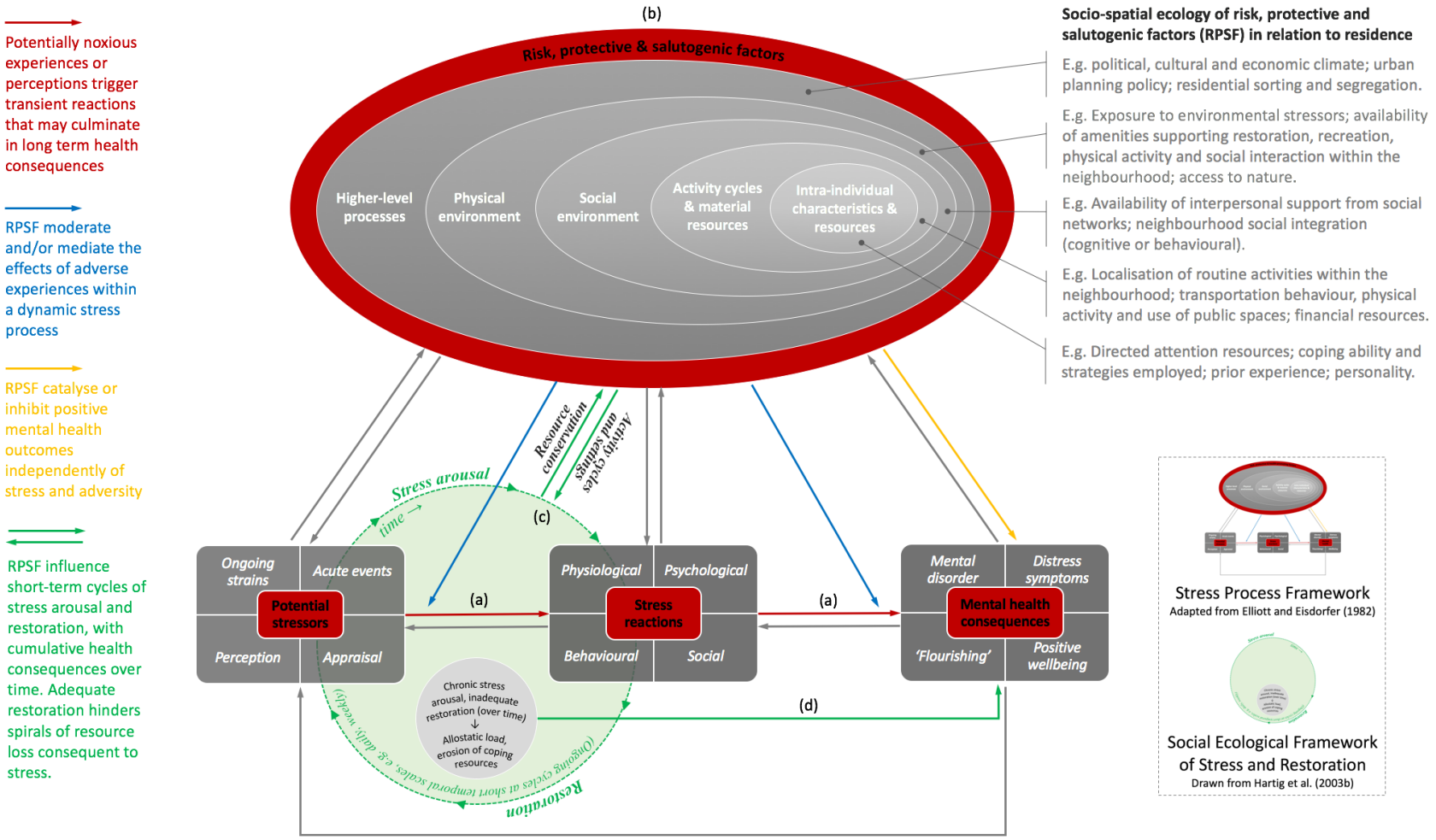


Figure 2: Theoretical framework describing sources of inter-individual variation in mental health, with attention to: (a) the translation of adverse experiences into longer-term mental health outcomes via short-term stress reactions within a dynamic stress process; (b) the socio-spatial ecology of risk, protective and salutogenic factors that shape outcomes of the stress process as well as opportunities for thriving independently of stress and adversity; (c) the bi-directional relationship of those factors as both amenable to, and supported by, short-term temporal cycles of stress arousal and restoration; and (d) the cumulative long-term consequences of inadequate restoration over time.

2.1 A spatio-temporal framework for adaptive stress processes

2.1.1 Stress: a complex system across multiple levels of organisation

In an early framework of adaptive stress processes, Elliott and Eisdorfer (1982) succinctly organise myriad influences across multiple levels of organisation into a four-component structure for understanding the translation of stressful stimuli into health outcomes (Stress Process Framework, Figure 2, p.16). This is a complex system in which potentially noxious experiences or perceptions (**stressors**) trigger transient physiological, psychological and behavioural **reactions** that, whether through acute or cumulative processes, may culminate in significant long term **consequences** for the health of the individual[3]. Stressors might include acute events (e.g. job loss or marital separation) or enduring strains (e.g. ongoing conflict in employment or marital roles), while stress reactions (e.g. anger or agitation) are generally distinguished from consequences (e.g. mental disorder) by their persistence in time.

At each stage (stressors → reactions; reactions → consequences), this causal sequence may be channelled through and/or modified ('buffered') by characteristics of the individual, the environment, or situation-specific appraisal and coping processes (**stress mediators** and **moderators**[4]). These conditions exert a marked influence on susceptibility to the demands being faced and, collectively, are considered as central explanatory factors underlying inter-individual variability in the translation of stressful experiences into health outcomes[5.] More specifically, these factors work together to determine whether change results in psychological growth; the re-establishment of some psychological baseline or 'set point'; or the development of psychopathology (Esch et al., 2002, Chrousos, 2009, Caron and Liu, 2011, Feeney and Collins, 2015). Influential conditions might include characteristics of the individual (e.g. personality, temperament, physical condition, past experiences, or personal resources); the environment (e.g. the physical, cultural, social or economic climate); or the processes enacted

---

[3] In this sense, I distinguish between stressors (demands, frequently observable in the sociophysical environment, that the individual considers potentially threatening or harmful) and the stress process (the mechanisms by which stressors 'get under the skin' to generate observable health consequences).

[4] We distinguish between stress 'mediators', which explain (lie on the causal path between) an exposure (stressor) and outcome (reaction/consequence), and stress 'moderators', which modify the magnitude or direction of this effect but whose values are not necessarily attributable to (caused by) the exposure.

[5] Pearlin (1999) highlights the emergence of secondary stressors, subsequent to an initial stressful experience, as a complementary driver of inter-individual variability in health outcomes, but notes that the aforementioned moderators may still factor into this process by influencing the likelihood of stress proliferation itself.

in the face of stressful stimuli (e.g. appraisal of a stressor as meaningful or significant, and the coping strategies employed to negate its effects on wellbeing).

Chief among these are the functional psychosocial resources and capabilities, including social support and coping responses, which may be crucial in shaping the individual's ability to alter or meet challenging life circumstances, and have repeatedly been shown to mitigate the detrimental effects of stress on physical and mental health (Hobfoll, 2002, Turner, 2010)[6]. These moderating factors will be a focus of this thesis. Social support refers broadly to whether a person's basic social needs – affection, esteem, approval, belonging, identity, and security – are satisfied through interactions with others, and to the accessibility of instrumental, informational and emotional support from other individuals and groups (Cobb, 1976, Thoits, 1995, Cohen, 2004). Notably, even in the absence of stress or adversity, supportive relationships may serve as a 'secure base' and a catalyst for participation in life opportunities that enable individuals to thrive (Feeney and Collins, 2015). Coping responses, on the other hand, include the variety of behaviours, cognitions and perceptions that the individual invokes, him or herself, in the face of difficult conditions (Pearlin and Schooler, 1978, Pearlin et al., 1981). Frequently, this involves a rational process of seeking and utilising information to reappraise possibilities and deal with changing situations (Henry and Stephens, 1977).

While conceptually illuminating, the description above belies the true complexity of the dynamic, bi-directional interrelationships between components of the stress process. Stressors themselves do not exist as isolated risk factors but continually surface and recede across the landscapes of individual social roles and circumstances, from the momentary to the enduring, to produce an evolving, intertwined 'constellation' of threatening events and enduring strains (Pearlin, 1989). Each of these demands is liable to induce a variety of reactions across

[6] These resources may themselves be diminished in response to stressful experiences, highlighting the distinction between the processes of stress mediation (where the factor of interest lies directly in the causal path between exposure and outcome) and moderation (where the factor modifies the magnitude or direction of an effect, but is not necessarily directly linked to either exposure or outcome). In this work, we emphasise the role of stress moderators as important sources of inter-individual variability in the aetiology of stress-related diseases and a potential point of intervention in ameliorating health outcomes for individuals exposed to potentially noxious demands. As discussed by Pearlin (1999), the decision to focus on stress moderation is a conceptual choice, and is not intended to discount the role of mediation processes. As we highlight in the ensuing discussion, we fully accept that some intervening factors (e.g. psychosocial resources) may be altered by the very conditions whose effects they moderate (Holahan et al., 1999). However, in the context of this thesis, we are concerned with the influence of environmental variables (i.e. POS) that are unlikely to be shaped by individual experiences of stress, and as such, mediation processes are not of primary interest.

multiple levels of organisation – from molecular and physiological to psychological, behavioural and social – that each figure in the evolution of longer-term consequences in these domains. Over time, the outcomes of innumerable prior stress sequences converge to shape the number, scope and severity of demands that might be faced in future, and the resources and capabilities available to meet them. This is a system in constant flux, within which each constituent part continually modifies and is modified by the others, generating complex feedback loops and interactions among them. Consider, for instance, the endogeneity of stress moderators over time. These are often intertwined (the appraisal of stressors as threatening and the choice of coping strategies, for example, may be influenced by personality, past experiences, psychological and material resources, or the physical, social and cultural circumstances that condition behaviour) and act in concert to modify stress reactions and consequences; in turn, those reactions and consequences may change the individual, altering the moderators of the stress process in ways that affect future stress responses (Elliott and Eisdorfer, 1982).

A key value of Elliott and Eisdorfer's (1982) framework is its scope for the unification of diverse theoretical perspectives, across disciplines, to understand how a broad variety of influences interact to affect health. For instance, through its explicit integration of interrelated forces at all levels of organisation, the framework provides a touchstone at which the fields of psychiatry and sociology may converge (e.g. Galea et al., 2011, Lederbogen et al., 2011). The intersection of these disciplines motivates the identification of aspects of social organisation and experience that generate dysfunctional psychological consequences and is highly relevant to spatial epidemiology, as described in the following sections.

2.1.2 A sociological perspective on stress

A sociological approach to the study of stress emphasises the manner in which broader structural arrangements bear on individual functioning, where the conditions governing individual lives are considered primary factors in the provenance of stress and the ability to mobilise resources that might moderate its translation into adverse health outcomes (Turner, 2010). This perspective paints stress as a typical consequence of the individual's involvement in social life, where ordinary pursuits, taking place at the intersection of widely shared roles, responsibilities and value systems, cultivate constellations of stressors and strains that interact over time to determine the demand for adaptation (Pearlin, 1989). Importantly, the persistence

of these structural arrangements highlights the potential for repeated exposure to particular sets of stressors in daily life, and the chronic depletion of adaptive resources in the face of such intractable problems.

Individual exposures, reactions, and consequences to potential stressors are affected by multiple interdependent social contexts across various levels of the social hierarchy. Micro-level influences, such as individual roles, status, belief systems and inter-personal interactions, are embedded within a broader climate of meso- and macro-level systems through space (e.g. highly localised versus national or global contexts) and time (e.g. across the life course, between generations, or through changing social, economic and political climates), resulting in a socio-spatio-temporal patterning of stress and resiliency (Wheaton, 1994, Turner et al., 1995, Pearlin, 1999, Wheaton and Clarke, 2003, Galea et al., 2005, Blair et al., 2014). In this sense, physical, social, economic, and cultural contexts have the potential to pervade the daily lives and experiences of individuals, such that the differential placement of individuals within these larger systems may generate inequalities in health and wellbeing over time (Stokols et al., 1996, Pearlin, 1999). Social support, for instance, arises not only within a set of dyadic relationships between individuals but also at the extra-individual level, within and between organized groups and informal social structures (Felton and Shinn, 1992). Support is therefore derived both from the individual's personal social networks *and* from contextual factors such as a sense of cohesiveness, solidarity or community among broader social groups, where the internalisation of group identity may confer a sense of meaning, security, comfort and control to the individual (Haslam et al., 2009, Greenaway et al., 2015). Both forms of support have been found to protect and promote mental health (Pretty et al., 1994, Prezza et al., 2001, Hobfoll, 2002, Kawachi and Berkman, 2001, De Silva et al., 2005, Mair et al., 2008, Blair et al., 2014, Greenaway et al., 2015).

With respect to the spatial delineation of these systems, the residential neighbourhood is offered as a prime example of a context that intersects with many domains of daily social life, generating experiential similarities among people residing in the same area (Massey, 1998, Pearlin, 1999, Jackson, 2003, Aneshensel, 2009, 2010). While 'neighbourhood' is an amorphous concept for which no universally accepted definition exists, this can be considered broadly as a "bundle of spatially based attributes associated with clusters of residences" (Galster, 2001, p.2112) including structural, infrastructural, demographic, class status, public service, environmental, social-interactive and sentimental characteristics. The social and

psychological importance of 'home' as a place of refuge and the centre of many social relationships and leisure activities confers upon residential neighbourhoods a special potential to permeate the lives of individuals; these places could expose the individual to repeated or enduring stressors that are seemingly inescapable and/or provide highly accessible emotional and instrumental coping value (Dupuis and Thorns, 1998, Korpela et al., 2001, Hartig et al., 2003b, Wheaton and Clarke, 2003). Neighbourhoods, in turn, are shaped by broader systems of social stratification, through both top-down (e.g. direct amendments to the built and physical context, such as the potential for disproportionate situation of 'locally undesirable land uses' in low income areas) and bottom-up processes (e.g. through the sorting of individuals into different neighbourhoods according to social status, or the collective actions of residents) (Stokols et al., 1996, Verheij, 1996, Galea et al., 2005). Thus, over time, the neighbourhood may intensify and perpetuate systems of inequality existing at the level of individuals and families (Massey, 1998).

When examining the influence of neighbourhoods on health, the relevant parsing of urban space is likely to differ depending on the attributes of interest (Galster, 2001). This thesis treats the individual, and the precise location of his or her home, as the spatial centre of the 'neighbourhood'. In relation to environmental attributes, the 'neighbourhood' is conceived as being bounded within a specified walkable distance of that location. In relation to social-interactive and sentimental characteristics, on the other hand, the 'neighbourhood' is bounded informally within the space perceived as relevant by the individual.

2.1.3 Stress and restoration in the residential milieu

Given the aims of this research, it is beneficial to supplement Elliott and Eisdorfer's (1982) framework with a model that more explicitly embeds adaptive stress processes within the spatio-temporal context of day-to-day residence and activity cycles. For this purpose, Hartig et al.'s (2003b) Social Ecological Framework of Stress and Restoration is employed to emphasise interaction with the residential milieu as integral to the manner in which individuals and groups manage the challenges of daily life. Treating stress arousal as a typical and frequent occurrence, the framework focuses on the efficacy of intermittent periods of 'restoration' – temporary "breathers" from stress that assist in the recovery of functional resources and capabilities depleted during adaptation to demanding circumstances (Ulrich,

1993) – and the manner in which opportunities for restoration are constrained by the organisation of routine activities within a particular structural context.

The core aspect of this framework is an ongoing cycle of stress arousal and restoration, reflecting the continual disruption and reinstatement of some condition of adaptation over time. The authors emphasise the short-term (e.g. daily or weekly) operation of these processes, purposefully drawing attention to the significance of everyday activities (e.g. commuting) and settings (e.g. residential context) in the restoration of physical and cognitive vigour, positive emotional states, and physiological homeostasis. Following relatively mild stressors, complete restoration may occur in a matter of minutes (Ulrich, 1993). In the longer term, however, frequent arousal of the stress process or incomplete restoration may shift the individual towards an unsustainable or problematic adaptive condition that increases susceptibility to poor mental and physical health (Esch et al., 2002, Hobfoll, 2002). In a physiological sense, the long-term cost stemming from chronically fluctuating or elevated stress responses is reflected in allostatic load; cumulative biological 'wear and tear' marked by a change in the set-points of neuroendocrine responses and enduring dysregulation in their function which may, in turn, stimulate deleterious disease processes (Seeman et al., 1997, McEwen, 1998b, Esch et al., 2002). Allostatic load has emerged as a key biological mechanism underlying the social gradient of health (O'Dea and Daniel, 2001) and the transmission of place effects on health (Daniel et al., 2008), lending support to the relevance of restoration theory in the present research.

Allostatic load has also been associated with the chronic depletion of coping resources ('burnout') marked by emotional exhaustion, physical fatigue, and cognitive weariness (Melamed et al., 1999); and executive malfunction, marked by suboptimal planning, performance, decision making, and social interaction, that feeds into a 'vicious cycle' of behavioural maladjustment and problematic psychosocial functioning (Chrousos, 2009, Marin et al., 2011). Restoration can therefore also be considered from the standpoint of maintaining a sufficient reserve of cognitive and psychosocial resources able to sustain the individual throughout periods of stress without triggering increasingly rapid and serious cycles of stress proliferation and resource deterioration (Hobfoll, 2002, Holahan et al., 1999, Kiviruusu et al., 2012). In this respect, the framework is consistent with Conservation of Resources theory, which places the loss of cognitive, psychosocial, material, and health resources at the centre of the stress process. Conservation of Resources theory describes how the investment of resource

reserves to combat the deleterious impact of stressful conditions can, without adequate recovery, beget increasing vulnerability to negative stress sequelae and escalating spirals of resource loss as the stockpile available to be drawn upon is drained (Hobfoll, 2001, Hobfoll, 2002).

Following the above discussion, Hartig et al.'s (2003b) stress-restoration cycles are situated within Elliott and Eisdorfer's (1982) framework as a recurring pattern of exposure to **stressors** and the consequent arousal of stress **reactions**, where the extent to which the individual is able to **restore** depleted adaptive resources modifies the individual's capacity to respond effectively to future stressors (Figure 2, p.16). In this sense, opportunities for restoration **moderate** the stress process, regulating the availability of resources for mobilisation in subsequent situations (potentially influencing the type, intensity and duration of stress reactions, i.e. stressor → reactions path) and altering the likelihood that stress reactions will translate into health consequences by shifting (or maintaining) the baseline adaptive condition of the individual (i.e reactions → consequences path). Effective stress restoration may also inhibit the proliferation of stressors by preventing hardships in one domain of life from influencing actions and reactions in others (Pearlin, 1999).

The speed and completeness of restoration depends on a similar constellation of individual, environmental and procedural stress moderators described previously, but relies particularly heavily upon the individual's ability to distance themselves (mentally or physically) from stressful demands and to engage with positive distractions (Hartig et al., 2003b). Stress-restoration cycles are thus constrained by the performance of regular patterns of activity within a constellation of settings that, to differing degrees, present opportunities to encounter potential stressors (arousal) and/or recover diminished functional resources and capabilities (restoration). In turn, these activity cycles and the features of the settings in which they take place are influenced by higher-level social, economic and political processes that determine, among other things, "the constellations of settings that individuals move among and the distances between them; the stressfulness and restorativeness of those settings; the frequency and character of the individuals' movements among those settings; choices among transportation modes for moving among settings; the average level of demands faced across settings; and the stress and restoration values assigned to particular settings" (Hartig et al., 2003b p.618).

One important contribution of Hartig et al.'s framework is that the authors draw particular attention to the importance of salutary (cf. noxious) influences in the restoration (cf. depletion) of coping resources required to maintain an optimal adaptive balance, and emphasise the significance of settings quite removed from those in which the individual encounters stressful demands. This has important implications for mental health promotion at the population level, indicating that residential environments amenable to restoration may assist individuals to offset the impact of intractable demands in other settings (Hartig et al., 2003b). Unlike 'active' health promotion efforts that target the individual and require a voluntary and sustained effort on their behalf, 'passive' interventions targeting the residential environment can efficiently enhance the health of large numbers of residents without requiring the conscious compliance of individuals (Stokols et al., 1996). Indeed, features of the neighbourhood context could even influence the health of residents through non-perceived mechanisms, as described in the following section.

2.1.4 Conscious and non-conscious pathways linking residential context to restoration and mental health

The preceding sections have broadly introduced the notion that residential contexts shape and interact with individual experiences to influence the development of health outcomes over time. To aid in the interpretation of findings from this thesis, it is useful to further delineate the mechanistic underpinnings of these 'place effects' into (i) non-conscious and (ii) conscious pathways. Daniel et al. (2008) framed the biological basis for transmission of place effects in these terms, distinguishing between causal mechanisms predicated upon (i) non-conscious biological stress responses and (ii) conscious perception of place attributes and resultant psychosocial and behavioural responses. These mechanisms reflect the direct and indirect effects of residential context, respectively. Whereas direct-contextual mechanisms reflect the influence of non-perceived contextual cues, indirect-cognitive mechanisms rely upon the conscious processing of environmental stimuli. Thus, the direct pathway provides for cognition below higher consciousness or awareness, and might explain the salutogenic or pathogenic effects of environmental attributes to which the individual has grown accustomed or takes for granted (Daniel et al., 2008). Both pathways are relevant to the evolution of mental health outcomes and are implicated in cycles of stress and restoration through their relationship to allostatic load. They are both also relevant to the research aims of this thesis, a point to which I return later in the chapter.

2.2 The two-continua model of mental health and thriving as a process independent of reactions to environmental stressors

Once considered primarily in a binary pathogenic sense as the presence or absence of mental illness, mental health is now increasingly viewed as a complete state in which a lack of psychopathology is accompanied by high levels of emotional, psychological, and social wellbeing (Keyes and Michalec, 2010). From this perspective, health and illness are not opposite ends of a single continuum, nor are they mutually deterministic; the absence of mental illness does not imply the presence of mental health, and vice versa (Keyes, 2005b, 2007). Rather, these constitute two related but distinct dimensions that combine to determine the overall state of wellbeing (Headey et al., 1993, Keyes, 2005b, Westerhof and Keyes, 2010). This conceptualisation of mental health has found support in numerous samples of adults and adolescents in developed nations (Headey et al., 1993, Greenspoon and Saklofske, 2001, Keyes, 2005b, Westerhof and Keyes, 2010, Suldo and Shaffer, 2008, Renshaw and Cohen, 2014).

The two-continua model highlights differences in the degree of wellbeing among the majority of the population unafflicted by clinical disorders and, indeed, among those suffering from a disorder (Keyes, 2007). These distinctions are reflected, for instance, in the individual's perceived ability to engage in productive and fruitful activities; maintain fulfilling relationships; navigate, belong and contribute to society; and, generally, feel positively about his or her life (World Health Organisation, 2010). Evidence suggests that the absence of clinical mental disorder may only infrequently be accompanied by such states of hedonic and eudemonic wellbeing that the individual is considered to be 'thriving' or 'flourishing', and that anything less than this state of 'complete' mental health is associated with functional impairment and disability (Keyes, 2002, 2005b, Keyes and Grzywacz, 2005, Suldo and Shaffer, 2008, Keyes et al., 2012, Renshaw and Cohen, 2014)[7]. Given the potentially large proportion of the population that is free from mental illness but reports suboptimal levels of positive mental health, promoting subjective wellbeing may be a particularly cost-effective means of reducing the health-related burden to individuals and society (Keyes, 2007).

[7] Likewise, many individuals with a clinical mental disorder appear able to maintain a moderate level of positive mental health associated with better functional outcomes in relation to work productivity, health limitations and positive psychosocial functioning (Keyes, 2002; Keyes, 2005b; Keyes, 2005a; Keyes & Grzywacz, 2005; Weich et al., 2011; Keyes et al., 2012)..

This perspective suggests that positive and negative dimensions of mental health may follow different developmental trajectories, rather than varying simultaneously across the lifespan, and may be differentially related to attributes of the individual and the environment (Greenspoon and Saklofske, 2001, Keyes, 2007, Westerhof and Keyes, 2010). It also intimates that the role of some attributes in the promotion of optimal wellbeing transcends their function as 'harm minimisers'. To this point, I have focused on a *stress-buffering* model of mental health, which suggests that the primary function of personal and environmental resources is to enable the individual to cope with hardship and *protect* against the damaging consequences of stress arousal. However, the literature on stress and coping has long distinguished this mechanism from a more general *main-effect* model, which posits that personal and environmental resources *promote* mental health by shaping and supporting the pursuit of opportunities for personal growth and development (Cohen, 2004). This distinction – illustrated in the conceptual framework on page 16 using blue arrows to demonstrate stress buffering effects and a yellow arrow to demonstrate a main effect – has important implications for public health because it describes who is likely to benefit most from interventions targeting a particular resource. Whereas a stress-buffering model suggests that a particular resource is increasingly relevant to the health of individuals facing greater adversity, the main-effect model implies that a resource is broadly beneficial to all individuals, irrespective of their exposure to stress. Thus, whereas interventions under a main effect mechanism might efficiently promote population health through more universal approaches (e.g. generic city-wide planning standards), a stress-buffering effect might require interventions that are tailored and targeted specifically to individuals or communities at greater risk.

The two mechanisms are not necessarily mutually exclusive and may capture distinct functions of ostensibly similar resources, as indicated in research on social relationships. For instance, Feeney and Collins (2015) deconstructed the functions of social support relevant to 'flourishing' into those that provide a source of strength in the face of adversity (stress-buffering) versus those that act as a catalyst for participation in life opportunities and support efforts to learn, explore, and achieve goals (main effect). This delineation of support functions is consistent with the notion that aetiologies of the two continua of mental health may differ, since the functions differ in purpose, context, and contribution to the pursuit of positive emotions and fulfilment. Thus, a thorough understanding of salutogenic effects in relation to the overall state of wellbeing could require attention to multiple causal pathways.

Hobfoll (2001) similarly argues that a resource-based view of the stress process, as described in the previous section, is not confined to understanding the nature of reactions to environmental stressors. People also actively engage in 'proactive coping' efforts to maintain and build the reservoir of psychosocial resources with a view to their goals as well as potential obstacles and advantages that will be encountered in future (Hobfoll, 2001). These efforts may even permit the individual to avert impending stressors through heightened vigilance, or, by ensuring the availability of a strong resource reservoir, place them in an advantageous position to prevent the proliferation of stressors within or across domains of life. In this sense, the availability of psychosocial resources might support health by positioning the individual to prevent exposure to stress, rather than buffering against the effects of stress. Understanding the mechanisms linking environmental resources to mental health, and the dimension(s) of mental health to which they are pertinent, is important in order to guide interventions that cultivate the most efficacious aspects of those resources. However, these questions remain underexplored in place-health research.

2.3 Biophilia and the psychosocial benefits of access to nature

In the aftermath of the industrial revolution, Frederik Law Olmsted (1870) appealed strongly for an urban planning paradigm that ensures the designation of publicly accessible open space, with natural elements such as grass and trees, for the purposes of restoration, recreation and respite from the inherent hostility of the urban environment. This space, he argued, provides "opportunity and inducement to escape from conditions requiring vigilance [and] wariness…toward other men" (p.40), "to give the lungs a bath of pure, sunny air [and] the mind a suggestion of rest from the devouring eagerness and intellectual strife of town life" (p.42), that is crucial to the maintenance of "a temperate, good natured, and healthy state of mind" (p. 40). Recognition of the unique restorative potential of natural settings has a long philosophical history (Marcus and Barnes, 1999), supplemented in recent decades by growing attention to the theoretical and empirical underpinnings of these suppositions.

From an evolutionary perspective, internal psychological mechanisms comprise a set of functional adaptations designed to promote survival and reproduction in the face of those routine and persistent selection pressures experienced by the thousands of generations of hunter-gatherer societies dominating human history (Cosmides and Tooby, 1992). The evolution of the human mind has overwhelmingly taken place in natural environments, and as

a species, we are hypothesised to have acquired an innate affinity with nature ('biophilia') that is expressed through a fairly universal inclination to attend to, value, and respond positively to natural settings (Wilson, 1984). Manifestations of biophilia include a tendency for fascination, wonder and awe at the beauty, diversity and complexity of the natural world; an intense curiosity and urge for exploration of the natural world; an aesthetic preference for natural scenes and patterns over man-made substitutes; a tendency to find a fundamental meaning, order, and harmony in nature that transcends day-to-day concerns; and a predisposition to feelings of attachment, affiliation and affection toward elements of the natural environment (Kaplan, 1992a, Kellert, 1993, 1997)[8]. These responses are expressed with reasonable consistency across taxonomic, behavioural, demographic, and cultural contexts, and are presumed to be encoded into the gene pool due to their historic importance for the physical, emotional and intellectual prosperity of the human race (Kellert, 1993).

Thus, the biophilia hypothesis posits that the constellation of rewards (and dangers) associated with natural settings was sufficiently critical to human survival and progress to favour individuals who readily learned and retained certain adaptive associations and responses towards these settings (Ulrich, 1993). The material basis for a biophilic disposition is most intuitive; water, green vegetation, and flowers have, throughout the ages, signalled the likely availability of hydration and sustenance, and should therefore readily elicit attention, approach, and positive affect (Ulrich, 1993). These responses helped to solve a longstanding, recurrent reproductive problem and presumably evolved into efficient information processing mechanisms conducive to survival in our ancestral environment. By contrast, humans have lived in urban and industrialised settings for an insufficient period of time to permit complex adaptation through natural selection, and there has been little opportunity for psychological mechanisms to adjust to attendant changes in life circumstances. Synthetic elements of the built environment, such as glass and concrete, simply do not possess the evolutionary significance of grass and trees. Rapid urbanisation has created a residential environment that is 'out of tune' with the functional adaptations of the human brain, and biophilic instincts will continue to influence the manner in which we process, perceive, and respond to stimuli in

[8] However, innately aversive or 'biophobic' reactions also provide compelling evidence of inherited learning rules, such as the tendency to fear or reject threatening aspects of nature such as spiders, snakes, and heights (Ulrich, 1993).

modern environments (Orians and Heerwagen, 1992, Kellert, 1993, Wilson, 1993, Charlton, 1996).

Consistent with this hypothesis, a vast body of experimental evidence has revealed dependable affective, cognitive and physiological responses to elements of the natural environment that differ in important ways from those toward built or man-made environments (Ulrich, 1993). In many instances, reactions to natural stimuli are involuntary and instantaneous – requiring minimal conditioning or reinforcement, and liable to occur without conscious recognition of the stimulus being presented – indicating the operation of biologically prepared learning mechanisms that predispose humans to the acquisition and retention of certain responses (Ulrich et al., 1991, Ulrich, 1993). By contrast, the speed, valence and strength of responses, and the preparedness to learn and retain them, tend to differ significantly toward man-made stimuli with little evolutionary significance.

More than an evolved proclivity to obtain material benefits such as food and shelter, an inclination to connect with, explore and thrive in nature surely promoted a much broader range of psychological, social and spiritual advantages central to human advancement. For instance, these tendencies may have fostered creativity, imagination and knowledge acquisition or a sense of belonging, order and purpose to the existence of oneself and others (Kellert, 1997; Terhaar, 2009). Access to nature may therefore continue to play an important role in building and maintaining the reserve of protective psychosocial resources available to protect and promote mental health.

2.3.1 Nature promotes restoration from stress and cognitive fatigue

Of particular interest in the present context is a biologically prepared capacity for rapid physical and psychological restoration within natural settings. The ability to recover quickly from stressful and fatiguing demands (thus augmenting the effectiveness of responses in subsequent situations) would be crucial to the survival chances of early humans, and a growing body of experimental evidence[9] indicates the supremacy of natural over manmade

[9] The experimental studies described here each impose 'nature experience' either as a walk in a natural setting, such as urban green space, or viewing images or videos of a natural setting. All include a randomised control group that completes an analogous activity within a manmade urban setting, such as busy streets characterised by buildings and vehicles and largely devoid of natural stimuli, for comparison. Most studies induce stress or attentional fatigue (e.g. a stressful film or cognitive task with an accompanying socio-evaluative threat) in order to determine the efficacy of recovery under natural versus built environmental conditions. Various modes of outcome measurement are adopted, including participant self-reports, objective tests of cognitive performance,

scenery in achieving this (Ulrich, 1993). Following the acute arousal of stress, exposure to natural settings rapidly regulates the autonomic nervous system; promotes positive affect; and often diminishes negative affective states such as anxiety, fear, frustration and anger (Ulrich et al., 1991, Cackowski and Nasar, 2003, Hartig et al., 2003a, Bowler et al., 2010, Berman et al., 2012, Brown et al., 2013, Bratman et al., 2015a, van den Berg et al., 2014). Natural settings also exert powerful positive effects on cognitive function, inhibiting maladaptive rumination and improving the performance of executive attention, working memory, and impulse inhibition (Berman et al., 2008, Bratman et al., 2012, Bratman et al., 2015a, Berman et al., 2012)[10]. These effects may accrue rapidly (Ulrich et al., 1991, Barton and Pretty, 2010) and typically are evident to a much lesser extent, or not at all, following a comparable exposure to manmade urban scenery (Velarde et al., 2007).

The restorative benefits of nature are hypothesised to arise from two distinct, yet complementary, mechanisms (Kaplan, 1995, Hartig et al., 2003a, Grahn and Stigsdotter, 2003). The first, described by Ulrich's (1983) Stress Reduction Theory (SRT), emphasises changes in mood and physiological arousal as the direct result of primitive, preconscious emotional reflexes conditioned by the evolutionary advantages described previously. Under this theory, improvements to cognitive functioning are understood as incidental benefits to the primary psychophysiological stress regulation mechanism (Ulrich et al., 1991, Chrousos, 2009). By contrast, Kaplan and Kaplan's (1989) Attention Restoration Theory (ART) situates the replenishment of attentional resources facilitating cognitive control as the primary mechanism underlying restoration, where the depletion of these resources might predispose the individual, indirectly, to psychophysiological stress reactions. It is outside the scope of this thesis to contribute to debate over the primacy of SRT or ART, but the latter perspective merits further explanation in relation to the potentially important role of nature in supporting cognitive coping processes.

---

collection of physiological measures (such as heart rate, blood pressure and skin conductance), and neural imaging, often in some combination within a single study.

[10] In addition to improved performance on psychological tests of affective and cognitive functioning, nature experience has been shown to decrease neural activity in a region of the brain linked to risk factors for mental disorder including rumination, negative autobiographical narratives, and behavioural withdrawal (Bratman et al., 2015). By contrast, increasing degrees of urbanity in the location of current residence and childhood upbringing are associated with increasing activation of distinct, but related, neural mechanisms implicated in the development of mental disorder (Lederbogen et al., 2011).

Attention Restoration Theory begins from the premise that the ability to voluntarily and deliberately maintain focus on particular stimuli, while suppressing distractions, is an effortful process underpinned by a finite cognitive resource ('directed attention') that may be depleted by the accumulation of information-processing demands (Kaplan, 1992b, Hobfoll, 2002, Kaplan and Berman, 2010). Recent centuries have borne witness both to an explosive proliferation of information, and a relatively abrupt transformation in the kinds of information that are of pressing concern to human beings. Consequently, many of the settings and tasks that characterise modern life are neither fundamentally attractive or interesting to the evolved mind, yet must vie for attention amongst a plethora of competing stimuli (Kaplan, 1992b). In this context, the negotiation of everyday affairs requires the individual to wilfully direct their attention towards the task at hand, while inhibiting irrelevant information. The ability to direct attention in this manner plays an important role in higher order cognitive functions such as reasoning, flexibility and problem solving, as well as the self-regulation of thoughts, emotions, and behaviour required for effective adaptation to trying circumstances (Korpela et al., 2001, Kaplan and Berman, 2010). However, without adequate replenishment, prolonged use of directed attention may result in mental fatigue; characterised by an inability to concentrate, solve problems or transcend momentary pressures, as well as inattentiveness, irritability, and impulsivity (Kaplan, 1995).

To rest and restore directed attention, use of this resource must be rendered temporarily unnecessary; this requires that the individual distances herself, physically or psychologically, from demanding circumstances and becomes sufficiently engaged by pleasing environmental distractions (Kaplan, 1995, Hartig et al., 2003b). Consistent with the notion of biophilia, ART proposes that natural environments are especially conducive to cognitive restoration because they comprise countless stimuli that are intrinsically attractive or 'fascinating' to the human mind (Kaplan and Kaplan, 1989). These stimuli involuntarily and effortlessly draw attention, thereby allowing the neural mechanisms underlying directed attention a chance to rest and replenish. Moreover, natural environments are specially placed to provide other necessary components of restorative experience, such as a feeling of 'being away' from routine activities and demands and a resonance or 'compatibility' with the inclinations of the individual, both of which support effortless functioning and create an environment conducive to reflection on unresolved problems, life goals and priorities (Herzog et al., 1997, Kaplan and Berman, 2010).

The restoration of directed attention has important implications for effective coping in the face of stressful circumstances. A person whose directed attention resources have been replenished should be able to focus their attention, think more clearly, and engage more easily in effortful problem solving and reasoning. This might assist them to identify effective solutions to challenging situations, resist the urge to react to potential stressors, and seek out resources that fortify them against life stress (Wells and Evans, 2003). Importantly, proponents of ART claim that restoration does not only result from complete immersion in a natural environment but may also accrue merely from repeated viewings of natural surroundings. For instance, natural views from the home or in transit may have incremental effects by allowing involuntary attention to come briefly to the forefront of mental mechanisms and thereby providing brief periods of replenishment for directed attention (so-called 'micro-restorative opportunities') (Tennessen and Cimprich, 1995, Kaplan, 2001).

2.3.2 Nature supports positive social cognitions and behaviours

Biophilic tendencies are also thought to have played an important role in social evolution, where their manifestation in an emotional or spiritual connection to aspects of the environment may have promoted the development of relational bonds and a sense of kinship, affiliation and identity within the broader ecology that encourages cooperative and altruistic behaviour (Kellert, 1997, Terhaar, 2009). Consequently, natural settings – even within urban environments – have been found to evoke a sense of spiritual tranquillity or belonging, order and purpose to the existence of oneself and others (Chiesura, 2004, Irvine et al., 2013). This evolved psychological architecture, shared across individuals and across cultures, supports a mutual understanding that is conducive to successful communication and interaction (Cosmides and Tooby, 1992). Since social exchanges are context dependent (Curtis, 2010), the potential for natural environments to activate perceptions of shared group identity – of being a small part of the greater whole – might calibrate patterns of social exchange towards the pursuit of group advancement. As Haslam et al. (2009 , p.8) state, "a shared social identity can be seen as the basis for all forms of productive social interaction between people – including leadership, motivation, communication, cooperation, helping, trust, and organisation" (Haslam et al., 2009). From a different perspective, if natural environments support enhanced self-regulation through restoration from stress or the replenishment of directed attention resources, they may serve to inhibit socially inappropriate behaviours that lead to negative social interactions (Kaplan, 1995, von Hippel and Gonsalkorale, 2005, Kaplan and Berman, 2010).

In both respects, the consequences of biophilia appear relevant not only to the psychological wellbeing of individuals, but also to the relational characteristics of broader social structures.

2.3.3 Beyond biophilia: natural settings as therapeutic landscapes

Whereas the biophilia hypothesis suggests a universal and innate tendency to respond positively to natural settings, broader theoretical conceptions of 'therapeutic landscapes' contend that the salutogenic potential of places results from a more complex convergence of their physical, social, and symbolic characteristics (Williams, 1999, Curtis, 2010). In particular, this body of literature emphasises the manner in which prior experience, the attribution of meaning, and sociocultural norms may synergise or counteract biophilic responses to determine the effect of natural spaces on body and mind (Williams, 1998) and their perception as a source of healing, relaxation and rejuvenation (Williams, 1999, Curtis, 2010). In this respect, genetically encoded 'biophilic responses' are but one component of a multifaceted health-place dynamic that also comprises the socially, culturally and experientially encoded frames of reference accrued throughout the individual's lifetime (Curtis, 2010, Windhorst and Williams, 2015, Thomas, 2015). Thus, while responses to natural stimuli may be partly non-conscious, they are also likely to comprise a perceptual component. For example, Milligan and Bingley (2007) summarise the historical breadth of religious, spiritual, cultural and mythical meanings attributed to trees, arguing that our physical and psychological response to these aspects of the natural environment cannot be separated from those meanings. Similarly, familiarity with a particular environment and a history of positive transactions within that space are likely to play a role in the extent to which it promotes wellbeing (Windhorst and Williams, 2015). Because the experience of a landscape is not merely the sum of responses to its physical attributes, therapeutic landscapes may not be reducible to simple aesthetic or infrastructural criteria (Gesler, 2005, Milligan and Bingley, 2007, Thomas, 2015). In fact, it has been argued that no setting is intrinsically therapeutic, because different users attain a sense of wellbeing in different places for different reasons (Conradson, 2005, Cattell et al., 2008). Rather, the therapeutic potential of places is context dependent and variable between individuals (Gesler, 2005, Milligan and Bingley, 2007, Thomas, 2015).

3 Facilitating access to the psychosocial benefits of nature in urban environments

Altogether, the notion of biophilia suggests that the cumulative, interactive and synergistic impact of affiliation with nature contributes to psychosocial fulfilment, whereas deprivation of nature may have significant implications for the adaptive mobilisation of cognitive, emotional, and social resources in demanding situations. Echoing Olmsted's (1870) sentiments, some 130 years later, Kellert (2004 p.14) proposed that, "the health and vitality of the city ultimately depends on our experiencing nature in aesthetically attractive, ecologically sound, and materially accessible ways", and decried "the current lack of meaningful and adequate contact with healthy natural process [as] a design deficiency rather than an intrinsic flaw of modern urban life". Others have proposed perceptions of neighbourhood aesthetics as a key modifiable pathway linking residential environments to depression, but uncover a dearth of robust research attention to the influence of aesthetically pleasing attributes in this regard[11] (Blair et al., 2014). Given the seemingly innate aesthetic preference of humans for natural stimuli, these present a promising starting point for such investigations (Ulrich, 1983). Accordingly, this thesis explores the notion that the provision of 'greener' public open space (POS) in urban residential environments, by virtue of enabling relatively frequent, easy or incidental access to nature, may help to create an environment that is supportive of mental health. This section briefly elaborates a selection of proposed psychosocial mechanisms by which POS might influence mental health, and calls attention to the relative 'greenness' of these spaces as a potentially causally relevant characteristic that could influence their salutogenic effects. The following section reviews the body of research that has explicitly tested these mechanisms, in order to highlight the novel contribution of this thesis.

3.1 POS may enhance restoration from stress and psychological coping ability

Through the restoration of directed attention, or the direct reduction of emotional and physiological stress responses, green POS could promote mental health by ameliorating the

[11] Aesthetically displeasing attributes, such as graffiti or vacant housing, are more frequently measured but typically treated as indicators of underlying social disorder rather than measured for their inherent aesthetic disamenity value.

individual's ability to cope with stressful demands or otherwise pursue opportunities that allow them to thrive. Although a substantial body of experimental evidence demonstrates the immediate restorative effects of acute exposure to natural stimuli, fewer studies have employed population-based samples to assess whether and how these effects accrue, over the longer term, to improve the function of adaptive stress processes among individuals with better residential access to nature. This is an important point, because the generalisability of experimental findings is often hampered by the use of student samples in a controlled environment wholly removed from the residential context (see e.g. Velarde et al., 2007). Moreover, experimental studies, by design, force the individual to submit to nature experience. This raises questions about the ecological validity of their findings and reservations as to what extent the mere provision of natural environments – without prescribed usage – will benefit the general population.

Population-based studies have found that perceived proximity to natural POS (Grahn and Stigsdotter, 2003, Nielsen and Hansen, 2007, Stigsdotter et al., 2010), the total proportion of natural POS in the neighbourhood (Fan et al., 2011, Ward Thompson et al., 2012, Roe et al., 2013), and the overall 'greenness' of the neighbourhood (De Vries et al., 2013, Beyer et al., 2014) are associated with lower levels of perceived stress and stress-related symptoms. Altogether, these studies indicate that individuals with better access to natural POS feel a greater sense of control over the potentially stressful demands in their lives, and are less likely to perceive those demands as exceeding their ability to cope. Two studies supplemented these findings with assessments of diurnal salivary cortisol patterns among unemployed adults residing in socioeconomically deprived areas, finding that the proportion of green space in the home environment was an independent predictor of the circadian cortisol cycle[12] (Ward Thompson et al., 2012, Roe et al., 2013). Specifically, a lower proportion of green space was associated with abnormally flat patterns of cortisol production characterised by a blunted daytime peak shortly after awakening. This pattern of cortisol production is indicative of hypothalamic-pituitary-adrenal (HPA) axis dysregulation and allostatic load (McEwen, 1998a). Thus, the findings of these studies are consistent with the proposed role of stress-restoration cycles in explaining the salutogenic effects of urban nature, as depicted in the

[12] Ward Thompson et al. (2012) served as an exploratory study for Roe et al. (2013). The two samples were merged in the latter analysis, which confirmed the findings of the exploratory study.

conceptual framework for this thesis (Figure 2, p.16). Similarly, Honold et al. (2016) found that a greater quantity and diversity of vegetation in views from the home (assessed using independent ratings of photos taken from all windows of all rooms) and regular usage of a nearby nature trail were independently associated[13] with lower hair cortisol levels, indicating a lower incidence of HPA axis hyperactivity. HPA axis hyperactivity is another manifestation of allostatic load (McEwen, 1998a), providing further support for the conceptual framework. Although the samples were small (combined n=138), these unique studies present promising physiological evidence to support the notion that better access to natural POS might enhance resilience against chronic stress associated with socioeconomic disadvantage. Importantly, Honold et al.'s (2016) study further indicates that visual access to natural stimuli could make an important contribution to cycles of restoration independently of POS usage.

Additional studies have shed light on the cognitive pathways by which POS might improve the ability to cope with stress. Two natural experiments[14] conducted in a deprived inner-city public housing development found that residents living in buildings with barren surroundings reported more procrastination in facing major issues, and evaluated their issues as more severe, less soluble, and more longstanding, than did residents with greener surroundings (Kuo, 2001). They also reported greater levels of aggression and violence (Kuo and Sullivan, 2001a), indicating suboptimal behavioural self-regulation that might reflect the depletion of directed attention resources (Kaplan and Berman, 2010). In both studies, these relationships were mediated by levels of mental fatigue, providing further support for the notion that nearby nature assists residents to resolve short- and long-term challenges by replenishing cognitive resources. In a similar setting, Taylor et al. (1998) found that girls with more natural views from their inner-city homes exhibited greater self-discipline, reflected in better scores on tests of concentration, impulse inhibition, and delay of gratification. Wells (2000) and Tennessen et al. (1995) also identified associations between natural window views and increased cognitive function in low-income children, and adult residents of university dormitories, respectively.

The results of these studies are consistent with the notion that natural scenery in the vicinity of the home could help to relieve mental fatigue, with possible ancillary benefits of enhanced coping and self-regulation. However, these associations have largely been assessed within the

[13] Although the effect of vegetation quantity and diversity became marginally non-significant when the predictors were added to the model together (p=0.06) the small sample size should be noted.
[14] Further details pertaining to these experiments are presented in Section 3.6.

context of significant individual or residential-area socioeconomic disadvantage, and the extent to which findings are generalisable to a broader range of conditions remains unclear. Poverty places extraordinary demands on attentional resources, because fulfilling even basic needs such as rent and food can require effortful problem solving and reasoning; by contrast, the restorative influence of natural scenery may be less important in more affluent areas.

3.2 POS may influence neighbourhood social integration

In modern urban settings, where individuals are forced into close quarters with unfamiliar people and residential mobility results in the continual migration of inhabitants from/to existing communities, the potential to interact with nature in public spaces may have important implications for the social fabric of a neighbourhood. In particular, the power of POS to facilitate positive interpersonal exchanges and foster place attachment is hypothesised to stimulate the social integration of individuals into the local community. Neighbourhood social integration, reflecting feelings of communality and belonging (cognitive) and the scope of local social networks or participation in community affairs (behavioural), appears in turn to be protective of mental health (Cohen, 2004, De Silva et al., 2005).

Public open space affords opportunities to meet and engage with other people in the neighbourhood, whether actively or passively, intentionally or by chance encounter. These interactions facilitate recognition and familiarity and may contribute to the development of local social networks, neighbouring behaviour, and a sense of community and mutual trust (Kweon et al., 1998, Völker et al., 2007, Abraham et al., 2010, Peters et al., 2010, Lee and Maheswaran, 2011, Francis et al., 2012a, Kaźmierczak, 2013). Importantly, the nature of POS as 'neutral ground', freely accessible to all residents without discrimination, endows it with a special ability to foster social inclusion and cohesion (Cattell et al., 2008, Swanwick et al., 2003, Peters et al., 2010, Hordyk et al., 2015). Even cursory interactions can put people at ease with strangers, leading to a feeling of comfort, home, and security over time (Henning and Lieberg, 1996, Peters et al., 2010). Shared biophilic affinities, as well as the mood enhancing properties of natural settings, might augment the potency of these encounters for building a sense of trust and reciprocity when experienced in natural environments proximate to the home. Indeed, recent evidence indicates that individuals who report a greater frequency or duration of visits to outdoor green space also report higher levels of perceived social cohesion,

after adjusting for age, sex, income, education, days of employment per week, presence of children in the home, and area socio-economic deprivation (Shanahan et al., 2016).

In addition to enabling social interaction, the physical attributes of a neighbourhood contribute to the development of place attachment (affective bonds between person and place) and identity (identification with the distinct character of a place) (Stedman, 2003, Kim and Kaplan, 2004). These emotional or symbolic attachments and meanings are constructed through the individual's experience with a particular spatial context, and appear to be particularly responsive to the presence of POS and natural features (Korpela et al., 2001, Bow and Buys, 2003, Kim and Kaplan, 2004, Peters et al., 2010, Arnberger and Eder, 2012, van Herzele and de Vries, 2012). This might reflect a tendency for individuals to grow attached to familiar restorative settings identified, through past experience, as being beneficial for wellbeing (Korpela et al., 2009) or the power of nature to evoke a sense of unity or connectedness with one's surroundings (Chiesura, 2004, Terhaar, 2009). Indeed, individuals with better access to POS in their neighbourhood appear to grow more attached to those spaces (Zhang et al., 2015). Person-place bonds are associated with individual wellbeing (Theodori, 2001, Rollero and De Piccoli, 2010) and might explain why the salutogenic effects of POS are not solely attributable to usage (Nielsen and Hansen, 2007, Sturm and Cohen, 2014). These bonds also precipitate other domains of local social integration, strengthening sense of community beyond the purely social characteristics of the neighbourhood; stimulating interactions among neighbours; and motivating efforts to improve the neighbourhood through participation in community affairs (Kim and Kaplan, 2004, Manzo and Perkins, 2006, Long and Perkins, 2007). For instance, Peters et al. (2010) found that people who lived nearby, and frequently used, a well-known park felt a greater sense of attachment to the park and were more likely to communicate with local government to express their wishes and concerns about its management.

Other studies have identified positive associations of neighbourhood 'greenness' (reflecting the general extent of natural stimuli in public and private space) (Sugiyama et al., 2008, De Vries et al., 2013), the number of POS within proximity of the home (Cohen et al., 2008), the average duration of visits to local POS (Kaźmierczak, 2013), and perceived (Francis et al., 2012a) or objective POS quality attributes (Kuo et al., 1998b, Kweon et al., 1998) with cognitive (social cohesion, sense of community, collective efficacy) and behavioural (local

social interaction, local social ties) dimensions of neighbourhood social integration[15]. These findings are discussed in greater detail throughout the remainder of this review.

3.3 POS may augment support from social networks

Neighbours and other residents usually form just a small part of residents' social networks (Moore et al., 2011), and likewise, POS does not only facilitate social interaction among these individuals. On the contrary, POS is a popular meeting place for members of social networks (e.g. friends and family) propagated outside the neighbourhood, and these interactions tend to be deeper and more enduring than incidental encounters (Bow and Buys, 2003, Peters et al., 2010, Kaźmierczak, 2013). In this manner, POS might serve to strengthen personal social networks located both internally and externally to the neighbourhood context, thereby enhancing the perceived availability of support from these networks in times of need. This thesis refers to such a resource as 'network-based social support'. In comparison with the notion of neighbourhood social integration discussed above, which may not derive purely from interpersonal exchange but relates specifically to a given spatial context, the concept of network-based social support is inherently more individualistic and relational, and the sources of support are likely to be more spatially dispersed. Grounded in an explicitly interpersonal realm, it captures exchanges between people in the individual's self-identified personal social network; friends, family members, coworkers, community members, and so on (Shumaker and Brownell, 1984). Because this network centres upon the individual and not the neighbourhood, it may relate less strongly to physical features of the environment compared with the community-based social resources described previously (Hartig et al., 2014). However, some studies have identified a positive association between the quantity of POS in the vicinity of the home and the perceived availability of social support from networks not specifically located within the neighbourhood (Maas et al., 2009b, Fan et al., 2011).

[15] The frequency of POS usage does not appear to fully explain its influence on sense of community (Francis et al., 2012a; Kuo et al., 1998b), indicating that the manner in which it contributes to the character of a neighbourhood (additional to facilitating social interaction) might influence the cognitive social integration of residents.

3.4 POS may especially buffer the effects of acute or repeated acute stressors

The extent to which residential contexts affect human health may be conditional upon individual attributes and circumstances (Stokols et al., 1996, Aneshensel, 2010). For instance, a person already under stress is likely to be especially susceptible to environmental influences (Elliott and Eisdorfer, 1982). Characteristics of the residential environment might therefore exacerbate (or ameliorate) the harmful impact of negative events or strains in the lives of individuals, leading to heterogeneity in the effects of otherwise equivalent neighbourhood exposures (Cutrona et al., 2006). At the individual level, the notion of psychosocial resources and restoration as 'moderators' of the stress process (i.e. stress-buffers) implies that they provide the greatest benefit to those facing the greatest adversity; for instance, persons who experience acutely stressful events, or repeated acute stressors, compared with persons in more stable situations (Cobb, 1976, Pearlin et al., 1981, Thoits, 1995, Wheaton, 1985). A salutogenic environment that supports those moderators – such as an environment rich in POS – might, in turn, be especially beneficial to individuals exposed to acutely stressful events (Bowler et al., 2010).

3.5 POS may influence other components of the stress process

Before continuing, it is worth noting that residential POS may intervene in the stress process in a number of ways that are not directly related to the availability of psychosocial resources. For instance, POS might directly reduce exposure to environmental stressors including harmful noise (Gidlöf-Gunnarsson and Öhrström, 2007), perceptions of density and crowding (Cheng, 2010), a lack of perceived social safety or exposure to crime (Kuo et al., 1998a, Kuo and Sullivan, 2001b, Maas et al., 2009a), and thermal discomfort within urban microclimactic 'heat islands' (Chen and Ng, 2012, Gaitani et al., 2007). POS might also facilitate behavioural moderators of the stress process such as physical activity (Fox, 1999, Kaczynski and Henderson, 2007, McCormack et al., 2010) or healthy sleep duration (Astell-Burt et al., 2013a). Assessment of these explanatory pathways is outside the scope of this thesis, and for the sake of brevity, they are not elaborated further.

3.6 Is all POS created equal? The importance of 'greenness'

The mere availability of neighbourhood POS may not adequately explain its relationship to mental health. The quality of POS – including its size, the density and condition of vegetative

cover ('greenness'), availability and maintenance of amenities, or perceived safety – is also likely to be important (Corti et al., 1996, Bedimo-Rung et al., 2005, Seaman et al., 2010, Kaźmierczak, 2013). These attributes have variously been linked to levels of usage (Tester and Baker, 2009, Cohen et al., 2010, McCormack et al., 2010, Veitch et al., 2012) and physical activity (Giles-Corti et al., 2005, Kaczynski et al., 2008, Sugiyama et al., 2010, Ward et al., 2014) as well as the strength of social ties, sense of community, and neighbourhood satisfaction among nearby residents (Kuo et al., 1998b, Kweon et al., 1998, De Jong et al., 2012, Francis et al., 2012a)[16]. In keeping with prior discussion of biophilia and the psychosocial benefits of nature experience, this thesis focuses on the influence of one particular quality attribute: POS 'greenness'.

The 'greenness' of urban POS contributes to its aesthetic value, both visually and auditorily (Irvine et al., 2009), and is theoretically intimately tied to its restorative potential. Aesthetic preference, which has consistently been documented in relation to natural settings, has a strong affective character and is typically accompanied by pleasurable feelings (Ulrich, 1983). Moreover, expansive settings with a greater quantity and diversity of natural elements constitute a richer, more coherent environment, with greater scope to evoke involuntary fascination and a feeling of 'being away', and could therefore be most beneficial for restoration from stress and mental fatigue (Kaplan, 1995, Fuller et al., 2007, Grahn and Stigsdotter, 2010, Carrus et al., 2013). This is relevant not only to active users of public open space, but also to those who happen upon (visually or physically) these natural stimuli in a manner incidental to the performance of unrelated activity cycles. For instance, as mentioned earlier, there is evidence that greater quantities of vegetation visible from the home could assist in the healthful regulation of physiological stress responses (Honold et al., 2016).

Consistent with this notion, people tend to perceive a greater likelihood of restoration in spaces with structural natural elements, such as grass and trees, over those with decorative natural elements, such as flowers (Nordh et al., 2009, Nordh et al., 2011). Moreover, there are indications that people prefer trees with widely spreading and denser canopies, and that these tree forms elicit more positive emotions and reduce blood pressure to a greater extent than those with rounded or more open canopies (Lohr and Pearson-Mims, 2006). These structural

16 Most of these studies account for the overall accessibility of POS, illustrating the independent contribution of POS quality to the outcomes described.

elements contribute substantially to overall 'greenness', providing some indication that this is an important contributor to restoration in urban environments. However, this question has rarely been assessed directly. One recent laboratory experiment found evidence for a linear association between streetscape tree density in a virtual landscape and self-reported stress reduction following exposure to an acute stressor (Jiang et al., 2014b). Others provided limited support for the influence of relative tree density in streetscapes or POS, indicating a differential in the effectiveness of restoration only between low and moderate levels of greenness as well as a possible dependence of this effect on gender (van den Berg et al., 2014, Jiang et al., 2014a). It should be noted, however, that all of the studies described here employed virtual (e.g. video or photo) exposure to nature, which appears to have less dramatic effects on restoration than actual exposure to nature (Mayer et al., 2009).

In addition to promoting restoration, POS 'greenness' may encourage greater usage through aesthetic attraction (Ulrich, 1993), conscious restoration-seeking behaviour (e.g. Staats et al., 2010), or concomitant benefits including improved thermal comfort conditions (Chen and Ng, 2012, Lin et al., 2013) and a greater presence of birdlife (Corti et al., 1996). Affective reactions to natural stimuli are likely to motivate stronger approach impulses including seeking out, exploring, and staying in open spaces (Ulrich, 1983). As well as increasing the number of restorative opportunities accessed by the individual, increased POS usage may facilitate greater social interaction not only within POS but throughout the neighbourhood more broadly. Proximity to attractive[17] POS is associated with more recreational walking within the neighbourhood (Sugiyama et al., 2010), which might facilitate a greater number of passing encounters between POS users and non-users. This phenomenon is particularly pronounced when a park that is both large and highly attractive is accessible within walking distance, indicating the potentially synergistic effects of these attributes (Sugiyama et al., 2010).

However, increased opportunity for social interaction is not the only mechanism by which POS greenness might enhance neighbourhood social integration. As foreshadowed in Section 2.3.2 (p.32), a greater presence of pleasing natural stimuli in the residential environment might improve the quality of those interactions through the evocation of shared psychological

[17] 'Attractiveness' was assessed as a weighted mean score of 9 attributes including the presence of walking paths, shade, water features, irrigated lawn, lighting, sporting facilities, and birdlife; type of surrounding roads; and being adjacent to a beach or river.

architecture and biophilic responses, as well more indirectly via enhanced self-regulation supported by opportunities for restoration. In fact, cognitive dimensions of social integration may be supported by POS greenness even in the absence of interaction with other humans. For instance, greener POS are more likely to elicit positive affect than spaces with sparse vegetation (Ulrich, 1993) and might thereby play a greater role in the development of emotional attachments to the neighbourhood as a spatial construct (De Jong et al., 2012). They may also have greater scope to elicit feelings of spiritual tranquillity and identification of the self within the ecology of living beings, stimulating a sense of belonging and kinship in a broader sense (Chiesura, 2004, Irvine et al., 2013).

A series of natural experiments conducted within two Chicago public housing developments has illustrated the potential importance of POS 'greenness' in promoting neighbourhood social integration. Each housing development contained a number of equal sized courtyard areas situated at the junctures of architecturally identical buildings, to which a highly homogenous group of residents (the heads of households were almost exclusively African American and unemployed) were assigned in a quasi-random fashion. In this context, the level of vegetative cover was positively associated with the level of usage and social activity within those common spaces (Coley et al., 1997, Sullivan et al., 2004). Kuo et al. (1998b) found that higher levels of vegetation in those courtyards predicted stronger neighbourhood social ties and sense of community among adjacent residents, a relationship partially mediated by usage; residents living adjacent to greener courtyards also felt safer, and considered themselves to be better adjusted to living in the development. Analogous associations were evident for elderly adults in the same context (Kweon et al., 1998), while differential perceptions of safety were corroborated by variation in police records of property and violent crime over a two year period (Kuo and Sullivan, 2001b). While these findings are compelling, their generalisability to other neighbourhood contexts is uncertain. The studies pertain to residents of impoverished, high density public housing developments within which POS greenness varied dramatically; while some common spaces consisted of grass and trees, others were barren concrete and devoid of vegetation (Coley et al., 1997, Kuo et al., 1998b, Kweon et al., 1998). Thus, the relative contribution of 'extra' greenness in other settings, where many open spaces are likely to contain some level of vegetation, may be far less influential.

3.7 Conscious and non-conscious pathways linking POS 'greenness' to restoration and mental health

Earlier in this chapter (Section 2.1.4, p.24) a distinction was raised between conscious (indirect-cognitive) and non-conscious (direct-contextual) mechanisms for the transmission of place effects on health (Daniel et al., 2008). Notably, this conceptualisation accords with the two primary mechanisms by which characteristics of nature within POS (e.g. the level of vegetation) have been hypothesised to influence mental and social health, both within this chapter and in an unrelated study published in *Scientific Reports* this June (Shanahan et al., 2016).

Conscious (indirect-cognitive) mechanisms primarily pertain to the manner in which the conscious perception of POS greenness is conducive to healthful outcomes through increased usage. For example, theory and empirical evidence suggest that the combination of inherent biophilic preferences with prior experiences of restoration will guide people into natural environments when they are experiencing heightened levels of stress or fatigue (Hartig et al., 2014, Korpela et al., 2001, Staats et al., 2003, Herzog et al., 2003, Grahn and Stigsdotter, 2010, Staats and Hartig, 2004, Hartig and Staats, 2006). Indeed, Staats and Van Gemerden (2010) found that stated preferences for urban nature were greater when individuals imagined being attentionally fatigued, compared with when they imagined being in a non-fatigued state. By contrast, other urban environments with the potential to aid restoration became less desirable under these conditions. In this way, the conscious perception of 'greener' spaces in the urban environment might encourage individuals to engage with these spaces due to their visual appeal or an awareness of the potential for beneficial outcomes from visitation.

By contrast, non-conscious (direct-contextual) mechanisms relate to the non-perceived, autonomic generation of: psychophysiological stress reduction responses; restoration from attentional fatigue; and positive affect. While these pathways are clearly intertwined (i.e. non-conscious mechanisms are likely to be activated through conscious seeking out of public open spaces), the crucial difference is that non-conscious mechanisms may be activated without purposeful engagement with POS, and indeed, without conscious recognition of these spaces within the environment. This is a potentially important pathway because a sizeable proportion of the population rarely 'uses' their local parks (Moore et al., 2010, Kaźmierczak, 2013, Ward et al., 2014). As already mentioned, restoration does not necessarily require complete

immersion in a natural environment and could accrue simply from repeated viewings of natural surroundings. Thus, POS greenness might support restoration through the accumulation of incidental 'micro-restorative opportunities' (Tennessen and Cimprich, 1995, Kaplan, 2001) or simply an unconscious understanding that the resources are available, should they be needed.

The distinction between these mechanisms could have important implications for the design and targeting of interventions related to residential POS, as they imply a different role of individual awareness and behaviour in the provenance of salutogenic effects. Although data pertaining to POS usage were unavailable for this thesis, the delineation of these pathways presents a useful structure by which to guide the interpretation of research findings.

4 Overview of associations between public open space and mental health, with attention to hypothesised psychosocial mechanisms

The previous section has detailed evidence pertaining to the manner in which POS influences the availability of individual psychosocial resources (coping and social support) that might moderate the influence of stress on mental health or otherwise promote wellbeing, and argued for the need to draw distinctions between POS quality and accessibility, as well as positive and negative dimensions of mental health, in this field of research. This section summarises the body of existing empirical evidence for an association between residential POS and mental health, paying special attention to those conceptual distinctions and the psychosocial mechanisms described above. The review focuses on research in urban settings[18] where POS is considered in relation to the residential environment and mental health measures are intended to capture somewhat enduring states of wellbeing. In this respect, the review does not include experimental evidence pertaining to the transient effects (e.g. on mood, cognitive restoration, or physiological reactions) of isolated instances of 'nature experience' or 'green

[18] A few exceptions are made for studies in rural (or combined urban and rural) settings that boast unique designs and contribute knowledge relevant to the questions in this thesis that remain unaddressed by research in strictly urban settings. These exceptions are noted where applicable.

exercise'[19], nor evidence pertaining to the non-residential milieu (e.g. hospitals, workplaces, or origin-destination travel paths). Evidence for an overall association between POS and mental health is reviewed first (Section 4.1), with attention to identifying what is known about the role of POS quality – and particularly POS greenness – in these relationships. Next, I review studies that have explicitly tested indirect psychosocial (Section 4.2) or stress buffering pathways (Section 4.3) as potential mechanisms underlying salutogenic benefits of POS. The section ends with a discussion of key limitations and research opportunities emerging from this review (Section 4.4).

4.1 Associations between residential POS and mental health

The present discussion is apportioned between the bodies of cross-sectional and longitudinal evidence and, within these subsections, between evidence pertaining to POS accessibility and POS quality. At the commencement of this PhD research, a considerable array of evidence existed to support cross-sectional associations between residential POS accessibility and mental health. No longitudinal studies had been published, however, and this significant gap in the literature was a primary motivating factor for the present research (Lee and Maheswaran, 2011). This section is thus structured to (a) delineate purposefully between bodies of evidence with differing inferential strength in relation to the identification of causal effects and (b) to provide some historical context for the present study by isolating those longitudinal studies published since its initiation.

4.1.1 Cross-sectional evidence

4.1.1.1 POS accessibility

A large number of studies have demonstrated an inverse association between residential POS accessibility and self-reported levels of psychological distress, after accounting for a range of potentially confounding individual characteristics including age, sex, education and income. These studies measure 'accessibility' in various ways, including the proportion of the living environment that comprises green space[20] (De Vries et al., 2003, Maas et al., 2009b, van

[19] Where applicable, interesting research findings from these domains were noted in the previous section in their capacity to support hypothesised causal pathways linking POS and mental health. A number of extensive reviews of this literature are available elsewhere (Barton & Pretty, 2010; Bowler et al., 2010; Bratman et al., 2012; Logan & Selhub, 2012).

[20] Data pertaining to the distribution of POS are frequently sourced from land cover classification databases in which small parcels of land are categorised according to the dominant land use in that area. Thus, many studies

Dillen et al., 2012, Astell-Burt et al., 2013b, Richardson et al., 2013); the presence of any green space within a specified distance of the home (Triguero-Mas et al., 2015); distance from the home to a specified large park (>13,500m^2) (Sturm and Cohen, 2014); the relative absence of barriers to access and usability in neighbourhoods with similar total quantities of green space (Zhang et al., 2015); or the general level of neighbourhood 'greenness'[21], measured objectively (De Vries et al., 2013, Beyer et al., 2014, Triguero-Mas et al., 2015) or as perceived by residents (Sugiyama et al., 2008). Maas et al. (2009c) report congruent findings in relation to physician-assessed episodes of anxiety disorders and depression, drawn from the records of medical practices, which were less prevalent among individuals with a greater proportion of green space within approximately one kilometre of the home[22]. Nutsford et al. (2013) similarly linked objective records of treatment for mood or anxiety disorders to the availability of green space in an ecological study of small statistical areas[23] across Auckland, New Zealand. Adjusting for neighbourhood socioeconomic status, both a greater proportion of green space within three kilometres of the population-weighted centroid (PWC) and shorter distance from the PWC to the nearest green space were associated with lower treatment rates.

The studies described above all took place in developed countries, most frequently in the Netherlands, and overwhelmingly employed geographic information systems (GIS) to objectively quantify the accessibility of neighbourhood POS. The majority were restricted to urban populations, while those analyses spanning a spectrum of urban and rural settings (Maas et al., 2009c, Astell-Burt et al., 2013b, Beyer et al., 2014, Triguero-Mas et al., 2015) were adjusted to avoid confounding by level of urbanity. There is certainly a compelling body of evidence for an inverse cross-sectional association between POS accessibility, or related exposures such as neighbourhood greenness, and the level of psychological distress. Few

---

focus specifically on 'green space' measured through its classification as urban green, agricultural green, forest, nature area, etc. These areas, although dominated by natural elements, are not necessarily designed for recreational use, particularly in rural areas, and might incorporate swathes of dense vegetation or agricultural land. These exposures are referred to as 'green space' throughout this review to distinguish them from POS in the narrower sense, which is likely to make up a sizeable amount (but possibly not all) of 'green space'.

[21] Measurement of neighbourhood 'greenness' in these studies conflates the presence of green POS with streetscape greenery and vegetation visible in private gardens. As discussed later in this review, these elements of 'greenness' may exert distinct effects on mental health.

[22] Anxiety disorders were also associated with POS in the wider environment (<3km from the home) but mood disorders were not.

[23] The units of analysis (meshblocks) are the smallest statistical aggregation units in New Zealand. Meshblocks are typically homogenous in size, averaging 0.04km^2 in area.

published studies have failed to identify any such association (e.g. Ambrey, 2016)[24], but several have reported findings that are sensitive to methodological and contextual subtleties, such as differing neighbourhood spatial scales (e.g. De Vries et al., 2003, Nutsford et al., 2013) or population densities (Maas et al., 2009a).

Only recently has attention begun to turn to the effects of POS accessibility on strictly positive dimensions of mental health[25]. Frequently, these analyses are motivated by a desire to determine the economic value of urban green spaces, using their influence on life satisfaction (relative to income) as a proxy for residents' willingness to pay for these public goods. Two such studies, set within major cities of Australia (Ambrey and Fleming, 2013) and Germany (Bertram and Rehdanz, 2015), control for a comprehensive range of variables at the level of individuals (demographic, socioeconomic, health condition, and dwelling characteristics) and neighbourhoods (socioeconomic disadvantage, population density, degree of urbanity, and proximity to undesirable land uses in the former; house prices and availability of schools in the latter). Adjusting for these factors, Ambrey et al. (2013) identified a positive association[26] between the proportion of green space in census collection districts[27] of Australian capital cities and residents' self-reported life satisfaction. In Berlin, Bertram and Rehdanz (2015) similarly found that the proportion of green space within 1000 metres of the home, as well as distance to the nearest moderately sized POS (>5000m^2), were significantly associated with greater life satisfaction. These associations were non-linear and each followed an inverted-u shape, with the maximum utilities of POS accessibility estimated at 11.2% (for total proportion) and 600m (for proximity). This suggests that absolute proximity to moderately sized POS has undesirable consequences for life satisfaction, perhaps by exposing residents to disamenities such as congestion or fear of crime. Notably, however, the associations between

[24] Ambrey (2015) measured the proportion of POS within census collection districts with a mean and median area equivalent to circular buffers with radii 530m (mean) and 231m (median). Thus, the study measured POS in very close proximity to the home, potentially explaining the null findings.

[25] Some studies already discussed (Sugiyama et al., 2008; Richardson et al., 2013; Ambrey, 2015) use the SF-36 and SF-12 scales to assess the total state of mental health using a combination of items pertaining to the experience of mental distress symptoms (negative) and psychosocial well-being (positive).

[26] This association was marginally non-significant (p=0.063) but was, as already described, adjusted for a vast number of area- and individual-level covariates. Given that the primary aim of the study was to ascertain the relative financial value of accessibility to POS as a public good, rather than assess the salutogenic effects of POS as such, the authors appear to have favoured over-adjustment of the analyses in order to obtain the most refined regression parameter estimate for comparison against the 'value' of household income (holding less concern for the statistical power to detect an effect on life satisfaction).

[27] The mean area of census collection districts in the sample was 1.85km^2, equivalent to a circular buffer with a radius of 750m.

POS accessibility and life satisfaction did not hold across smaller buffer sizes (500m, 300m) or for proximity to smaller (>1000m^2) or larger (>10,000m^2) POS, possibly indicating differences in the function and value of parks of different sizes[28].

In a rare study in the context of a developing nation, Sarmiento et al. (2010) found that the total proportion and mean size of residential POS in Bogotá, Colombia,[29] were each associated with greater health-related quality of life and the extent to which residents felt positively about the future. These associations were independent of individual demographic and socioeconomic characteristics[30] and consistent across highly localised (500m circular buffer) and wider (1000m around predefined statistical neighbourhood boundaries) spatial scales. Other studies assessing the association of POS to positive mental health have failed to report conclusive results due to limitations in study design. Van Herzele and De Vries (2012) compared two densely populated inner-city Belgian neighbourhoods purposefully selected because they differed substantially in terms of accessibility to green POS[31] but were largely comparable across a range of other factors including population density, demographics, socioeconomic status, housing characteristics, and other attributes of the built environment relevant to health. Residents in the neighbourhood with a greater quantity of POS reported greater global happiness than those in the comparison area, but the study was unable to rule out residual confounding by a greater prevalence of gardens and 'green views' in that area[32]. Finally,

---

[28] Proximity to small parks, for instance, may enhance the aesthetic appeal of the neighbourhood without creating significant disamenities, but provide only limited opportunities for passive recreation and restoration. Thus, the detriment to living either very close or very far away from these areas may be minimal. On the other hand, large parks tend to have more attractive attributes and support a wide range of activities, which might encourage residents to venture further from the home to use these areas (Giles-Corti et al., 2005; Sugiyama et al., 2010). These areas tend to be more diffusely distributed, perhaps explaining why the proportion of POS in the wider neighbourhood is more important than that in immediate proximity to the home.

[29] Neighbourhoods in the wealthiest and poorest of six neighbourhood SES strata were excluded from the study due to ethical concerns and prior difficulties obtaining survey response.

[30] Multivariate analyses were adjusted for sex, age, marital status, education, occupation, topography (slope of the neighbourhood), and socioeconomic status.

[31] One neighbourhood featured two smaller POS (one <1ha, and one >1ha) within 400m of the SLA centroid as well as two larger (>5ha) POS within 800m of the SLA centroid. The other neighbourhood contained only a single small POS (smaller than 1ha, and split in half by a road) within 1.6 kilometres of the centroid.

[32] Despite an almost identical distribution across other health related characteristics, residents in the 'greener' area were nearly twice as likely to have a garden at home and more than twice as likely to have a 'green view' from their living room. Thus, the degree to which neighbourhood POS contributes independently to the difference in happiness – over and above the presence of a garden or streetscape greenery – is unclear. Gardens have previously been found to influence wellbeing (De Vries et al., 2003; Stigsdotter & Grahn, 2004; Nielsen & Hansen, 2007) and may contribute significantly to the aesthetic value of the neighbourhood, particularly in inner-city areas where these resources are uncommon. In Van Herzele and De Vries' (2012) study, a 'green view' from the living room fully explained distinctions in neighbourhood satisfaction between the matched areas, which in

Tavano Blessi et al. (2015) failed to identify an association between residential proximity to POS and overall wellbeing in Milan, Italy, but only assessed distance to 12 of 78 parks and gardens in the city. These parks were selected for their size, level of attendance, and use for hosting cultural, sporting and social events, and may have precluded the identification of wellbeing benefits from smaller parks and gardens proximate to the residence.

4.1.1.2 POS Quality

Whereas there exists a sizeable body of evidence pertaining to the influence of POS accessibility on mental health, few studies have tested the distinct effects of POS quality. Two studies used researcher-administered rating systems to assess POS quality in terms of *general impressions* (e.g. naturalness, colourfulness, variation, shelter, maintenance, safety in van Dillen et al., 2012) and *tangible amenities* (e.g. paths, lighting, playgrounds, shade, irrigated lawn, sporting facilities in Francis et al., 2012b), with mixed results; Van Dillen et al. (2012) concluded that the quantity (but not quality) of POS in the neighbourhood was associated with lower levels of psychological distress, while Francis et al. (2012b) found that objective quality (but not quantity) of POS was related to lower levels of distress[33]. Interestingly, Francis et al. (2012b) also included a participant-rated measure of POS quality that tapped into a similar set of *general impressions* as those assessed in Van Dillen et al.'s (2012) study. Subjective assessments correlated weakly with the objective ratings (r=0.12), and were not associated with psychological distress. Together, these studies suggest that 'POS quality' encompasses distinct dimensions – emotive, subjective qualities versus tangible, observable qualities – and that the latter may be most influential for wellbeing. These are useful distinctions, however it should be noted that *general impressions* have not yet been assessed using purely objective tools. While a researcher-administrated rating system is likely to ensure consistency of measurement across spaces, and is objective in the sense that ratings are unlikely to unduly correlate with potentially confounding characteristics of the study participant, they still rely on human perception in order to verbalise somewhat ineffable qualities.

---

turn explained the full extent of differences in happiness. While part of the variance in 'green views' is surely attributable to the presence of POS, the relative importance of these resources is uncertain.

[33] Both studies controlled for individual age, gender, and education. Van Dillen et al. (2012) also controlled for household income, while Francis et al. (2012) also controlled for marital status, the presence of children in the home, work status and hours worked, as well as area-level socioeconomic status. and perceptions of crime in the neighbourhood, self-reported BMI,

Other studies provide support for the importance of broader impressions, but with certain caveats. In a sample of British adults aged 65 and over, Sugiyama et al. (2009) found that the perceived pleasantness[34] and safety of POS were associated with life satisfaction independently of participant age, functional status, and educational attainment. However, it is possible that these attributes are particularly well suited to the manner in which older adults – who may be limited in their mobility – use public open space, and that these findings are not generalizable to the broader population. De Vries et al. (2013) found that the quality of vegetation visible from the street – which might include POS, but also vegetation in private gardens and on the sidewalk – rated by objective observers according to a set of *general impressions* (e.g. variation, maintenance, and orderly arrangement) was significantly associated with lower levels of psychological distress, and rendered the overall quantity of greenery redundant. However, it is important to note that conflation of POS with other sources of streetscape greenery; these neighbourhood attributes appear to exert distinct influences on mental health (van Dillen et al., 2012) and may do so through different mechanisms (Fan et al., 2011).

Few studies have objectively isolated the influence of broader structural qualities of POS, such as the size or overall greenness, on mental health. As mentioned earlier, Sarmiento et al. (2010) found that the average size of POS was positively associated with health-related quality of life in neighbourhoods of Bogotá, Colombia. This is a promising finding that merits further investigation (e.g. developed countries) using more dimensionally specific outcome measures to determine the manner in which POS size contributes to wellbeing. Kardan et al. (2015) estimated the proportions of statistical dissemination areas (DA) in Toronto, Canada, that were covered by the canopy of trees (a) on the streets and (b) within parks and private gardens, finding that neither measure was related to the number of mental disorders reported by inhabitants of the DA. However, this research only assessed the effects of tree canopy in very close proximity to the home[35] and, once again, conflates tree canopy in POS with that in private gardens. It is also possible that the outcome measure – a count of self-reported

[34] 'Pleasantness' encompassed perceptions that POS contains attractive trees and plants; is good for chatting with people; supports many different activities; is good for children to play in; and has good facilities such as toilets and showers. 'Safety' reflects perceptions that POS is safe to walk in after dark and is free from crime.
[35] The mean area of sampled DAs was only 0.17km^2, equivalent to the size of a circular buffer with a radius of 234m. Therefore, the study may have failed to take into account the influence of green POS in the broader environment.

depression, anxiety and substance use disorders – was not sensitive enough to detect distinctions in the level of distress.

Very recently, Shanahan et al. (2016) used LiDAR mapping technology to measure the structural complexity of vegetation (reflecting the total volume of vegetation across layers of space at various heights from the ground) in outdoor green spaces reported to have been visited by residents of Brisbane, Australia, in the seven days prior to completion of a survey. They found that the 'greenness' of the most heavily vegetated space visited by the individual was not associated with the level of depressive symptoms reported in that survey. These findings suggest that the inherent 'greenness' of POS might not confer additional benefits to POS users. However, it is important to note that the analyses focused on isolated 'nature experiences' rather than the characteristics of residential POS. 'Outdoor green space' was defined by the individual reporting visitation, and did not need to be located near the residence. In addition, the analyses excluded close to half the sample who did not report any visits to outdoor green space during this period. For this reason, the results might not capture the full range of mechanisms by which POS greenness could influence population mental health; for instance by attracting greater numbers of users to the space, or through direct non-conscious pathways that do not operate through POS usage.

4.1.1.3 Limitations to causal inference in cross-sectional research

Although the role of quality attributes remains under investigated, there is certainly cross-sectional support for an association between residential access to POS and mental health. However, the inferential limits of cross-sectional research in the identification of causal place-health relationships are well documented (e.g. Lee and Maheswaran, 2011). Simultaneous measurement of neighbourhood exposures and health outcomes fails to reflect the historical, life-course and temporally ordered social stratification processes that give rise to spatial health inequalities (Kaplan, 2004). Broadly speaking, geographic variations in health may be attributable to either causal ('breeder') and/or selection ('drift') mechanisms (Verheij, 1996). Spatial epidemiologists generally intend to estimate the former; causal neighbourhood 'treatment effects' where, for instance, differential accessibility of POS *results in* a spatial patterning of mental health outcomes because groups of individuals accrue benefits, directly or indirectly, from access to these resources. However, identification of causal effects is easily confounded by the operation of complex spatial selection processes that systematically sort

individuals with certain characteristics into different neighbourhoods (Oakes, 2004). Individuals are not randomly distributed across residential environments, nor are the majority blessed with an unconstrained choice of where to live; rather, the set of possible locations within which an individual may reside is constrained by the availability of material and personal resources (Hartig et al., 2003b).

To consider the causal mechanism just proposed, an equally plausible explanation for the same spatial patterning of outcomes may be that persons with poor mental health, or other characteristics that render them susceptible to poor mental health, are selected into or find it difficult to leave areas with worse access to POS (Groenewegen et al., 2006). Norman et al. (2005), for instance, have documented how selective migration of people in good/poor health towards less/more socioeconomically deprived areas can, over many years, widen health inequalities between the least and most deprived areas. Meanwhile, area-level deprivation has been linked to discrepancies in the distribution or quality of POS across neighbourhoods (Estabrooks et al., 2003, Martin et al., 2004, Powell et al., 2004, Crawford et al., 2008, Mitchell et al., 2011, De Jong et al., 2012, Astell-Burt et al., 2014a). Within neighbourhoods, proximity to POS has a positive influence on property values, and may further influence the selection of individuals with immediate access to these resources (Crompton, 2005, Brander and Koetse, 2011). Together, these migratory forces might lead to geographic variations in health associated with, but *not caused* by, differential access to POS.

While the phenomenon of spatial selection hinders causal inference in many forms of observational research, potentially casting doubt on the exchangeability of individuals between environmental exposure conditions (Oakes, 2004, 2006), it poses a particular threat to the internal validity of cross-sectional studies that cannot control for individuals' prior levels of the outcome[36] (Gollob and Reichardt, 1987, Cole and Maxwell, 2003). Although all of the studies described above attempt to rule out indirect selection effects by conditioning their analyses on individual sociodemographic characteristics, they remain unable to rule out direct (health-related) selection effects and are particularly prone to residual confounding by unknown or omitted variables that determine the distribution of susceptible persons across

[36] These prior values reflect unmeasured exogenous factors that may correlate with both the dependent and predictor variables and threaten to bias estimates of the pathways between those variables (Gollob & Reichardt, 1987; Cole & Maxwell, 2003; Selig & Preacher, 2009). Thus, obtaining measurements at more than one time point allows one to rule out the possibility that an association between two variables is simply an artefact of the variables already being correlated for some other reason (Selig & Little, 2012).

neighbourhoods. Causal processes between place-based exposures and health outcomes can only be ascertained through longitudinal research (Gollob and Reichardt, 1987, Clark et al., 2007, Daniel et al., 2008) which, until recently, was notably absent in the POS literature (Lee and Maheswaran, 2011, Park et al., 2011).

4.1.2 Longitudinal evidence

Since the commencement of this PhD research, seven published studies have employed longitudinal research designs to address the limitations outlined above. Of these, six studies assess negative mental health outcomes (psychological distress or major depression) and two assess positive mental health outcomes (life satisfaction)[37]. Five studies evaluate the effects of POS accessibility, and only two assess the effects of POS quality. All take place in developed contexts, with five of the seven papers stemming from just two large cohort studies set in the United Kingdom and Southern Sweden.

4.1.2.1 POS accessibility

Three longitudinal studies of POS accessibility used panel data from the British Household Panel Survey (BHPS), employing multilevel or fixed effects regression analysis to investigate associations with mental health while controlling for time-invariant (e.g. personality) and time-varying (e.g. income, physical health) individual characteristics (White et al., 2013, Astell-Burt et al., 2014b, Alcock et al., 2014). The BHPS features a nationally representative panel of households in the United Kingdom from which data were collected annually between 1991 and 2009. The aforementioned studies employed similar individual observation periods, ranging roughly from five to nine years, but differed fundamentally in their temporal design. White et al. (2013) analysed over 50,000 BHPS observations to assess whether within-person differences in positive and negative dimensions of mental health were associated with residence in areas with differing amounts of green space. In other words, the authors compared outcomes for the same individuals residing in different areas at different points in time, using longitudinal data simply as a means to account for time-invariant inter-individual heterogeneity. Astell-Burt et al. (2014b) took a similar approach, but employed an accelerated longitudinal design to investigate how the effects of green space vary across the life course. Analysing 29,626 male and 35,781 female observations, the authors also assessed gender differences in these relationships. By contrast, Alcock et al. (2014) sought specifically to

[37] One study (White et al., 2013) assesses the effects of POS on both psychological distress and life satisfaction.

identify the temporal sequence of changes to mental health around known residential relocation events where individuals moved to a 'greener' (n=594) or 'less green' (n=470) urban area. Thus, a focus of their study was to ascertain not only whether relocation was associated with a change in the level of distress, but also the rapidity of these changes and their stability over time.

In each instance, individual data from the BHPS were linked to predefined statistical geographic areas (i.e. 'lower-layer super output areas' (LSOA) or 'wards') for which the proportion of 'green space' was determined from land use databases[38]. The three studies were restricted to urban areas and individuals aged over 15 years. Each used the 12-item General Health Questionnaire (GHQ-12) to measure psychological distress outcomes. White et al. (2013) also analysed a single-item measure of global life satisfaction. Finally, each study accounted for a comprehensive range of time-varying individual covariates including age, sex, education, marital status and employment status. White et al. (2013) and Alcock et al. (2014) also accounted for work-limiting illness and potential confounders related to area-level socioeconomic status, including rates of social benefit assistance, educational attainment, unemployment, and crime.

White et al. (2013) analysed over 50,000 BHPS observations (mean individual observation periods of five-to-seven years) using fixed effects regression to assess whether within-person differences in positive and negative dimensions of wellbeing were associated with residence in urban areas with differing amounts of green space. They found that the average person reported lower levels of psychological distress and higher levels of life satisfaction when living in an area with a greater proportion of 'green space', compared with another time when they were living in a less green area[39]. These effects were diminished, but still apparent, when each model was conditioned on the alternative mental health outcome, suggesting that green

[38] Two studies include private land (i.e. domestic gardens) in the definition of green space, but both noted in secondary analyses that excluding gardens did not impact substantive conclusions from the research. White et al. (2013) note that coefficients for both psychological distress and life satisfaction remained significant after excluding private gardens from the definition of 'green space', but that the effect sizes were approximately halved. Alcock et al. (2014) note that excluding gardens did not significantly influence the categorisation of participants who moved to 'greener' or 'less green' areas.

[39] The authors contextualise these results by comparing effect sizes for the proportion of green space to those of within-person changes in other known determinants of wellbeing. Living in an area 1 standard deviation above (cf. 1SD below) the mean level of 'green space' was associated with a reduction in psychological distress roughly a third as large (35%) as that associated with being married (cf. unmarried) or a tenth as large (12%) as that associated with being employed (cf. unemployed). The effect on life satisfaction was equivalent to 28% of the effect of being married and 21% of the effect of being employed.

space may influence positive and negative dimensions of mental health through both shared and distinct mechanisms.

Astell-Burt et al. (2014b) identified an association between green space and psychological distress in urban areas, but also found that the nature of this relationship differed according to gender and life course stage. Overall, among male participants, the proportion of residential green space was negatively and linearly associated with the level of psychological distress. However, the benefits of greater green space accessibility did not appear to emerge until the age of 30, and began to dissipate beyond the age of 60. By contrast, among all females, the relationship between green space and psychological distress was curvilinear, indicating that a moderate quantity of urban green space is optimal for mental health. This distinction only emerged around the age of 40, after which the benefits of 'moderate' green space exposure continued to accumulate with advancing age[40].

Alcock et al. (2014) provided further insight into the temporal evolution of changes in psychological distress following relocation to 'greener' or 'less green' areas, tracking individuals' levels of distress throughout the five-year period surrounding such a move[41]. On average, participants moving to a 'greener' area reported significant declines in the level of psychological distress within twelve months following their relocation. Levels of distress then stabilised and remained at this reduced level throughout a further two years of post-move measurement, indicating a 'shifting baseline' process that suggests fairly rapid and sustainable benefits of moving to a greener urban area. By contrast, participants who moved to a 'less green' area experienced a significant spike in psychological distress in the year *preceding* their relocation. This deterioration in mental health was short lived, however, and those individuals returned to baseline levels of psychological distress within twelve months after the move. In other words, individuals moving to 'less green' areas appeared to adapt to their new circumstances quite quickly. Although intuitively appealing, the findings of this observational

[40] Somewhat surprisingly, there was little difference in the course of distress symptoms between women living in areas with very low or very high proportions of green space. However, this finding is consistent with prior evidence that there may be some disamenity associated with living in an urban location with very high accessibility of POS (e.g. Bertram and Rehdanz, 2015).

[41] Participants were assigned to a group according to whether they relocated to a 'more green' or 'less green' area based on differences in the proportion of green space in the LSOA of their old and new residences. Psychological distress was measured for approximately two years preceding and three years following residential relocation (Time T). The first measurement (T-2) was taken as the baseline level of psychological distress against which GHQ-12 scores at subsequent observations

study must be interpreted with an awareness that individuals were not randomised across 'movement' conditions and therefore these effects could be confounded by other influences, particularly the reasons underlying the move. The authors recognise this fact, noting that reported motivations for relocation were broadly similar between individuals moving to 'greener' and 'less green' areas, and do not appear to explain the differing temporal processes that were observed[42].

Outside of Britain, Gariepy et al. (2015) analysed ten years of biennial data from the Canadian National Population Health Study[43] to determine whether access to a local park, among other features of the neighbourhood built environment, was associated with depressive symptoms among adults aged 18 to 80 at commencement of the study (n=7,114). Unlike the BHPS studies, Gariepy et al. (2015) used the Composite International Diagnostic Interview Short-Form screening survey (CIDI-SFMD) to identify participants likely to have suffered an episode of major depression in the year preceding each interview. Using logistic latent class growth analysis (LCGA), the sample was partitioned into three subpopulations ('low', 'moderate' and 'high prevalence' classes) reflecting the individual's long-term probability of experiencing an episode of major depression throughout the ten-year observation period[44]. Among participants in the 'low' and 'moderate' prevalence classes, residing within 500m of any POS at a given survey cycle was associated with a downward shift in the long-term probability of experiencing a depressive episode after accounting for other key determinants including age, sex, marital status, education, family income adequacy, family history of depression, chronic health conditions, and significant childhood life events. This association was not evident for individuals in the 'high' prevalence class; thus, POS appears to be a

[42] However, they do acknowledge a potential bias due to selective attrition processes (dropout may have been elevated among participants whose mental health worsened following relocation) since the analyses were restricted to participants with six consecutive waves of complete data.

[43] The full sample includes participants residing in both urban and rural environments, but the authors state that results were largely unaffected by the exclusion of rural participants.

[44] The 'low prevalence' class contains approximately three quarters of the sample (76%), with a very low (<1%) expected prevalence of major depression at each survey cycle. The 'moderate prevalence' class contains fewer participants (19%) with a somewhat higher expected prevalence of major depression at each survey cycle (15-20%). The 'high prevalence' class contains a small number of participants (3% of the sample) with a high prevalence of major depression at each survey cycle (59-68%); these individuals appear to be following a fairly chronic course of depression throughout this 10 year period. This method accounts for time-invariant individual characteristics (similar to a fixed effects analysis) but also allows the investigation of effect heterogeneity according to the individual's longer-term mental health status.

significant protective factor for individuals already following a reasonably low probability trajectory of depressive episodes.

Most recently, Krekel et al. (2016) performed a fixed-effects analysis of life satisfaction using 33,782 observations from 6,959 participants in the German Socioeconomic Panel.[45] Only individuals residing in cities with over 100,000 inhabitants were included in the study. As anticipated, greater proximity to urban green space, and a higher total proportion of POS within 1km of the home, were each associated with increased life satisfaction after adjusting for potential confounders at the individual level (demographic characteristics, human capital characteristics, and economic conditions, as well as household characteristics and housing conditions) as well as macroeconomic conditions of the city, and geographic characteristics of household location within the city (e.g. distance to the city centre and city periphery). Consistent with prior studies (Astell-Burt et al., 2014b, Bertram and Rehdanz, 2015 1068) there was evidence of a non-linear (inverted-u) association between the total proportion of POS and life satisfaction, indicating declining marginal returns from increasing quantities of POS. There also appeared to be a non-linear relationship between distance to POS and life satisfaction, suggesting that individuals residing closest to urban POS accrue disproportionately greater benefits compared with those living somewhat further away[46]. However, in both instances, the effects of POS accessibility on life satisfaction were small; an increase of 100m in distance to green space (compared against the mean distance of 279m) was associated with only a 0.01 standard deviation decrease in life satisfaction, while an

[45] The research method was largely analogous to that adopted in White et al.'s study (2013) but differed in two important ways. First, Krekel et al. (2016) adopted participant-centred measures of the residential environment (a 1000m radial buffer and Euclidean distance to the nearest POS) in order to ensure consistency in the measurement of environmental exposures between participants; by contrast, White et al. (2013) measured POS coverage using predefined statistical areas, whose geographic size is determined based on the number of residents and may differ substantially depending on population density. Second, Krekel et al. (2016) included fixed effects for the city of residence as well as the individual, thereby identifying the effects of changes in urban POS accessibility associated with a move between cities. The analysis of between-city movers was intended to reduce the influence of personal attributes or preference on selection into greener neighbourhoods, on the basis that these individuals are less likely to move for reasons related to the characteristics of their current neighbourhood. The authors report that the results remained qualitatively similar if city-level fixed effects were removed from the model in order to assess the effect of movement to greener areas both within and between cities.

[46] The quadratic term was, however, only marginally significant ($p<0.1$). Interestingly, the minimum size criterion employed by Krekel et al. (2016) (0.25ha or 250m^2) was much smaller than the 5ha (5000m^2) criterion applied by Bertram and Rehdanz (2015), who concluded that residing 600m from POS (and not closer) was optimal for enhancing life satisfaction. This reinforces previous comments in relation to the possible influence of POS size on the importance of proximity to POS.

increase of 1 hectare of green space coverage (compared against the mean of 23ha) was associated with a 0.004 standard deviation increase in life satisfaction.

4.1.2.2 POS quality

Two longitudinal studies assessed the effects of POS quality on mental health, using data from a cohort of residents in Skåne County, Sweden.[47] Participants in this cohort study were initially interviewed in the year 2000 (aged 18-80 years) and followed up at five-year intervals thereafter (Annerstedt et al., 2012, Weimann et al., 2015). Like the BHPS studies, the Skåne studies each used the GHQ-12 to measure outcomes of psychological distress. However, they differ substantially in terms of exposure definition. Whereas the BHPS studies calculated the total proportion of 'green space' coverage, the Skåne studies focused on access to a range of 'green qualities' in the residential environment. These qualities describe, roughly, the extent to which the local landscape possesses 'serenity', 'wilderness', 'species richness', 'spaciousness', and/or a sense of 'cultural history'[48]. Thus, it is important to note that these studies did not exclusively measure qualities of POS, even though POS might contribute significantly the presence of 'green qualities' in the broader landscape. Moreover, neither study was restricted to urban populations, but each included participants residing in rural areas and small towns. In fact, Annerstedt et al. (2012) entirely excluded participants residing in larger inner city areas. This is particularly noteworthy given the potential for agricultural land and forested areas to provide access to 'green qualities'. Both Skåne studies utilised large samples (n≈9000) and accounted for individual-level covariates including age, sex, country of origin, marital status, housing type, and financial stress, among other study-specific variables. Neither study accounted for area-level covariates.

Like Alcock et al. (2014), Weimann et al. (2015) used residential mobility as an opportunity to identify the intra-individual effects of changing exposure to 'green qualities' on levels of psychological distress throughout a ten-year (three-wave) follow-up period. The authors drew upon subjective individual assessments of the five green qualities, collected from a large independent sample, to compute a summary 'green score' for 1km^2 areas across the

[47] Skåne is the southernmost county of Sweden. It covers an area of 10,939km^2 and counts Malmö, Sweden's third largest city, as its capital.

[48] These qualities are a selected subset of eight basic landscape characteristics identified throughout a decade of research in Sweden. In relation to previous discussions of POS quality, these studies could most aptly be described as capturing *general impressions* of the landscape (rather than the availability of *tangible amenities*).

county. This score was linked to each observation based on the 1km^2 area in which the participant was residing at the time of the interview.[49] The authors identified null ($p<0.10$) effects of both ongoing (average) residence in areas with more of the five green qualities, and of moving to an area with more green qualities.[50] However, the study did not adjust for degree of urbanity in the place of residence. This is noteworthy because participants were drawn from across Skåne County using a stratified sampling plan to gather data from diverse geographic areas including inner-city areas of large cities, suburbs, small towns, and rural locations. It is plausible that the effects of 'green qualities' could differ between these locations; for example, whereas small increases in accessibility of green qualities might markedly improve quality of life in inner-city areas, a greater level of ambient exposure to nature in rural areas might render these gradations are less meaningful.

Moreover, limitations arise when residents (albeit from an independent sample) are asked to report on the characteristics of the environment in which they live. Participants involved in the task of measuring green qualities were asked to "think of nature" within 5–10 minutes walking distance from the home and describe the sensory qualities of those natural environments. This measurement approach is predicated upon an assumption that individuals (a) consciously perceive and (b) can communicate the sensory qualities of those environments in a manner that accords with the knowledge structures imposed by researchers (Young, 1980). Yet, the sense of 'wonder' or 'awe' that is often elicited in theorising on nature experience has been described as an ineffable physiological sensation occurring outside of the brain's verbal processing areas (Terhaar, 2009). Weimann et al.'s study further assumes that acclimatisation to the presence of natural stimuli throughout the course of residence plays no role in one's ability to report them, while also failing to take into account the influence of the total quantity of "nature" in this area.

Whereas Weimann et al. (2015) measured the five 'green qualities' using subjective self-reports, Annerstedt et al. (2012) derived objective measures from refined classifications of

[49] Individual means (across all measurement occasions) and time-specific deviations of this 'green score' were entered simultaneously into a multilevel regression model to reflect average exposure as well as relocation to a greener or less green area, where applicable.

[50] There was no significant heterogeneity in these relationships according to participants' baseline prognosis for good mental health, but the authors highlight that individuals who may benefit the most from increased exposure to greenness (i.e. those most vulnerable to poor health) may lack the resources and opportunities to move to greener environments.

land and vegetative cover stored in a GIS[51]. The presence or absence of each quality was assessed for highly localised residential areas, falling within 300m of the participant's baseline address, and used to predict the relative odds of experiencing poor mental health at a five-year follow-up. The authors also investigated whether access to green qualities interacts with other personal factors measured at baseline – including financial stress, living conditions, and leisure time physical activity – to determine mental health outcomes. All analyses accounted for baseline mental health status in addition to the covariates mentioned previously. No direct protective effects of the various green qualities, considered either individually or summed to reflect total access, were evident. Among women, however, access to *Serene* or *Spacious* nature synergised the benefits of regular physical activity to further reduce the odds of elevated psychological distress at follow-up. These interactions were not significant for men, nor did any of the green qualities interact with financial stress or housing arrangements to determine mental health outcomes. These findings suggest that access to specific qualities of nature, particularly places that provide a sense of "peace, silence and care" or "a restful feeling of entering another world" may be beneficial for mental health, but that the transmission of these protective effects depends on individual behaviours and characteristics. However, this study entirely excluded residents of larger inner city areas, and so the relationships may not be generalisable to metropolitan locations for the reasons outlined previously. Overall, the Skåne studies provide only limited insight into the relevance of 'green landscape qualities' to mental health in urban areas, primarily due to the sampling procedures employed.

4.2 Psychosocial resources in the relation between POS and mental health

This review identified nine cross-sectional studies that have explicitly tested the mediating role of psychosocial resources in explaining relationships between POS and mental health. Six of these studies relate to POS accessibility, two to 'neighbourhood greenness', and only one to POS quality. Most assess associations with psychological distress, with the exception of one study in which happiness was the primary outcome.[52] Associations between POS and mental

[51] For instance, an area is deemed to possess *Serene* green qualities if it includes broad-leaved forest, mixed forest, pastures, island marshes, wet mires, other mires, water courses, or lakes and ponds.
[52] In addition, Sugiyama et al. (2008) use the SF-12 to assess the total state of mental health using a combination of items pertaining to the experience of mental distress symptoms (negative) and psychosocial well-being (positive).

health have most frequently been assessed for mediation by behavioural dimensions of neighbourhood social integration[53] (two studies), cognitive dimensions of neighbourhood social integration (four studies), and network-based social support (four studies) or social contacts (two studies). None specifically assess mediation by coping abilities, although one study tests the explanatory role of perceived stress and another the role of attentional capacity. No longitudinal studies were identified in this review.

All of the studies described here identified protective effects of POS on mental health, but conclusions regarding mediation by the various classes of psychosocial resources are mixed. For instance, two studies found that POS accessibility did not predict the perceived availability of functional network-based social support (Triguero-Mas et al., 2015) or the frequency of social contact with other individuals and groups located within and outside the neighbourhood (Astell-Burt et al., 2013b). Nor could the protective effect of POS quality, measured objectively by the presence of functional amenities, be explained by perceived network-based social support or the size of close personal networks (Francis et al., 2012b). On the other hand, Fan et al. (2011) found that the total quantity of POS within 800 meters of the home indirectly mitigated perceived stress levels by fostering a general sense of social support, although this relationship was modelled indirectly using instrumental variables. Maas et al. (2009b) similarly concluded that a greater proportion of green space within one kilometre of the home protected residents against (a) feelings of loneliness and (b) a perceived shortage of social support, and that these variables, in turn, (a) partially and (b) fully mediated the association with psychological distress. Interestingly, the relative quantity of POS had no bearing on the frequency of contact with neighbours or friends in the area, nor on the number of supportive interactions received by participants, leading the authors to suggest that this resource promotes social wellbeing by strengthening place attachment rather than supporting actual interactions between neighbours[54].

---

[53] This refers to measures of social contact or interaction with other residents of the neighbourhood, specifically, rather than broader social networks (which may include contacts in the neighbourhood).

[54] Interestingly, Völker et al. (2007) also found that neighbourhoods with a greater availability of potential meeting places (a range of facilities, including POS) exhibited stronger 'community' in the sense that residents realised more social wellbeing goals (comfort, stimulation, affection, and status) within the neighbourhood, but this was not reflected in the inclusion of more neighbours within their personal networks. This might also explain why Astell-Burt et al. (2013) failed to identify an association with social contacts despite adopting a very similar spatial exposure measure (proportion of green space within 1km of the home) to those used by Fan et al. (2011) and Maas et al. (2009).

Consistent with this notion, Sugiyama et al. (2008) found that although residents who perceived their neighbourhood to be 'greener' did engage in more local social interaction, this could not explain their better self-reported mental health. Meanwhile, both Sugiyama et al. (2008) and De Vries et al. (2013) concluded that protective effects of 'neighbourhood greenness' were partially mediated by perceptions of local social cohesion. These studies each provide support for the importance of cognitive forms of neighbourhood social integration as a vehicle for the psychological benefits of access to nature in urban environments. Yet, as already mentioned, measures of neighbourhood 'greenness' conflate POS with streetscape greenery, and these exposures may exert distinct effects (van Dillen et al., 2012) through different mechanisms (Fan et al., 2011).[55]

Other studies investigating associations with POS attributes specifically, rather than natural stimuli distributed throughout the neighbourhood more broadly, provide mixed support for mediation by cognitive neighbourhood social integration. For instance, Francis et al. (2012b) concluded that neither sense of community or sense of place were plausible explanations for the relationship between POS quality (measured in relation to *tangible amenities* such as the presence of paths, lighting, playgrounds, shade, irrigated lawn, and sporting facilities) and psychological distress. It is interesting to consider these findings in conjunction with a related study of the same sample (Francis et al., 2012a), in which sense of community was positively related to participant-rated *general impressions* of POS (e.g. comfort, safety, attractiveness and maintenance), but not the observer-rated measures of *tangible amenities* assessed for mediation by Francis et al. (2012b). As discussed in Section 4.1.1.2 (p.50), these measures of POS quality are only modestly correlated, and it is possible that variation in resident perceptions pertinent to building a sense of community (e.g. emotive judgments and attachments) are not amenable to measurement using objective audit tools (Koohsari et al., 2015).

Van Herzele and De Vries (2012) provide some support for the notion that neighbourhood satisfaction, a key indicator of place attachment (Ringel and Finkelstein, 1991), could explain an association between POS availability and happiness. By contrast, the authors did not find

[55] Fan et al. (2011) concluded that POS accessibility indirectly mitigates stress by augmenting perceived social support, whereas the opposite was true for the overall level of neighbourhood vegetation. For vegetation, a direct stress reduction effect was counteracted by a negative influence on social support, resulting in a net positive effect on perceived stress.

any evidence for mediation by social cohesion, perceived stress, or ability to concentrate. This observational study only compared, however, between two neighbourhoods and was therefore particularly vulnerable to residual confounding (as raised in Section 4.1.1.1). In relation to the lack of an association with social cohesion, for example, it was noted that the 'less green' neighbourhood featured greater street connectivity and better access to local shops, both of which could contribute to 'walkability' and incidental interactions within the area to offset the effects of a lack of POS (Leyden, 2003). Besides Van Herzele and De Vries (2012), only De Vries et al. (2013) have assessed mediation by perceived stress, which they found to mediate associations between both quantity and quality of streetscape greenery and psychological distress.

4.2.1 Limitations to causal inference in cross-sectional analyses of mediation

Cross-sectional research may be particularly problematic in the assessment of mediation hypotheses (Selig and Preacher, 2009, Cole and Maxwell, 2003, Maxwell and Cole, 2007, Maxwell et al., 2011). For instance, Maxwell et al. (2011) have demonstrated that cross-sectional correlations can imply the existence of a substantial mediated effect even when the longitudinal effect is zero, or else fail to distinguish between very different sets of underlying longitudinal parameter values. While the causal relationships implied by mediation models take time to unfold, the use of cross-sectional data erroneously implies that these effects are instantaneous (Gollob and Reichardt, 1987, Selig and Preacher, 2009). Temporal precedence is an important condition in establishing causality; but whereas some minimum period of residence might be imposed (in conjunction with objectively sourced data) to 'artificially' induce temporality between exposure (X) and outcome (Y), it is typically the case that mediators (M) and outcomes (Y) are measured using contemporaneous self-reports. This makes it difficult to empirically distinguish the veracity of the proposed model (X to M to Y) from alternative models that explain the data equally well (e.g. X to Y to M) (Iacobucci et al., 2007, MacKinnon et al., 2007). Single-source bias might result in spurious cross-sectional associations between, for example, perceptions of the social environment (M) and mental health (Y), either because the measurement error in both reports is correlated or because the outcome affects the report of the mediator (Diez-Roux, 2007). For instance, it is possible that people with poor mental health will report lower levels of social cohesion or support, or withdraw from local social interaction, as a result (rather than a cause) of their psychological state (Mair et al., 2008). In this respect, longitudinal research is required to establish true

temporal precedence between the constructs that are hypothesised to constitute causal mechanisms linking POS to mental health.

4.3 POS as a buffer against the detrimental effects of stressful events

As discussed earlier, individuals under stress may be particularly susceptible to environmental influences (Elliott and Eisdorfer, 1982) and psychosocial resources may be especially beneficial to people who experience acutely stressful events (Pearlin et al., 1981); thus, the protective effects of neighbourhood POS may be especially great following such events (Bowler et al., 2010). Consistent with this hypothesis, Mitchell et al. (2015) found that differences in positive mental wellbeing associated with socioeconomic inequality were diminished among individuals with better perceived ease of access to POS[56]. Specifically, the gap in wellbeing scores between individuals under high versus low levels of financial strain (measured as the perceived ease of 'making ends meet' each month) was 40% narrower among those who reported very easy access to POS, compared with those reporting great difficulty in accessing POS. Although the authors did not specifically investigate the incidence of acutely stressful events in the lives of these individuals, their findings do suggest that accessibility of POS helps to buffer the detrimental impact of enduring strains associated with socioeconomic deprivation.

Van den Berg et al. (2010) assessed the protective effects of POS accessibility specifically in relation to the experience of stressful life events (SLE), among an adult sample residing across varying degrees of urbanity[57] in the Netherlands. The proportion of green space within three kilometres of the home exerted a small buffering effect for those who had recently experienced a SLE, but this did not reach statistical significance (p=0.10). Additionally, there was no evidence for a buffering effect of green space closer to the home (within one kilometre). However, the authors did not distinguish between respondents who had experienced one SLE or several, despite the fact that multiple SLEs increase the likelihood of experiencing psychological distress (Gill, 2009). Nor did they differentiate between events that might be more or less stressful, and therefore more or less threatening to mental health

[56] Analysis controlled for the perceived accessibility of other neighbourhood services (postal, banking, public transport, cinema/theatre/cultural centre) and neighbourhood problems (noise, air quality, crime/violence/vandalism, litter or rubbish, and traffic congestion) as well as a range of individual covariates.
[57] The authors controlled for the degree of urbanity as well as gender, age, level of education and income.

(Kessler, 1997). It is possible that stronger buffering effects for those in greater need (i.e. who had experienced a greater number or more stressful events) were masked by more limited effects for those under less stress. Additionally, the retrospective cut-off for SLE measurement was only three months prior to the health assessment; given the cross-sectional design, it may be that persons in the comparison group were still suffering from the effects of SLE prior to this cut off, diminishing the discriminatory power in the analyses.

Wells and Evans (2003) performed a similar analysis but restricted their study to the influence of 'nearby nature' on the effects of SLE among rural children. Here, the authors assessed the influence of natural stimuli in the immediate vicinity of the home, including the naturalness of views from living areas, the naturalness of the yard, and the presence of indoor plants. They found that a greater presence of natural stimuli was broadly associated with lower levels of psychological distress and a higher sense of self-worth, and also served to moderate (buffer) associations between SLE and these outcomes. Specifically, the detrimental effects of SLE on psychological distress and self-worth were weaker among children residing among a greater quantity of natural stimuli. An alternative (but complementary) interpretation of this moderated effect is that 'nearby nature' exhibits a stronger protective effect for those children under greater stress; specifically, the differential in psychological outcomes between children with high versus low levels of 'nearby nature' grew wider as the numbers of SLE increased, indicating a greater sensitivity to environmental influences under these conditions. It remains to be investigated whether this finding would hold for adults in strictly urban communities, and when taking into account accessibility of POS that is not necessarily visible from the home.

4.4 Key limitations and research opportunities

Throughout the past decade, there has been a proliferation of research into the salutogenic benefits of residential POS. Attention has turned, over time, from the effects of these resources on the level of stress, to negative dimensions of mental health such as psychological distress and disorder, and most recently, to positive dimensions of mental health, such as life satisfaction. Research has also begun to disentangle the effects of POS accessibility versus POS quality, and to elucidate the psychosocial mechanisms by which observed associations with mental health might accrue. Many of these avenues of inquiry remain in their infancy, and present promising opportunities for novel and rigorous contributions to knowledge in this

field. This section outlines the key limitations to the existing body of research, in order to summarise the context for the conceptual framework and research questions of this thesis presented in the following section.

4.4.1 Preponderance of cross-sectional designs

This review has already described serious limitations to causal inference in cross-sectional research, arising due to fallibilities with respect to spatial selection, temporal design, reporting biases, and uncontrolled prior values of the variables of interest (Gollob and Reichardt, 1987, Selig and Preacher, 2009, Cole and Maxwell, 2003, Maxwell and Cole, 2007, Maxwell et al., 2011). The preponderance of cross-sectional designs thus remains a central deficiency of research in this field despite a trend towards longitudinal research in recent years. A small number of longitudinal studies have presented compelling evidence that the availability or accessibility of urban POS is protective against psychological distress symptoms (four studies) and promotes life satisfaction (two studies). However, this evidence remains limited in terms of its generalisability across geographical contexts and the scope of measures used to assess urban POS exposures and mental health. For instance, three of four studies linking POS accessibility to psychological distress used data from the British Household Panel Study, while both studies assessing POS quality attributes were situated in Southern Sweden and either did not include, or were not restricted to, urban areas (these studies also assess 'green qualities' in the broader landscape that are not necessarily attributable to POS). Five of seven longitudinal studies test only one measure of POS exposure, and all use only one spatial scale – frequently a predefined administrative area – to define the local 'neighbourhood'. These issues are elaborated further in the following sections as they pertain to the wider body of evidence linking POS and mental health. Importantly, no published longitudinal research has moved beyond assessment of the overall relationships between POS and mental health to investigate the explanatory mechanisms underlying those relationships; this is a significant limitation and a primary motivation for the present research.

4.4.2 Limited evidence regarding POS 'greenness'

Despite indications that quality attributes might influence POS usage, as well as the extent to which this resource could promote social integration and restoration from stress, only a handful of studies have attempted to verify the effects of POS quality on mental health. Here, the focus appears to have moved towards composite assessments of (a) various tangible

facilities and amenities or (b) various desirable impressions or qualities, without truly understanding the importance of simple structural attributes such as size and the level of vegetative cover.

These remain fundamental and policy-relevant questions with specific, quantifiable and readily available spatial indicators[58] and operationally feasible implications for urban planning (Byrne and Sipe, 2010, Villanueva et al., 2015, Jennings et al., 2016). For instance, whereas many studies assess the total quantity of POS in the living environment, few have distinguished whether POS is concentrated in a few large areas, or dispersed across many smaller areas, and how this might influence the observed relationships. In this respect, questions of POS size and accessibility are intimately linked, and speak to the favourability of equitable (even distribution of many smaller spaces, designed to minimise the costs of usage to all individuals) versus efficient (less evenly distributed but larger spaces, designed to maximise overall usage) allocation principles in determining the optimal location, size, and spacing of POS within a neighbourhood- or city-wide network (McAllister, 1976, Oh and Jeong, 2007). It is not, however, within the purview of this thesis to consider the intricacies of POS allocation.

Rather, as foreshadowed throughout the exposition of the conceptual underpinnings of this research, the thesis focuses on the role of relative POS 'greenness' as a potentially causally relevant quality attribute. To date, most studies exploring the effects of relative 'greenness' in the local residential area neglect to use objectively derived measures, and conflate natural stimuli situated within POS with other sources of neighbourhood greenness. For instance, measures of 'greenness' employed in previous studies do not differentiate between public (e.g. vegetation in public parks) and private greenness (e.g. vegetation in privately owned yards), even though the latter may contribute significantly to the aesthetic value of the neighbourhood, provide more immediate green views from the home, and influence wellbeing independently of the characteristics of public land (De Vries et al., 2003, Stigsdotter and Grahn, 2004, Nielsen and Hansen, 2007, Sugiyama et al., 2008, Kardan et al., 2015, Weimann et al., 2015). These sources of 'greenness' are also likely to derive from different spatialising processes; whereas public greenness may find its provenance in top-down processes (i.e. urban planning

[58] This is in contrast with measures of quality pertaining to the provision of facilities and amenities and general impressions of aesthetics, maintenance, and safety, which are inconsistently collected; difficult to source; expensive to acquire for large geographical areas; and prone to temporality issues.

policy), private greenness is likely to arise through bottom-up processes (i.e. the cultivation of vegetation by individual households). 'Private' greenness is therefore more likely to cluster in affluent neighbourhoods and less amenable to direct intervention through public policy.

4.4.3 Limited evidence regarding positive dimensions of mental health

As discussed previously, the two continua model suggests that positive and negative dimensions of mental health may follow different developmental trajectories and relate differently to attributes of the individual and the environment (Greenspoon and Saklofske, 2001, Keyes, 2007, Westerhof and Keyes, 2010). For instance, qualitative research indicates a perception among residents of Toronto, Canada, that natural elements of the residential environment (such as parks and green areas) are highly beneficial for the promotion of positive mental health but much less important in preventing psychological distress (O'Campo et al., 2009). Despite this, quantitative studies of the association between POS and mental health have generally failed to investigate, concurrently, the effects of these neighbourhood resources on both positive and negative dimensions of mental health. Despite this, quantitative studies of the association between POS and mental health focus overwhelmingly on negative manifestations of poor mental health (stress, psychological distress, mental disorder). Fewer studies have addressed the question of whether POS promotes positive dimensions of mental health, such as life satisfaction, and only one study has assessed positive and negative outcomes concurrently (White et al., 2011). This discrepancy is particularly striking when considering the near absence of consideration for positive mental health outcomes in relation to the effects of POS quality, or in assessments of the explanatory mechanisms linking POS to mental health; these questions have only been assessed among older adults (Sugiyama et al., 2009) and in a comparative study of two neighbourhoods that might be especially prone to residual confounding (van Herzele and de Vries, 2012).

4.4.4 Explanatory pathways: scope of measures and constructs

Although attention is increasingly turning to identification of the explanatory pathways linking POS and mental health, this research has primarily focused on explaining the influence of POS availability. For instance, no study has yet assessed the influence of relative POS 'greenness' (or indeed broader measures of neighbourhood 'greenness') in relation to a stress-buffering mechanism. A handful of studies have attempted to identify the indirect (mediated)

effects of 'greenness' on mental health, but these conflate natural stimuli situated within POS with other sources of neighbourhood vegetation (see Section 4.4.2).

While numerous studies have investigated indirect effects of POS via cognitive dimensions of neighbourhood social integration (e.g. social cohesion), social contacts within and/or outside of the neighbourhood, and perceptions of support from broader social networks, there has been a noteworthy lack of attention to the role of coping abilities in explaining associations with mental health. This is somewhat surprising given the emphasis that is so frequently placed on stress reduction and attention restoration mechanisms in forming the rationale and discussion for attention to POS as a population health resource. There also remains scope to assess mediation by functional behavioural manifestations of neighbourhood social integration, such as the localised exchange of support (neighbouring behaviour) or formal participation in community affairs (community participation), and particularly to test these pathways against perceptions of the local social environment (social cohesion).

These are distinct but interrelated forms of local social capital (Perkins and Long, 2002) that might relate to neighbourhood POS and mental health via distinct pathways. For instance, neighbouring behaviour might be most responsive to increased contact and interaction between residents and the formation of neighbourhood social ties, whereas community participation might rely less on interpersonal contact and more on emotional attachments to the neighbourhood, which motivate efforts to improve it (Manzo and Perkins, 2006). These behavioural manifestations of social participation are hypothesised to promote mental health through the formation of protective support networks and a sense of power and agency in affecting change in the neighbourhood (Blair et al., 2014). By contrast, social cohesion might be closely linked to feelings of place attachment or the perception of an identifiable community character as well as investment in local relationships (Kim and Kaplan, 2004, Long and Perkins, 2007, Völker et al., 2007) and is thought to impact the potency of those relationships through an increased sense of trust and reciprocity (Blair et al., 2014). These distinctions lend theoretical interest to understanding which dimensions of neighbourhood social integration explain associations with mental health and speak to the benefits of testing competing pathways within a particular piece of research.

5 Research aims and analytic models

The theoretical frameworks of stress, psychosocial restoration, and biophilia present a compelling basis for the assertion that access to natural scenery could promote social and psychological wellbeing among residents of urban environments. Accordingly, I have argued throughout this chapter that the relative 'greenness' of public open spaces may be a causally relevant quality attribute influencing their salutogenic potential. Advancing our understanding of the spatial characteristics and psychosocial mechanisms that explain the contribution of POS to the creation of therapeutic urban landscapes has important implications for urban planning and public health policy seeking to leverage their health benefits. This knowledge could, for instance, assist policymakers to dictate the physical attributes required of POS; to direct POS interventions towards populations likely to benefit the most due to their standing on causally relevant variables relating to stress exposure, coping, or social integration; and to integrate these into synergistic and effective packages of area-based interventions. This thesis therefore seeks to further understanding of the causal relationships between urban residential public open space (POS) 'greenness' and mental health, through the analysis of prospective, individual-level associations with the research aims outlined in Table 2.|

Table 2: Research aims

Research aims		Key study	Key chapter(s)
1	To evaluate whether POS 'greenness' exerts a protective 'stress-buffering' effect against the potential psychological harm of acutely stressful life events	1	5
2	To evaluate whether POS 'greenness' exerts a 'main' salutogenic effect independently of exposure to acutely stressful life events	2	6
3	To evaluate the mediating role of psychosocial resources at three levels – within the individual, within the neighbourhood social environment, and within broader social networks – in explaining prospective associations between POS 'greenness' and mental health	2	6
4	To explore whether these findings differ according to the dimensionality (positive or negative) of the mental health outcome under consideration	1, 2	5, 6

These aims are addressed across two studies, for which the analytic models to be tested are presented below in Figure 3 (p.73) and Figure 4 (p.76). Each model is nested within the broader theoretical framework presented earlier in this chapter (Figure 2, p.16) in order to contextualise the constructs of interest within the broader system of influences on mental health. Components of the framework that are not central to the study in question are greyed out, although it should be noted that all analyses account for a range of socio-demographic characteristics at the individual- and area-levels that have the potential to confound the key associations of interest. Note also that whereas the underlying theoretical framework acknowledges the reciprocal nature of relationships among stressors, RPSF, and mental health outcomes, this thesis considers only unidirectional effects – from stressors to mental health, and from broader to narrower domains of the social ecology of RPSF. The assumed direction of causality is implied by the ordering of constructs in accordance with the passage of time, from left to right, and assessed within a longitudinal framework that enforces this temporal order (as detailed shortly in Chapter 3). The model is operationalised at the individual level, employing objective, participant-centred measures of POS characteristics linked to three waves of geocoded data from a psychiatric epidemiological cohort in a metropolitan region of Montréal, Canada.

5.1 Analytic model: Study 1

The aspects of the analytic model presented in Figure 3 on the following page illustrate the proposed role of POS 'greenness' as a moderator of the stress process. This figure addresses Aims 1 and 4 of this thesis and serves as the basis for analyses presented in Chapter 5. The red arrow from 'acute events' to 'mental health' illustrates the documented aetiological link between stressful life events and adverse psychological outcomes (e.g. Kendler et al., 1999). The blue arrow illustrates the proposed stress-buffering effect of POS 'greenness', indicating that the effects of acute stressors might differ depending on the level of this resource. Study 1 estimates longitudinally, across a four-year period, the effects of accumulated stressful events on trajectories of change in mental health, then tests whether residential POS 'greenness' moderates this relationship (Aim 1). The proposed stress-buffering effects are tested in relation to two mental health outcomes – reflecting change in a negative dimension of mental health (psychological distress) and a positive dimension of wellbeing (life satisfaction) – to explore their consistency across distinct dimensions of mental health (Aim 4).

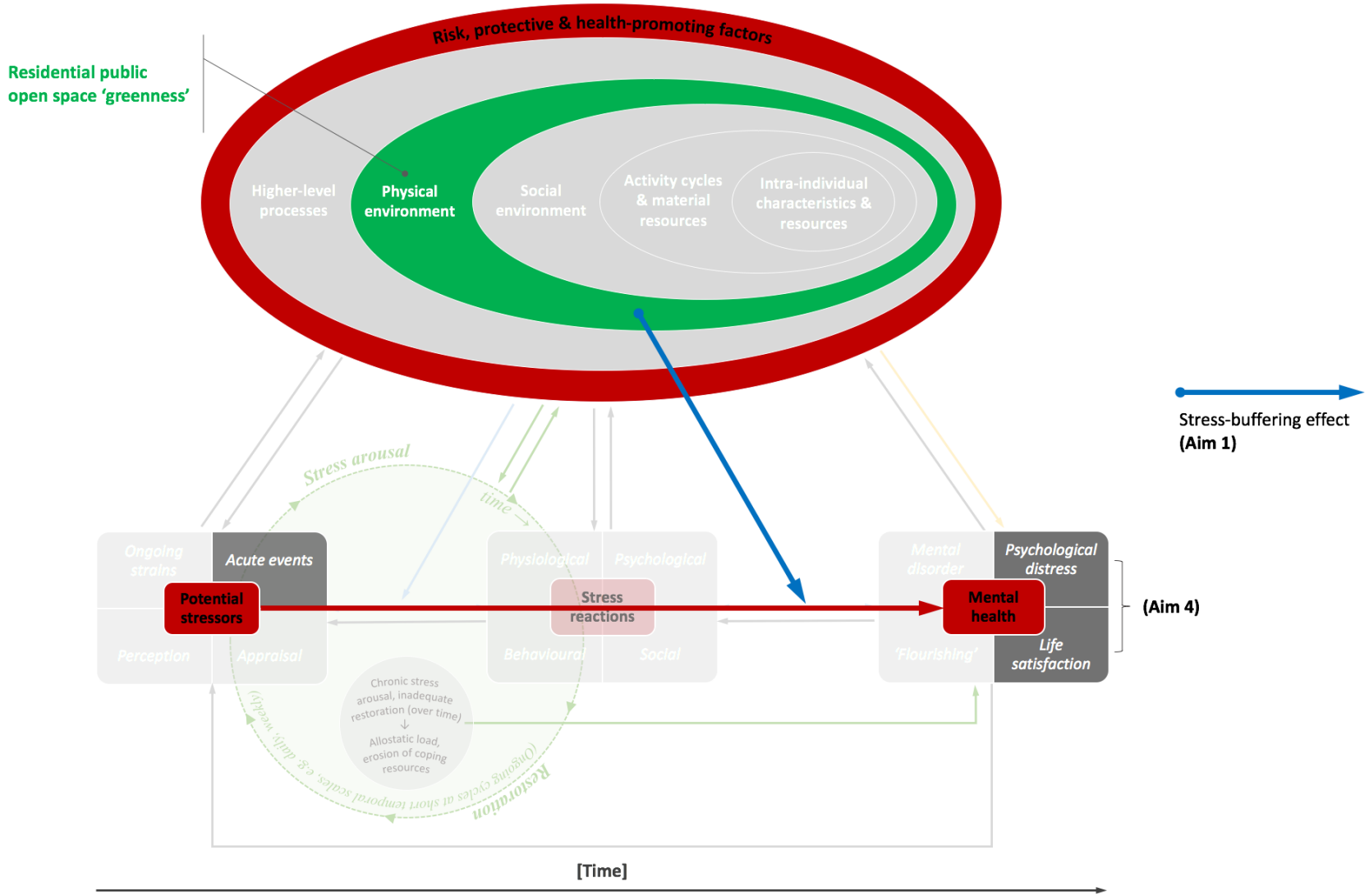


Figure 3: Analytic model to be tested in Study 1, depicting the proposed 'stress-buffering' effect of public open space 'greenness' in relation to the effects of stressful life events on positive and negative dimensions of mental health (arising from the conceptual framework presented on page 16).

5.2 Analytic model: Study 2

The aspects of the analytic model presented in Figure 4 (page 76) illustrate the proposed main salutogenic effects of POS 'greenness', operating independently of the effects of stressful life events. This figure addresses Aims 2, 3 and 4 of this thesis and serves as the basis for analyses presented in Chapter 6. A yellow arrow from 'physical environment' to 'mental health' depicts the proposed 'main' effect of POS 'greenness' on prospective trajectories of mental health (Aim 2). The figure also illustrates, with dashed arrows, the proposed mechanisms of mediation by features of the 'social environment' and 'intra-individual resources' (Aim 3). These indirect effects suggest a chain of relations in which an intermediary variable transmits – wholly or partially – the effect of one variable onto another (MacKinnon et al., 2007). In other words, Study 2 tests whether features of the 'social environment' or 'intra-individual resources' comprise part of a causal sequence between POS 'greenness' and mental health (Aim 3). As described in relation to Study 1, above, the total and indirect effects of POS are assessed longitudinally in relation to prospective changes in both psychological distress and life satisfaction to explore their consistency across distinct dimensions of mental health (Aim 4).

Features of the 'social environment' are measured in relation to (1) neighbourhood social integration and (2) the perceived availability of support from broader social networks, i.e. those not necessarily centred within the neighbourhood. In turn, neighbourhood social integration is measured along three dimensions that may be influenced by physical context to varying degrees, and through varied pathways at differing levels of abstraction (Perkins and Long, 2002). The first measure, *social cohesion*, is a cognitive dimension of neighbourhood social integration that reflects a sense of community, trust and unity among residents, of shared norms and values, and of acceptance and belonging. Social cohesion may develop from the motivation and opportunity to invest in local relationships, but also from spatially-oriented feelings of place attachment and the perception of an identifiable community character (Kim and Kaplan, 2004, Long and Perkins, 2007, Völker et al., 2007). *Neighbouring behaviour*, on the other hand, involves the highly localised and informal exchange of instrumental, functional, informational, or personal forms of social support (Farrell et al., 2004) and might be driven to a greater extent by actual contact and interaction between residents and the formation of neighbourhood social ties. Finally, *community participation* reflects a more formal set of neighbourhood-based behaviours such as purposeful engagement with local

organisations and decision-makers. This behaviour may be driven to a lesser extent by interpersonal contact, and more so by emotional attachments to the neighbourhood that motivate efforts to improve it (Manzo and Perkins, 2006). Consistent with the measurement of POS characteristics within individually defined areas, measures of neighbourhood social integration are also operationalised as individual-level (rather than collective) constructs. The availability of support from broader social networks is similarly conceptualised as the extent to which the individual perceives their current social relationships (not necessarily located within the neighbourhood) to provide a range of support functions. Finally, 'intra-individual resources' are measured in relation to the individual's perceived ability to cope with day-to-day demands or unexpected and difficult events.

6 Summary

The narrative review of literature presented in this chapter has integrated existing theories of stress, psychosocial restoration, and biophilia into a conceptual framework describing possible mechanisms by which public open space might influence the mental health of residents in urban environments. It has identified an opportunity for a greater focus on the relative 'greenness' of POS as a potentially causally relevant characteristic of these spaces; a need for further longitudinal research to strengthen the basis for causal inference, particularly in studies assessing mediation by psychosocial resources; and a lack of attention to the influence of POS on positive dimensions of mental health, such as life satisfaction. Based on this review, the chapter has described the research aims of this thesis and presented the analytic models to be tested.

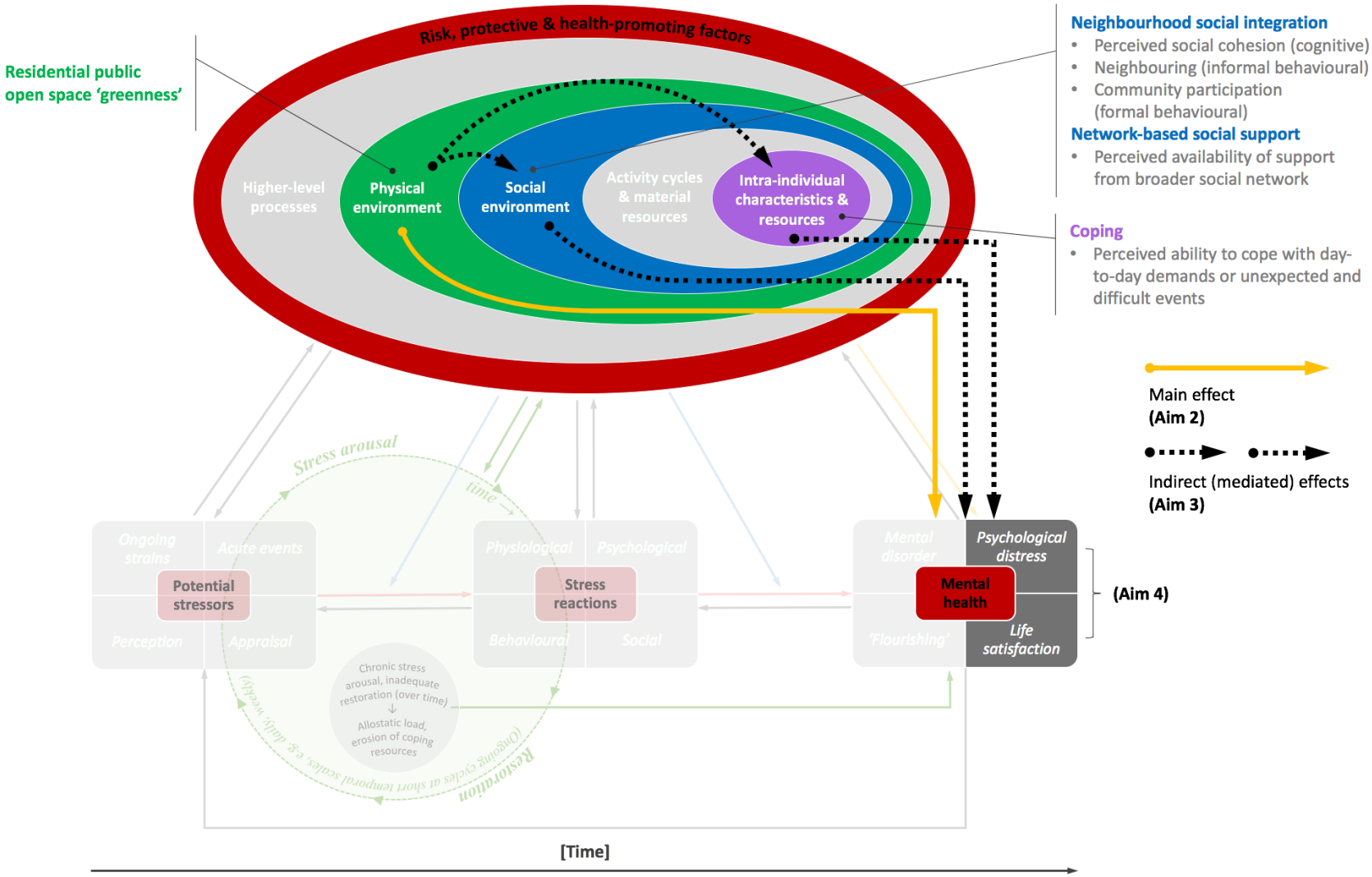


Figure 4: Analytic model to be tested in Study 2, depicting the proposed 'main' effect of residential public open space 'greenness' on positive and negative dimensions of mental health, operating independently exposure to acute stressors and mediated through the social environment and intra-personal resources, over time (arising from the conceptual framework presented on page 16).

CHAPTER 3
Methodology

1 Introduction

This chapter details the research method of this thesis, including a description of the setting and context within which the study takes place (Section 2); sampling and recruitment procedures, including the extent of sample losses due to attrition and exclusion and the sociodemographic alignment of the final sample to the study region population (Section 3); and an analysis of potential sources of bias due to selective participation and sample losses (Section 4). The following sections focus on the data sources (Section 5) and measures (Section 6) used to capture the constructs of interest in this study, and the treatment of missing data (Section 7). The chapter concludes with a brief overview of the temporal design (Section 8) and data analysis procedure (Section 9). Specific details pertaining to the analysis are presented in Chapters 4 to 6.

2 Setting and Context

This thesis presents a secondary analysis of data collected as part of a research program to establish a psychiatric epidemiological catchment area (ECA) in the south-western region of Montréal, Québec, Canada. The *Zone d'Épidémiologie Psychiatrique du Sud-Ouest de Montréal* (ZEPSOM) encompasses the four boroughs of Saint-Henri/Pointe St-Charles, Lachine/Dorval, Lasalle, and Verdun (Figure 5, p.79). There were 269,720 people living in this zone at the time of recruitment; around 15% of the population of Montréal Island, and 7% of the population of Greater Montréal (Statistics Canada, 2007, 2012b). The establishment of the ZEPSOM was funded by a Canadian Institutes of Health Research (CIHR) team grant in 2006 (#154150) and a CIHR operating grant in 2011 (#245417). The project was approved by the Douglas Mental Health University Institute Ethics Committee in accordance with the Canadian Tri-Council Guidelines (Appendix 3.1). A geographically representative cohort of residents aged between 15 and 69 was recruited from the study region and interviewed in 2007-8 (T1; n=2433), then reinterviewed in 2009-10 (T2; n=1822) and 2012-13 (T3; n=1304).



Figure 5: The Zone d'Épidémiologie Psychiatrique du Sud-Ouest de Montréal (ZEPSOM)

The ZEPSOM research program was initiated with specific objectives to investigate the impact of physical, social, and economic aspects of neighbourhoods on mental health, and to examine the interactions between individual determinants and neighbourhood ecology in shaping mental health outcomes (Caron, 2012b). This research program is the first longitudinal epidemiological catchment area study of mental health in Canada, and the first epidemiological catchment area study in North America to utilise a geographic information system (GIS) that allows the linkage of individual-level health measures to detailed information on residential environmental risk conditions and accessibility to resources (Caron et al., 2007, Caron, 2012b). Individual surveys containing validated measures of a broad spectrum of mental health outcomes, social and psychological resources, neighbourhood perceptions, service use, and the experience of stressful events, were geocoded and integrated with a comprehensive GIS developed for health research in the Montréal region (MEGAPHONE: *Montréal Epidemiological and Geographic Analysis of Population Health Outcomes and Neighbourhood Effects*) (Daniel and Kestens, 2007).

A GIS is an automated system for the storage, retrieval, and analysis of spatial data (Clarke, 1990), within which layers of information are linked using geographic location as a common identifier. MEGAPHONE contains a wide range of spatial databases and analysis tools necessary for characterising neighbourhoods in terms of social, built, and physical environmental exposures (including a public open space database) and analysing these in relation to health outcomes. Although this thesis makes use of secondary data from the ZEPSOM epidemiological catchment area study, an original effort was made by the candidate to (a) validate a spatial database of public open spaces within the study region and (b) link this information, via the residential locations of individual participants, to the survey measures existing within the ZEPSOM database. Combining geo-coded individual surveys with a GIS is an optimal strategy to situate mental health in an ecological system with multidimensional influences, permitting investigation of the contribution of environmental living conditions to mental health outcomes while controlling for individual-level risk and protective factors.

The south-west sector of Montréal offers interesting characteristics for the establishment of an epidemiological catchment area. According to the 2006 Canada Census (Statistics Canada, 2006) the proportion of low-income households (36%) in the region is greater than that in the whole province of Quebec (23%), but equivalent to that of Montréal (35%), which has a high poverty rate in comparison with other large Canadian cities. The region is home to a large number of immigrants (17%), although less than that of Montréal generally (26%). Within the region, sociodemographic composition is varied and neighbourhoods exhibit distinct profiles (Caron et al., 2007). For instance, in Saint-Henri and Pointe-Saint-Charles, close to half of households live under the low-income threshold and over a quarter receive social assistance. In contrast, in the neighbourhoods of Lachine or LaSalle, little over a quarter of the population live under the low income threshold and fewer than 10% receive social assistance. The distribution of POS also differs somewhat across neighbourhoods, with Saint-Henri and Verdun exhibiting particularly dense coverage of POS both within their borders and in the immediate surrounds (Figure 6, p.82). The zone therefore offers a sufficient level of diversity to allow inter-neighbourhood comparisons in the study of contextual risk and protective factors for mental health.

The ZEPSOM study is undertaken in partnership with all institutions and community organisations offering mental health services in the region, and brings together a committee of researchers, policy makers, and stakeholders to guide the development and transfer of

knowledge from the catchment area to aid policy development and program planning for mental health promotion. The interdisciplinary nature of the research team and committee stands to enrich understanding of the complex interactions that contribute to mental health.

3 Sampling, recruitment, and the final sample

This section outlines the sampling procedure for this study. It begins by outlining the sampling frame (Section 3.1) and the execution of a stratified random sampling plan to recruit a geographically representative cohort of participants from the ZEPSOM epidemiological catchment area (Sections 3.2 and 3.3). It then details losses of participants across the second and third waves of data collection (Section 3.4), including the imposition of post-hoc exclusion criteria to ensure the suitability of the final sample for the research questions being addressed (Section 3.5). Lastly, it describes the sociodemographic composition of the final sample and compares this against the population of the study region as a whole (Section 3.6).

3.1 Sampling frame

The study was restricted to persons aged between 15 and 69 years and residing in the geographically delimited ZEPSOM study region. This region housed a total population of 269,720 people in 2006, including 198,585 inhabitants aged 15 to 69, across the four boroughs of Saint-Henri/Pointe-St-Charles (29,680), Lachine/Dorval (42,850), Lasalle (53,635) and Verdun (72,420) in South-Western Montréal (Caron, 2012a). The region comprised 468 inhabited Census Dissemination Areas[59] with an average population of 422 people aged between 15 and 69 (standard deviation: 161), themselves nested within 75 Census Tracts with an average population of 2,648 people aged 15 to 69 (standard deviation: 1,251) (Statistics Canada, 2006).

[59] Census Dissemination Areas (DA) are the smallest census units for which compositional socioeconomic data are available. There were 470 DAs in the catchment area, of which 468 were inhabited with an average population of 422 people aged 15 to 69 in 2006 (standard deviation: 161) (Statistics Canada, 2006).

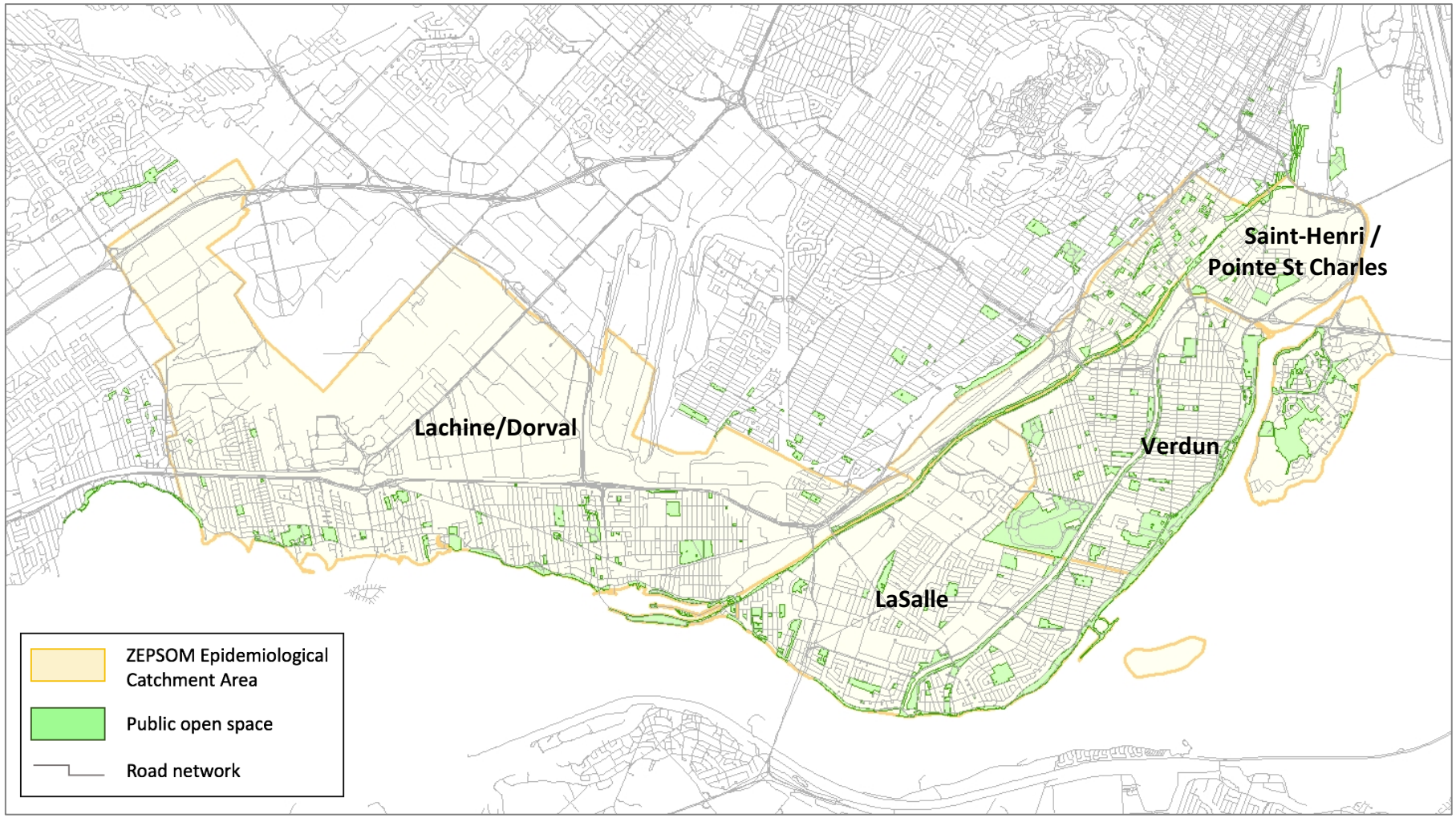


Figure 6: Public open spaces within the ZEPSOM Epidemiological Catchment Area (the 'study region') and immediate surrounds

3.2 Stratified sampling plan

The ZEPSOM was established with a specific objective to investigate the effect of residential environmental attributes on mental health. It was therefore important to obtain a sample that was representative of the study region not only with regards to its socio-demographic profile, but also with regards to the spatial distribution of residents across neighbourhoods and, accordingly, exposure to different environmental living conditions. A stratified sampling plan was built to recruit participants proportionally to the population of 15 to 69 year olds within each Dissemination Area (DA), in order to achieve a sample that was representative with regards to geographic location, population density, and socioeconomic status (SES) based on the educational attainment structure of the territory (Caron, 2012b). Recruitment targets were set at 600 participants per borough.

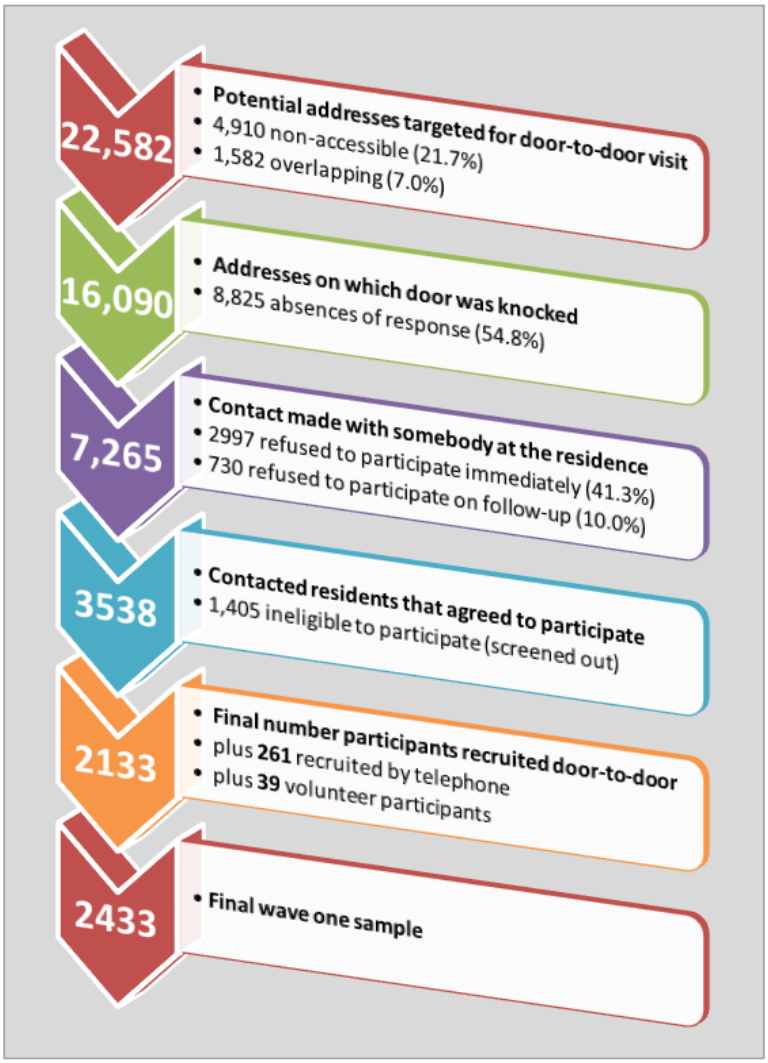
A 2004 City of Montréal valuation role provided a list of 132,194 residential dwelling units across the study region, and a random sample of dwelling addresses was drawn from within each DA. The number of addresses selected within each DA was proportional to its population, and inversely proportional to expected participation rates on the basis of DA-level SES, in accordance with previously observed participation rates for the Canadian Community Health Survey (Kestens et al., 2012). Specifically, DAs were classified into tertiles based on the proportion of inhabitants with a university degree, where expected participation rates were 70% for DAs in the highest education tertile, 65% for those in the median tertile, and 60% for those in the lowest education tertile. This process resulted in a total shortlist of 3,708 target addresses. For each target address, one adult resident was randomly selected for recruitment.

3.3 Recruitment to baseline (T1) interview

A private company was hired to obtain telephone contact information and provided landline phone numbers for 1,581 of the 3,708 shortlisted addresses (42.6%). Using this list, 261 participants were recruited by telephone between April and October of 2007. However, in response to low participation rates using this approach, the telephone recruitment campaign was terminated in favour of a door-to-door on-site recruitment campaign. To maximise the efficiency of the door-to-door recruitment campaign, the original shortlist of addresses was expanded to establish a list of targeted address ranges. Each address range included the initial target address plus up to thirteen neighbouring properties, including the three directly either

side of the target address and seven on the opposite side of the road. This approach offered a higher probability of recruiting a participant within the address range, because each initial target address now offered a 'pool' of up to fourteen recruitment opportunities. Recruiters visited the target address first, then worked systematically through the address range until either a participant had been recruited or all fourteen addresses had been visited. To achieve a geographically representative sample of the study region, recruitment numbers within each DA were restricted based on their population size and the target of 600 participants per borough.

Figure 7: Recruitment of the ZEPSOM wave one sample



Address ranges linked to the 261 participants already recruited by telephone were excluded from the door-to-door campaign. In addition, the study saw 39 'atypical' recruitments, resulting from direct volunteering to the study by people living in the study region. In most cases, these were acquaintances of participants recruited through the telephone and door-to-door campaigns. Their addresses were matched to the closest targeted address range in the door-to-door recruitment shortlist, and recruitment for this address range was considered complete. Of the 39 atypical recruits, 14 were living within a targeted address range and 25 were living outside, but close to, a targeted address range. Among those outside a targeted address range, the mean distance to the nearest target was 106 meters (SD=213 meters).

Discounting the 261 phone recruitments and 39 atypical recruitments from the initial shortlist of 3,708 addresses, 3,408 target addresses were converted into address ranges for the door-to-door recruitment campaign. The theoretical potential number of doors to be visited was 47,712 (= 3,408*14) (Caron, 2012b). Altogether, door-to-door recruiters attempted to visit 22,582 addresses. Among these, 4,910 addresses were not accessible; either because they did not exist or because security measures physically prevented access to the door. In addition, there was some overlap in the address ranges defined by the initial list of target addresses. In 1,582 cases, a residence was found to exist in two address ranges and was visited only once in order to avoid double recruitment. Altogether, recruiters knocked on 16,090 doors (=22,582 - 4,910 - 1582). In 8,825 cases this resulted in an absence of response (absence rate = 54.8%).

Among 7,265 cases in which contact was made with a person at the residence, 3,727 people (51.3%) refused to participate in the study either immediately at first contact (80.4%) or later upon follow-up for interview confirmation (19.6%). The remaining 3,538 contacted persons agreed to participate. Of these, 1,405 (39.7%) were found to be ineligible after screening, and 2,133 completed the interview. Accordingly, the minimum response rate (RR1) from the door-to-door campaign, i.e. the proportion of knocked doors that resulted in completion of an interview, was 13% (American Association for Public Opinion Research: AAPOR, 2011):

$$RR1 = \frac{\mathrm{N}_{\mathrm{complete}}}{\mathrm{N}_{\mathrm{complete}} + \mathrm{N}_{\mathrm{immediate\ refusal}} + \mathrm{N}_{\mathrm{refusal\ on\ follow\ up}} + \mathrm{N}_{\mathrm{no\ contact}}}$$

Thus, recruiting one person required knocking on an average of 7.7 doors. The cooperation rate (CR1) for the door-to-door campaign, i.e. the proportion of completed interviews among people who were contacted and eligible to participate, was estimated at 42% (AAPOR, 2011):

$$CR1 = \frac{N_{complete}}{N_{complete} + e\left(N_{immediate\ refusal}\right) + N_{refusal\ on\ follow\ up}}$$

where *e* is the estimated proportion of cases of unknown eligibility (immediate refusals that did not complete the screener) that were in fact eligible to participate in the study. This eligibility rate was estimated from 2006 census data as the proportion of residents in the

ZEPSOM region aged between 15 and 69 (=74%) (Smith, 2009, AAPOR, 2011). Area-level characteristics associated with study participation are discussed later in Section 4.1.

Overall, the ZEPSOM recruitment phase yielded a total sample of 2,433 participants, comprising 2133 door-to-door recruits, 261 telephone recruits, and 39 volunteer recruits. These participants were interviewed between April 2007 and October 2008 (T1). The distribution of participants across the study area closely matched initial recruitment targets, with approximately 600 participants in each borough (Saint-Henri/Pointe St-Charles n=612; Lachine/Dorval n=602; LaSalle n=585; Verdun n=634) and at least one participant in 467 of the 468 inhabited DAs (mean 5.2 participants per DA, SD 2.62).

3.4 Follow-up to second (T2) and third (T3) interviews

The second wave of ZEPSOM data collection (T2) was completed between June 2009 and November 2010 and the third wave (T3) between January 2012 and July 2013. In both cases, all participants who had completed the previous wave of data collection were contacted by telephone and invited to take part in another interview. Where telephone contact failed, various alternative communication avenues including email, postal communication, and telephone calls to relatives were used to recontact as many participants as possible. However, in order to preserve the geographic delimitation of the catchment area, participants were ineligible to continue in the study if they were residing outside the ZEPSOM region when recontacted.

Of the 2433 participants who completed a T1 interview, 1822 went on to complete the interview at T2 (attrition from T1: n=611, 25.1.%) and 1304 completed the interview at T3 (attrition from T2: n=518, 28.4%). The loss of participants was largely attributable to the relocation of participants outside the study region. As illustrated in Figure 8 (p.87), the rate of attrition due to refusal was low (T2 n=138, 5.7%; T3 n=135, 7.5%). Many more participants were lost because they left the region (T2 n=230, 9.5%; T3 n=236, 13%) or could not be contacted despite efforts through multiple communication channels (T2 n=231, 9.5%; T3 n=137, 7.5%). Less than 1% of participants at each wave of follow-up were identified as having died (T2 n=12, 0.5%; T3 n=10, 0.5%). Individual- and area-level characteristics associated with loss-to-follow up, and their implications for potential selection biases, are discussed in Section 4.2.

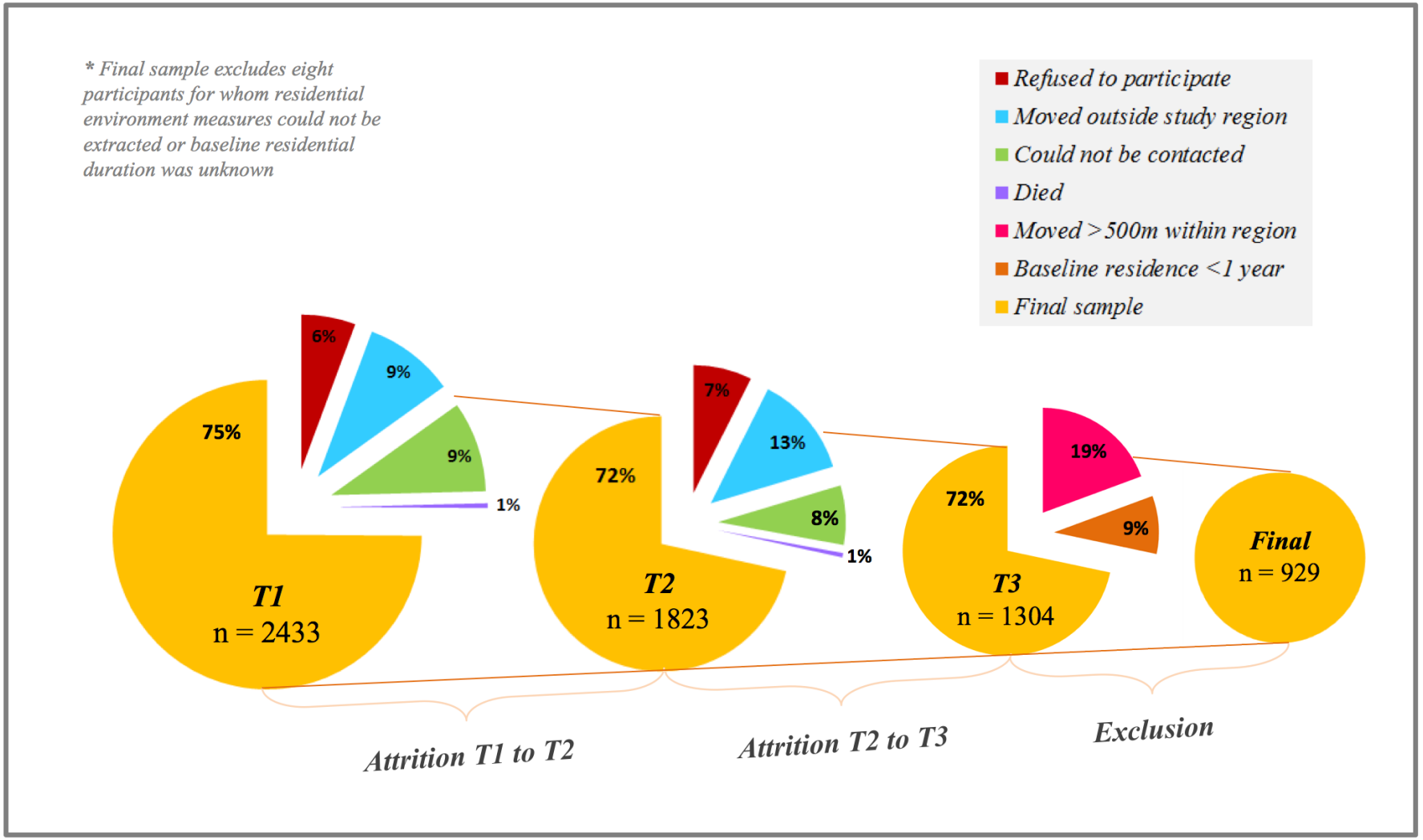


Figure 8: Final sample size and sources of sample loss arising from attrition and exclusion criteria

Follow-up interviews among those who were willing and eligible to continue in the study were scheduled as close as possible to two years from the date of their last interview. For participants in the final sample (described in s.3.6) the average length of time between T1 and T2 interviews was 22 months (mean 655 days; SD 81 days). The time lag between T2 and T3 interviews was typically longer, with an average interval of 29 months (mean 869 days; SD 116 days). Overall, the total observation period for these respondents averaged four years and two months (mean 1524 days; SD 143 days) with a minimum of three years and four months and a maximum of five years and ten months (Figure 9).

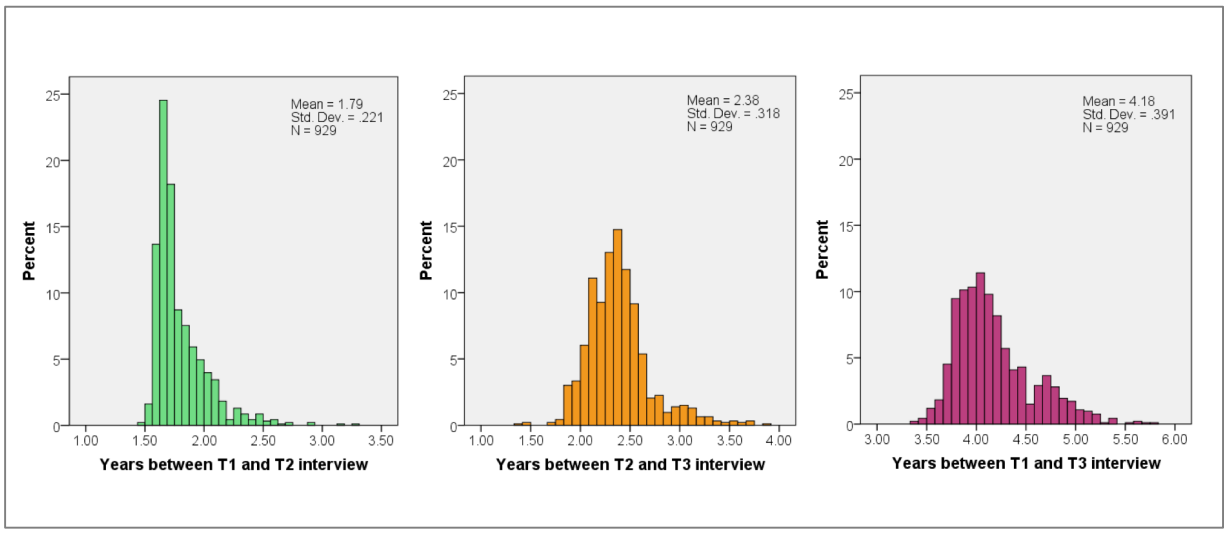


Figure 9: Number of years between first, second and third interviews among final participants (n=929)

3.5 Post hoc exclusion of residentially mobile participants

As already mentioned, ZEPSOM participants were ineligible to continue in the study if, at the time of follow up, they were residing outside the delimited study region. On the other hand, those who relocated to a residence within the study region remained eligible to participate. Due to the nature of the research questions addressed in this thesis, and the relatively small scales at which environmental exposures were assessed, it was deemed necessary to impose further post hoc exclusion criteria to address issues arising from residential mobility. In brief, the exclusion criteria were intended to avoid situations in which (a) baseline measures of POS exposure no longer adequately reflected the participant's residential environment at the time of follow-up, or (b) the participant had lived at their

baseline address for an insufficient length of time to reasonably assume that POS exposures might have affected other variables measured at T1. Altogether, 375 (28.7%) of the 1,304 participants who completed a T3 interview were excluded from the final sample for these reasons. Contributions of the exclusion criteria to sample losses were illustrated graphically in Figure 8 (p.87) alongside sources of attrition. The following sections describe the criteria that were imposed. Individual- and area-levels predictors of exclusion from the final sample are detailed later, in Section 4.2.

3.5.1 Exclusion criterion (a): residential relocation within the zone

As will be described in Section 6.1, POS exposures in this study were defined for the participant's baseline (T1) residential address using objective data at two spatial scales, namely a 500-metre and a 1000-metre pedestrian road network buffer. This approach is based on an assumption that the POS characteristics under investigation (location, size, and greenness) remain highly stable in the medium term; accordingly, baseline measures of POS exposure should adequately reflect the participant's local area over a period of several years, provided that the participant does not relocate. This is a common assumption in longitudinal research of POS and mental health (see e.g. White et al., 2013, Krekel et al., 2016).

For this reason, participants were excluded from the final sample if their residential address at the time of T2 or T3 data collection was further than 500 metres along the pedestrian road network from their T1 address. Hypothetically speaking, an updated 500-metre buffer for a participant who has moved 500 metres would exhibit approximately 50% overlap with the buffer around their initial address. The threshold for this exclusion criterion therefore achieves a reasonable compromise between maintaining geographic authenticity in measures of POS exposure and the need to retain statistical power by preserving sample size. Of the 1,304 participants who completed a T3 interview, 251 (19%) were excluded from this study because they had relocated further than 500 metres from their baseline address. The median distance moved by individuals excluded from the sample was 2344 metres with first and third quartiles at 1192 and 4357 metres, respectively.

3.5.2 Exclusion criterion (b): insufficient residential tenure at baseline

A further 116 (8.9%) participants were excluded because they had resided at their baseline address for less than one year prior to the first occasion of data collection. This restriction was deemed necessary for a number of reasons. First, on conceptual grounds, it allows a

reasonable period of time within which POS exposures might exert a causal effect on the availability of psychosocial resources (Little et al., 2007). These variables were measured contemporaneously at T1, but it is implausible to presume that the proposed associations (particularly between POS 'greenness' and behavioural factors such as neighbouring or community participation) would unfold instantaneously (Macintyre et al., 2002). In this respect, a conceptually sound approach to data analysis requires some temporal lag between exposure and outcome, and a twelve-month period was chosen to maintain consistency with prior studies relating public open space to health outcomes (De Vries et al., 2003, Astell-Burt et al., 2014b). This exclusion criterion was also implemented in order to ensure some element of stability in residential exposures leading into the first assessment of mental health outcomes. Excluding recent movers helps to avoid confounding by unobserved reasons for the move, for instance conditions including, or likely to precipitate, a decline in mental health. Moreover, we did not possess complete information regarding the prior addresses of individuals who had recently moved, and therefore could not ascertain whether these participants had relocated from a 'greener' or 'less green' area, and how this would influence the effects of the current residential landscape on unfolding trajectories of mental health.

Six participants who did not report how long they had been living at their baseline address, and two participants for whom residential environment measures could not be extracted from the GIS, were also excluded from the sample. This resulted in a final sample of 929 participants (Figure 8, p.87). Overall, residential mobility proved to be a significant hindrance to the retention of participants in this study. In total, 29% (n=717) of the initial baseline sample was lost due to residential relocation within or outside the ZEPSOM region during the study. A further 5% of otherwise eligible participants (n=122) were lost because they had changed residence within a one-year period prior to commencement of the study, while 15% (n=368) could not be recontacted; many of whom, presumably, had also moved house. Of the participants excluded for moving within the study zone, half (n=130, 52%) had already moved more than 500m by the second wave of data collection.

3.6 Final sample composition and representativeness

Altogether, 929 (38.2%) of the 2433 participants recruited at T1 were retained in the final sample, while 1139 (46.8%) did not complete all three interviews (Section 3.4), and a further 375 (15.4%) were excluded from the analysis (Section 3.5). Participants were retained from

each of the 74 census tracts and 392 of the 467 census dissemination areas originally sampled. The loss of representation among some DAs is unsurprising given that 52 (11%) contained only one or two participants at T1. Table 3 (p.92) compares the sociodemographic composition of the study region population at the 2006 Canada Census (Statistics Canada, 2006) to that of the cohort at each wave of data collection and following the imposition of final exclusion criteria. All variables are reported at their T1 values to avoid conflating the effects of selective attrition (see Section 4.2) with other anticipated transitional processes (e.g. aging, marriage/divorce, or educational attainment) throughout the study. Time-specific values of these variables among the final sample are presented later in Table 22 (Section 6.6, p.137).

Representativeness of the final sample was assessed against characteristics of the catchment area population using chi-square tests for the difference in two proportions within WinPEPI (Abramson, 2011). Chi-square statistics were adjusted for the clustering of individuals within census tracts through the use of design effects, also known as variance inflation factors, as suggested by Wears (2002). The design effect represents the analytic efficiency of clustered designs and is used to adjust statistics naively generated under the assumption of independence. The design effect was calculated as a function of the Intra-Class Correlation (ICC) coefficients for each variable, which quantifies the proportion of the total variability attributable to between-cluster variations. The ICCs were estimated using two-level random intercept multi-level linear models with no predictors and census tracts as clustering variables.

Compared with the broader population, the final sample under-represents males (36% cf. 49%), persons aged less than 25 years at commencement of the study (6.8% cf. 16%), persons under the Statistics Canada (2010) Low Income Measure cut-off (18% cf. 32%), and those who have never been married (30% cf. 45%). Conversely, the sample over-represents persons aged 45 to 64 at commencement of the study (54% cf. 37%), those with some post-secondary school education (76% cf. 40%), and those who were married or in a common law relationship (51% cf. 34%). These discrepancies were evident at recruitment, but were also exacerbated by selective attrition and exclusion processes (see Section 4.2). For example, the sample became noticeably less representative of the population age distribution across the three waves of data collection. Residents of Verdun and LaSalle were under-represented compared with their share of the regional population, but this was an intentional consequence of pursuing a geographically representative cohort with equal numbers of participants in each of the four unequally populated boroughs.

Table 3: Socioeconomic characteristics of the study area population and characteristics of T1, T2 and T3 samples (unweighted data, all participants in each wave)

Variable (T1)		ZEPSOM (%) 2006 census	T1 (%) n=2433	T2 (%) n=1822	T3 (%) n=1304	Final (%) n=929
Gender	Male	49	38	37	36	36**
	Female	51	62	63	64	64**
Age[a]	15 to 24	16	12	10	8.0	6.8**
	25 to 44	41	45	43	41	37*
	45 to 64	37	41	45	51	54**
	65 to 69	5.5	1.4	1.5	1.7	2.0**
Highest level education[b]	No high school diploma	24	15	14	13	12**
	High school diploma	23	12	12	12	12**
	Some post-secondary	40	73	75	75	76**
Marital status	Single	45	36	34	32	30**
	Married, common law	34	46	48	48	51**
	Divorced, separated, widowed	21	18	18	19	19
Income[b,c]	Mean household income	49,614	57,814	61,116	62,999	67,711
	Median household income	39,766	46,000	50,000	50,000	55,000
	Statistics Canada LIM[d] (%)	32	23	22	19	18**
Borough of residence[a,f]	Verdun	37	25	25	25	24**
	LaSalle	27	24	24	25	25
	Lachine/Dorval	22	25	26	27	27**
	Saint-Henri/Pointe St-Charles	15	26	25	24	24**
Primary language[d]	French	83[e]	66	66	67	67**
	English	17[e]	34	34	33	33**

a. *Census data on proportions in each age group and borough of residence is for total population 15 to 69 years.* ***b.*** *Census data on education level and household income is for total population 15 years and over.* ***c.*** *Sample sizes for income calculations exclude persons who did not report their income (W1: n=2202, W2: n=1587, W3: n=1068, final sample: n=976). Incomes are reported in Canadian Dollars.* ***d.*** *Primary spoken language of ZEPSOM participants reflects the language in which the interview was completed.* ***e.*** *At the time of writing, data on primary spoken language could not be accessed for the study region specifically.* ***f.*** *Chi-square tests for borough of residence were not adjusted for clustering of individuals within census tracts because clustering is inherent to the definition of the construct. These figures reflect language most spoken at home in the Montreal Census Metropolitan Area, reweighted to exclude 'other languages' (original distribution French 70.5%, English 14.9%, Other 14.6%). Chi-square test of difference in proportions between the final sample and the catchment area population:* ***^p≤0.10 *p≤0.05 **p≤0.01***

4 Potential selection biases in recruitment, attrition and sample exclusion

This section explores potential sources of selection bias by investigating whether characteristics of individuals or neighbourhoods were associated with the likelihood of (a) initial recruitment into the ZEPSOM study or (b) attrition or exclusion from the final sample of individuals analysed in this thesis.

4.1 Area-level factors associated with baseline recruitment

This section describes associations between neighbourhood characteristics and study participation during the initial ZEPSOM recruitment phase described in Section 3.3, in relation to door-to-door absence and cooperation rates. Unfortunately, the characteristics of individuals who could not be reached or refused to participate are unknown. It is possible, however, to compare aggregate absence and cooperation rates across neighbourhoods with different characteristics. Kestens et al. (2012) divided the sampled dissemination areas (n=465) into quartiles along a number of aggregate social, economic and structural variables drawn from the 2006 Census, and tested for ordered differences in the distribution of absence and cooperation rates across quartiles (Jonckheere-Terpstra trend tests with alpha=0.05). Variables tested include DA-level educational attainment; individual and household income; family structure; ethnic composition; residential stability; and provincial and federal election participation rates. No statistically significant relationships were evident between any of the DA-level characteristics and door-to-door cooperation rates (Table 4, p.95).

By contrast, some statistically significant variation was evident in the ease of reaching households across DA quartiles (Table 5, p.95). Absence rates were positively related to the average level of income, the proportion of residents with a university degree, and the proportion of couples with children in the DA, and inversely related to the proportion of lone parents in the DA. The fact that these analyses did not account for clustering of individuals within neighbourhoods is noted as a limitation. Implications for the validity of research findings are explored in the final chapter of the thesis (Chapter 7, Section 4.2.4).

4.2 Predictors of attrition and exclusion

To assess the existence of selective attrition and exclusion processes, I tested whether lost participants differed from those in the final sample in terms of a wide range of individual- and area-level characteristics measured at T1[60]. To do so, I estimated a multilevel logistic regression model with a dichotomous indicator of attrition or exclusion (vs. retention in the final sample) as the outcome (Miller and Hollist, 2007). T1 participants (level 1, n=2433) were nested within census tracts (level 2, n=74) and a random level-2 intercept was specified to capture spatial variation in the likelihood of sample losses between census tracts (Chaix et al., 2011). This approach permitted testing for neighbourhood-level determinants of sample losses while accounting for the characteristics of individual participants.

Variables were entered in blocks in order to ascertain the independent effects of various groups of factors anticipated to be more or less proximal to the reasons underlying sample losses. Because the majority of sample losses were attributable to residential mobility, rather than refusal to continue participating in the study, sociodemographic characteristics were expected to be particularly relevant to the processes of attrition and exclusion. The first model adjusted only for key sociodemographic factors of individual age, sex, and highest level of education (block 1) and these variables were retained in all further analyses. Additional blocks of variables were then added sequentially to the model, retaining only those variables at each step that were independently associated with participation.

[60] All individual-level variables were measured at the T1 interview, which was roughly contemporaneous with the measurement of externally-sourced area-level variables. Detailed descriptions of these measures appear later in this chapter. For POS exposures, see Section 6.1. For mental health measures, see Section 6.2. For neighbourhood perceptions, see Section 6.3. For social support, coping and stressful life events see Section 6.4 & 6.5. For sociodemographic variables at the individual and area levels, see Section 6.6. Variables that do not appear in those sections (e.g. because they are not used in the key analyses of this thesis) or are operationalised in a different manner are described briefly in Table 6.

Table 4: Mean cooperation rates (% completed interviews among people who were contacted and eligible to participate) in relation to quartiles of Dissemination Area profiles (n=465)

Quartile	% with university degree	Average individual income	Average household income	% immigrants	% lone parents	% couples with children	% people moved in last year	2003 Provincial Election participation	2004 Federal Election participation
Q1 (low)	50.0	49.0	46.0	43.0	47.0	44.4	50.3	50.8	50.4
Q2	46.0	46.0	51.0	51.0	51.0	46.3	48.6	49.2	49.8
Q3	48.0	49.0	51.0	51.0	49.0	52.9	49.5	47.5	45.6
Q4 (high)	49.0	48.0	47.0	47.0	45.0	48.6	44.3	46.6	48.0
Jonckheere Terpstra sig.	0.546	0.460	0.128	0.575	0.438	0.095	0.063	0.227	0.383

Table 5: Mean absence rates (% doors knocked with no response) in relation to quartiles of Dissemination Area profiles (n=465)

Quartile	% with university degree	Average individual income	Average household income	% immigrants	% lone parents	% couples with children	% people moved in last year	2003 Provincial Election participation	2004 Federal Election participation
Q1 (low)	57.9	58.2	49.4	58.0	64.6	55.7	61.6	65.0	65.4
Q2	58.7	54.6	70.8	70.8	70.6	62.3	66.2	60.7	62.7
Q3	63.4	67.3	69.3	69.3	63.3	66.7	64.3	62.6	60.6
Q4 (high)	70.0	69.6	51.6	51.6	51.2	64.8	68.5	63.7	63.2
Jonckheere Terpstra sig.	.055	**.002**	**.000**	.266	**.005**	**.036**	.296	.596	.947

Four subsequent blocks of variables were measured at the individual level, including additional sociodemographic factors (block 2), mental health (block 3), psychosocial stress and resources (block 4), and neighbourhood social integration (block 5). Finally, the last block of variables measured aggregate sociodemographic attributes of the residential area (block 6). Therefore, there were six steps in the sequential model building process (and six models estimated in total). The definition and ordering of variable blocks reflects a gradually widening perspective on possible selection processes from the influence of life stage and SES-related influences; through personal psychosocial factors that could interact with sociodemographics to determine residential mobility or lead more directly to the refusal of continued study participation; and finally to more diffuse attributes of the local social environment that could reflect different norms relating to residential mobility or active participation and concern with community-related issues (e.g. indicated in voting rates) which might in turn reflect a greater commitment to participation in locally-relevant research.

Table 6 (p.97) outlines the six blocks of variables and briefly describes each measure. Because most of these variables were employed in the substantive analyses of this thesis, further detail on the measures can be found in the sections of this chapter referenced in the far right column. Although the area-level variables were moderately to highly correlated (absolute correlations ranging from 0.55 to 0.72) there was no indication of problems associated with multicollinearity (Variance Inflation Factors<2.8). Continuous predictors were centred at their sample means, and missing data on household income (n=231), perceived coping abilities (n=278), and twelve-month mental disorders (n=200) were imputed 50 times using a model identical[61] to that developed for the main analyses in this thesis (see Section 7). Parameter estimates and standard errors were combined across the imputed datasets using Rubin's (1987) rules.

On the following page, Table 7 (p.98) presents results from the multilevel analysis in relation to the estimated change in the odds of attrition or exclusion, relative to retention in the final sample, attributable to a one-unit increase in individual (within CT) and area-level (between CT) predictors. For brevity of presentation, estimates are reported following the addition of predictor blocks 2, 3 and 6 (i.e. at the second, third, and sixth steps in sequential model specification process) and are adjusted for all variables listed in the same column.

---

[61] With the exception that only T1 variables (not T2 or T3) were used to impute values for this analysis.

Table 6: Variable blocks entered as predictors of attrition or exclusion within a multilevel model

Variable block	Variables entered within block (and descriptive statistics)	Chapter 3 section with further information
Block 1 Key individual socio-demographic variables (n=2433)	Age (years) Mean=41.4 , SD=13.3, Min=15, Max=69	s.6.6.1
	Sex Female (61.5%) (Reference); Male (38.5%)	s.6.6.1
	Educational attainment No secondary school diploma (15%); Secondary school diploma or lower tertiary education (53%) (Reference); Bachelor or postgraduate degree (31%)	s.6.6.1
Block 2 Additional individual socio-demographic variables (n=2433)	Household income (natural logarithm) Transformed for purpose of imputation. Mean=10.6 , SD=0.88, Min=4.7, Max=13.1	s.6.6.1
	Marital status Single (never married) (36.4%); Married or in common law relationship (45.6%) (Reference); Divorced, separated or widowed (17.9%)	s.6.6.1
	Length of residence at T1 address (years) Mean= 6.84, SD=7.70, Min=0.01, Max=46.0	s.6.6.1
Block 3 Mental health (n=2433)	Any twelve-month mental disorder (yes/no) Includes major depression, mania, social phobia, panic disorder, agoraphobia, alcohol or drug dependence. Measured using the Canada Community Health Survey (CCHS 1.2) version of the Composite International Diagnostic Interview. T1 prevalence = 19%.	N/A
	Psychological distress: K10 scale (total score) Mean=8.47, SD=6.76, Min=0, Max=37	s.6.2.2
	Life satisfaction: Reduced Satisfaction with Life Domains scale (total score). Mean=93.5 , SD=14.4, Min=20, Max=119	s.6.2.1
Block 4 Stress, coping, social support (n=2433)	Stressful life events in past 12 months (total count). Excludes moving house. Mean=3.25 , SD=2.47, Min=0, Max=16	s.6.5
	Social support: Social Provisions Scale (total score) Mean=80.4 , SD=9.95, Min=35, Max=96	s.6.4.1
	Perceived ability to cope with stress Mean=2.56 , SD=0.93, Min=1, Max=5	s.6.4.2
Block 5 Neighbourhood perceptions and behaviours (n=2433)	Perceived social cohesion scale Mean=17.2 , SD=3.71, Min=5, Max=25	s.6.3.1
	Neighbouring behaviour scale Mean=9.20 , SD=8.49, Min=0, Max=40	s.6.3.2
	Community participation scale 0 activities (65.3%) (Reference); 1+ activities (34.7%)	s.6.3.3
Block 6 Residential area-level variables (at the level of census tracts) (n=74)	Socioeconomic deprivation Average of seven standardised variables from the 2006 Census: % living in rented accommodation; % aged >25 that are unemployed; % without secondary school diploma; % without a university degree; % lone parent households; Median household income; % households below Low Income Cut Off (after tax). Cronbach alpha = 0.92. Mean=0.00, SD=0.80, Min=-1.78, Max=1.92	s.6.6.2
	Residential density and mobility Average of five standardised variables from the 2006 Census: Population density; Household density; % residents moved house in past 5 years; % single person households; % single (never married) persons. Cronbach alpha = 0.83. Mean=0.00 , SD=0.80, Min=-2.13, Max=2.17	N/A
	Voting rates Measured at 2004 Federal election (%) Mean=50.1, SD=6.20, Min=34.3, Max=64.4	N/A

Table 7: Multilevel associations of individual and area-level characteristics at T1 with attrition or exclusion of participants from the final sample

Predictor block (see Table 6)		Model 2 (Blocks 1-2) OR[a]	[95% CI]	Model 3 (Blocks 1-3) OR[a]	[95% CI]	Model 6 (Blocks 1-6) OR[a]	[95% CI]
1.	Age (years)	0.97**	[0.96, 0.98]	0.97**	[0.97, 0.98]	0.98**	[0.97, 0.98]
	Male gender	1.07	[0.89, 1.29]	1.09	[0.91, 1.30]	1.03	[0.86, 1.24]
	Education						
	No secondary diploma	1.34*	[1.01, 1.77]	1.29^	[0.98, 1.71]	1.32^	[1.00, 1.74]
	Secondary diploma, lower tertiary[b]	1	---	1	---	1	---
	Bachelor, postgraduate degree	1.01	[0.80, 1.26]	1.05	[0.83, 1.31]	1.06	[0.85, 1.33]
2.	Household income[c]	0.76**	[0.67, 0.85]	0.77**	[0.69, 0.87]	0.80*	[0.65, 0.98]
	Marital status						
	Single (never married)	0.93	[0.75, 1.17]	---	---	---	---
	Married, common law[b]	1	---	---	---	---	---
	Divorced, separated, widowed	1.18	[0.87, 1.60]	---	---	---	---
	Length of residence	0.93**	[0.92, 0.95]	0.93**	[0.92, 0.94]	0.94**	[0.92, 0.95]
3.	Psychological distress	---	---	1.02*	[1.00, 1.04]	1.01	[1.00, 1.03]
	Life satisfaction	---	---	1.01	[1.00, 1.01]	---	---
	Any 12-month mental disorder	---	---	1.21	[0.88, 1.67]	---	---
4.	Count stressful life events	---	---	---	---	1.07**	[1.02, 1.12]
	Coping ability	---	---	---	---	---	---
	Social support	---	---	---	---	---	---
5.	Social cohesion	---	---	---	---	0.97**	[0.95, 0.99]
	Neighbouring behaviour	---	---	---	---	0.99**	[0.97, 1.00]
	Community participation	---	---	---	---	0.83^	[0.68, 1.01]
6.	Area socioeconomic deprivation	---	---	---	---	1.09	[0.92, 1.30]
	Area residential density, stability	---	---	---	---	1.09	[0.93, 1.28]
	Area voting rates	---	---	---	---	1.01	[0.98, 1.04]

a. *Relative odds of attrition or exclusion with a one unit increase in the predictor. Estimated within a multilevel logistic regression model with participants retained in the final sample as the reference group.* ***b.*** *Reference category.*
c. *Transformed to natural logarithm for purposes of multiple imputation, as detailed in Section 6.6.*
^p≤0.10 *p≤0.05 **p≤0.01.

The odds of attrition or exclusion from the sample were elevated among people who were younger, less educated[62], reported lower household income, and had been living at their T1 address for a shorter period of time. Participants who reported greater levels of psychological distress at T1 were also more likely to be lost from the sample, but this relationship was no longer statistically significant after controlling for the number of stressful life events experienced in the preceding 12 months. Unadjusted for stressful events, a difference in psychological distress scores equivalent to the interquartile range at T1 (IQR=8) related to

[62] The association with education was only marginally significant once adjusted for the number of stressful life events (p=0.053)

1.20 times greater odds of attrition or exclusion. This estimate was only slightly higher if 12-month mental disorders were also omitted from the model (OR=1.25). Life satisfaction at T1 was not associated with sample losses, even when unadjusted for psychological distress, 12-month mental disorders, or stressful life events. On the other hand, the three dimensions of neighbourhood social integration – perceived social cohesion, neighbouring behaviour, and community participation – were each inversely and independently associated to the likelihood of sample losses (although the effect of community participation was marginally non-significant, p=0.06).

No statistically significant associations between area-level characteristics and the likelihood of attrition or exclusion were evident in the multilevel model. In other words, census tract socioeconomic deprivation, residential density and mobility, and voting rates did not appear to influence the likelihood of sample losses after accounting for individual characteristics. This finding is reflected in the relatively consistent geographic distribution of the T1 cohort and final sample across the four boroughs of South-West Montréal (Figure 10). Rates of attrition or exclusion differed slightly between the boroughs, ranging from 58.1% in Lachine/Dorval to 64.4% in Verdun, but these differences were not statistically significant (χ^2=6.689, df=3, p=0.082).

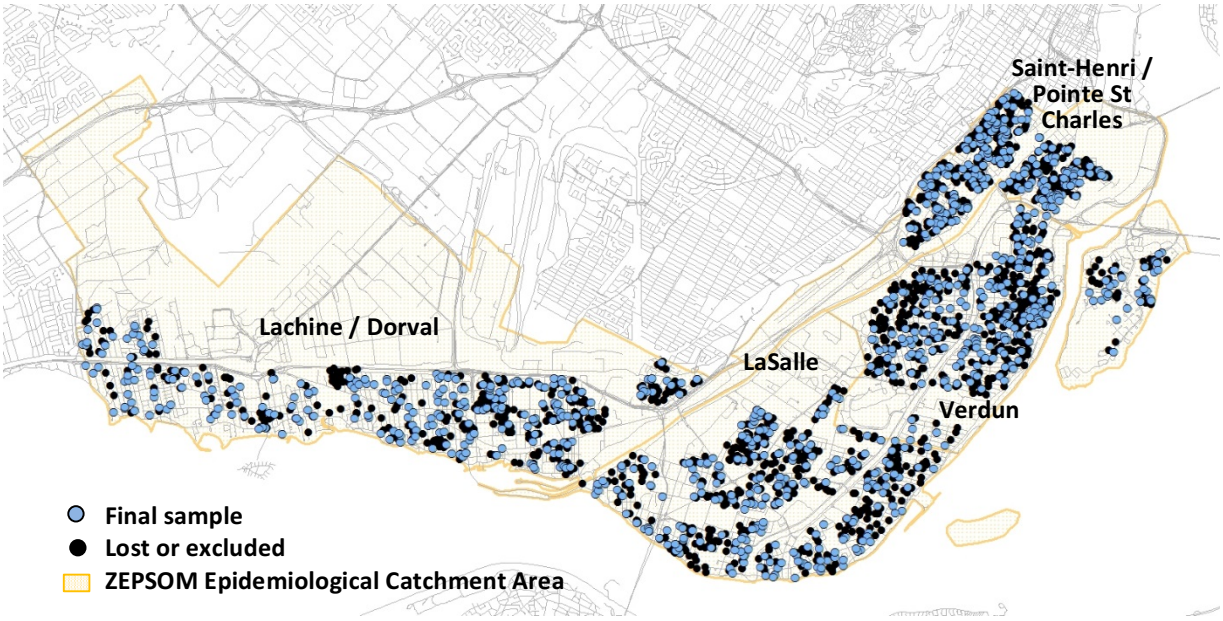


Figure 10: Sample losses and final sample participation throughout the study area

There was some limited evidence of selective sample losses in relation to the characteristics of public open space in participant-centred residential environments at T1. Table 8 (p.100) reports the rate of attrition or exclusion across quartiles of POS accessibility and quality indicators, measured at the individual level in relation to 500- and 1000-metre road network buffers around each participant's baseline residential address. Specific details pertaining to the definition and measurement of these POS indicators are presented later in this chapter (Sections 4.1 and 6.1). Briefly, I tested for differential sample losses in relation to the total proportion of each buffer that comprises POS *(POS availability*); the number of POS intersected by each buffer (*Count POS*); the mean size of POS intersected by each buffer (*Mean size*); and the mean 'greenness' of POS intersected by each buffer, measured by the Normalised Difference Vegetation Index (*POS Greenness*). In addition, I tested the influence of overall proximity to POS, measured by the total road network distance to the nearest POS (*POS Distance*). Statistically significant ordered differences in the distribution of sample losses across POS quartiles were identified using Jonckheere-Terpstra trend tests with an alpha level of 0.05.

Table 8: Prevalence of sample losses (attrition or exclusion) in relation to quartiles of public open space accessibility and quality characteristics in participant-centred residential environments at T1 (n=2433)

		1000-metre road network buffer				500-metre road network buffer			
Quartile	POS Distance	POS avail-ability	Count POS	Mean size	POS green-ness	POS avail-ability	Count POS	Mean size	POS green-ness
Q1 (low)	61.4	65.1	61.0	60.3	65.6	60.6	62.3	64.8	65.0
Q2	63.5	62.4	60.6	62.6	63.9	62.3	58.2	56.9	63.4
Q3	60.3	59.1	61.3	60.0	58.1	59.9	62.2	61.7	57.9
Q4 (high)	62.2	61.8	64.2	64.2	59.4	62.1	62.0	62.9	59.9
Jonckheere Terpstra sig.	.914	**.048**	.262	.295	**.006**	.807	.762	.930	**.021**

Sample losses were not associated with the number or size of POS within 500m or 1000m of the home, nor with distance to the nearest POS. However, sample losses were inversely associated with POS 'greenness', both within a 500-metre buffer (p=0.006) and a 1000-metre buffer (p=0.021). Specifically, sample losses varied from 59-60% among participants living in the highest quartile of *POS Greenness* at baseline to 65-66% among those in the lowest

quartile. Finally, there was tenuous evidence for a weak inverse association between total availability of POS within 1000m and sample losses. (65% in Q1 versus 62% in Q4, p=0.048).

These trends could possibly indicate that the amenity value of POS resources, or other neighbourhood attributes with which they are correlated, is associated with a greater desire to remain in the neighbourhood. However, it is perhaps more likely that these bivariate associations are explained by characteristics that remain unaccounted for. Household income, for example, is associated with reduced attrition and could also relate to POS greenness. These trends do bear consideration, however, because selective attrition associated with exposure to POS greenness could bias the relationships of interest in this thesis. It is comforting to note that despite the findings outlined above, absolute differences in mean values of *POS greenness* and *POS availability* between retained and lost participants were negligible. The mean difference in *POS greenness*, for either buffer size, was statistically different from zero but only equivalent to roughly one-tenth of the T1 sample standard deviation of the measure[63]. The mean difference in *POS availability*, on the other hand, was not statistically significant[64].

4.2.1 Summary of factors associated with attrition or exclusion

In summary, the odds of attrition or exclusion from the sample were elevated among people who were younger, possessed lower educational qualifications, reported lower household income, and had been living at their T1 address for a shorter period of time. There was some evidence of selective sample losses among individuals reporting higher levels of psychological distress at the first occasion of data collection, but this association was largely explained by the number of acute stressors experienced in the twelve months prior to T1. Additionally, sample losses were lower among participants reporting higher levels of social cohesion, neighbouring behaviour, or community participation at T1; or with access to 'greener' POS (on average) within 500m or 1000m of the home. Implications for the validity of research findings are explored in the final chapter of the thesis (Chapter 7, Section 4.2.4).

---

[63] **500m buffer:** retained respondents mean = 2.02, lost respondents mean = 2.01, mean difference = 0.08. Independent samples t-test: t=2.831, df=2290, p=0.005. T1 standard deviation of *POS Greenness* = 0.65. **1000m buffer:** retained respondents mean = 2.07, lost respondents mean = 2.01, mean difference = 0.06. Independent samples t-test: t=2.760, df=2428, p=0.006. T1 standard deviation of *POS Greenness* = 0.54.

[64] **1000m buffer:** retained respondents mean = 8.91, lost participants mean = 8.92, mean difference = -0.010. Independent samples t-test: t=-0.049, df=2428, p=0.961. T1 standard deviation of *%POS* = 4.897.

5 Data collection and data sources

Individual-level data on mental health outcomes, community-related cognitions and behaviours, the availability of network-based social support, the perceived ability to cope with stress, and the experience of stressful life events, were collected via face-to-face interviews at T1-T3 of the ZEPSOM study described above. Given that the majority of the data had been collected prior to the commencement of this PhD candidature, I was not involved in the selection of measures representing these constructs. Wave one data collection took place between April 2007 and October 2008, wave two data collection took place between June 2009 and November 2010, and wave three data collection took place between January 2012 and July 2013. The research was approved by the Douglas Mental Health University Institute Ethics Committee in accordance with the Canadian Tri-Council Guidelines (Appendix 3.1). Each participant was required to sign a consent form before taking part in the interview, and had the option to choose the language (English or French) of their interview. In addition, respondents could choose whether to complete the interview in their home or at a specially designated office space at the Douglas Institute. For participants aged 15 to 17, parental consent was required before the interview (Fleury et al., 2011). Specially trained interviewers implemented the questionnaires using a portable computer, and interviews during each wave lasted approximately 1.5 to 3 hours, depending on whether mental disorders were detected (Caron, 2012b). Each participant's residential address was geocoded and integrated into the MEGAPHONE GIS to allow the linkage of survey data to indicators of environmental living conditions.

Public open space data were extracted specifically for this project from the MEGAPHONE GIS and validated by the candidate, with onsite training and collaboration from the ZEPSOM research team's geospatial expert at the University of Montréal Spatial Health Research Lab. For the purposes of this thesis, POS includes 'spaces within the urban environment that are readily and freely accessible to the wider community, regardless of size, design or physical features and are intended primarily for amenity or recreation purposes – whether active or passive' (adapted from Kellett, 2009). This definition includes, for example, parks, ovals, playgrounds, public squares, and community gardens. It excludes divided road median strips, sidewalk nature strips and street greenery, cemeteries, and vacant house blocks. A previously validated polygon map layer of parks larger than 11,500 square meters, issued by the City of

Montréal in 1996, was updated with a polygon layer of parks and recreational areas of any size, issued in 2007 by Desktop Mapping Technologies Inc. (DMTI)[65], and a City of Montréal list of community gardens (Ville de Montréal, 2013). Together, these data sources were used to identify and map the geographic distribution of likely POS parcels within the study region plus a one-kilometre buffer around the study region. In a final stage of POS identification, high-resolution satellite imagery and Google maps of the study region were visually scanned for spaces that might fit the criteria for POS but were not yet included in the POS map layer. Before inclusion in the study, all spaces identified by any data source were subject to a remote validation procedure to ensure that they satisfied the aforementioned definition of POS and that their boundaries were accurately recorded. The validation procedure is described in detail in Appendix 3.2.

5.1 Seasonal influences on data collection

Given the aims of this thesis, it is important to consider and account for the possible influence of seasonal variation within and between the three occasions of data collection. The very nature of public open space means that its perceived accessibility, value, and usage may be dictated, to some extent or for some people, by the seasons. Indeed, seasonal trends have been documented both in relation to POS usage (Nikolopoulou et al., 2001, Ward et al., 2014) and mental health (Partonen and Lönnqvist, 1998, Mersch et al., 1999, Ayers et al., 2013), while some authors have noted that "winter 'green' differs from summer green" (Richardson et al., 2012, p.163). These factors indicate that seasonality may be a causally relevant feature in the definition of POS exposure (Cole and Frangakis, 2009). This is likely to be particularly relevant at higher latitude locales in North America, such as Montréal (Mersch et al., 1999), where the ability of residents to access POS may be limited by extreme cold, and snowfall, and heavy precipitation events throughout the winter months.

Each wave of ZEPSOM data collection was completed in approximately 18 months and took place across all four seasons of the year. Due to differences in the commencing month of data collection between waves one (April), two (June), and three (January), each wave favoured the completion of interviews during a particular season to some extent (Figure 11, p.104). A noteworthy distinction was that wave one interviews were more likely to take place

[65] DMTI is a commercial provider of digital mapping and location based data.

in summer (34% cf. 19% at T2, 24% at T3) and less likely to take place in winter (16% cf. 25% at T2 and T3) compared with those at later waves. It was also apparent that wave two interviews were spread more evenly across the seasons (ranging from 19% in summer to 29% in autumn) than those at wave one (16% winter to 34% summer) and wave three (7% autumn to 43% spring).

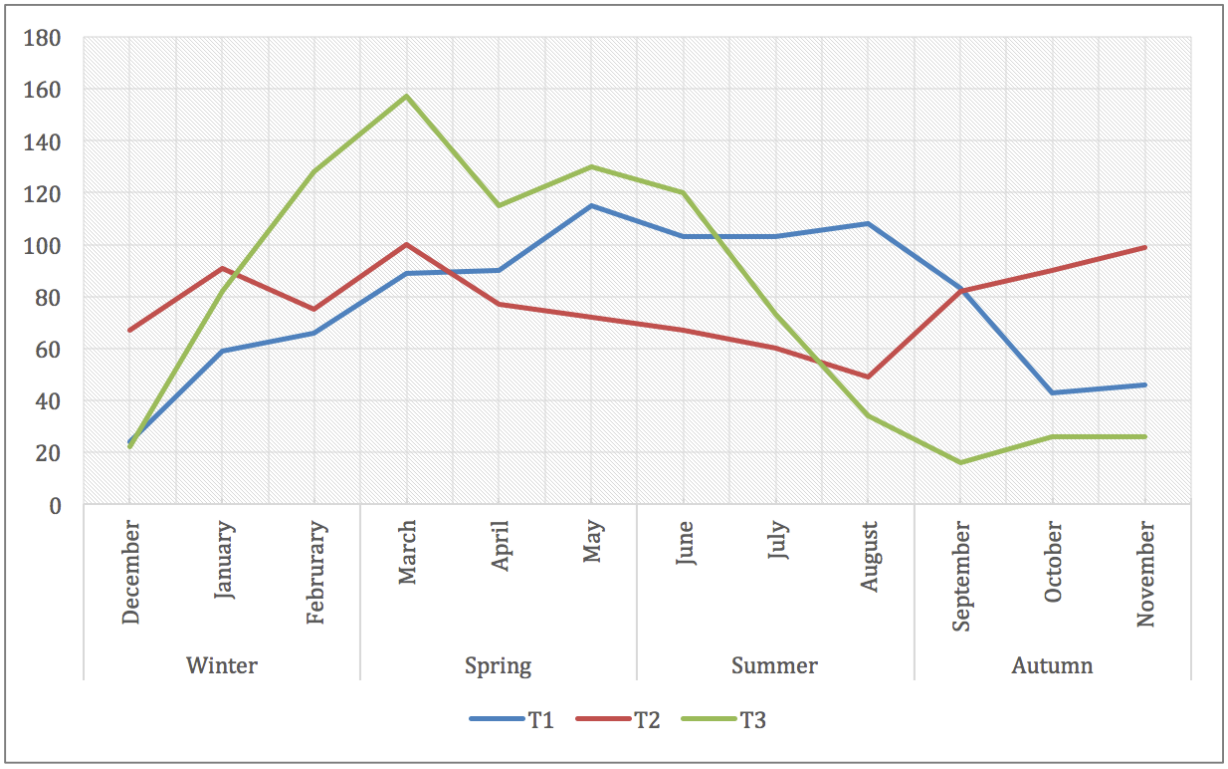


Figure 11: Completed interviews by month of the year (final sample, n=929)

At the individual level, it was fairly uncommon for participants to participate in an interview during each of the divergent seasons of summer and winter. This occurred in 19.5% (n=181) of cases, among which the majority involved commencement of the study in summer (n=121) and completion in winter (n=108). For the remaining 80.5% of participants, all three interviews were completed during either a combination of spring/summer/autumn or autumn/winter/spring. To ensure that methods of recruitment or follow-up had not resulted in distinct patterns of seasonal variation throughout areas of differing greenness, generalised estimating equation (GEE) models adjusted for the clustering of individuals within census tracts (n=74) were used to determine whether individuals interviewed in summer versus winter at each wave of data collection differed in relation to the level of residential POS 'greenness' (see section 6.1.2 for a description of this measure). At no time point did these models indicate

statistically significant differences in POS 'greenness' between individuals interviewed in summer versus winter.

In summary, seasonal variations at the individual level appeared overwhelmingly as the completion of a first interview in summer and later interviews in winter, while variations at the aggregate level indicated that people completing their final interview in winter had greener POS available within close vicinity of the home, compared with those completing in summer. Considering the estimation of associations between POS greenness and trajectories of mental health from T1 to T3, the influence of such patterns would presumably be to dampen the observed impact of POS greenness on mental health trajectories, as worsened thermal comfort conditions inhibit POS usage and deciduous trees lose their foliage in the later stages of the study. However, it is important to emphasise that the thesis investigates the long-term effects on mental health of living in a neighbourhood with greener POS, and that the study utilises objectively derived measures of this characteristic, rather than measures of POS usage or perceived greenness. Therefore, seasonal factors have no influence on the actual measurement of the exposure variables.

6 Measures

This section describes the measures of residential public open space characteristics, psychosocial resources, stressful life events, and mental health outcomes used in this thesis. It also details the individual- and area-level covariates incorporated into the analyses to account for potential confounding and self-selection effects.

6.1 Exposure variables: public open space

This section describes the operationalisation and extraction of indicators of residential POS availability and characteristics used in this thesis. All indicators were derived at the individual level using address at T1 to define a unique local residential area (LRA) for each participant. The LRA was defined at two spatial scales, represented by 500m and 1000m pedestrian road network buffers around the participant's home. Each buffer was intersected with a validated polygon map layer of POS using the spatial analytical functions of ArcGIS 10 (ESRI, 2011) in order to summarise the characteristics of POS in the LRA.

As detailed in Chapter 2 (Section 3.6), the primary exposure of interest in this thesis is the relative 'greenness' of public open space (*POS greenness*) in the local residential area (LRA). The measure of *POS greenness* is described in detail shortly, but can be summarised as follows:

- Mean level of healthy vegetation in POS accessible within the local residential area, measured using the Normalised Difference Vegetation Index (*POS Greenness*)

In exploring relationships between *POS greenness* and mental health, it may also be important to control for the total availability and typical size of public open spaces in the local residential area. These attributes are potentially relevant to the mechanisms by which POS might foster better mental health, and could also correlate with the level of 'greenness'. For example, the total quantity of POS in the residential environment has frequently been associated with better mental health (e.g. White et al., 2013, Astell-Burt et al., 2014b, Alcock et al., 2014). Similarly, larger POS provides more varied potential for recreational opportunities, and evidence to date suggests that POS size is positively related to preference and usage (Veal, 2001, Giles-Corti et al., 2005, Cohen et al., 2010). There are also some indications that larger POS are more protective of mental and physical health than smaller POS (Mitchell et al., 2011, Sarmiento et al., 2010). While the 'greenness' of POS is hypothesised to be particularly relevant in determining its restorative potential, POS size is also likely to be important, and may even synergise the effects of POS greenness; natural environments are said to be restorative when they give users a sense of being away from their usual setting, which may be more likely in larger POS (Kaplan and Kaplan, 1989). Finally, the total area of POS – whether in relation to the neighbourhood as a whole or a specific land parcel – might influence the extent to which it is covered by vegetation. The measures of *POS availability* and *POS size* in this thesis are detailed shortly, but may be summarised as:

- Proportion of the local residential area that comprises POS *(POS availability*)
- Median size (area in hectares) of POS in the local residential area (*POS Size*)

This measure of *POS availability* is analogous to area-level instruments used in an urban planning policy context (Veal, 2013, Villanueva et al., 2015), while the size of POS parcels is a central characteristic in typologies of POS used for this purpose (Byrne and Sipe, 2010, Villanueva et al., 2015). *POS availability captures* the overall saturation of POS throughout

the LRA, but disregards the nature of its spatial distribution (La Rosa, 2014). In contrast, *POS size* helps to capture the manner in which POS is spread across variably sized parcels of land.

The following subsection details the demarcation of the LRA and the manner in which this was imposed to measure residential POS availability and characteristics. Then, I describe the specific methods by which the POS indicators were extracted from the GIS. Summary statistics are presented in Table 9 (p.116) and Table 10 (p.116) at the end of this section.

6.1.1 Defining the local residential area

The purpose of defining the specific local residential area (LRA) in this study was to enable the identification of readily accessible POS around each ZEPSOM participant's home. Here, I consider accessibility as the ease with which a person can reach an activity site, or their relative level of opportunity to interact or come into contact with those sites (Hansen, 1959, Nicholls, 2001, Gregory et al., 2009). High accessibility will thus generally manifest as a greater number of activity sites located near the home, a lower degree of spatial separation from those sites, and/or a lower cost of overcoming that separation, for instance due to greater choice in transportation modes (Gregory et al., 2009).

Appendix 3.3 describes and contrasts three primary approaches to the objective definition of residential areas in place-health research, including the use of predefined spatial administrative units (such as statistical local areas, census tracts, or planning neighbourhoods) and the derivation of egocentric Euclidian (circular) or road-network buffers around individual places of residence. This thesis employs geocoded locational information (i.e. home address at T1) to define unique egocentric road-network buffers reflecting the LRA for each participant at two spatial scales (D = 500m, 1000m). Specifically, starting at the participant's home address, the road network was followed in all possible directions until D metres had been travelled, and the end points of these paths were connected to create a continuous buffer.

The use of two spatial scales reflects best practice in place-health research, permitting assessment of the sensitivity of findings to the choice of areal unit and exploration of the spatial scale most relevant to the mechanisms of interest (Diez Roux, 2001). Importantly, the spatial scales were chosen a priori to suit the objectives of this research. A distance of 1000m equates to an estimated walking time of 12 minutes at a pace of 5km/h. This has commonly been reported as a distance that people are willing to walk to access resources (Lee and Moudon, 2006) and is well beyond the median distance (650m) of walking trips to work,

school, shopping and leisure destinations by Montréal residents (Larsen et al., 2010). The distribution of demand for resource outlets and locations generally follows a decay curve, where people residing near to a location place greater value on it than those residing further away (Larsen et al., 2010). Unsurprisingly, proximity to POS has frequently been found to be positively related to its usage (McCormack et al., 2010). The 500m buffer was therefore chosen to capture POS in the more immediate vicinity of the home, which may have greater potency in terms of propensity for usage, provision of everyday restorative experiences, and facilitation of local community building. In addition, the smaller buffer more closely approximates the bounds of pedestrian accessibility for persons who are physically unfit, elderly or not able-bodied.

The two chosen buffer sizes correspond approximately to the service areas around mini-parks (400m) and neighbourhood parks (400-800m) recommended by the American National Recreation and Park Association (1983) and the American Planning Association (2006), reflecting distances within which it is generally accepted that residents should have access to POS resources. The spatial scales employed in this research are therefore meaningful with regards to accepted guidelines for resource provision. They also capture the residential area in which the psychosocial functions of neighbourhood are expected to be strongest. This 'home area', typically considered to fall within a 5 to 10 minute walk from the home, has the potential to fulfil many needs including relaxation, belonging, and connection with others (Kearns and Parkinson, 2001). This ensures a reasonable level of spatial correspondence between measures of POS exposure and the measures of neighbourhood social integration employed in this thesis, which draw on subjective participant-defined notions of the 'neighbourhood' (see Section 6.3 for further information).

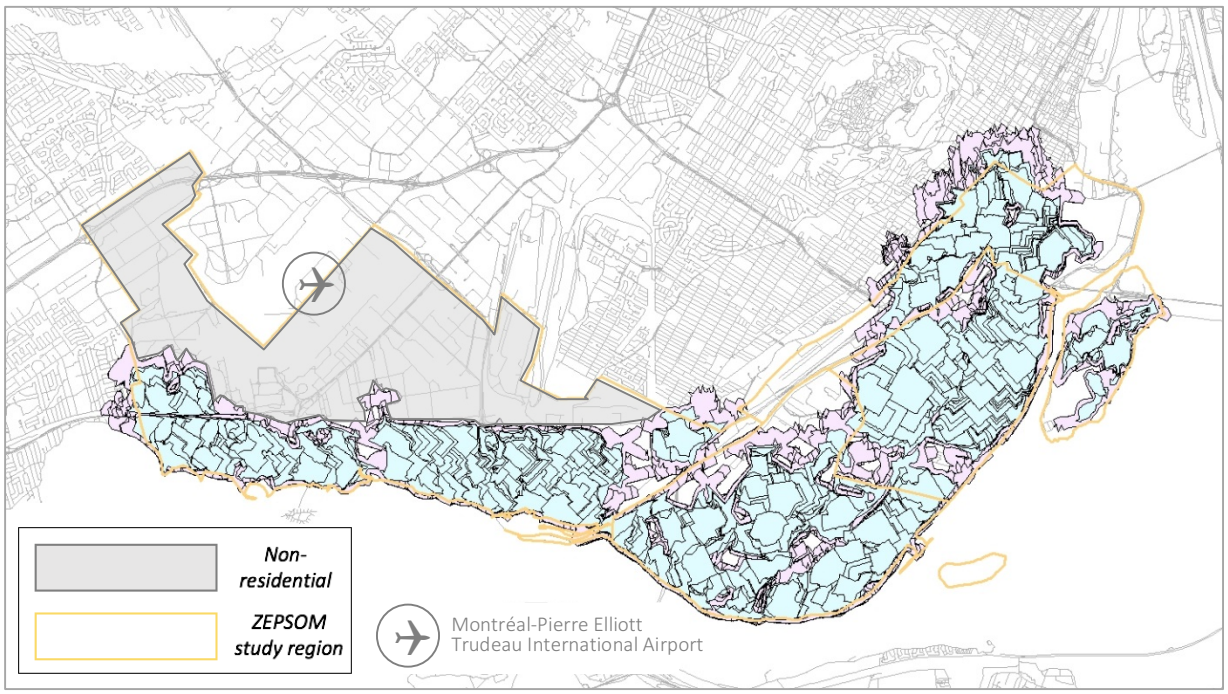


Figure 12: 500m (blue) and 1000m buffers (pink) for final sample participants

The 500m and 1000m road network buffers were created for each ZEPSOM participant in ArcGIS 10 (ESRI, 2011) using the service area function of the network analyst extension. Buffers were operationalized to represent pedestrian movement rather than vehicular movement, due to the nature of the research questions and the relatively small size of the buffers. Specifically, the road network used to create the buffers was constrained to prevent movement along ice and ferry routes and roads without pedestrian access (e.g. highways). Movement along pedestrian tracks (e.g. those traversing POS) was allowed, and one-way and turn restrictions on roads (e.g. no left hand turn) were ignored. The chosen road network parameters excluded two participants from analysis, because their residential location was snapped to a highway (with no pedestrian access) and buffers could not be created. As illustrated in Figure 12, above, LRA buffers for the final sample covered the majority of the study region with the exception of a large industrial area in the borough of Lachine/Dorval that includes, among other non-residential uses, an international airport, railway yards, and two golf courses.

To identify POS in each participant's local residential area, the 500m and 1000m road network buffers were intersected with the validated POS layer using the intersect function of the ArcGIS 10 spatial analyst extension (ESRI, 2011). This procedure identifies POS that are

either wholly or partially encompassed by the buffer in question, and therefore accessible to the participant by walking 500m or less, or 1000m or less, respectively. Among participants in the final sample, 51 (5.5%) did not have access to any POS within 500m of the home[66]. These individuals were excluded from analyses for the 500m buffer size to avoid conflating a lack of any POS whatsoever with a lack of POS 'greenness'. Figure 13, below, depicts the residential location of a single ZEPSOM participant, marked with a cross, in relation to the road network used to create LRA buffers. A 500m road network buffer around this location encompasses the area shaded in blue. All segments of POS intersected by this buffer are highlighted in purple, while green polygons represent POS existing outside the boundaries of the selected buffer.

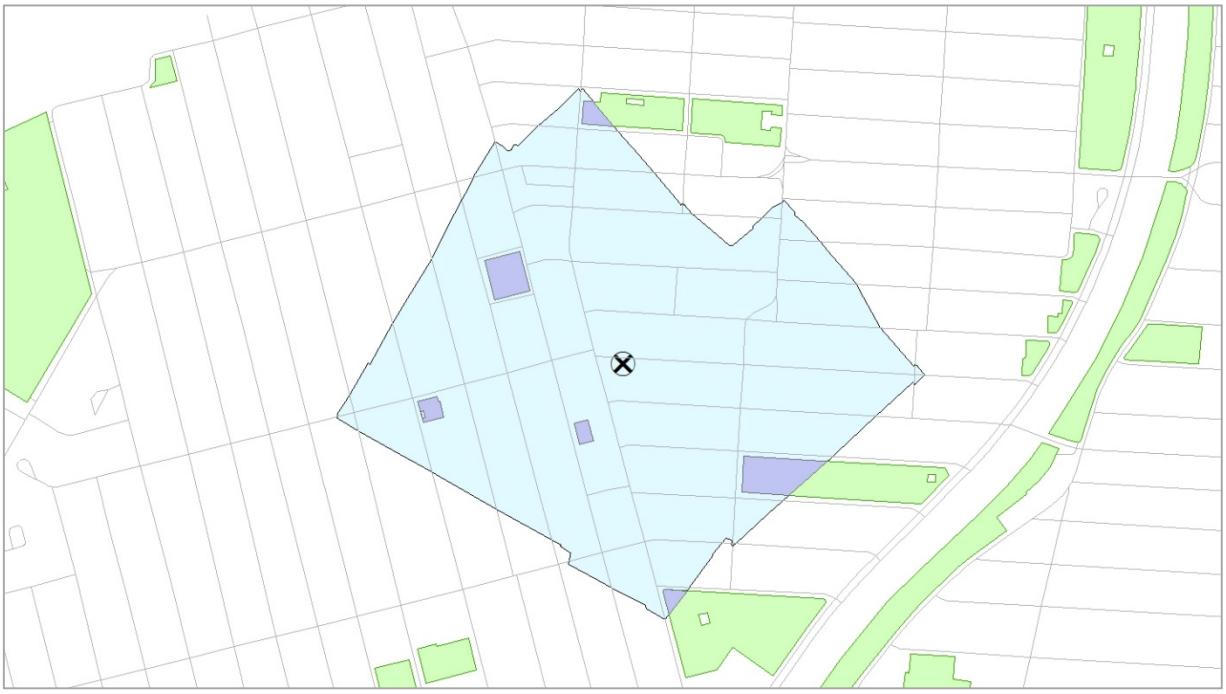


Figure 13: Intersection of Public Open Spaces with a 500m road network buffer

As indicated in Figure 13, POS polygons may exist partially within, and partially outside of, an LRA buffer. POS intersected by a buffer were always considered to exist in the LRA, even if not contained wholly within it, and therefore contribute to measures of POS availability, size, and greenness for the participant in question. However, when computing these measures, a distinction was drawn between the use of 'clipped' and 'unclipped' POS

[66] Of these, 48 did not have access to any POS within the 500m buffer if the intersection was performed using the primary POS polygon layer used to compute *POS greenness* and *POS availability.* A further three were excluded following amendments to the POS polygon layer, whereby thin trails (<25m wide) connecting segments of the linear parks beside the canal and river were deleted in order to compute the *POS Size* measure. The distinction between the two layers is discussed further in Appendix 3.2.

polygons. *POS availability* was calculated using 'clipped' POS polygons, wherein only the segments of POS fully contained within the buffer were taken into account. In effect, the POS polygons were trimmed at the buffer line and any segments falling outside the buffer were disregarded. On the other hand, *POS size* and *POS greenness* were calculated using 'unclipped' POS polygons. Here, intersection by the buffer was still a requirement for POS to be considered accessible within the living environment; once deemed accessible, however, the full POS polygon – not only the segment within the buffer – was taken into account. Figure 14 illustrates this difference, depicting in purple the areas of POS included in calculations with clipped and unclipped POS polygons. This is a particularly important distinction when considering the implications for measures of POS size, which might differ drastically if large portions of POS polygons falling outside the LRA buffer were disregarded.



Figure 14: Clipped (left) and unclipped (right) parcels of POS, shaded in purple

The following subsections outline the specific procedures used to obtain the POS measures outlined at the beginning of this section. Descriptive statistics for these measures and cut points for the categorisation of selected variables are provided in Table 9 (p.116).

6.1.2 'Greenness' of POS in the local residential area (POS greenness)

The 'greenness' of POS in the local residential area was defined as the average of the mean Normalised Difference Vegetation Index (NDVI) values of POS intersected by the 500m and 1000m road network buffers (*POS greenness*). NDVI provides an objective metric for levels of healthy vegetation through assessment of the photosynthetic activity of land surface cover, and is a commonly used measure of neighbourhood 'greenness' (James et al., 2015). It has been validated for this purpose against expert ratings of 'greenness' by environmental

psychologists, and was found to perform equally well in neighbourhoods with high and low residential density (Rhew et al., 2011).

The index is based on the principle that healthy green vegetation absorbs more radiation in the visible (red) region of the sunlight spectrum, and reflects more radiation in the near-infrared region, when compared against unhealthy vegetation or to non-vegetated surfaces. The more healthy leaves a plant has, the more these wavelengths of light are affected; consequently, spectral imagery of areas with dense, healthy vegetation shows high values in the infrared band, but low values in the visible red band. NDVI is calculated as the difference in the near-infrared and red spectral reflectance of a land surface, divided by the sum of the two (DeFries and Townshend, 1994), and is influenced by the proportional cover of the ground by vegetation, vegetation density, and vegetation health; all of which contribute to 'greenness'. NDVI values fall between -1 and +1, where higher values are associated with greater vegetation density and greenness. Values approaching -1 correspond to deep water, while barren areas of rock, sand, or bare soil generate values close to zero. Shrubs and grass produce low, positive values (approximately 0.2 to 0.4) while trees generate higher values depending on the density and health of the vegetation. A rainforest, for example, would return a value of 1. While negative values of NDVI do occur, they generally correspond to the presence of water, clouds, snow, or bright non-vegetated surfaces (Yin and Williams, 1997). Beyond indicating a lack of vegetation, these values provide no meaningful information on the 'greenness' of an area and may represent atmospheric "noise" (Pettorelli et al., 2005, Beck et al., 2006, Bradley et al., 2007, Hird and McDermid, 2009, Santin-Janin et al., 2009).

Landsat 7 satellite imagery was used to calculate the mean value of NDVI for each POS in the study region (Figure 15, p.113). This satellite image was captured during the Northern Hemisphere summer of 2008 and is therefore contemporaneous with the collection of T1 survey data. The image has a spatial resolution of 30m by 30m, with each grid cell (pixel) assigned a single NDVI value. To facilitate the analysis of vegetation levels in smaller POS, the image was resampled to a resolution of 10m using the 'nearest neighbour' methodology to split pixels into smaller dimensions without changing the original cell values. Pixels with negative NDVI values were set to zero, based on the assumption that negative values represent non-vegetated surfaces and may be data errors (Pettorelli et al., 2005, Beck et al., 2006, Bradley et al., 2007, Hird and McDermid, 2009, Santin-Janin et al., 2009). The POS polygon map layer was overlayed on the resampled Landsat satellite image in order to compute the

mean NDVI value for each POS, using all pixels completely encompassed within the POS boundary. To account for the dilution effect of water bodies on mean NDVI values, larger bodies of water such as lakes were clipped from the POS polygons before performing this calculation. Due to the 30m resolution of the satellite imagery and the fact that each grid cell is assigned a single NDVI value, I was unable to exclude smaller bodies of water, such as swimming pools, from the calculation of POS NDVI. However, POS containing swimming pools are generally larger POS of which the body of water comprises only a small portion, and these bodies of water should exert only a very mild dilution effect. Mean values of NDVI for POS within the study region were approximately normally distributed with a mean of 0.20 and standard deviation of 0.09. The range of mean values was between 0 and 0.45.



Figure 15: Landsat 7 satellite imagery indicating NDVI across the ZEPSOM region in Summer, 2008

POS greenness was calculated as the average of the (mean) NDVI of POS intersected by the 500m and 1000m road network buffer, using unclipped POS parcels to assess the greenness of the full POS entity, not only the segment contained within the buffer. Consistent with prior studies, *POS greenness* was rescaled by a factor of 10 to facilitate the meaningful interpretation of regression coefficients (e.g. Bell et al., 2008, Grigsby-Toussaint et al., 2011, Almanza et al., 2012). After rescaling, a 1-unit increase in *POS greenness* (i.e. an increase of

0.1 in mean NDVI) corresponds to meaningful variations in land cover for POS in urban settings; for instance, from a barren site with little vegetation to a playground with moderate greenness, or from a grassy oval to a park with lush vegetation (Bell et al., 2008).

6.1.3 Total availability of POS in the local residential area (POS availability)

The total availability of public open space in the local residential area was defined as the proportion of the LRA that comprises POS (*POS availability*). This measure has frequently been used to measure residential availability of POS for specific individuals (e.g. Fan et al., 2011, van Den Berg et al., 2010, Paquet et al., 2013, Sturm and Cohen, 2014, Sugiyama et al., 2014) and also corresponds with area-level measures of accessibility adopted in the urban planning policy context (Veal, 2013, Villanueva et al., 2015). The total area of POS segments fully contained within the 500m and 1000m road network buffers (clipped POS parcels) was calculated, and divided by the full area of the buffer to control for differential sizes of the LRA across participants. This proportion was then multiplied by 100 to convert it to a percentage. Referring to Figure 13 (p.110) this measure represents the area of all segments of POS contained within a buffer (marked in blue) as a proportion of the total area of that buffer (marked in yellow and blue). Note that bodies of water excluded from the calculation of *POS greenness* were included in the total area of POS when calculating *POS availability.*

6.1.4 Size of POS in the local residential area (POS size)

The size of POS in the local residential area was defined as the median area of POS intersected by the 500m and 1000m road network buffers (*POS size*). POS area was calculated for unclipped POS parcels to assess the size of the full POS entity, not only the segment contained within the buffer. The median was chosen a measure of central tendency to minimise the influence of extremely large POS on the *POS size* summary statistics. However, this approach was not infallible in cases of low POS accessibility, and the resulting distributions of *POS size* were heavily skewed to the right with small numbers of valid outliers (500m skewness 3.47; 1000m skewness 9.14). The largest outliers occurred where there existed only one or two POS in the LRA buffer, but one of those spaces was incredibly large. For instance, within the 1000m buffer, eight participants (0.9%) had access to just one POS with an area of 97 hectares; by contrast, for 95% of participants, the median area of POS accessible in the LRA was less than 5 hectares. This problem was exacerbated for the smaller LRA spatial scale, because fewer POS were accessible to 'dilute' the influence of extremely

large spaces. Within the 500m buffer, 38 participants (4.1%) had access to just one POS with an area over 88 hectares, while the median area of POS was less than 5 hectares for 72% of participants. These outliers are valid observations but may exert an undue level of influence on the estimation of relationships between *POS size* and the outcomes under study. I therefore dichotomised POS Size, at both spatial scales, using a median split. Specifically, the distribution of median POS sizes (as a measure of central tendency for POS existing within an egocentric LRA buffer) was in turn split at its median value to create two equally sized groups of participants. Individuals in the reference group were those for whom POS were typically smaller. Note that bodies of water excluded from the calculation of *POS greenness* were included in the total area of POS when calculating *POS size.*

Table 9: Descriptive statistics for continuous measures of local area POS characteristics (final sample, n=929)

Measure	Description	LRA buffer (metres)	Mean	Min	Max	Standard deviation	Skewness	Kurtosis
POS Greenness	Average of mean Normalised Difference Vegetation Index (NDVI) values of (unclipped) POS intersected by LRA buffer. Rescaled by factor of x 10.	500*	2.10	0.77	4.17	0.64	0.15	-0.62
		1000	2.05	1.05	3.56	0.54	0.53	-0.002
POS	Total area of (clipped) POS segments intersected by LRA buffer as a percentage of the total buffer area.	500	7.09	<0.01	33.7	5.44	1.12	1.56
		1000	9.19	0.15	32.6	4.47	1.18	2.46
POS Size	Median area (in hectares) of (unclipped) POS intersected by LRA buffer.	500*^	7.65	0.06	97.0	19.9	3.47	11.1
		1000^	2.57	0.13	97.0	9.39	9.14	87.3

*Local residential area (LRA) buffers and distances were computed using the road network, operationalised to reflect pedestrian (rather than vehicular) travel: movement along pedestrian tracks was allowed, one-way and turn restrictions on roads were ignored, and movement along ice and ferry routes and roads without pedestrian access (e.g. highways) was not allowed. LRA buffers were created by following the road network in all possible directions from the geocoded location until 500m/1000m had been travelled. The end points of these paths were then connected to create the buffer. * Calculation excludes participants with no POS in the 500m buffer (n=51). ^The continuous version of this measure was not analysed due to concerns about its distribution within the sample.*

Table 10: Descriptive statistics for categorical measures of local area POS characteristics (final sample, n=929)

Measure	Description	LRA buffer (metres)	Category	Values	N	(%)
*POS Size^*	Median area (in hectares) of (unclipped) POS intersected by LRA buffer.	500^*	Low (Reference)	0 to 1.24	439	(50)
			High	≥1.24	439	(50)
		1000	Low (Reference)	0 to 0.93	462	(50)
			High	≥0.93	467	(50)

See notes re: Table 9.

6.2 Dependent variables: mental health

The thesis assesses mental health outcomes in relation to two constructs: *Life satisfaction* measures a positive dimension of mental health, while *Psychological distress* measures negative symptomatic manifestations of poor mental health. These constructs are commonly used to describe and measure mental health status and its effects on the individual (World Health Organisation, 2001). Both constructs were measured at three time points (waves 1 to 3 of the ZEPSOM study) to allow longitudinal analysis of individual trajectories of change with respect to these variables. Non-normality in both measures was accommodated using the analysis method of growth mixture modelling. This method (detailed in Chapter 4) is appropriate for the analysis of skewed outcome data and, indeed, is often used as a method to approximate otherwise intractable non-normal distributions.

6.2.1 Life satisfaction

Life satisfaction was measured using an adaptation of the Satisfaction with Life Domains scale (Baker and Intagliata, 1982, Corten et al., 1994). The scale consists of 20 items in which participants were asked to indicate their level of satisfaction with varied aspects of life by choosing one of seven faces ranging from a "delighted" face (large upturned smile, scored 7) to a "terrible" face (deep frown, scored 1). The scale captures aspects of psychosocial functioning pertaining to both the micro-level context of daily living and the macro-level realisation of goals conducive to a vital life (Ro and Clark, 2009).

The French translation of the scale has been validated for use in Québec and was found to have excellent internal consistency (Cronbach alpha = 0.92) and good one-month test-retest reliability (r=0.73) (Caron et al., 1997). The scale possesses a five-factor structure capturing distinct domains of life (*daily life and social relations*, *personal relationships*, *spare time activities*, *autonomy*, and *housing & neighbourhood*) with a single second order factor representing overall life satisfaction; internal consistency was good for each of the subscales (Cronbach alphas between 0.71 and 0.84) and one-month test-retest reliability was acceptable (Pearson's r between 0.64 and 0.75) with the exception of the *spare time activities* subscale (r=0.50) (Caron et al., 1997). However, the greater temporal instability of *spare time activities* was likely explained by the fact that the student sample completed their second interview in the weeks preceding final exams. Three items comprising the *housing & neighbourhood* subscale were dropped from the analysis due to concerns that their inclusion may spuriously

inflate correlations between neighbourhood characteristics and life satisfaction. These items assessed the participant's satisfaction with their place of residence, their neighbourhood, and with local services and facilities. Scores were summed across the 17 remaining items to provide a continuous scale from 7 (very low life satisfaction) to 119 (very high life satisfaction). Internal consistency reliability estimates for this sample using Cronbach's alpha (Cronbach, 1951) were excellent for the 17-item scale (0.91 at T1; 0.90 at T2; 0.90 at T3) and good for the subscales (Cronbach alphas between 0.62 and 0.84) at each wave of data collection (Table 11). Only the total score was used in this research, as we sought to utilise a comprehensive measure of life satisfaction and avoid multiple testing across related outcomes.

Table 11: Satisfaction with Life Domains scale. Items and Cronbach alphas for scale and subscales (final sample, n=929)

Subscales	Items Which item best expresses how you feel about (your)…	Cronbach alpha (Subscales) T1	T2	T3
Daily life and social relations	1. Food 2. Clothing 3. Friends 4. Health 5. Occupation 6. How you get along with others	0.78	0.76	0.75
Personal relationships	7. The people you live with 8. Love life 9. Relationship with family	0.69	0.66	0.62
Spare time activities	10. How you spend your spare time 11. Hobbies / recreational activities	0.79	0.81	0.80
Autonomy	12. Life in general 13. Self-confidence 14. How others perceive you 15. Freedom 16. Responsibilities 17. Financial situation	0.83	0.81	0.84
Cronbach alpha (17-item scale)		0.91	0.90	0.90
Housing / Neighbourhood*	18. Place of residence* 19. Neighbourhood* 20. Local services and facilities* **Excluded from analysis*	0.66	0.65	0.67

Sample response distributions of *Life Satisfaction* at each wave of data collection were negatively skewed, with fairly constant sample means (and standard deviations) of 94.7 (13.9) at T1, 94.6 (12.8) at T2, and 94.5 (13.1) at T3 (Table 12). The level of skewness ranged from -0.86 to -1.18 across the three time points and was statistically significant ($p<0.0001$), indicating it is very likely that the population distribution of *Life Satisfaction* is negatively skewed to some extent. The response distributions were also leptokurtic, with statistically significant excess kurtosis averaging 1.87 across the three time points ($p<0.0001$).

Table 12: Reduced Satisfaction with Life Domains scale (17 items). Descriptive statistics (final sample, n=929)

	T1	T2	T3
Mean	94.7	94.6	94.5
Median	97.0	97.0	96.0
Mode	102.0	101.0	97.0
Standard deviation	13.9	12.8	13.1
Skewness (SE)	-1.18 (0.08)	-1.05 (0.08)	-0.86 (0.08)
Kurtosis (SE)	2.18 (0.16)	2.41 (0.16)	1.03 (0.15)
Skewness / SE	-14.80	-13.16	-10.76
Kurtosis / SE	13.61	15.03	6.44

6.2.2 Psychological distress

Psychological distress is measured using the K10 Psychological Distress Scale (Kessler et al., 2002). The K10 is a well-accepted and widely used tool for quantifying the mental health of individuals and populations (Price, 2008, Australian Bureau of Statistics, 2012) that identifies emotional, cognitive, and psychophysiological manifestations of non-specific psychological distress (Kessler et al., 2003). The scale possesses a four-factor structure of symptoms (*nervousness*, *negative affect*, *fatigue*, and *agitation*) with a two-factor second-order structure pertaining to symptoms of depression and anxiety (Brooks et al., 2006). It consists of ten 5-point Likert-type items, where participants estimate the frequency with which symptoms were experienced in past month (0- never; 1- rarely; 2- sometimes; 3- most of the time; 4- all of the time) (Table 13, p.121). The items range from low-threshold symptoms that many people endorse (e.g. nervous; restless or fidgety), through to high-threshold symptoms that very few will endorse (e.g. so sad nothing could cheer you up; worthless) (Coombs, 2005).

Scores were summed across the 10 items to provide a continuous scale from 0 (no distress) to 40 (severe psychological distress). The distribution of scores is typically heavily skewed, with the majority of people reporting little or no distress (Andrews and Slade, 2001, Kessler et al., 2003).

The K10 had previously been shown to have excellent internal consistency (Cronbach alpha = 0.92, 0.93) (Kessler et al., 2002, Kessler et al., 2003) and excellent two-week test-retest reliability (ICC test-retest correlation=0.92) (Australian Institute of Health and Welfare, 2004). Internal consistency reliability estimates for this sample using Cronbach's alpha (Cronbach, 1951) were excellent at each wave of data collection (0.88 at T1; 0.89 at T2; 0.90 at T3). The K10 exhibits strong concurrent validity with other common measures of distress symptomatology or disability. K10 scores are significantly related to scores on the General Health Questionnaire 12 (a measure of psychological distress) and the Short Form 12 (a measure of health status and disability), and to consultations for a mental health problem in the last twelve months (Andrews and Slade, 2001). It has been argued, however, that the K10 is preferable to the GHQ-12 because it has a wider range of questions along the distress continuum, and to the SF-12 because it is designed to measure levels of distress, not disability (Andrews and Slade, 2001).

Numerous studies also indicate convergent validity of the K10 with diagnoses of mental disorder. For example, the K10 can be used to screen for broadly defined mental disorders (Coombs, 2005) and discriminates well between community cases and non-cases of DSM-IV disorders (Kessler et al., 2002, Furukawa et al., 2003) and serious mental illness (Kessler et al., 2003). High scores on the K10 are strongly associated with current DSM-IV diagnoses of anxiety or affective disorders, and to a lesser extent to diagnoses of other mental disorders such as personality or substance use disorders (Andrews and Slade, 2001). Very high levels of distress may indicate a need for professional help, and the K10 is therefore a useful tool for estimating population need for mental health services. In this respect, the Australian Bureau of Statistics (2012) categorises scores according to four levels: low (0-5), moderate (6-11), high (12-19) and very high (20-40). K10 is not categorised in this research, but instead the total score is analysed as a continuous variable. In either case, the points made above are likely to be useful to the interpretation of findings.

Table 13: K10 psychological distress scale. Items and Cronbach alphas (final sample, n=929)

Scale	Items	Cronbach alpha (full scale)		
		T1	T2	T3
	In the last month, how often did you feel…			
Psychological distress (K10)	1. Tired out for no good reason 2. Nervous 3. So nervous that nothing could calm you down[a] 4. Hopeless 5. Restless or fidgety 6. So restless that you could not sit still[a] 7. Sad or depressed 8. So depressed that nothing could cheer you up[a] 9. That everything was an effort 10. Worthless	0.88	0.89	0.90

a) This question was not posed to participants who responded 'Don't know' to the preceding question (deemed non-applicable).

Sample means and standard deviations of the *Psychological Distress* measure remained constant across the three time points, at 7.5 and 6.0 respectively. The sample response distributions at each wave of data collection were positively skewed, with many people reporting low-to-moderate levels of psychological distress and few people reporting very high levels of distress. The level of skewness ranged from 1.15 to 1.23 across the three time points and was statistically significant ($p<0.0001$), indicating it is likely that the population distribution of *Psychological Distress* is positively skewed. Sample distributions were censored at zero, with 5 to 6% of the sample scoring 0 out of 40 at each wave of data collection. No participant recorded the maximum possible score of 40 at any time point.

Table 14: K10 psychological distress scale. Descriptive statistics (final sample, n=929)

	T1	T2	T3
Mean	7.5	7.5	7.6
Median	6.0	6.0	6.0
Mode	3.0	3.0	5.0
Standard deviation	6.0	6.0	6.0
Skewness (SE)	1.15 (0.08)	1.23 (0.08)	1.23 (0.08)
Kurtosis (SE)	0.91 (0.16)	1.78 (0.16)	1.66 (0.15)
Skewness / SE	14.35	15.35	15.43
Kurtosis / SE	5.62	11.14	10.38

6.3 Mediating variables: neighbourhood social integration

This thesis assesses the effects of POS on neighbourhood social integration in relation to its cognitive (*Social Cohesion*), informal behavioural (*Neighbouring Behaviour*), and formal behavioural (*Community Participation*) dimensions. These are distinct but interrelated constructs (Perkins and Long, 2002) reflecting the manner in which the individual perceives and participates in the neighbourhood social ecology. Each is measured using a multiple-item scale within the first survey of the ZEPSOM study (T1), contemporaneous with the collection of POS exposures and the first occasion of data collection for the mental health outcomes. Consistent with the measurement of POS characteristics within individually defined areas, measures of neighbourhood social integration are also operationalised as individual-level constructs (i.e. they are not aggregated across respondents to create a collective measure). Scale items and Cronbach alphas for the three measures are summarised in Table 15 (p.123), while available evidence pertaining to test-retest reliability is presented in text throughout the following sections. Finally, descriptive statistics for the scales are presented in Table 16 (p.124).

6.3.1 Social cohesion

Social cohesion represents a sense of community, trust and unity among residents and is a generalised, intra-psychic reflection of the quality of neighbourhood life (Perkins and Long, 2002). Social cohesion was measured as per Sampson et al. (1997). The scale consists of five items, listed in Table 15. Responses are collected on a five-point Likert scale (1- strongly disagree to 5- strongly agree) and reverse coded for statements (4) and (5). Scores were aggregated for each respondent across the five items to provide a continuous scale from 5 to 25, where a higher score represents greater perceived social cohesion.

The scale has previously demonstrated good internal and test-retest reliability among: a largely Latino and African American sample in a socioeconomically deprived area of New York City (Cronbach alpha=0.82, 0.86; test-retest correlation=0.90) (Echeverria et al., 2004); a sample of females without breast cancer matched by age, race, and geography to a sample with breast cancer (Cronbach alpha=0.86, 0.86; test-retest ICC =0.71) (Pruitt et al., 2012); and a socioeconomically and ethnically representative sample from three U.S. states (Cronbach alpha =0.74, test-retest correlation=0.65) (Mujahid et al., 2007).

The internal consistency estimate for the present sample using Cronbach's alpha (Cronbach, 1951) was 0.78 (Table 15, p.123). The sample distribution of social cohesion scores at T1 was roughly symmetric with mean 17.9 and standard deviation 3.6 (Table 16).

Table 15: Social cohesion, neighbouring behaviour, and community participation scales: items and Cronbach alphas (final sample, n=929)

Scale	Items R = Reversed item	Cronbach alpha T1
Social cohesion	How strongly would you agree that… 1. People around here are willing to help their neighbours 2. This is a close-knit neighbourhood 3. People in this neighbourhood can be trusted 4. People in this neighbourhood generally don't get along with each other (R) 5. People in this neighbourhood do not share the same values (R)	0.78
Neighbouring behaviour	How many times in the last year have you been asked by somebody in your neighbourhood to… 1. Watch their home while they are away 2. Loan them a tool 3. Help them in an emergency 4. Offer advice on a personal problem 5. Discuss a problem on the block with them	0.73
Community participation	In which of the following activities have you participated in the past twelve months… 1. Participated in a block group, neighbourhood association, or local community action group 2. Attended a public hearing, town hall meeting or city council meeting 3. Called or sent a letter to an elected public official 4. Contacted an organisation (e.g. police, local council) or attended a public meeting to deal with a local problem	0.52

Table 16: Social cohesion, neighbouring behaviour, and community participation scales. Descriptive statistics (final sample, n=929)

	Social cohesion T1	Neighbouring behaviour T1	Community participation T1
Mean	17.9	10.4	0.60
Median	18.0	8.0	0.00
Standard deviation	3.6	8.7	0.91
Skewness (SE)	-0.38 (0.08)	1.08 (0.08)	1.68 (0.08)
Kurtosis (SE)	0.13 (0.16)	0.78 (0.16)	2.60 (0.16)
Skewness / SE	4.75	13.5	21.0
Kurtosis / SE	0.80	4.87	16.3

6.3.2 Neighbouring behaviour

Neighbouring behaviour involves the highly localised exchange of instrumental, informational, personal, or functional forms of social support (Farrell et al., 2004) and was measured using the 'neighbouring given' component of Perkins et al.'s (1990) Neighbouring Behaviour Scale (Perkins and Long, 2002, Long and Perkins, 2003). Participants were asked to recall how many times in the last year their assistance had been requested by somebody in their neighbourhood, in relation to the five behaviours listed in Table 15 (p.123). Responses were coded according to the number of times the respondent was asked in the last year (i.e. once=1, twice=2) up to 8 times or more (=8) and scores were summed for each respondent to provide a continuous scale from 0 to 40. The scale has been shown previously to exhibit acceptable internal consistency (Cronbach alpha = 0.76-0.78) (Perkins et al., 1990, Perkins and Long, 2002, Long and Perkins, 2003). While its temporal stability remains to be investigated, Mujahid et al. (2007) describe a similar scale that showed high two-to-three week test-retest reliability (test-retest correlation=0.73). Three items of their five-item "Activities with Neighbours" scale are analogous to those above, asking how often neighbours (1) watch over others' property when they are away, (2) do favours for each other, including lending garden or house tools, and (3) ask each other for advice about personal matters.

The internal consistency reliability estimate for this sample using Cronbach's alpha (Cronbach, 1951) was 0.73 (Table 15). The sample distribution of neighbouring behaviour scores at T1 was positively skewed (skewness=1.08, $p<0.0001$) with mean 10.4 and standard deviation 8.7 (Table 16, p.124). The distribution was censored at zero, with 7.5% of participants scoring 0 out of 40, and somewhat leptokurtic with excess kurtosis of 0.78 ($p<0.0001$).

6.3.3 Community participation

Community participation was measured using an adaptation of scales developed by Ziersch et al. (2005) and Nario-Redmond et al. (2000) to measure local civic action and activity. The four-item scale measures the degree of involvement in neighbourhood organisation, asking whether the respondent has participated in any of the following activities during the past twelve months: (1) Participated in a block group, neighbourhood association, or local community action group; (2) Attended a public hearing, town hall meeting or city council meeting; (3) Called or sent a letter to an elected public official; (4) Contacted an organisation (e.g. police, local council) or attended a public meeting to deal with a local problem[67]. These activities reflect instrumental forms of social participation motivated by political or functional concerns and a desire to protect local interests (Swaroop and Morenoff, 2006). 'Yes' responses were coded as 1 and summed for each respondent to create a scale from 0 to 4, where a higher score represents a greater degree of formal community participation.

Internal consistency reliability was poor for this sample (Cronbach alpha=0.52) (Table 15, p.123) with weak inter-item correlations between items (ranging from 0.17 to 0.27). This is unsurprising, however, given that the scale comprises a small number of dichotomous items achieving relatively low levels of endorsement (8.4% to 19.4%). Cronbach's alpha is a function of the number of items in a scale and the average inter-item correlation between them. On one hand, the Cronbach alpha will increase with the addition of items to the scale even if inter-item correlations remain unchanged (Streiner, 2003). On the other, low base item prevalences can lead to smaller inter-item correlations and therefore a smaller Cronbach alpha when comparing between scales with the same number of items (Skinner et al., 2002). As a consequence, the reliability coefficient will suffer in shorter scales with homogenous samples, such as this one. Finally, the community participation scale is arguably formative (rather than reflective) in the sense that its items are intended to capture a collection of defining behaviours that combine to explain the meaning of the construct (rather than a set of measures that tap into an underlying cause). In this situation, internal consistency is not expected to be high (Edwards, 2011).

[67] A fifth item ('Attended a church or religious service in the neighbourhood') was dropped from the scale because (a) it is conceptually distinct from the other items and risks confounding instrumental participation with religiosity; (b) it correlated very weakly with other items in the scale (inter-item correlations ranging from 0.03 to 0.14); and (c) it was the most frequently endorsed item in the scale.

Unfortunately, information pertaining to test-retest reliability of the community participation scale could not be located. The sample distribution of community participation scores at T1 was positively skewed (skewness=1.31, $p<0.0001$) with mean 0.91 and standard deviation 1.07 (Table 16, p.124). Nearly half of the final sample (44%) did not participate in any of the four activities, while a further third (34%) participated in one. Fewer than 10% participated in more three or more activities. The response distribution was significantly leptokurtic, with excess kurtosis of 1.49 ($p<0.0001$). Due to the limited variation in responses, the measure was dichotomised to distinguish between people who participated in none of the listed activities (n=410) and those who participated in at least one activity (n=519). Follow-up analysis tested the sensitivity of results to this categorisation by modelling community participation as count (Poisson-distributed) variable. The results of this sensitivity analysis are reported in Appendix 6.1 and briefly discussed in Chapter 6 (Section 3.1).

6.4 Mediating variables: network-based social support & coping

The thesis assesses the effects of POS on the availability of intrapersonal and proximal interpersonal psychosocial resources in relation to the participant's perceived availability of support from their social network (*Social support*) and perceived ability to cope with stress (*Coping*). *Social support* was measured using a multiple-item scale, summarised in Table 18 (p.128), while *Coping* was measured using a single item. Each construct was measured at T1, contemporaneous with the collection of POS exposures and the first occasion of data collection for the mental health outcomes. Descriptive statistics for these measures are presented in Table 17 (p.127) and Table 19 (p.130).

6.4.1 Network-based social support

The Social Provisions Scale (Cutrona and Russell, 1987) was used to measure the degree to which the respondent's current social relationships provide various dimensions of social support. The scale captures Weiss' (1974) six functions of social relationships: *attachment* (perceived emotional closeness and security), *social integration* (perceived belonging to a group of people with shared interests and activities), *reassurance of worth* (perceived acknowledgement by others of one's competence), *reliable alliance* (perception that one will receive advice and information from others if desired), and *opportunity for nurturance* (perceived responsibility for the wellbeing of another person). Each function was evaluated using four questions, two of which describe the presence of a type of support (e.g. "there are

people I can depend on to help me if I need it") and two of which describe the absence of a type of support (e.g. "I lack a feeling of intimacy with another person"). This results in a total of 24 items (6 dimensions x 4 questions). Respondents use a four-point scale (1- strongly disagree to 4- strongly agree) to indicate their level of agreement in relation to current social relationships. Negatively worded items were reversed, and a total score was computed by summing across all items. This creates a continuous scale from 24 to 96, where a higher score indicates a greater degree of perceived network-based social support.

Factor analysis has confirmed a six-factor structure corresponding to the six social provisions, but also a second order factor representing a global measure of support (Cutrona and Russell, 1987, Caron, 1996). The Cronbach alpha coefficient for the scale as a whole was 0.92 and for the subscales ranged from 0.65 to 0.76 (Cutrona and Russell, 1987). The French translated version of the scale was validated for use in Québec and found to have internal consistency of 0.87 for the whole scale and Cronbach alpha coefficients from 0.56 to 0.76 for the subscales; one month test-retest reliability of the whole scale was satisfactory (Pearson test-retest correlation=0.66) (Caron, 1996). Internal consistency reliability estimates for this sample were excellent for the full scale (Cronbach alpha = 0.94) and good for the subscales (Cronbach alphas ranging from 0.73 to 0.85) (Table 18, p.128).

The sample distribution of social support scores at T1 was moderately negatively skewed (skewness=-0.42, $p<0.0001$) with mean 81.0 and standard deviation 10.1 (Table 17). The distribution was censored from above, with 4% of participants recording the maximum possible score of 96, while the minimum recorded score was 42.

Table 17: Social support scale. Descriptive statistics (final sample, n=929)

	Social support T1
Mean	81.0
Median	82.0
Standard deviation	10.1
Skewness (SE)	-0.42 (0.08)
Kurtosis (SE)	-0.38 (0.16)
Skewness / SE	5.20
Kurtosis / SE	2.36

Table 18: Social support scale. Items and Cronbach alphas for scale and subscales (final sample, n=929)

Subscales	Items (R = Reversed item) To what extent do the following phrases reflect the way you think or feel…	Cronbach alpha (Subscales) T1
Reliable alliance	1. There are people I can depend on to help me if I really need it 2. There are people I can count on in an emergency 3. If something went wrong, no one would come to my assistance (R) 4. There is no one I can depend on for aid if I really need it (R)	0.82
Social integration	5. There are people who enjoy the same social activities I do 6. I feel part of a group of people who share my attitudes and beliefs 7. There is no one who shares my interests and concerns (R) 8. There is no one who likes to do things I do (R)	0.76
Reassurance of worth	9. I have relationships where my competence and skills are recognised 10. There are people who admire my talents and abilities 11. Other people do not view me as competent (R) 12. I do not think other people respect my skills and abilities (R)	0.78
Attachment	13. I have close relationships that provide me with a sense of emotional security and wellbeing 14. I feel a strong emotional bond with at least one other person 15. I feel that I do not have close personal relationships with other people (R) 16. I lack feeling of intimacy with another person (R)	0.75
Guidance	17. There is someone I could talk to about important decisions in my life 18. There is a trustworthy person I could turn to for advice if I were having problems 19. There is no one I can turn to for guidance in times of stress (R) 20. There is no one I feel comfortable talking about problems with (R)	0.85
Opportunity for nurturance	21. There are people who depend on me for help 22. I feel personally responsible for the well-being of another person 23. There is no one who really relies on me for their well-being (R) 24. No one needs me to care for them (R)	0.73
Cronbach alpha (24-item scale)		0.94

6.4.2 Coping

Perceived ability to cope was measured using two items drawn from the Canadian Community Health Survey-Cycle 1.2 (CCHS-1.2, Statistics Canada, 2002). Participants were asked how, in general, they would evaluate their ability to cope with either (1) the stress of daily life or (2) unexpected or difficult problems. Responses were collected on a 5-point scale (1- poor; 2- fair; 3- good; 4- very good; 5- excellent). Analysis of a representative random sample of 36,984 individuals in the CCHS-1.2 study found that the two items, taken together, accounted for approximately 5% of total cross-sectional variance in psychological distress (controlling for a key stressors, social support, and sociodemographic characteristics) (Caron and Liu, 2011). In the present study, due to the small numbers of participants reporting a 'poor' or 'fair' ability to cope with stress, the coping variables were dichotomised at the median to distinguish individuals with 'poor', 'fair', or 'good' coping ability (reference group) from those with 'very good' or 'excellent' coping ability. Follow-up analyses tested the sensitivity of results to this categorisation by (i) employing an alternative binary cut point ('poor' or 'fair' coping ability versus 'good' or better) and (ii) modelling coping as an ordered categorical variable. The results of this sensitivity analysis are reported in Appendix 6.1 and briefly discussed in Chapter 6 (Section 3.1).

Unfortunately, an error in the administration of this measure at T1 meant that the English and French versions of the questionnaire each included only one of the two coping items. French-speaking participants (n=618) were asked exclusively about coping with the stress of daily life, while English-speaking participants (n=306) were asked exclusively about coping with unexpected or difficult problems. As a consequence, only one item was measured for each participant at T1 and this item differed depending on whether they completed the questionnaire in French or English. Descriptive statistics for each item are presented in Table 19 on the following page. English speaking participants rated their ability to cope with unexpected problems somewhat lower than French speaking participants rated their ability to cope with daily life stress, although these differences were not striking.

Clearly, the two items reflect different requirements and applications of the coping process. It is plausible that both questions should tap into the participant's latent potential for dealing with stress and will effectively measure the same phenomenon of interest despite their

semantic differences. Importantly, in the Canadian context, the items do not differ greatly in terms of their cross-sectional associations with the level of psychological distress[68] and there appears to be no independent effect of first language (French or English) over and above other sociodemographic characteristics and access to psychosocial resources (Caron and Liu, 2011).

Table 19: Coping scale. Descriptive statistics (final sample, n=929)

	Coping T1 French (n=618)		Coping T1 English (n=306)	
Ability to cope with…	*Stress of daily life*		*Unexpected or difficult problems*	
	n	%	n	%
Excellent	70	11.3	26	8.5
Very good	208	33.7	119	38.9
Good	199	32.2	87	28.4
Fair	43	7.0	32	10.5
Poor	15	2.4	8	2.9
Missing	*83*	*13.4*	*34*	*11.1*

Five participants for whom the language of interview was not recorded were excluded from the analysis

Both coping items were administered to all participants at later waves of the ZEPSOM study, and, although the data were not used in this research, it is worth noting the reasonably strong, positive correlations between the items at T2 (Spearman's ρ=0.58) and T3 (Spearman's ρ=0.68). Most participants rated equally their ability to cope with day-to-day and unexpected stressors (55% at T2, 64% at T3). For those who felt their ability to handle unexpected problems was worse (31% at T2, 26% at T3) or better (14% at T2, 10% at T3) than their ability to handle daily stress, the difference in ratings was rarely greater than one point on the scale (12% at T2, 13% at T3). When testing the association between POS greenness and coping, sensitivity to this measurement artefact was investigated by adding (i) a dummy covariate for interview language and (ii) an interaction term between interview language and coping score. Results are reported in Appendix 6.1 and briefly discussed in Chapter 6 (Section 3.1). However, it is worth noting here that the findings were not sensitive to those changes.

[68] Although, the perceived ability to handle unexpected events does appear to be slightly less influential among non-low-income populations (when compared against the same measure in low-income populations and against coping with day-to-day demands across both income strata).

A second noteworthy issue for the coping measure pertains to the conspicuous rates of missingness on these items, arising from a skip pattern in the questionnaire. As a precursor to administration of the coping measure, all participants were presented with a list of possible sources of stress and asked to select those that they felt contributed the most to feelings of stress in their everyday life. This list included a wide range of stressors such as time pressures, the participant's state of health, their financial situation, family responsibilities, schooling, and employment. In addition, the participant could cite any 'other' source of stress. If a participant selected "nothing" as their response to this question, or if they stated that they "do not know", they were not asked to respond to the coping item. As detailed in Appendix 3.4, this resulted in missing data for 12.7% of participants, almost exclusively attributable to the participant identifying "nothing" as a key source of daily stress (98%) rather than uncertainty about how to respond.

The problem posed by this selection design is essentially one of range restriction; I wish to estimate relationships between POS greenness and coping, and between coping and mental health, but the correlations observed between these variables may be underestimated due to the exclusion of participants with 'no' main source of daily stress (Sackett and Yang, 2000). Fortunately, this range restriction problem can be treated as a missing data problem in which the selection mechanism is the missing data mechanism (Mendoza, 1993). This approach enables consistent and efficient estimation of population-level relationships from the restricted sample (Sackett and Yang, 2000) and is discussed further in Section 7.

6.5 Stressful life events

Exposure to acute stressors was measured using a prompted inventory of stressful life events, administered at each wave of the ZEPSOM study, using an additive approach to reflect the overall magnitude of eventful change in the year preceding each interview (Pearlin et al., 1981). The stressful life events instrument was drawn from Laurin's (1998) scale developed to measure life events among the homeless, which was itself based on three other instruments: those of Morse et al. (1985), the Québec Health Survey (1988), and the Survey on Lifestyle and Mental Health of Montréal residents (Kovess and Fournier, 1990). Participants were asked whether they have experienced, during the twelve months preceding the interview, any of 22 objective stressful life events (SLE) linked to five main themes of income, love, links with family and friends, housing, and experiences of aggression (Table 20, p.132).

Table 20: Stressful life events inventory. List of items (reference period: 12 months preceding interview)

Theme	Events	T1		T2		T3	
		n	%	n	%	n	%
Income	Unemployed for one month or more	296	31.9	207	22.3	173	18.6
	Income greatly diminished	170	18.3	170	18.3	146	15.7
	Laid off or fired, or had problems with an employer	119	12.8	121	13.0	109	11.7
	Had a serious debt problem	85	9.1	82	8.8	73	7.9
	Stopped receiving social or unemployment assistance	36	3.9	18	1.9	17	1.8
	Became bankrupt	10	1.1	14	1.5	14	1.5
Love	Experienced a breakup (other than separation or divorce)	82	8.8	62	6.7	59	6.4
	Became separated or divorced	29	3.1	30	3.2	21	2.3
Links with family and friends	Somebody close to you has been seriously ill	401	43.2	373	40.2	363	39.1
	Somebody close to you died	261	28.1	254	27.3	244	26.3
	Had problems with friends or neighbours	223	24.0	198	21.3	181	19.5
	Lost something of sentimental value	148	16.0	131	14.1	107	11.5
	You have been seriously ill	108	11.6	99	10.7	82	8.8
	Cut ties with family	78	8.4	65	7.0	43	4.6
	Cut ties with children	25	2.7	27	2.9	29	3.1
Housing	Problem with housing (condemned, fire, heating, electricity, plumbing)	153	16.5	106	11.4	137	14.7
	Moved house	23	2.5	26	2.8	25	2.7
	Evicted from housing	4	0.4	3	0.3	2	0.2
Aggression	Victim of robbery	76	8.2	65	7.0	51	5.5
	Victim of physical assault	18	1.9	7	0.8	13	1.4
	Victim of rape	4	0.4	1	0.1	2	0.2
Other	Other (open response)	248	26.7	225	24.2	207	22.3

The participant was also asked to indicate how stressful each event they experienced was for them personally (1- not stressful, 2- a little stressful, 3- quite stressful, 4- very stressful). The mean level of stress attributed to each SLE was calculated and used to weight the events based on their comparative severity. Specifically, the mean stress rating for a given SLE was divided by the average of the mean ratings for all events in the inventory ($SLE_{1, 2, \ldots 22}$), such that the experience of a particularly stressful event (e.g. death of a loved one) was scored at >1 and the experience of less stressful event (e.g. problems with friends or neighbours) was scored at <1. Non-applicable items (e.g. 'cut ties with children' for participants without

children) were scored as a non-event (=0). Total scores for SLE were then constructed by summing the weighted experiences of each participant at each time point, with possible scores ranging from 0 to 22. More than 80% of participants at each wave of data collection reported having experienced at least one SLE on the inventory in the past twelve months (88% at T1, 85% at T2, 81% at T3). As anticipated, the distributions of weighted SLE scores were positively skewed (skewness ranging from 1.05 to 1.32) with low mean values (2.8 at T1, 2.4 at T2, 2.2 at T3) (Table 21, p.133).

Scores across the three waves were then amalgamated into two indicators to approximate: (1) the 'initial' (i.e. prevailing) level of exposure to acute stressors in the twelve months prior to commencement of the study (i.e. stressors reported at T1) and (2) exposure to 'new' (i.e. incident) life stressors arising throughout the observation period (i.e. stressors reported at T2 and T3). 'New' life stressors were taken as the primary exposure of interest in order to permit estimation of the effects of SLE on trajectories of mental health while controlling for prior values of the outcome (i.e. mental health at T1). However, 'initial' exposure to stressors was also included in the models as a covariate, to control for any lagged effects of SLE prior to the first occasion of mental health measurement, particularly in relation to initial values of distress or life satisfaction.

Table 21: Stressful life events inventory: weighted total scores. Descriptive statistics (final sample, n=929)

	T1 ('initial' SLE)	T2	T3	(T2 + T3) ('new' SLE)
Mean	2.77	2.43	2.20	4.63
Median	2.59	1.99	1.92	4.02
Mode*	3	2	2	3
Standard deviation	2.12	2.00	1.89	3.28
Skewness (SE)	1.05 (0.08)	1.32 (0.08)	1.23 (0.08)	1.30 (0.08)
Kurtosis (SE)	1.23 (0.16)	2.92 (0.16)	2.45 (0.16)	2.99 (0.16)
Skewness / SE	13.14	16.44	15.43	16.28
Kurtosis / SE	7.61	18.24	15.33	18.7

** Weighted scores are rounded to the nearest integer to ensure a representative estimate of the distribution mode*

6.6 Covariates

A range of individual- and area-level covariates were included in all analyses in order to control for potential confounding and selection effects.

6.6.1 Individual-level covariates

Analyses in this study were conditioned upon a large number of individual-level covariates including age, sex, annual household income, highest education level (as a proxy for social position), marital status, self-reported physical health, and whether the participant had worked at any time during the 12 months prior to the interview. These variables are known determinants of mental health and wellbeing (Turner and Marino, 1994, Mirowsky and Ross, 1995, Andrews et al., 1999, Cotten, 1999, Fryers et al., 2003, Dolan et al., 2008, Gadalla, 2009, Mirowsky and Ross, 2010, Westerhof and Keyes, 2010, Ambrey and Fleming, 2013) and are also liable to influence area of residence and the availability of psychosocial resources (Turner and Marino, 1994, Thoits, 1995, Smyth et al., 2015), including the extent of cognitive and behavioural integration into local communities (Hummon, 1992, Kasarda and Janowitz, 1974, Cuba and Hummon, 1993, Perkins and Long, 2002). Age and marital status have also been associated with park use (Moore et al., 2010). Failing to account for their influence would therefore introduce the potential for confounding bias in the estimation of relationships between public open space, psychosocial resources, and mental health.

In addition to the demographic variables already stated, two further individual-level covariates – season of interview and length of residence at baseline – were included in all analyses. Each wave of data collection took a little over a year to complete, such that interviews took place during all four seasons of the year (see Section 5.1). Seasonal factors may exert systematic short-term effects on park usage (Nikolopoulou et al., 2001, Ward et al., 2014) and on mental health (Partonen and Lönnqvist, 1998, Mersch et al., 1999, Ayers et al., 2013). These influences were broadly controlled using a single dummy variable at each time point to distinguish between participants that completed their interview in the warmer months of the year (May to October; reference group) versus the colder months of the year (November to April). Length of residence at the T1 address, which varied from one year to more than 20 years, was also broadly controlled using a baseline dummy covariate to distinguish between participants who had lived in the home for more than five years (reference group) and those who had lived there for less time, because factors influencing the choice to remain in a

neighbourhood might also affect mental health. This variable may therefore act to some extent as a proxy control for unmeasured neighbourhood influences, while also capturing temporal opportunities for assimilation into the local community and the relative extent of shared history with a local area and its inhabitants (Kasarda and Janowitz, 1974). Length of residence has a strong positive effect on neighbourhood social integration, including the strength of neighbourhood social ties, place attachment, neighbouring behaviour, the likelihood of partaking in local activities and civic action, and perceived sense of community (Kasarda and Janowitz, 1974, Chavis et al., 1986, Sampson, 1988, Adams, 1992, Perkins and Long, 2002, Kang and Kwak, 2003, Lewicka, 2005, Kaźmierczak, 2013). In other cases, it is possible that a lack of residential mobility reflects entrapment in a residential area that is (or is becoming) detrimental to the wellbeing of the individual. This variable could therefore confound relationships between POS greenness, neighbourhood social integration, and mental health, particularly if patterns of residential stability varies across neighbourhoods.

Table 22 (p.137) summarises the covariates used in this study, outlining any applicable categorisation schemes and reference groups; whether the variable was modelled at its baseline (T1) value or as a time-varying covariate (T1-T3); and the prevalence (or mean and standard deviation) of each categorical (or continuous) variable at applicable time points. Missing data are excluded from the table and described later in Section 7. With the exception of household income and physical health status, all covariates were categorised and entered into statistical models using k-1 dummy variables. Given the large number of covariates and complexity of the statistical analysis to be undertaken, a conscious effort was made to limit the number of dummy variables added to the model and to ensure sufficient numbers of participants in each category. Sparseness in the analysed frequency table poses a distinct threat to the convergence of mixture models, which effectively partition the sample size into smaller groups and may be prone to singularities in the sample covariance matrix. For this reason, binary categorisations were frequently employed even though in some instances it may have been preferable to specify a greater diversity of groups.

Age was categorised into three groups based on years of age at the first interview (15 to 35; 36 to 50; 51 and over). These groupings represent broadly distinct life stages and are consistent with age cohorts delimited by the WHO in a cross-national investigation that identified greater projected lifetime risk of anxiety, mood and substance use disorders among younger cohorts (Kessler et al., 2007b). They also roughly delineate the stages relevant to

overall life satisfaction, which appears throughout different parts of the world to follow a u-shape with age, typically reaches a minimum in the mid-to-late forties (Blanchflower and Oswald, 2008). Highest level of education was dichotomised according to whether the participant had completed a Diploma of College Studies (DCS) or higher qualification (versus those that had not). The DCS is the first level of higher education in Québec. It is awarded following two years of general education or three years of vocational education and acts as a bridge between secondary school and university. Marital status was dichotomised according to whether the participant was legally married or in a common law relationship at the time of interview (versus those who were never married, divorced, separated, or widowed). I recognise that assuming homogeneity in 'singlehood' may be imprecise and mask important differences between various groups, such as the role and relationship transitions experienced by divorced persons compared with those who were never married (Gove et al., 1983, Cotten, 1999). However, only 17-18% of the final sample was separated or divorced and 2-3% widowed at any time point, and these groups were merged with the 'never married' to ensure sufficient numbers in the reference group. Length of residence was dichotomised according to whether the participant had been living at their current residence for five years or less at T1 (versus more than five years) on the basis that length of residence may exert the most pronounced effect on community cognitions and behaviours within the first several years (Caplow et al., 1964). 'Season' of interview was accounted for using a single dichotomous variable representing whether the interview was completed in the colder half (November-April) or the warmer half of the year (May-October).

Physical health status was measured using a five-point item that asked the respondent to report their perceived state of physical health (1-poor, 2-fair, 3-good, 4-very good, 5-excellent) and was modelled as a continuous variable, centred at three ('good' physical health). Household income was measured in Canadian dollars, but significant levels of non-response to the this variable necessitated its log transformation (base-e) in order to better satisfy the multivariate-normal assumption of the multiple imputation missing data method used in this thesis (see Section 7). This alters the interpretation of regression coefficients from reflecting the effect of a unit change in dollars of income to a unit change in log(dollars) of income and implies a non-linear relationship between household income and mental health outcomes. Specifically, it assumes that the effect of a one-dollar rise in income is increasingly attenuated at higher levels of income. This is a conceptually sound assumption in the context of mental

health research (Dolan et al., 2008, Caron and Liu, 2011). Log-transformed measures of household income at each time point were centred at the T1 sample mean in order to capture both collective and individual-level changes in income over time.

Table 22: Descriptive statistics for individual-level covariates (baseline and time-varying)

Covariate	Baseline or time-varying	Categories	% or [mean; SD]		
			T1	T2	T3
Sex	Baseline	Male	37.0	-	-
		Female (ref)	63.0	-	-
Age (years)	Baseline	15 to 35	20.5	-	-
		36 to 50 (ref)	40.0	-	-
		>50	39.5	-	-
Highest level of education	Baseline	DCS or higher	58.3	-	-
		Less than DCS (ref)	41.7	-	-
Duration of residence (years)	Baseline	1 to 5		-	
		>5 (ref)		-	
Natural log household income ($CAD)	Time-varying	[Continuous variable]	[10.81; 0.86]	[10.83; 0.87]	[10.88; 0.83]
Worked in past 12 months	Time-varying	Yes	75.8	72.5	72.7
		No (ref)	24.2	27.5	27.3
Marital status	Time-varying	Married or common law relationship	50.5	50.7	50.3
		Other (ref)	49.5	49.3	49.7
Physical health (self-reported)	Time-varying	[5-point item]	[3.41; 1.02]	[3.20; 1.06]	[3.19; 1.06]
Season of interview	Time-varying	November-April	40.3	54.8	57.1
		May-October (ref)	59.7	45.2	42.9

6.6.2 Area-level covariates

Area-level socioeconomic deprivation (area SED) and population density were measured at the census tract level using data from the 2006 Canada Census (Statistics Canada, 2006) and recorded as baseline covariates for individuals (n=929) residing in the respective census tracts (n=74) at T1. Area SED has been demonstrated to exert a deleterious effect on residents' mental health beyond the influence of their individual socioeconomic circumstances (Truong and Ma, 2006, Kim, 2008, Mair et al., 2008, Blair et al., 2014), while there is some evidence that population density may be inversely related to neighbourhood satisfaction (Hummon, 1992). These neighbourhood attributes might also be associated with POS characteristics.

For instance, POS in densely populated areas might (a) comprise less land or smaller parcels of land; (b) have to support more residents; and/or (c) be valued more highly as a source of relief from overcrowding (Brander and Koetse, 2011). Together, these factors might influence the manner in which POS facilitates restorative experience and neighbourhood social integration. There is also evidence that population density is related to the perceived proximity of POS, after accounting for objective distance to the nearest POS, area-level income, and individual sociodemographic characteristics (Moore and Kestens, 2011).

In relation to area SED, numerous studies have linked neighbourhood-level disadvantage to lower POS accessibility (Estabrooks et al., 2003, Powell et al., 2004, Wolch et al., 2005, Astell-Burt et al., 2014a) and size (Boone et al., 2009, Mitchell et al., 2011) as well as the inferior availability or condition of amenities within POS (Cradock et al., 2005, Crawford et al., 2008). Area SED also appears to be inversely associated with the prevalence of POS usage (Moore et al., 2010). Area SED could therefore confound associations between POS and mental health, and is an important variable upon which to condition the analyses. Doing so also serves as a final adjustment for residual confounding due to differences in neighbourhood composition not captured by the individual-level covariates (Oakes, 2004) and for potential selection biases arising from differential absence rates, during recruitment, across dissemination areas with soecioeconomically distinct profiles (Section 3, this chapter).

Population density was measured at the census tract level by the number of residents per $100m^2$ (mean 69.1, SD 38.36). Area SED was also measured at the census tract level, this time by combining seven indicators from the 2006 Canada Census (Statistics Canada, 2006) into a single summary score. The choice of indicators accords with widely accepted conceptions of neighbourhood disadvantage as the collective absence of economic, social, and human capital, as reflected in the prevalence of poverty, home ownership, education, and single-parent households (Ross and Mirowsky, 2001). Specifically, area SED was computed as the average standard z-score of the following statistics:

<table>
<tr><td>Median household income (reversed)</td><td>% 15 and over without a high school diploma</td></tr>
<tr><td>% living in rented accommodation</td><td>% aged 15 and over without a university degree</td></tr>
<tr><td rowspan="2">% under a low income cut-off (LICO)

LICO (see e.g. Statistics Canada, 2010) reflects >20% more after-tax income spent on food, shelter and clothing than the average household of equivalent size and location</td><td>Unemployment rate for the population aged 25 or over</td></tr>
<tr><td>Proportion of lone parent families</td></tr>
</table>

Cronbach's alpha for the indicators of area SED was 0.91. The resulting variable had a mean of zero and standard deviation 0.82. As predefined administrative areas, it is worth noting that census tracts do not correspond perfectly to the local residential area (LRA) for most individuals, nor do they match the LRA buffers generated to measure POS exposures (Oliver et al., 2007). However, they do provide a stable geographic framework with reliable and readily available measures of the indicators just outlined. Although only two area-level covariates were entered into the statistical models, controlling for individual length of residence (as described in the previous section) may also help to account for unobserved area-level factors that could influence both the choice to remain in a given neighbourhood and mental health outcomes.

7 Missing data and imputation strategy

Appendix 3.4 presents a comprehensive discussion of the problem of missing data in epidemiological research, highlighting the need to explicitly investigate and account for missing data using principled methods. It describes the three basic processes that underlie missing data in order to guide the diagnosis and treatment of the missing data mechanism in this research. It then develops an imputation strategy through an exploration of (1) missing data on items within multiple-item scales and (2) missing data on covariates and scale totals.

Generally speaking, the proportion of missing data among final sample participants was low. Within the multiple-item SLDS and K10 scales, fewer than 2% of participants were missing responses to more than 10% of items. Provided that a participant had responded to at least half of the items in the scale, any missing responses were substituted with his or her mean score across the other (complete) items (Hawthorne and Elliott, 2005). This imputation technique is suitable for multiple-item scales, such as the SLDS and K10, which capture a single, well-defined domain and exhibit high levels of internal consistency (Graham, 2009). Following this procedure, only the household income variables were missing more than 1% of responses at any wave of data collection (7.4-12.8% at T1-T3). Income missingness was predicted by participant age, gender, education level, employment status, and marital status, lending support to the plausibility of a 'missing at random' (MAR) mechanism. All remaining missing data were imputed 50 times using parametric Markov Chain Monte Carlo (MCMC) techniques in M*plus* 7.2 (Muthén and Muthén, 2012) under a saturated variance-covariance

model including all variables described in the preceding sections (Graham, 2009, Asparouhov and Muthén, 2010c). Parameter estimates and standard errors were combined across the 50 imputed datasets using Rubin's (1987) rules.

It is important to note that these strategies were only applied to data missing due to non-response at the item level (incomplete information collected within an occasion of measurement) and not due to attrition at the unit level (no information collected from a participant at an occasion of measurement). As outlined in Section 3 of this chapter, any individual that did not complete all three interviews was excluded from the participant pool.

8 Temporal design

Figure 16 (p.140) depicts graphically the temporal design for this research, illustrating the manner in which observations at each wave of data collection were used to achieve the thesis aims. In the figure, dots indicate the point(s) in time at which a measure was collected, while lines indicate the assumed temporal span of a measure. These timeframes were enforced either at the time of data collection (e.g. using retrospective recall instruments) or through the approach to data analysis and sample definition, as detailed throughout this chapter.

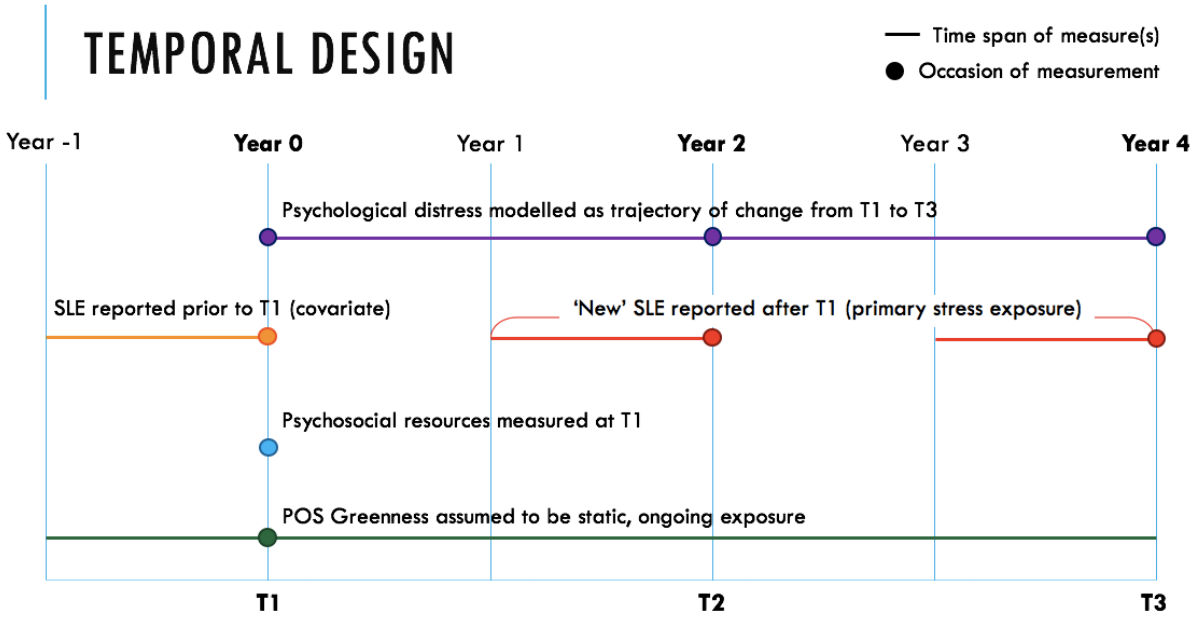


Figure 16: Graphical depiction of temporal design, indicating occasions of measurement and applicable time spans for key measures in the thesis

POS greenness was measured using satellite data contemporaneous with the first occasion of ZEPSOM data collection (T1) and is assumed to be a static, ongoing characteristic of the residential environment existing throughout the full span of the research. Psychosocial resources were also measured at T1, whereas mental health outcomes were measured at all three measurement occasions and modelled as trajectories of change from T1 to T3. Stressful life events (SLE) were measured using retrospective self-reports of events experienced in the twelve months prior to each interview, and summed to reflect the total number of 'new' (i.e. incident) events occurring after the baseline interview (i.e. total events reported at T2 and T3). This measure was employed as the primary exposure against which stress-buffering effects were assessed, in order that the measure of mental health at T1 should account for prior values of the outcome. A secondary measure of SLE (total events reported at T1) was included as a covariate to account for the lagged effects of events occurring in the lead-up to this first observation.

Thus, the first occasion of measurement in the longitudinal analysis of mental health outcomes (T1) corresponded temporally with the measurement of POS greenness and psychosocial resources. Estimated trajectories of mental health outcomes from T1 to T3 reflect prospective changes in mental health status over the ensuing four-year period. Finally, the measure of SLE captured events reported (roughly) throughout the latter three of these four years, which might therefore influence the observed trajectory of mental health outcomes. The retrospective nature of this measure implies a temporal lag between the measurement of SLE and the final assessment of mental health symptoms.

This temporal design introduces a longitudinal element to the analysis of all research questions in this thesis, but with some caveats. Aim 1 ("To evaluate whether POS 'greenness' exerts a protective 'buffering' effect against the potential psychological harm of acutely stressful life events") was addressed using a study design conceptually similar to a parallel process model, to evaluate how POS 'greenness' moderates the unfolding association between SLE reported after T1 and changes in mental health from T1 to T3[69]. Although SLE and

[69] A parallel process model would assess the correlation between concurrent longitudinal trajectories of to evaluate how the exposure and outcome unfold contemporaneously, using latent variables to represent initial status and rate of change over time. In this study, a similar approach is adopted to model trajectories of mental health, whereas SLE is measured using two manifest variables reflecting reported exposure prior to T1 (≈ initial status) and the number of 'new' events reported after T1 (whose effects are conditional upon the initial level of SLE; ≈ rate of change). The buffering effects of POS 'greenness' are assessed against 'new' SLE.

mental health were measured on the same occasions, the use of a past-year SLE measure does introduce some element of a chronological lag between stress exposure and psychological outcomes, in the hypothesised direction of influence. Aim 2 ("To evaluate whether POS 'greenness' exerts a 'main' salutogenic effect independently of exposure to acutely stressful events") was addressed using a fully longitudinal design in which POS exposures at T1 were used to predict prospective changes in life satisfaction or psychological distress from T1 to T3. Aim 3 ("To evaluate the intermediary role of psychosocial resources in explaining prospective associations between POS 'greenness' and mental health") was addressed using a half-longitudinal mediation design, which assesses the contemporaneous relationship between POS 'greenness' and psychosocial resources measured at T1, and the prospective relationships of those variables to trajectories of mental health from T1 to T3. All analyses attempt to account for confounding and self-selection processes using a range of baseline (T1) and time-varying (T1-T3) covariates at the individual- and area-level.

9 Analytic approach

All research questions were tested at the individual level through the application of a general latent variable modelling framework within the M*plus* program (Muthén and Muthén, 2012). The analysis utilises what have been termed 'second-generation' structural equation modelling (SEM) techniques, combining the use of categorical and continuous latent variables with observed data to build flexible models of individual growth trajectories and their relationships to other variables (Muthén, 2001). This section summarises the broad approach to statistical analysis employed in this thesis, while the three following chapters present detailed descriptions of the methods of data analysis common among (Chapter 4) and specific to (Chapters 5 and 6) each study.

Broadly speaking, the aims of this analytic approach were to model intra-individual changes in psychological distress and life satisfaction over time, then predict inter-individual differences in these change trajectories according to the level of residential POS greenness. To achieve this, the thesis adopts the novel and statistically complex method of Growth Mixture Modelling (GMM) to empirically identify groups of individuals that follow qualitatively distinct symptomatic trajectories over time (Muthén and Muthén, 2000). Using this approach, the measures of psychological distress and life satisfaction recorded at each wave of the

ZEPSOM study were used as manifest indicators of a latent longitudinal trend in a particular dimension of mental health for each individual. Individuals were then probabilistically classified into unobserved groupings ('latent classes') such that the inferred longitudinal trends are similar within classes but differ in a meaningful way between them. In this manner, the latent classes succinctly summarise the variety of substantively distinct trajectories of change observed in the population at large. The prediction of membership in a certain class may then serve as the focal point of efforts to estimate relationships between the change process and other variables of interest; for instance, does a certain antecedent variable influence the likelihood that the individual follows a course of increasing distress symptoms over time? (Muthén and Shedden, 1999, Muthén, 2004, Nagin and Odgers, 2010). The centrality of these classifications is depicted in Figure 17, below, which illustrates how a preliminary analysis of trajectory class membership (Chapter 4) is expanded upon to achieve the substantive aims of Study 1 (Chapter 5) and Study 2 (Chapter 6).

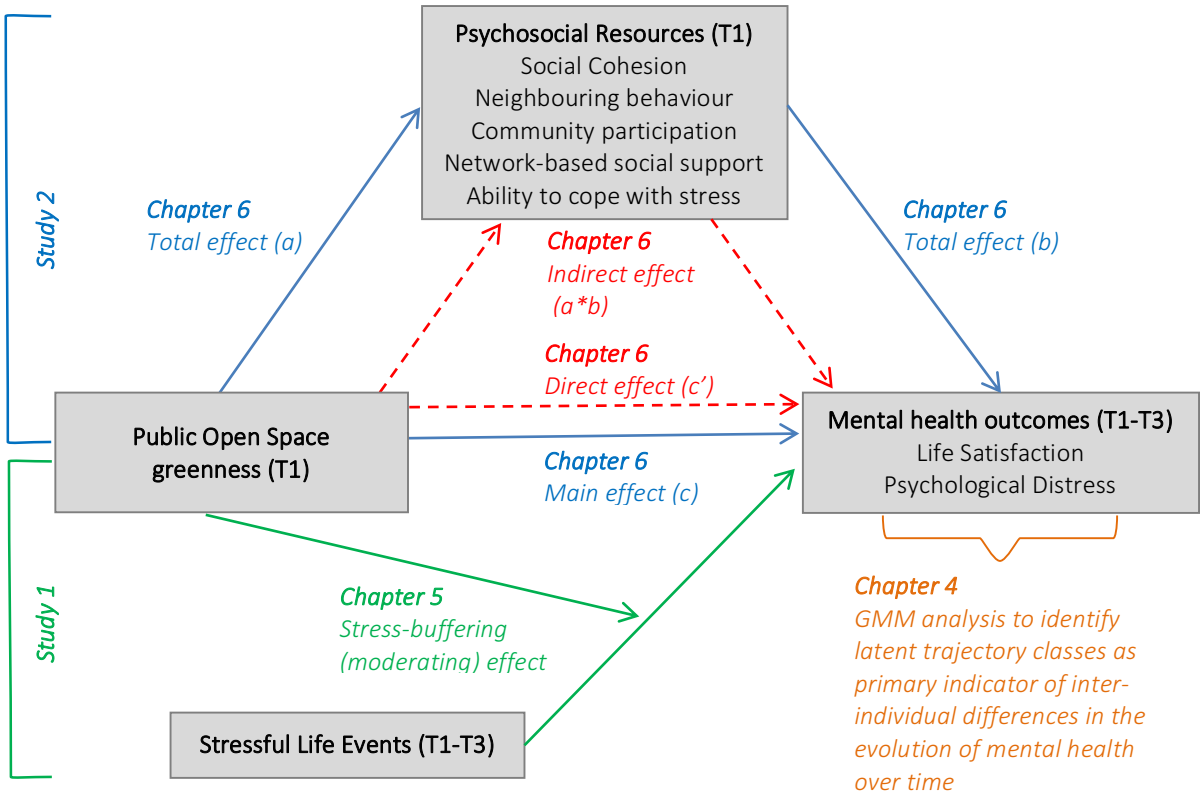


Figure 17: Summary of data analysis procedure as distributed across Chapters 4 to 6

Chapter 4 describes the statistical foundations of GMM and details its specific procedural components. This includes a brief overview of the modelling framework within which the analyses were conducted, outlining the general latent growth curve approach to modelling change over time and the extension of this approach to accommodate multiple subpopulations of individuals with distinct patterns of change (GMM). Linear GMM analysis was then performed in order to enumerate and describe distinct latent classes of participants based on intra-individual trajectories of change in positive (life satisfaction) and negative (psychological distress) dimensions of mental health. Having established the optimal latent class solution, Chapter 4 presents an analysis of the associations between individual- and area-level socio-demographic covariates (described in Section 6.6 of this chapter) with class membership and within-class variability in mental health trajectories.

This analysis serves two key purposes. First, mapping the latent class variable onto theoretically relevant auxiliary variables provides support for the validity of the latent class solution by ensuring the alignment of covariate effects with theory and previous empirical evidence (Muthén, 2004, Bauer and Curran, 2004). Second, the model-building process establishes a base covariate model for each mental health outcome, to which the key predictors of substantive interest in this thesis will be added. As discussed in Chapter 4, there are several potential pitfalls when adding covariates to a GMM that may lead to bias in both the measurement and structural parts of the model. Thus, the analysis in Chapter 4 aims to achieve a suitable specification of sociodemographic effects that comprises the basis for all further analyses in Chapter 5 and Chapter 6. While this chapter does not explicitly address the research aims of the thesis, it provides the statistical basis upon which these may be explored in the following chapters.

Chapter 5 extends the GMMs of psychological distress and life satisfaction beyond associations with socio-demographic covariates to estimate the influence of stressful life events (SLE) on membership in the various trajectory classes. It then evaluates whether the level of POS ‘greenness’ in the residential environment moderates this relationship by interacting with SLE to determine trajectory class membership. This chapter addresses Research Aims 1 and 4 of the thesis.

Chapter 6 similarly extends the GMMs of psychological distress and life satisfaction to estimate the influence of *POS greenness* on membership in the various trajectory classes, holding SLE constant at the sample mean (Figure 17, path *c*). Then, cross-sectional associations between *POS greenness* and each measure of *psychosocial resources* were estimated separately (Figure 17, path *a*). Where a statistically significant association existed, the relationship between the selected resource and membership in the *mental health* trajectory classes was estimated (Figure 17, path *b*). These estimates were combined to determine the indirect effect of *POS greenness* on *mental health*, via *psychosocial resources* (Figure 17, path *a*b*), using a Monte Carlo method to obtain an asymmetric 95% confidence interval for the indirect effect (Preacher and Selig, 2012). This chapter addresses Research Aims 2, 3, and 4 of the thesis.

At all stages of analysis, maximum likelihood estimation was employed and standard error computations used a sandwich estimator to account for the spatial clustering of participants (n=929) within census tracts (n=74) (Muthén and Muthén, 2012).

10 Summary

This chapter has described the methodology of this thesis, including the data sources, measures, and analytic approach employed to achieve the research aims. Further details of the analytic method will be presented throughout Chapters 4, 5, and 6 as they relate to the specific research aims addressed in each of those chapters (see Chapter 1, Section 4.1 for an outline of the thesis). The present chapter has investigated potential threats to the validity of the research findings, particularly due to selective participant recruitment or attrition, as well as missing data within completed questionnaires, the implications of which are discussed further in Chapter 7.

CHAPTER 4

Growth mixture modelling to describe inter-individual variation in trajectories of mental health

1 Introduction

Growth mixture modelling (GMM) is a flexible technique for longitudinal data analysis that employs a combination of continuous and categorical latent variables to model heterogeneity in intra-individual development of outcomes over time (Muthén and Shedden, 1999, Bauer and Curran, 2003a, Muthén, 2004). This chapter first outlines the rationale for the use of GMM in this thesis, summarising key aspects of model specification and illustrating the relationship of GMM to the more widely known latent growth curve model (LGCM). It then presents the statistical methods and results of two exploratory linear GMM analyses performed to enumerate and describe latent classes of participants based on intra-individual trajectories of change in positive (life satisfaction) and negative (psychological distress) dimensions of mental health throughout roughly a four-year period. Following selection of the optimal unconditional GMM for each outcome, the chapter presents results pertaining to the associations of a range of individual and residential-area covariates with between- and within-class variability in prospective trajectories of each outcome, comparing the substantive conclusions of the GMM to a single-population LGCM. The chapter ends with an investigation of cross-classification agreement between trajectory classes derived from the life satisfaction and psychological distress models. The models devised in this chapter form the basis for all further analyses of the substantive research questions in this thesis, as described in the general approach to data analysis in Chapter 3. Non-statistical aspects of the research method, including details pertaining to sampling, recruitment, measures and missing data, were also presented in Chapter 3.

1.1 Longitudinal structural equation modelling: assessing 'true' change

The analyses in this thesis were performed within a structural equation modelling (SEM) framework. SEM covers a broad class of multivariate statistical models that estimate the magnitude and strength of effects within a hypothesised causal system that may comprise both manifest (observed) and latent (unobserved) variables. A key feature of this framework is the ability to specify a 'measurement model' that maps measured variables (manifest indicators) onto latent theoretical constructs. In the measurement model, latent constructs may be inferred from the values of observed variables to which it is believed they gave rise, while partitioning out the component of variation in those observed values that is not attributable to the

underlying latent factor (Curran and Hussong, 2002). SEM thereby permits the use of manifest indicators as proxies to quantify unobservable or unmeasurable theoretical constructs (e.g. 'true' change) for use in the structural model, while explicitly modelling and adjusting for sources of measurement error in the indicators (Little, 2009). In contrast to the use of simple difference scores, employing latent variables to summarise change over time serves to partition out occasion-specific sources of unreliability (e.g. random fluctuations in observed scores) and goes some way to protecting against related validity concerns such as regression to the mean (Muthén and Brown, 2009, Little, 2009). These characteristics make SEM a popular choice for longitudinal data analysis, with two broad classes of models – panel models and random coefficient (e.g. multilevel or growth curve) models – experiencing widespread usage in practical applications. These models reproduce different dimensions of change and accordingly present important inferential and interpretational distinctions in relation to longitudinal effects.

Longitudinal panel models (e.g. cross-lagged or autoregressive panel models) assess change in individuals' relative standings on the variable(s) of interest from one occasion of measurement to the next (Little, 2009). These models focus on sequential 'snapshots' or 'slices' of inter-individual variability at a series of discrete measurement occasions and aim to reproduce the patterns of covariation among variables over time. Deviations or dispersions between individuals are assessed separately at each time point with respect to a time-specific, sample-wide measure of central tendency (e.g. the mean) for the construct of interest. The model then describes the stability of these individual differences over time, or the extent to which there is a 'reshuffling' of individual standings between measurement occasions. Change implied by the model might reflect an adjustment to the rank order of participants or to the magnitude of the intervals between them, but does not divulge the nature of intra-individual change in the construct over time. This is because stability (or change) in individual differences is determined by the extent to which the value of a construct measured at one time predicts its value at a later time (the autoregressive coefficient), yet this tells us nothing about the stability of these values at the individual level. A lack of change in individual differences (a high stability coefficient) could equally imply that individual levels of the construct are not changing over time; that all individuals are changing to a notable degree along a similar trajectory; or even a systematic pattern of growth and decline dependent on the individual's initial level of the construct (Selig and Preacher, 2009, Selig and Little, 2012). Panel models

may therefore obscure the normative experience of change within the sample, which is often of substantive interest.

Random coefficient models (e.g. multilevel, latent growth curve or latent difference score models), on the other hand, focus primarily on intra-individual development with respect to the deviation across time of each individual's scores from his or her person-specific overall level on the variable (e.g. a random intercept). These models describe the average individual trend in levels of the construct over time, but also allow for inter-individual variability around that trend; for instance, there may be considerable variability between individuals in terms of the initial level of the construct or the rate at which it changes over time. This is of interest to researchers who wish to identify the antecedents and consequences of inter-individual differences in intra-individual change processes. Here, the between-person distribution of interest is one of within-person change scores (e.g. the distribution of a random linear slope) rather than the static distribution of individual differences at a given time point (Little, 2009). That distribution may be used as an outcome or predictor in further analyses, to test hypotheses pertaining to the differential development of outcomes over time while explicitly modelling the nature of the underlying trajectory. The ability to preserve the normative trajectory makes these approaches particularly attractive when a construct exhibits a meaningful course of change, such that its prior values are of interest from a theoretical standpoint and not only as a statistical control for prior correlations with other variables (Selig and Preacher, 2009). This was the approach adopted in this thesis. The following section provides a brief overview of the latent growth curve approach to modelling intra-individual change over time, and the extension of this approach to accommodate multiple subpopulations of individuals with distinct patterns of change (growth mixture modelling).

1.2 The latent variable approach to growth modelling

In the latent variable approach to growth modelling, intra-individual growth trajectories are defined linearly by continuous latent variables in the form of random intercept and slope growth factors, which themselves are inferred from manifest indicators comprising repeated measures of the outcome over time. A typical unconditional latent growth curve model with T time points and n individuals is specified in matrix notation on the following page (Petras and Masyn, 2010).

The simple latent growth curve model, without covariates, is written as:

$$Y_i = \Lambda\eta_i + \varepsilon_i \,, \tag{1}$$

$$\eta_i = \alpha + \zeta_i \,, \tag{2}$$

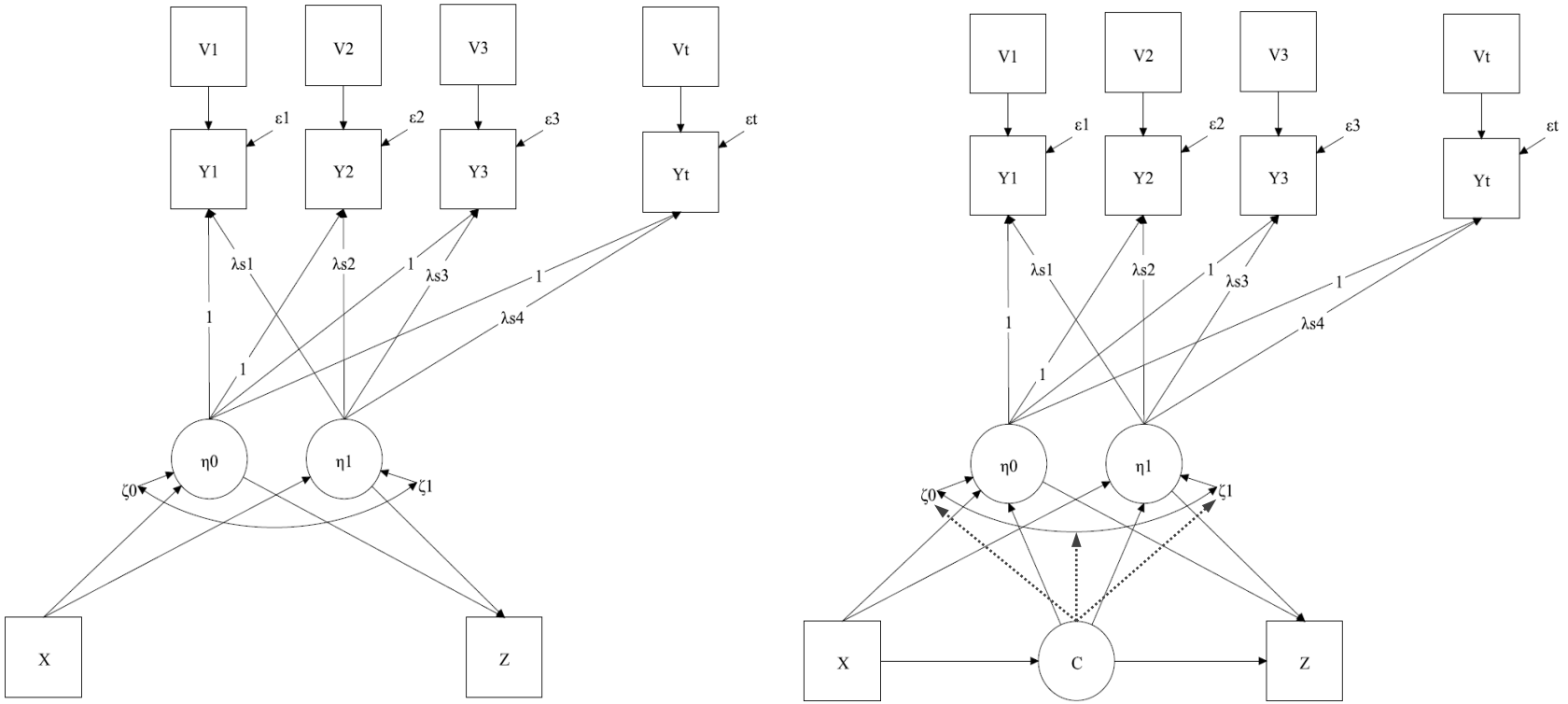
where $\mathbf{Y}_i$ is a (T x 1) vector of observed scores on outcome y for individual i (indicators for the latent growth factors); η_i is a (p x 1) vector of random latent growth factors (intercept, linear slope, quadratic slope, etc.); Λ is a (T x p) design matrix of factor loadings reflecting the timing of measurements, with each column corresponding to specific aspects of change (i.e. loadings for the intercept, linear slope, quadratic slope, etc.); and α is a (p x 1) vector of growth factor means. ε_i is a (T x 1) vector of time-specific measurement errors and $\boldsymbol{\zeta}_i$ is a (p x 1) vector of random effects representing individual deviation around the growth factor means. Both the errors and random effects are assumed to be multivariate normally distributed and uncorrelated with one another:

$$\varepsilon \sim \mathrm{MVN}(0, \Theta) \,, \tag{3}$$

$$\zeta \sim \mathrm{MVN}(0, \Psi) \,, \tag{4}$$

$$\mathrm{Cov}(\varepsilon, \zeta) = 0. \tag{5}$$

Equations (1) to (5) embody the SEM measurement model that defines the latent growth factors and thereby approximates change over time. Allowing the latent growth factors to vary randomly across participants parameterises the dependency among longitudinal observations that are nested within individuals and accounts for differential standings on the construct of interest at baseline. Additionally, the estimation of a distribution for the random factors allows for the prediction of inter-individual differences in intra-individual change processes, or the prediction of distal outcomes resulting from those differences (Muthén, 2004, Petras and Masyn, 2010). For instance, variation in the latent growth factors (η) and time-specific values of the outcome (Y_t) may be modelled as a function of time-invariant (X) and time-varying covariates (V_t), respectively, as indicated in Figure 18.



The class-specific nature of the GMM parameters is indicated by solid arrows from the latent class variable to the growth factor means, and dashed lines from the latent class variable to the growth factor variances and covariance. In both models, variation in the latent growth factors (η) and time-specific values of the outcome (Y) may be modelled as a function of time-invariant (X) and time-varying covariates (V), respectively (direct effects). In the GMM, trajectory class membership (C) may be used to predict a proximal outcome (Z) or may itself be regressed onto a set of predictors (X) to identify the indirect effect of those covariates on the growth factors.

Figure 18: Latent growth curve model for *t* time points with intercept (η_0) and linear slope (η_1) (left) and extension to GMM through the addition of a latent class variable (C) (right)

1.2.1 The growth mixture model

One potential drawback of the LGCM is the assumption that all individuals are drawn from a single population that can be adequately summarised by a common set of multivariate normal population growth factor parameters (Muthén, 2004, Berlin et al., 2013a). As indicated in Equation (2), each component of the growth process (intercept, linear slope, quadratic slope, etc.) is summarised by a single mean value plus some normally distributed variation of participant-specific growth factors about this mean. It is assumed that the combination of these mean values reflects a normative trajectory of change for the whole population, and that any true deviation from this trajectory is captured by the corresponding variability in random effects (Nagin and Odgers, 2010)[70]. In many practical settings, this assumption may be unrealistic. For instance, numerous studies have identified that although the majority of individuals experience low and stable levels of psychological distress over the course of a period of observation, smaller subpopulations characterised by qualitatively different trajectories (e.g. increasing or fluctuating symptom severity) are also likely to exist (e.g. Dekker et al., 2007, Costello et al., 2008, Morin et al., 2011, Mumford et al., 2013, Yaroslavsky et al., 2013).

Fortunately, the latent growth modelling framework can easily be extended to accommodate population heterogeneity in the change process by 'mixing' together any number of empirically identified subpopulations (latent trajectory classes) characterised by distinct patterns of change over time (Muthén and Shedden, 1999, Muthén and Muthén, 2000, Petras and Masyn, 2010). This methodological approach, termed growth mixture modelling (GMM), permits a flexible classification of individual participants according to a taxonomy of developmental trajectories that might reflect unique aetiologies of the outcome under study (Costello et al., 2008, Nagin and Odgers, 2010). Individuals are probabilistically classified into unobserved groupings such that the observed longitudinal trends are similar within classes but differ in a meaningful way between them (Muthén and Muthén, 2000). Thus, whereas LGCM assumes a singular population mean trajectory, GMM constructs a separate growth model for each latent class and allows class-specific estimation of numerous parameters

[70] The capacity for the LGCM to identify antecedents or consequences of individual differences in the pattern of change is subsequently limited by the degree to which those normally distributed random effects capture the full extent of variability in trajectories of change. Moreover, it is assumed that these covariate effects, too, are drawn from a single population and are equal for all members of the population regardless of their standing in the distribution of trajectory parameter values (Muthén, 2001, Bauer and Curran, 2003a).

including growth factor means and covariances; covariate effects; and even the form of the growth function (Muthén and Shedden, 1999, Muthén, 2004, Jung and Wickrama, 2008). This permits a complex specification of inter-individual variability in the course of change that can be useful for identifying extreme or uncommon trajectories, and unique aetiologies, that might otherwise be overlooked (Nagin and Tremblay, 2005, Costello et al., 2008, Berlin et al., 2013a).

The unconditional GMM is specified as follows (Petras and Masyn, 2010):

$$Y_i = \Lambda\eta_i + \varepsilon_i \,, \tag{6}$$

$$\eta_i = \alpha_k + \zeta_i \,, \tag{7}$$

where

$$\varepsilon \sim \mathrm{MVN}(0, \Theta_k) \,, \tag{8}$$

$$\zeta \sim \mathrm{MVN}(0, \Psi_k) \,, \tag{9}$$

$$\Pr(C_i = k) = \frac{\exp(\pi_k)}{\sum_{h=1}^{K}(\exp(\pi_h))} \,. \tag{10}$$

The GMM extends the LGCM specified in Equations (1) to (4) by allowing the growth factor means/intercepts (α_k), growth factor covariances (Ψ_k), and time-specific outcome residual covariances (Θ_k) to differ across *K* latent trajectory classes. In other words, the model assumes the existence of *K* subpopulations, each characterised by a different mean growth trajectory and, potentially, a different covariance structure, as illustrated in Figure 18 (p.151). Distributional assumptions for residuals on the growth factors and observed outcomes now apply only within each class, negating the requirement for multivariate normality at the overall population level. Instead, the distributions of these variables comprise a finite mixture of *K* normally distributed subpopulations in line with the relative size of each class (the mixing proportions) (Petras and Masyn, 2010). Here, C_i represents the latent trajectory class membership for individual *i* (with $C = 1, \ldots, K$), who is permitted fractional membership in all classes and consequently may have non-zero probabilities of belonging to each class (Clark and Muthén, 2009, Berlin et al., 2013a). These 'posterior probabilities' are estimated in order to weight the contribution of the observed values for each individual to the parameter

estimates of each class[71] (Muthén and Muthén, 2004). Finally, the mixing proportions ($\Pr(C_i=k)$) are estimated using multinomial logistic regression to determine the log odds of membership in Class k (π_k) relative to a given reference class.

1.2.1.1 Practical concerns in GMM specification: selecting the number of classes

In a growth mixture model, class membership is 'unobserved' in the sense that it is not defined a priori on the basis of some measured grouping variable(s), such as age or sex, which one might expect to influence the development of an outcome. Rather, class membership is inferred probabilistically from the pattern of indicator variables (i.e. observed scores on the outcome of interest over time) with the aim of identifying homogenous subsets of individuals who share the same basic growth structure. It is important to note, however, that the estimation of a *k*-class GMM rests on an assumption that *k* classes exist within the population, and that this number must be specified a priori. Deciding on a suitable number of classes is an important and technically challenging aspect of GMM and requires a systematic approach, as detailed shortly (Nagin and Tremblay, 2001).

1.2.1.2 Practical concerns in GMM specification: class-varying covariance structures

Although nearly all parameters may be allowed to vary across the latent trajectory classes, in practice it is common to constrain some parameters such as the growth factor and residual outcome covariances to equality (i.e. $\Psi_k = \Psi$ and/or $\Theta_k = \Theta$) (Bauer and Curran, 2003a, Jung and Wickrama, 2008, Berlin et al., 2013a, Petras and Masyn, 2010). In a further simplified case, known as latent class growth analysis (LCGA), the growth factor variances may be fixed to zero (i.e. $\Psi_k = 0$) such that the latent class variable is assumed to account for any inter-individual variability in the growth process (Nagin, 1999). These restricted parameterisations may be theory driven, but are also frequently motivated by practical considerations given the strong influence of model complexity on the rate of convergence.

The less restricted the mixture model, the more taxing its estimation becomes, both in terms of the number of parameters that must be estimated and the increasingly problematic nature of the likelihood function (Bauer and Curran, 2004). For instance, class-specific covariance matrices for the growth factors or outcome residuals result in an unbounded likelihood

[71] They also indicate the degree of certainty and precision in the classification, and should be taken into account in further analysis of class membership (Muthén, 2004) so that effect estimtes adequately reflect the ambiguity in assigning participants to latent classes (Muthén and Shedden, 1999, Clark and Muthén, 2009, Masyn, 2013).

function that is sensitive to outliers and may return classes of single individuals with zero variance, greatly increasing the chance of non-convergence (McLachlan and Peel, 2000). Placing invariance constraints on the covariance matrices is a convenient solution to eliminate these singularities, but is also likely to impact the number and size of the classes that are required to adequately recover the aggregate covariance matrix of the observed data (Bauer and Curran, 2004, Muthén, 2004, Hipp and Bauer, 2006). For instance, overly restricted measurement models are predisposed to the over extraction of latent classes with differing mean trajectories, as compensation for unaccommodated covariances among the repeated measures and inflexibility in the shape of the mixture distribution (Nagin and Tremblay, 2001, Bauer and Curran, 2004, Muthén and Muthén, 2000, Muthén, 2004, Liu and Hancock, 2014, Hipp and Bauer, 2006). Perhaps of greater concern is the potential for inadequate invariance assumptions to generate spurious changes to the substantive meaning and interpretation of the trajectory classes, potentially leading to erroneous conclusions about the fundamental nature of the growth trajectories that exist within the larger population (Enders and Tofighi, 2008, Petras and Masyn, 2010, Morin et al., 2011). It is therefore imperative to consider the potential for misspecification of the within-class measurement model and verify the suitability of invariance assumptions imposed therein.

1.2.1.3 Covariate effects in GMM: between-class (indirect) versus within-class (direct)

The GMM decomposes inter-individual differences in trajectories of change into a between-class component (differences in latent growth factor means between classes) and a within-class component (individual variation about the growth factor means within classes) (Bauer, 2007). Because the latent class variable succinctly summarises the distinct types of growth trajectories observed in the population at large, between-class differences are typically the focal point of efforts to estimate relationships between the change process and other variables of interest (Muthén and Shedden, 1999, Muthén, 2004, Nagin and Odgers, 2010). For instance, trajectory class membership (C) may be regressed onto a set of covariates (X) in order to identify factors that alter the probability of belonging to a class characterised by a particular mean growth trajectory ('latent class regression') (Muthén and Shedden, 1999). Such effects are termed 'indirect' in the sense that covariates influence the growth factors via their effect on class membership, which in turn indicates the 'type' of trajectory being followed. **The estimation of between-class (indirect) effects is the primary focus of the analyses in this thesis.**

Covariates may additionally exert a residual direct effect on the growth factors (or time-specific values of the outcome variables, in the case of time-varying predictors) after accounting for their influence on class membership. Although the indirect path is generally considered the most interesting covariate effect, it is important to stipulate these direct effects where they exist. If erroneously omitted from the model, the latent class variable alone must account for the full range of inter-individual variation attributable to the predictor (Huang and Bandeen-Roche, 2004, Muthén, 2004, Clark and Muthén, 2009). This distorts the relationship between the latent class variable and its indicators, potentially biasing estimates of class probabilities, class-specific parameter values (e.g. mean trajectories), and indirect covariate effects (Petras and Masyn, 2010, Asparouhov and Muthén, 2014). Figure 18 (p.151) illustrates graphically the distinction between direct and indirect covariate effects.

2 Statistical analysis

Trajectories of change in levels of psychological distress and life satisfaction were modelled as distinct processes, resulting in a separate linear GMM for each outcome. A full description of the measures of these outcomes was presented in Chapter 3 (Section 6.2). Following convention, the first aim of the analysis was to identify the optimal unconditional GMM for each outcome with respect to the number of latent classes and the specification of within-class variance-covariance structures[72] (Muthén, 2006, Clark et al., 2007, Morin et al., 2011, Petras and Masyn, 2010, Nylund-Gibson et al., 2014, Huang et al., 2010). Socio-demographic predictors were then added to the optimal unconditional model in order to estimate the effects of these variables on class membership and within-class differences in growth trajectories or time-specific values of the outcome variable. Figure 19 (p.159)

[72] The unconditional measurement model does not incorporate covariates, utilising only information from the outcome variable of interest in order to define latent classes. Thus, latent class assignments depend purely on differences in the mean (or variance-covariance) structure of unconditional growth trajectories. Tofighi and Enders (2008) have shown that including covariates in GMM measurement models can substantially impede the correct enumeration of classes, even if the covariates truly do influence class membership or within-class variation in the growth process. Ostensibly, covariates should provide useful information about class membership in such cases, increasing the multivariate distance between the classes and thereby aiding in class enumeration (Lubke and Muthén, 2008). However, if those covariate effects are misspecified – which can happen easily if, for instance, direct effects between the covariate and within-class variation in the growth factors are omitted – then over extraction of classes is liable to occur more frequently than when undertaking class enumeration with an unconditional model (Petras and Masyn, 2010).

summarises the analysis procedure, which is described in detail throughout this chapter; specifically, steps 1 to 4 are detailed in Section 2.1, and steps 5 and 6 in Section 2.2.

All analyses were performed in Mplus 7.2 using robust maximum likelihood estimation to account for the spatial clustering of participants (n=929) within census tracts (n=74) (Muthén and Muthén, 2012). To account for variation in the length of the total observation period between participants, the unconditional GMMs were specified initially using individually-varying time scores, coded as the number of years since a participant was first interviewed (t=0) (Muthén, 2004). However, this approach greatly increased estimation times and the rate of non-convergence when covariates were added to the model. Subsequent analysis presented in Appendix 4.1 indicated that the optimal unconditional GMMs (estimated using individually-varying time scores) were adequately replicated using fixed timing scores, specified as the average number of years since the first interview (T1 t=0, T2 t=1.79, T3 t=4.18)[73]. Given the substantial practical advantages to this discrete timing structure, all conditional GMMs were consequently estimated using fixed timing scores.

Because GMM likelihood surfaces often contain numerous local maxima, convergence to a solution is not a guarantee that the global maximum likelihood (ML) solution has been identified (Asparouhov and Muthén, 2012, Masyn, 2013). Failure to recognise this may lead to the adoption of an inferior, and potentially substantively divergent, local solution (Hipp and Bauer, 2006). To address this issue, model estimation was initiated using multiple sets of starting values derived through the random perturbation (default level of 5) of starting values automatically generated by the program (Muthén and Muthén, 2012, Li et al., 2014). The greater the proportion of starting values that converge to the optimal ML solution, the greater the assurance is that a global maximum has been identified and the model is correctly specified (Hipp and Bauer, 2006, Muthén and Muthén, 2004, Muthén, 2004, Li et al., 2014, Masyn, 2013). Up to 1000 sets of starting values were initiated (with 250 final stage optimisations) although generally many fewer (e.g. 200 starts with 50 final optimisations) were required to replicate the log likelihood for the best fitting models.

[73] The models returned equivalent results in terms of class proportions, class-specific growth trajectory means, and individual classifications based on the highest posterior probability, while the models with fixed timing scores were supported by more favourable scores on various information criteria.

2.1 Modelling trajectories of psychological distress and life satisfaction: selecting the optimal unconditional GMMs

For each mental health outcome, latent classes were enumerated under three different measurement models in order to assess the suitability of alternative growth factor covariance parameterisations. The first was a highly restrictive latent class growth analysis (LCGA) in which the growth factor variances were fixed to zero ($\Psi_k = 0$) (Nagin, 1999). In this model, classifications are determined by differences in the mean structure of unconditional growth trajectories and it is assumed that the latent class variable accounts for all inter-individual variability in the growth process. The second was a reasonably restrictive measurement model (GMM1), in which growth factor variances were constrained to equality across classes and the growth factors were assumed to be conditionally independent within classes (i.e. $\Psi_k=\Psi$, a diagonal matrix) (Petras and Masyn, 2010). In this model, classifications are determined by differences in the mean structure of unconditional growth trajectories between classes and it is assumed that the latent class variable explains the full extent of covariance among the growth factors. In the final measurement model (GMM2), equality constraints on the growth factor variances were released and the covariance among these variables was estimated (but not class-specific). Here, classifications are determined by differences in both the mean structure of unconditional growth trajectories and the level of variation about this mean, and covariance among the growth factors need not be solely attributable to the latent class variable. Residual outcome variances were fixed to equality across classes ($\Theta_k=\Theta$) in all three models.

Under each measurement model, a one-class solution was estimated first and then an increasing number of classes was added to the model until it became poorly identified (Masyn, 2013). The resulting class solutions were compared in order to ascertain what was a statistically and substantively adequate number of classes to describe heterogeneity in growth trajectories within population at large, and to optimise the specification of within-class covariance matrices (Morin et al., 2011, Nagin and Odgers, 2010, Masyn, 2013). The optimal class solution should achieve a suitable balance between model fit, parsimony, and the substantive utility of the solution with reference to classification quality and the size and interpretation of the extracted classes. The following sections (2.1.1 to 2.1.3) describe the assessment of these conditions. Appendix 4.2 presents a more detailed explication of the criteria employed to select between growth mixture solutions.

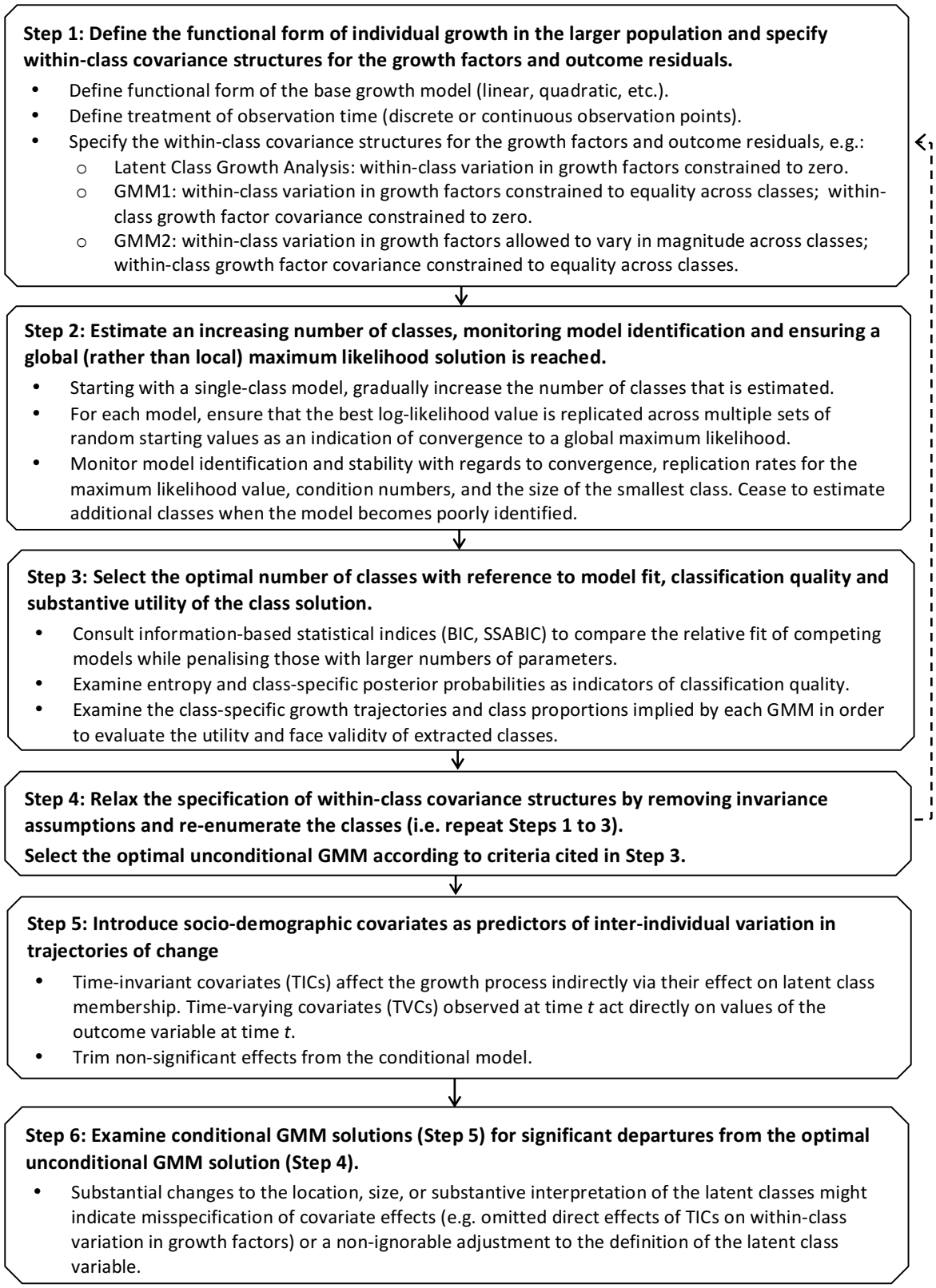


Figure 19: Procedure for selecting the optimal unconditional GMM t (Steps 1-4) and estimating associations with sociodemographic covariates (Steps 5-6)

2.1.1 Model fit and parsimony

Relative model fit was assessed using the Bayesian Information Criterion (BIC) (Schwarz, 1978) and Sample Size Adjusted BIC (SSABIC) (Sclove, 1987), with the lowest value of each criterion indicative of a better fitting (and/or more parsimonious) model. These indices have demonstrated a high level of accuracy in identifying the true number of classes in a population under varying levels of model complexity, class separation and relative mixing proportions (Nylund et al., 2007, Tofighi and Enders, 2008, Liu and Hancock, 2014). Current evidence indicates that BIC tends to favour the under-extraction of latent classes and may perform better in simpler models under population conditions conducive to the extraction of latent classes (i.e. high class separation with no very small classes). On the other hand, SSABIC tends to favour the over-extraction of latent classes but may perform better in very complex models under less ideal conditions (i.e. low class separation with a very small class) (Nylund et al., 2007, Tofighi and Enders, 2008, Liu and Hancock, 2014). Where the indices were in disagreement, BIC values were favoured in order to avoid overfitting the model and extracting meaningless classes (Dziak et al., 2012). To aid in their interpretation, BIC differences between competing models were converted into approximate Bayes Factors (BF) reflecting the relative odds of the model with lower BIC being the 'correct' model (Wasserman, 2000); a Bayes factor of 1 implies that the two models are equally likely, a Bayes factor of 10 implies that model with lower BIC is 10 times more likely, and so on (Nagin, 1999). Modern nested model tests designed for the comparison of two mixture models with differing numbers of classes[74] (e.g. the Lo-Mendell-Rubin test and the Bootstrap Likelihood Ratio Test) are presently unavailable in models with individually-varying times of observation (Muthén and Muthén, 2012) but BIC and SSABIC have been demonstrated to perform as well as, if not better, than those tests (Nylund et al., 2007, Tofighi and Enders, 2008, Liu and Hancock, 2014).

To refine the parameterisation of within-class covariance structures in the unconditional measurement models, scaled likelihood ratio chi-square (LRCS) tests were used to compare

[74] The standard likelihood ratio chi-square (LRCS) difference test is inappropriate for comparing between mixture models with differing numbers of classes, since a k-class mixture model is not a nested linear subspace of a k + 1 class model (Nagin & Tremblay, 2001). 'Nesting' these models requires that class probabilities for the *k + 1th* class are set to zero, forcing them to the boundary of the admissible parameter space (0 to 1) and violating the regularity conditions required for the test statistic to follow a chi-square distribution (McLachlan and Peel, 2000; Nylund et al., 2007).

the fit of nested *k*-class models that differed in their specification of those parameters but not in the number of classes (Satorra and Bentler, 2001, Bauer and Curran, 2004, Petras and Masyn, 2010, Morin et al., 2011). These tests were used to determine whether placing restrictions on certain parameters – such as fixing the within-class covariance among growth factors to zero, or specifying equality in growth factor variances for a subset of classes – significantly deteriorated model fit.

2.1.2 Substantive utility

Mixture model selection driven purely by likelihood-based statistics does not guarantee a solution that identifies distinct and meaningful classes of individuals (Celeux and Soromenho, 1996, Feldman et al., 2009, Petras and Masyn, 2010). This has important implications for the prediction of class membership or its distal consequences, which requires that the classes possess a sufficient degree of substantive utility in terms of their size, separation and differential interpretation. Special attention was therefore paid to the class-specific mean trajectories, class proportions and classification precision implied by the best fitting unconditional GMMs (Jung and Wickrama, 2008, Berlin et al., 2013b). Although these factors are not indicative of relative model fit, nor intended to drive model selection, they may be helpful in selecting between otherwise equally favourable models and to ensure the practical utility of a model for certain applications (Ram and Grimm, 2009, Nylund-Gibson et al., 2014).

2.1.3 Classification quality

Classification precision was assessed by summarising posterior probabilities of membership across the model as a whole (Entropy) and for specific classes (Average Posterior Probability; Odds of Correct Classification) (Nagin, 2009). Entropy is calculated for the full GMM as a function of each individual's posterior probability of membership in each class. Its value, which ranges from zero to one, will be positively affected by the extent of class separation (between-class variation) in the population and negatively affected by the degree of within-class variation (Celeux and Soromenho, 1996, Muthén, 2004). Higher scores indicate greater classification precision (Lubke and Muthén, 2007), and although there are no accepted cut-off criteria, Clark & Muthén (2009) suggest values of 0.4, 0.6 and 0.8 as corresponding to low, medium and high levels of entropy. It is also instructive to assess classification precision for each class individually, in order to determine whether some classes are easily differentiated

but others are not (Jung and Wickrama, 2008, Berlin et al., 2013b). Tabulating participants according to their modal class membership[75] (rows) and computing the row-wise average conditional probabilities of membership in all classes (columns) identifies the average posterior probability (APP_k) for each class (diagonal entries) (Muthén and Muthén, 2004). APP_k describes the probability of correct classification within class k, and should ideally be 0.7 or greater for each trajectory class (Nagin, 2009). The odds of correct classification into class k based on assignment to the modal class were also compared against the odds of correct classification based on random assignment in line with the base probability of membership in class k. Higher ratios of these values (OCC_k) indicate that model-implied posterior probabilities possess greater predictive power than random chance. Nagin (2009) identifies OCC_k values consistently greater than 5 as indicative of high assignment accuracy.

2.2 Estimating associations of socio-demographic covariates with trajectories of psychological distress and life satisfaction: specifying the conditional GMMs

Once the optimal unconditional GMM had been identified for each outcome process, socio-demographic covariates were added as predictors of inter-individual variation in the change process, using a model building approach to exclude non-significant effects. A full description of these measures was presented in Chapter 3 (Section 6.6). Baseline covariates were initially specified solely as predictors of class membership (between-class variation), with time-varying covariates (at time t) specified as predictors of observed outcome scores at time t (within-class variation). The first model (Model A) adjusted for age, sex and self-rated physical health. These variables are important determinants of mental health and were retained in the model regardless of their statistical significance. The second model (Model B) further adjusted for individual-level education, length of residence at the current address, household income, marital status, employment status and season of interview, as well as area-level socioeconomic deprivation and population density. In order to achieve a more parsimonious model, the joint null hypothesis that all non-significant effects ($p>0.10$ individually in Model B) were equal to zero was assessed using a Wald test with alpha=0.05[76]. If the Wald test failed

[75] The modal (most likely) class is the class with the maximum posterior probability for a given individual.
[76] Note: time-varying covariates were treated as a set and only tested if their effects were non-significant at all three time points.

to reject the null hypothesis, the effects in question were trimmed from the model, which was re-estimated in order to assess the stability of remaining parameters (Model C).

A single-step approach to the estimation of covariate effects was adopted, in which the latent class measurement model and the latent class regression model are combined and estimated simultaneously (Bolck et al., 2004, Vermunt, 2010, Asparouhov and Muthén, 2014, Bakk et al., 2013). Appendix 4.3 describes an alternative (three-step) method for latent class regression and outlines why a single-step method was chosen. This approach generates asymptotically unbiased, efficient, and consistent estimates of relationships between covariates and the latent class variable (Bolck et al., 2004) and has the potential to significantly reduce classification errors by increasing the multivariate separation between classes (Lubke and Muthén, 2007). However, because the relationship of covariates to trajectory class membership is estimated concurrently with the parameters that define the classes themselves, the addition of covariates in a single-step model may influence patterns of clustering (Huang et al., 2010) and alter the meaning of the latent class variable itself (Clark and Muthén, 2009)[77]. Thus, Model C solutions were examined to ensure that the size and substantive interpretation of the latent classes remained qualitatively similar to that of the unconditional model (Marsh et al., 2009). Departures of greater than 10% from the class sizes observed in the unconditional model were taken to indicate the potential misspecification of covariate effects, specifically the need for direct effects from baseline covariates to the growth factors (Petras and Masyn, 2010). In this instance, direct effects from all baseline covariates retained in Model C to within-class intercepts and slopes were specified (Model D). The joint null hypothesis that all non-significant direct effects ($p>0.05$ individually in Model D) were equal to zero was assessed using a Wald test with alpha=0.05[78]. If the Wald test failed to reject

[77] In an unconditional GMM, assignment to the latent classes occurs under the implicit assumption that variables other than the latent class indicators exert no influence on latent class membership or within-class growth trajectories. When a structural regression model is integrated and estimated simultaneously with the latent class measurement model, however, this one-step approach is liable to partition subjects according to their joint standing on both predictor and outcome, such that the latent classes are no longer defined solely by the intended indicator variables (Marsh et al., 2009, Huang et al., 2010). It is therefore important to examine conditional solutions from a one-step analysis to ensure that the number, size and substantive interpretation of the latent classes remains qualitatively similar to that of the unconditional model (Petras and Masyn, 2010). Significant departures from the unconditional model might point towards a misspecification of the associations among variables, such as omitted direct effects between covariates and the latent class indicators, that needs to be remedied (Bolck et al., 2004, Nylund and Masyn, 2008, Petras and Masyn, 2010).

[78] Note: time-varying covariates were treated as a set and only tested if their effects were non-significant at all three time points.

the null hypothesis, the effects in question were trimmed from the model, which was re-estimated (Model E) in order to assess the superiority of the solution with direct effects of baseline covariates to that in which the effects of baseline covariates were channelled solely through class membership (Model C).

Finally, for the sake of comparison, a single-population conditional LGCM was estimated for each outcome. Because there is no class membership to predict in the LGCM, socio-demographic covariates were entered as predictors of inter-individual variation in intercepts and slopes as well as time-specific values of the outcome (for time-varying covariates). Given that skewness in observed distributions of the outcomes might reflect a violation of multivariate normality in the growth factors, these models were estimated using both the raw data and data transformed to approximate normality. The K10 data were transformed by adding 3 points to the observed scores then taking the natural logarithm, resulting in distributions with negligible skewness (T1=0.03, T2=-0.05, T3=-0.2) and mild platykurtosis (T1=-0.62, T2=-0.62, T3=-0.51). SLDS scores were reversed then rescaled upwards by 15 points before taking the natural logarithm, resulting in distributions with negligible skewness (T1=0.11, T2=-0.06, T3=-0.10) and kurtosis (T1=0.00, T2=0.15, T3=-0.06). These transformations barely affected model fit and did not alter the direction or significance of covariate effects compared with analyses performed on the raw scores. Therefore, for the sake of brevity and ease of interpretation, only findings pertaining to the untransformed data are reported. As a final note, it could be helpful to remind the reader that growth mixture models are robust to non-normality (in fact, they may be used to approximate otherwise intractable non-normal distributions) and therefore no transformations were required for those analyses.

3 Results

3.1 Specification of unconditional GMMs

The following sections present results pertaining to the specification of unconditional growth mixture models of psychological distress (K10) and life satisfaction (SLDS), including enumeration of the classes and selection of an appropriate within-class growth factor covariance structure.

Table 23 (p.166) and Table 25 (p.171) outline model fit, number of free parameters (*p*), class size and classification quality statistics from the initial stages of class enumeration for each outcome under the three measurement models described previously. Figures in bold indicate the 'best fitting' model(s) for which statistical fit indices (BIC or SSABIC) reached a minimum value, where applicable. In some cases, the information criteria failed to reach a minimum value despite the extraction of a large number of classes, or else failed to mark a clear distinction between several competing models. In these cases, marginal gains in model fit with the extraction of each additional class were assessed graphically (Petras and Masyn, 2010). Figure 20 (p.167) and Figure 21 (p.172) plot values of BIC and SSABIC against the number classes extracted under the various measurement models for each mental health outcome. A pronounced angle ('elbow') in the curve was taken to indicate the point at which adding further classes may not be justified by the additional information they provide (Petras and Masyn, 2010, Masyn, 2013).

3.1.1 Psychological distress

The best fitting models indicated by BIC and SSABIC were, respectively, the GMM2 models with three (GMM2-3: BIC=16297) and four classes (GMM2-4: SSABIC=16237). Because SSABIC has a tendency to over extract classes, and only improved slightly with the addition of a fourth class, the three-class model was selected for further analysis. GMM2-3 featured (1) a low, flat trajectory; (2) an initially low, ascending trajectory; and (3) an initially high, declining trajectory. BIC differences between this model and the neighbouring two- and four-class solutions were -78.3 ($BF \approx 9.84*10^{16}$) and -13.2 ($BF \approx 718.4$), providing very strong evidence that the three-class model was preferable to those alternatives (Kass and Raftery, 1995). There was also substantial evidence to support the selection of GMM2-3 over the best-fitting models under simpler covariance structure parameterisations, i.e. the five-class GMM1 (BIC diff.=-28.7, $BF \approx 1.71*10^{6}$) and seven-class LCGA (BIC diff.=-65.0, $BF \approx 1.33*10^{14}$). Each of these models was, in turn, clearly preferable to the simple latent growth curve model (equivalent to the single-class GMM2 specification) on the basis of BIC values.

Table 23: Model fit, class size and classification quality statistics for GMMs of psychological distress with an increasing number of classes

LCGA: Class-specific growth factor means and zero growth factor variance. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
1	-8747.0	5	17528.2	17512.3	929	(100)	0	N/A	N/A	N/A
2	-8362.1	8	16779.0	16753.6	233	(25)	0	.83	.90	9.5
3	-8214.2	11	16503.7	16468.7	48	(5.2)	0	.84	.90	9.3
4	-8180.0	14	16455.7	16411.2	48	(5.1)	0	.82	.77	10.4
5	-8142.7	17	16401.6	16347.6	11	(1.2)	1	.84	.79	11.4
6	-8120.1	20	16376.9	16313.4	11	(1.2)	1	.73	.72	5.1
7	-8102.2	35	**16361.5**	16288.5	12	(1.3)	1	.75	.75	5.7

GMM 1: Class-specific growth factor means, class-invariant growth factor variances, and conditional independence of the growth factors within class. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
1	-8266.0	7	16579.8	16557.6	929	(100)	0	N/A	N/A	N/A
2	-8188.3	10	16444.9	16413.2	159	(17)	0	.85	.90	6.7
3	-8162.8	13	16414.5	16373.2	20	(2.2)	1	.88	.85	7.5
4	-8166.9	16	16343.1	16292.3	54	(5.9)	0	.87	.85	4.4
5	-8097.7	19	**16325.2**	16264.8	20	(2.2)	1	.85	.75	7.3
6	-8089.3	22	16328.9	16259.0	12	(1.3)	1	.82	.71	7.0
7	-8080.7	25	16332.3	16252.9	1	(0.1)	2	.83	.70	7.1

GMM 2: Class-specific growth factor means, class-specific growth factor variances, class-invariant growth factor covariance. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
1	-8264.8	8	16584.2	16558.8	929	(100)	0	N/A	N/A	N/A
2	-8142.9	13	16374.7	16333.4	449	(48)	0	.48	.81	4.0
3	-8086.7	18	**16296.5**	16239.3	247	(27)	0	.54	.77	4.2
4	-8076.2	23	16309.6	**16236.6**	89	(9.5)	0	.53	.74	3.7
5	-8068.3	28	16328.0	16239.0	69	(7.4)	0	.55	.62	4.4
6	-8063.2	33	16351.9	16247.1	1	(0.1)	2	.64	.78	4.0
7	-8058.3	38	16376.3	16255.6	1	(0.1)	2	.66	.69	3.5

Final unconditional GMM: Class-specific growth factor means, class-specific variance in intercept (declining class only), slope variance in healthful class fixed at zero, and conditional independence of the growth factors within class. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
3	-8087.7	14	16271.1	16226.6	250	(27)	0	.55	.78	4.2

Note. p = number of free parameters (indicative of model complexity); BIC = Bayesian information criterion; SSABIC = sample size adjusted BIC; APP_k = average posterior probability; OCC_k = odds of correct classification.

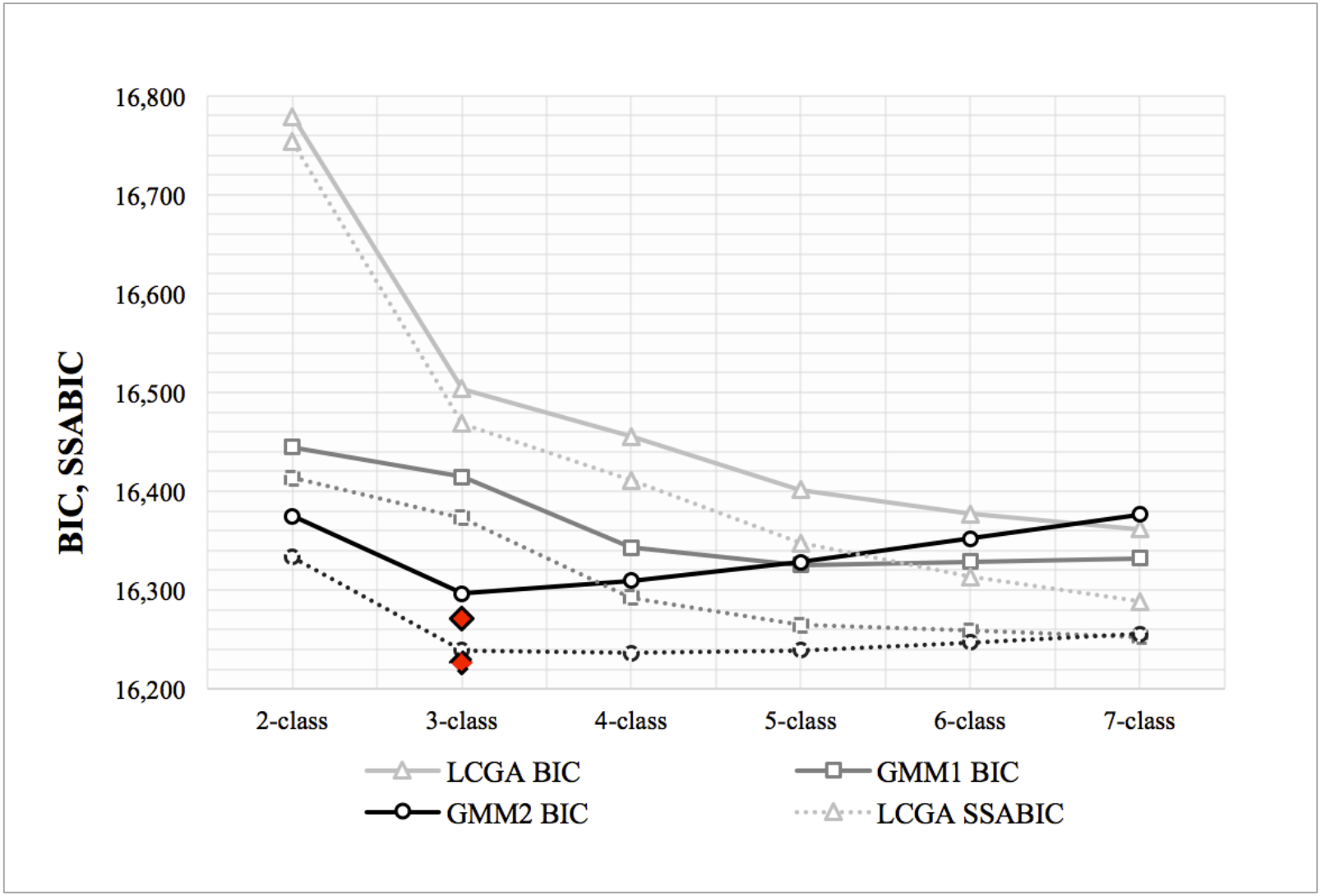


Figure 20: Elbow plots of BIC and SSABIC for GMMs of psychological distress with an increasing number of classes

Inspection of the class-specific growth factor covariance matrices estimated by GMM2-3 revealed some notable commonalities across classes and opportunities for simplification of the measurement model. To illustrate, class-specific growth factor covariance estimates (and standard errors) for the low-stable (LS), low-ascending (LA), and high-declining (HD) classes are reproduced below. Here, VAR(η0) reflects within-class variance in trajectory intercepts; VAR(η1) reflects within-class variance in trajectory slopes; and COV(η0,η1) reflects within-class covariance between the growth factors.

$$\Psi_k = \begin{bmatrix} VAR[\eta_0] & . \\ COV[\eta_{0.1}] & VAR[\eta_1] \end{bmatrix}_k$$

$$= \begin{bmatrix} 3.07\ (0.82) & . \\ -0.09\ (0.12) & 0.01\ (0.01) \end{bmatrix}_{LS}, \begin{bmatrix} 5.19\ (1.70) & . \\ -0.09\ (0.12) & 1.62\ (0.28) \end{bmatrix}_{LA}, \begin{bmatrix} 23.5\ (4.54) & . \\ -0.09\ (0.12) & 1.58\ (0.21) \end{bmatrix}_{HD}$$

To align with these between-class similarities in the covariance structure estimated under GMM2-3, the model was re-estimated with equality constraints on all within-class growth factor variances except for (1) intercept variance in the high-declining class, which was freely estimated as a class-specific parameter, and (2) slope variance in the low-stable class, which was fixed at zero. Intercept-slope covariance was also fixed at zero, reflecting conditional independence of growth factors within all classes. Compared with GMM2-3, these constraints did not significantly harm the fit of the model (LRT=2.078, df=4, p=0.72) and resulted in substantial improvements to BIC (16271.1) and SSABIC (16226.6) with minimal change to the classification statistics (entropy=0.55, min. APP_k=0.78, min. OCC_k=4.2). There were also no noticeable changes to the estimated class sizes or trajectory shapes. As such, this amended model was adopted this as the final unconditional K10 GMM.

Parameter estimates from the unconditional K10 GMM are reported in Table 24 (p.169). As alluded to previously, the model reveals three latent classes characterised by: (1) low and stable (LS 46%); (2) initially low and ascending (LA 27%); and (3) initially high but declining (HD 27%) mean trajectories of psychological distress. This trajectory typology is depicted graphically in Figure 22 (p.176) after adjustment for covariates. Membership in the LS class, the most prevalent of the three groups, represents a 'healthful' trajectory characterised by persistently low levels of distress symptomology. When compared against that class, the LA and HD classes are each markers of individuals experiencing relatively poor outcomes in relation to the level of psychological distress. Mean trajectories for these 'adverse' classes

roughly reflect transitions from a 'low' to 'moderate' level of distress (LA) or a 'high' to a 'moderate' level of distress (HD) over the four-year span of the study (Australian Bureau of Statistics, 2012)[79]. Table 24 also presents parameter estimates for the unconditional LGCM, in which the mean trajectory reflects 'moderate' and stable levels of psychological distress. The LGCM slope parameter was not significantly different from zero, and exhibited only a small and marginally significant (p=0.047) amount of variation across participants.

Table 24: Parameter estimates from the final unconditional psychological distress GMM and unconditional latent growth curve model

Parameter	Low-stable (LS, 46%) Est. (SE)	Low-ascending (LA, 27%) Est. (SE)	High-declining (HD, 27%) Est. (SE)	LGCM Est. (SE)
Intercept mean ($\alpha_{i,0}$)	3.92 (0.23)**	5.87 (0.44)**	14.7 (0.60)**	7.32 (0.23)**
Slope mean ($\alpha_{i,1}$)	-0.01 (0.01)**	1.00 (0.21)**	-0.88 (0.13)**	0.02 (0.06)
Intercept variance ($\Psi_{i,0, i,0}$)	3.72 (0.62)**	3.72 (0.62)**	23.3 (4.24)**	25.0 (2.43)**
Slope variance ($\Psi_{i,1, i,1}$)	0.00 (NA)	1.58 (0.16)**	1.58 (0.16)**	0.52 (0.26)*
Growth factor covariance ($\Psi_{i,0, i,1}$)	0.00 (NA)	–	–	-0.68 (0.51)
T1 error variance ($\Theta_{1,1}$)	6.44 (0.88)**	–	–	14.4 (2.13)**
T2 error variance ($\Theta_{2,2}$)	18.8 (1.50)**	–	–	15.1 (1.52)**
T3 error variance ($\Theta_{3,3}$)	3.04 (0.91)**	–	–	10.8 (3.16)**

Note. Trajectory classes are named according to mean intercept and slope characteristics: LS = low-stable; LA = low-ascending; HD = high-declining. Intercepts reflect K10 score at first interview; slopes reflect average change in K10 scores per year. Class proportions (%) based on estimated posterior probabilities. (NA) indicates a fixed parameter; '–' indicates a fully class-invariant parameter. ***^p≤0.10 *p≤0.05 **p≤0.01.***

It should be acknowledged that although the final unconditional K10 GMM was clearly the optimal solution in terms of statistical fit and parsimony, the model achieved only a moderate level of classification precision (Table 23, p.166). This implies uncertainty in the assignment of class membership, which must be explicitly integrated into analyses relating this trait to other variables (as in the single-step approach, which employs conditional probabilities of class membership directly in the estimation of structural relationships) (Bolck et al., 2004). Prior work suggests that entropy values below 0.6 may reflect misclassification rates of 20% or more when partitioning participants according to their maximum posterior probability (Lubke and Muthén, 2007). This is consistent with the mean value of APP_k estimated in the final GMM (class-size weighted mean 0.81, range 0.78-0.86). Classification certainty was

[79] The categorisation scheme employed here was presented in Chapter 3 (Section 6.2.2). It is worth noting that there was substantial variation in the initial level of psychological distress among members of the HD class, and it was not uncommon for these participants to commence the study with 'moderate' or 'very high' distress.

poorest for the healthful (low-stable) class (APP_k=0.78), with average posterior probabilities indicating a 17% chance that participants modally assigned to this class really belong in the worsening (low-ascending) class. Rates of modal classification error across all other class combinations were lower (5-10%). The difficulty of distinguishing between the healthful and worsening classes is unsurprising, given the similarity in their trajectory intercept means, and is likely to reflect a genuinely low level of separation between the classes (Lubke and Muthén, 2007). Despite this, values of APP_k for all classes, and OCC_k for the 'adverse'[80] classes of key substantive interest, exceeded suggested benchmark levels (Nagin, 2009).

It is worthwhile to reiterate that none of the classification statistics measure model fit, nor are they intended to guide model selection except perhaps in the presence of otherwise equivalent models; they simply describe the classification of participants assuming that the model is correctly specified (Nylund-Gibson et al., 2014). Tinkering with the measurement model to improve classification precision (e.g. by specifying class-invariant growth factor variances or extracting additional classes) cannot address the potential underlying causes of classification uncertainty (e.g. poor class separation or a large degree of within-class variation) but merely increases the risk model misspecification. For this reason, no amendments were made in an attempt to improve the classification precision achieved by the final GMM.

3.1.2 Life satisfaction

Table 25 (p.171) outlines model fit, complexity, class size and classification quality in the initial stages of class enumeration for the life satisfaction GMM. The absolute minimum values of BIC and SSABIC observed during this process were attributable to the GMM2 model with four classes (GMM2-4: BIC=20771, SSABIC=20698). However, the fourth class was trivial in size, containing a very small group of participants (n=11, 1.2%) with a mean growth trajectory characterised by extremely low levels of life satisfaction at commencement of the study and a steeply positive rate of change. In fact, all models with $k \geq 4$ were plagued by small class sizes, regardless of the parameterisation of within-class covariance matrices, and never achieved the recommended minimum of 25 participants in each class (Jung and Wickrama, 2008, Berlin et al., 2013b).

[80] All minimum OCC_k values reported in Table 23 were attributable to the healthful (LS) class, even when APP_{LS} was very high (≥0.9). This is explained by its large class proportion (46%), which corresponds to a higher relative probability of correct assignment through random chance and places the LS class at a distinct disadvantage on this metric. OCCk for the 'adverse' classes was consistently strong (>10).

Table 25: Model fit, class size and classification quality statistics for GMMs of life satisfaction with an increasing number of classes

LCGA: Class-specific growth factor means and zero growth factor variance. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
1	-11156.6	5	22347.3	22331.4	929	(100)	0	N/A	N/A	N/A
2	-10682.6	8	21419.9	21394.5	223	(24)	0	.84	.93	8.0
3	-10519.0	11	21113.2	21078.3	95	(10)	0	.80	.88	11.4
4	-10454.7	14	21005.0	20960.5	5	(0.5)	1	.83	.88	11.4
5	-10422.5	17	20961.1	20907.2	3	(0.3)	2	.85	.88	11.4
6	-10389.1	20	20914.9	20851.4	3	(0.3)	2	.82	.81	8.4
7	-10357.2	23	20871.5	20798.5	3	(0.3)	3	.80	.80	6.0

GMM 1: Class-specific growth factor means, class-invariant growth factor variances, and conditional independence of the growth factors within class. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
1	-10466.4	7	20980.6	20958.3	929	(100)	0	N/A	N/A	N/A
2	-10409.0	10	20886.4	20854.6	97	(10)	0	.85	.86	3.9
3	-10368.4	13	20825.7	20784.4	30	(3.2)	0	.89	.85	4.1
4	-10333.0	16	20775.4	20724.6	6	(0.6)	1	.91	.85	4.4
5	-10321.5	19	**20772.9**	20712.5	5	(0.5)	2	.90	.83	4.3
6	-10314.6	22	20779.5	20709.7	5	(0.5)	3	.90	.81	4.2
7	-10308.5	25	20787.8	**20708.4**	3	(0.3)	4	.91	.81	4.5

GMM 2: Class-specific growth factor means, class-specific growth factor variances, class-invariant growth factor covariance. Class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
1	-10465.8	8	20985.1	20959.7	929	(100)	0	N/A	N/A	N/A
2	-10355.6	13	20799.1	20757.8	196	(21)	0	.62	.84	2.8
3	-10331.9	18	20785.7	20728.6	51	(5.4)	0	.77	.77	3.2
4	-10307.5	23	**20771.2**	**20698.2**	11	(1.2)	1	.77	.81	3.4
5	-10298.4	28	20788.1	20699.2	11	(1.2)	2	.75	.69	6.2
6	-10293.2	33	20811.9	20707.1	11	(1.2)	2	.76	.66	6.4
7	-10289.3	38	20838.3	20717.6	11	(1.2)	1	.69	.69	5.5

Final unconditional GMM: Class-specific growth factor means, class-invariant growth factor variances excluding slope variance in healthful class (fixed at zero). Conditional independence of the growth factors within class and class-invariant residual outcome variances.

Classes	Log-likelihood	*p*	BIC	SSABIC	Smallest class n	(%)	Classes of n<25	Entropy	Minimum APP_k	OCC_k
3	-10335.4	13	20759.7	20718.4	73	(7.8)	0	.76	.82	2.8

Note. p = number of free parameters (indicative of model complexity); BIC = Bayesian information criterion; SSABIC = sample size adjusted BIC; APP_k = average posterior probability; OCC_k = odds of correct classification.

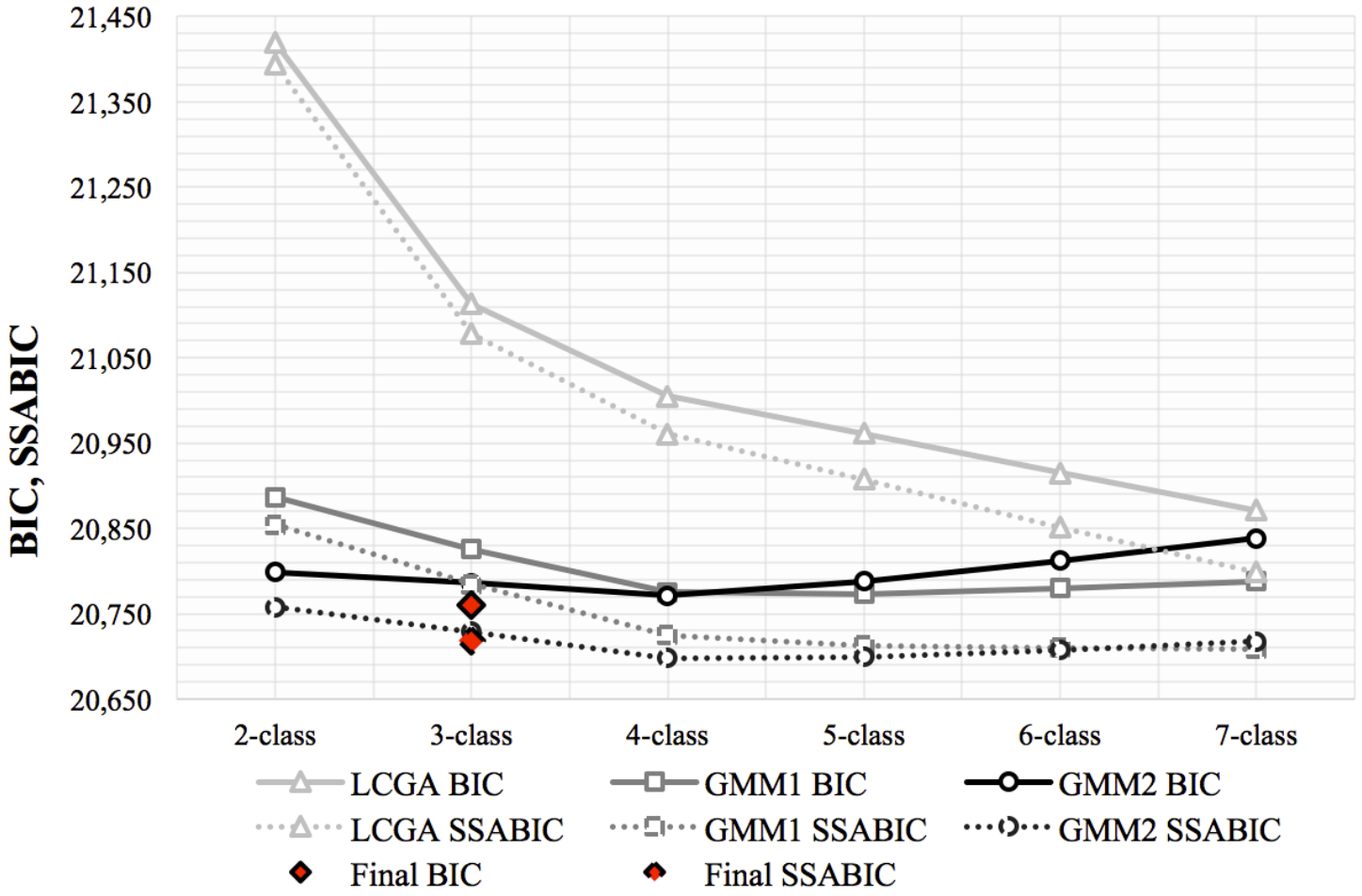


Figure 21: Elbow plots of BIC and SSABIC for GMMs of life satisfaction with an increasing number of classes

Because the broader aims of the analyses in this thesis were to predict class membership based on POS 'greenness', among other variables, this raised concerns about the implications of such low class prevalences for statistical power and precision, and for numerical problems arising from sparseness in the analysed contingency table (Bolck et al., 2004, Bakk et al., 2013). These small classes were consequently discarded from consideration and relative model fit was examined across the models with k<4. Among these, the three-class GMM2 model (GMM2-3, BIC=20785) fit the data best, followed by the three-class GMM1 model (GMM1-3, BIC=20826). The BIC difference between these models provided strong support for GMM2-3 as the preferable model (BIC diff.=-40.0, BF≈$4.8*10^8$). This model featured (1) a high, flat trajectory; (2) an initially high, declining trajectory; and (3) an initially low, ascending trajectory[81].

Inspection of the class-specific growth factor covariance matrices estimated under GMM2-3 again revealed notable similarities between classes and potential for simplification of the measurement model. Class-specific growth factor covariance estimates (and standard errors) for the high-stable (LS), high-declining (HD), and low-ascending (LA) classes are reproduced below. Again, $\Psi(\eta 0)$ reflects within-class variance in trajectory intercepts; $\Psi(\eta 1)$ reflects within-class variance in trajectory slopes; and $\Psi(\eta 0,\eta 1)$ reflects within-class covariance between the growth factors.

$$\Psi_k = \begin{bmatrix} VAR[\eta_0] & . \\ COV[\eta_{0.1}] & VAR[\eta_1] \end{bmatrix}_k$$

$$= \begin{bmatrix} 52.3\ (10.0) & . \\ 1.33\ (1.03) & 0.03\ (0.06) \end{bmatrix}_{HS}, \begin{bmatrix} 41.5\ (30.4) & . \\ 1.33\ (1.03)) & 6.32\ (3.21) \end{bmatrix}_{HD}, \begin{bmatrix} 110.7\ (24.2) & . \\ 1.33\ (1.03) & 7.87\ (2.93) \end{bmatrix}_{LA}$$

The model was re-estimated the model with equality constraints on all within-class growth factor variances except for (1) intercept variance in the low-ascending class, which was freely estimated as a class-specific parameter, and (2) slope variance in the high-stable class, which was fixed at zero. The intercept-slope covariance was also fixed at zero, reflecting conditional independence of growth factors within all classes[82]. Compared with GMM2-3, these constraints did not significantly harm the fit of the model (LRT=2.688, df=4, p=0.61) and

[81] Note that the fourth class discarded from the prima facie 'best fitting' GMM2-4 model is a more extreme variation of the 'initially low, ascending' trajectory class implied by GMM2-3, such that the latter model captures the key substantive 'themes' of variation in trajectory shapes.

[82] Note that this model is analogous to the final unconditional K10 GMM.

resulted in substantial improvements to BIC (20761) and SSABIC (20716). The level of classification quality fell slightly but was generally still high[83] (entropy=0.72, min. APP_k=0.79, min. OCC_k=2.7). There was no noticeable change to the estimated class sizes or trajectory shapes. This model was therefore adopted as the final unconditional SLDS GMM.

Parameter estimates from the final unconditional SLDS GMM are reported in Table 26 (p.174). As alluded to previously, the model reveals three latent classes characterised by: (1) high and stable (HS 79%); (2) initially high and declining (HD 8.0%); and (3) initially low but ascending (LA 13%) mean trajectories of life satisfaction. This trajectory typology is depicted graphically in Figure 23 (p.176) after adjustment for covariates. Membership in the HS class, the most prevalent of the three groups, represents a 'healthful' trajectory characterised by persistently high levels of life satisfaction. When compared against that class, the 'adverse' HD and LA classes are each markers of individuals experiencing relatively poor outcomes in relation to the level of life satisfaction, whether due to worsening levels of satisfaction over time (HD) or initially poor levels of satisfaction (LA).

Table 26 also presents parameter estimates for the unconditional LGCM, in which the mean trajectory reflects high and stable levels of life satisfaction. Neither the mean nor variance of the LGCM slope parameter was significantly different from zero.

Table 26: Parameter estimates from the final unconditional life satisfaction GMM and unconditional latent growth curve model

Parameter	High-stable (HS, 79%) Est. (SE)	High-declining (HD, 8.0%) Est. (SE)	Low-ascending (LA, 13%) Est. (SE)	LGCM Est. (SE)
Intercept mean ($\alpha_{\eta 0}$)	98.5 (0.82)**	93.8 (2.36)**	71.6 (2.90)**	94.7 (0.47)**
Slope mean ($\alpha_{\eta 1}$)	-0.08 (0.08)	-3.41 (1.28)**	2.31 (0.56)**	-0.03 (0.09)
Intercept variance ($\Psi_{\eta 0, \eta 0}$)	57.8 (9.01)**	57.8 (9.01)**	111 (24.5)**	129 (9.65)**
Slope variance ($\Psi_{\eta 1, \eta 1}$)	0.00 (NA)	8.04 (2.13)**	8.04 (2.13)**	1.15 (0.86)
Growth factor covariance ($\Psi_{\eta 0, \eta 1}$)	0.00 (NA)	–	–	-2.75 (1.83)
T1 error variance ($\Theta_{1,1}$)	41.0 (5.15)**	–	–	65.0 (11.6)**
T2 error variance ($\Theta_{2,2}$)	50.3 (6.58)**	–	–	41.0 (6.15)**
T3 error variance ($\Theta_{3,3}$)	28.6 (3.31)**	–	–	44.6 (8.57)**

Note. Trajectory classes are named according to mean intercept and slope characteristics: HS = high-stable; HD = high-declining; LA=low-ascending. Intercepts reflect SLDS score at first interview; slopes reflect average change in SLDS scores per year. Class proportions (%) based on estimated posterior probabilities. (NA) identifies a fixed parameter; '–' identifies a fully class-invariant parameter. ***^p≤0.10 *p≤0.05 **p≤0.01.***

[83] Minimum OCC_k values were again invariably attributable to the healthful (high-stable class), containing 79% of the sample, even when APP_{HS} was very high (≥0.9). OCC_k for the adverse classes was very strong (>35).

3.1.3 Interpreting trajectory classes: the influence of regression to the mean

The results just described in Sections 3.1.1 and 3.1.2 illustrate that the sample-wide distributions of prospective changes in psychological distress and life satisfaction were each characterised by a large group of participants who commenced the study in a healthful state and did not report any substantial changes across the ensuing four-year period (i.e. followed a stable 'healthful' trajectory). However, for both outcomes, there was also evidence of two 'adverse' subpopulations: one with initially good but 'worsening' mental health, and one with initially poor but apparently 'improving' mental health. These trajectories are depicted graphically on page 176, after adjustment for covariates within the final conditional GMM (Model E) described in the following section of this chapter.

Given that only three waves of data were available, it was necessary to assess the extent to which the observed longitudinal changes in these 'adverse' classes might be explained by regression to the mean (RTM). Appendix 4.4 evaluates, graphically and statistically, the expected influence of RTM on observed changes in psychological distress and life satisfaction according to the baseline cut-points by which these groups are defined. The primary aim of the analyses therein was to determine the extent to which the mean trajectory slopes that describe these classes reflect true change over time, or are merely statistical artefacts of the manner in which the GMM partitioned participants across the spectrum of mental health scores at T1. It concludes that RTM is likely to account fully for the mean decline in psychological distress among the 'improving' K10 class, and for most of the mean increase in life satisfaction among the 'improving' SLDS class. Conversely, RTM is unlikely to account for a significant portion of the change in these outcomes among the 'worsening' K10 or 'worsening' SLDS classes.

In light of this analysis, the 'high-declining' distress class is renamed the *chronic high-distress class*, and the 'low-ascending' life satisfaction class is renamed the *chronic low-satisfaction* class, to better reflect the extent to which initial scores define these trajectories and result in spurious mean rates of change over time. The 'low-ascending' distress class and 'high-declining' life satisfaction class are henceforth referred to as the *worsening* classes. Finally, the 'low-stable' distress class and the 'high-stable' life satisfaction class are henceforth referred to as the *healthful* classes.

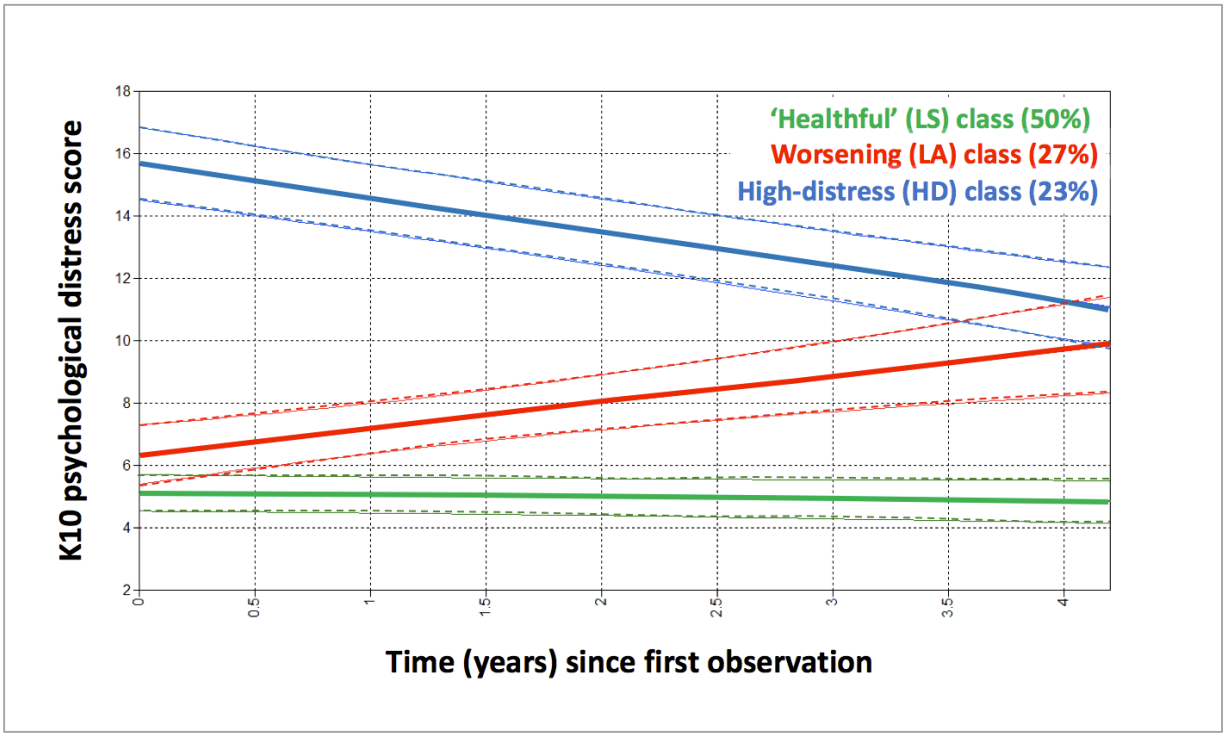


Figure 22: Covariate-adjusted mean trajectories of psychological distress (with 95% CI) from GMM E

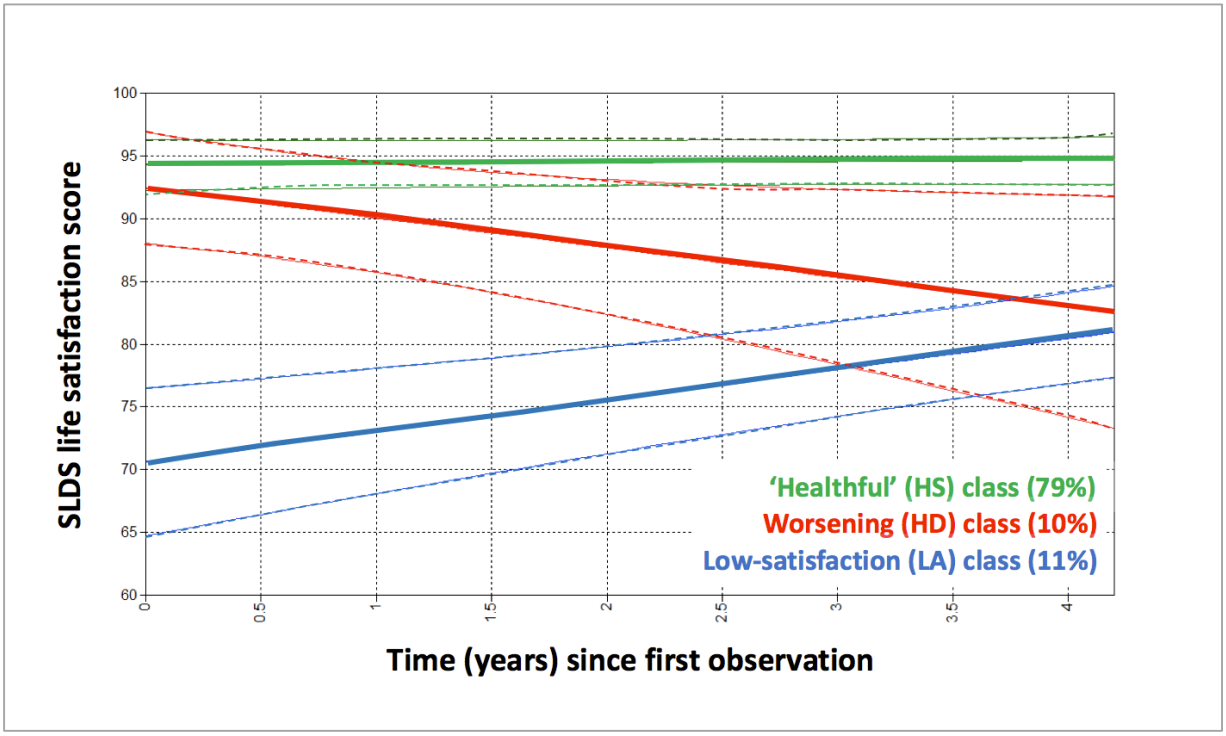


Figure 23: Covariate-adjusted mean trajectories of life satisfaction (with 95% CI) from GMM E

3.2 Covariate associations with mental health trajectories

This section presents results for the associations of socio-demographic covariates to inter-individual variation in trajectories of psychological distress and life satisfaction, modelled using single-population (LGCM) and multiple-subpopulation (GMM) approaches. Results at each stage of the GMM model building procedure (Models A to E) are presented across three tables for each outcome (psychological distress: Table 27 to Table 29, pp.178-180; life satisfaction: Table 30 to Table 32, pp.184-186). The tables include information pertaining to class sizes at each stage of the estimation (with reference to the class structure observed in the unconditional model) and the results of Wald tests (where applicable) that support the deletion of covariates or direct effects from the model. The Wald test is reported under models from which effects have been removed, to contextualise the sudden absence of certain parameters (marked '---'). The reader may find it helpful to refer back to Section 2.2 (p.162) which described the stages of the model building procedure and explained how these sets of information (class sizes and statistical tests) were used together.

For both outcomes, Model E was selected as the final conditional GMM. **These are the base covariate models used in all further analyses in this thesis.** Although the balance between fit and parsimony (reflected in BIC scores) was better for much simpler models (e.g. Model A), these were less able to replicate the unconditional class structure and also excluded a number of statistically significant variables that could confound associations between POS greenness and mental health. Discussion in the following sections is therefore limited to the findings from Model E and their comparison to the single-population LGCM. To aid in the interpretation, I reiterate that covariate effects for the GMM are partitioned into 'between-class' and 'within-class' components (see Section 1.2.1.3 of this chapter). Between-class effects refer to the prediction of latent class membership and were estimated using multinomial logistic regression with the healthful class as the reference group. Exponentiated regression coefficients (odds ratios) therefore reflect the change in the odds of membership in class *k*, relative to the healthful class, for a one-unit change in the predictor. Within-class effects capture the partial or residual effect of a predictor, conditional upon class membership, and are interpreted as the linear change in intercepts, slopes, or time-specific outcomes with a one-unit change in the predictor. Within the LGCM, all covariate effects are analogous to 'within-class' effects due to the single-population assumption imposed upon the data.

Table 27: Socio-demographic predictors of trajectories of psychological distress under GMM (class membership and within-class variation) and LGCM (variation about single population means) (1 of 3)

Unconditional class structure for comparison: LA (27%), HD (27%)		GMM: Model A *LA (30%), HD (23%) BIC = 16223.9*			GMM: Model B *LA (29%), HD (21%) BIC = 16284.6*		
Between-class	Baseline covariates	OR	[95%	CI]	OR	[95%	CI]
Worsening class (LA)	Age 15-35	2.13^	[0.93	4.83]	**2.18***	**[1.01**	**4.69]**
	Age 51+	0.79	[0.42	1.50]	0.68	[0.34	1.35]
	Male sex	0.60^	[0.35	1.04]	0.53^	[0.27	1.03]
	Education ≥ DCS	---	---		**0.56***	**[0.32**	**0.97]**
	LOR: 1-5 years	---	---		0.61	[0.30	1.25]
	Area SED	---	---		**1.76***	**[1.06**	**2.91]**
	Population Density	---	---		1.02	[0.95	1.10]
Chronic high-distress class (HD)	Age 15-35	1.81	[0.88	3.74]	1.63	[0.85	3.14]
	Age 51+	0.79	[0.51	1.21]	**0.55***	**[0.34**	**0.91]**
	Male sex	**0.62***	**[0.41**	**0.94]**	**0.55***	**[0.34**	**0.87]**
	Education ≥ DCS	---	---		**0.34***	**[0.19**	**0.61]**
	LOR: 1-5 years	---	---		0.69	[0.44	1.09]
	Area SED	---	---		1.37^	[0.97	1.93]
	Population density	---	---		**1.07***	**[1.01**	**1.12]**
Within-class	Baseline covariates	B	[95%	CI]	B	[95%	CI]
Intercept	Age 15-35	---	---		---	---	
	Age 51+	---	---		---	---	
	Male sex	---	---		---	---	
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		---	---	
	Population density	---	---		---	---	
Slope	Age 15-35	---	---		---	---	
	Age 51+	---	---		---	---	
	Male sex	---	---		---	---	
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		---	---	
	Population density	---	---		---	---	
Within-class	Time-varying	B	[95%	CI]	B	[95%	CI]
K10 (*t* = T1)	Physical health	**-1.06****	**[-1.29**	**-0.82]**	**-1.02****	**[-1.27**	**-0.77]**
	Log_e H'hold income	---	---		**-0.37***	**[-0.73**	**-0.01]**
	Married/Cohabiting	---	---		-0.53	[-1.17	0.11]
	Unemployed (1 yr)	---	---		0.12	[-0.51	0.76]
	Season (cold)	---	---		0.19	[-0.25	0.64]
K10 (*t* = T2)	Physical health	**-1.05****	**[-1.34**	**-0.75]**	**-1.01****	**[-1.31**	**-0.72]**
	Log_e H'hold income	---	---		-0.26	[-0.63	0.12]
	Married/Cohabiting	---	---		-0.31	[-0.96	0.34]
	Unemployed (1 yr)	---	---		0.41	[-0.28	1.11]
	Season (cold)	---	---		-0.23	[-0.72	0.26]
K10 (*t* = T3)	Physical health	**-1.09****	**[-1.38**	**-0.80]**	**-1.06****	**[-1.35**	**-0.76]**
	Log_e H'hold income	---	---		-0.14	[-0.52	0.24]
	Married/Cohabiting	---	---		-0.38	[-0.99	0.23]
	Unemployed (1 yr)	---	---		**0.81***	**[0.18**	**1.43]**
	Season (cold)	---	---		0.10	[-0.30	0.51]
Wald tests		N/A			N/A		

K10 = Kessler Psychological Distress Scale (total score). GMM = growth mixture model. LGCM = latent growth curve model. OR = odds ratio relative to membership in the healthful (low-stable) class. B = unstandardized regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. Baseline predictors entered at T1 values. Time-varying predictors entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion; BIC = Bayesian Information Criterion. N/A indicates wald test is not applicable because variables are being added to the model (not removed). ***^p≤0.10 *p≤0.05 **p≤0.01***

Table 28: Socio-demographic predictors of trajectories of psychological distress under GMM (class membership and within-class variation) and LGCM (variation about single population means) (2 of 3)

Unconditional class structure for comparison: LA (27%), HD (27%)		GMM: Model C ***LA (28%), HD (22%)*** *BIC = 16238.8*			GMM: Model D *LA (27%), HD (22%)* *BIC = 16295.4*		
Between-class	Baseline covariates	OR	[95%	CI]	OR	[95%	CI]
Worsening class (LA)	Age 15-35	1.94^	[0.93	4.08]	2.16	[0.84	5.56]
	Age 51+	0.74	[0.36	1.51]	1.04	[0.53	2.04]
	Male sex	0.53^	[0.27	1.03]	**0.52***	**[0.28**	**0.99]**
	Education ≥ DCS	**0.57***	**[0.33**	**0.97]**	0.73	[0.37	1.44]
	LOR: 1-5 years	---	---		---	---	
	Area SED	**1.69***	**[1.04**	**2.76]**	**2.23****	**[1.41**	**3.55]**
	Population Density	1.02	[0.95	1.09]	1.00	[0.93	1.08]
Chronic high-distress class (HD)	Age 15-35	1.54	[0.80	2.95]	1.41	[0.69	2.86]
	Age 51+	**0.60***	**[0.37**	**0.97]**	0.84	[0.52	1.36]
	Male sex	**0.55***	**[0.34**	**0.88]**	**0.51***	**[0.30**	**0.87]**
	Education ≥ DCS	**0.34****	**[0.19**	**0.61]**	**0.41****	**[0.22**	**0.77]**
	LOR: 1-5 years	---	---		---	---	
	Area SED	1.34^	[0.95	1.88]	**1.52***	**[1.05**	**2.21]**
	Population density	**1.07***	**[1.01**	**1.12]**	1.05^	[0.99	1.11]
Within-class	Baseline covariates	B	[95%	CI]	B	[95%	CI]
Intercept	Age 15-35	---	---		0.47	[-0.11	1.06]
	Age 51+	---	---		**-0.85****	**[-1.46**	**-0.25]**
	Male sex	---	---		0.39	[-0.22	1.00]
	Education ≥ DCS	---	---		-0.19	[-0.86	0.49]
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		**-0.31***	**[-0.59**	**-0.02]**
	Population density	---	---		0.01	[-0.07	0.10]
Slope	Age 15-35	---	---		-0.09	[-0.34	0.16]
	Age 51+	---	---		0.04	[-0.14	0.21]
	Male sex	---	---		-0.06	[-0.23	0.11]
	Education ≥ DCS	---	---		-0.10	[-0.28	0.09]
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		-0.07	[-0.18	0.04]
	Population density	---	---		0.01	[-0.01	0.04]
Within-class	Time-varying	B	[95%	CI]	B	[95%	CI]
K10 (*t* = T1)	Physical health	**-1.01****	**[-1.26**	**-0.75]**	**-1.01****	**[-1.25**	**-0.78]**
	Log_e H'hold income	**-0.48***	**[-0.85**	**-0.11]**	**-0.51***	**[-0.91**	**-0.12]**
	Married/Cohabiting	---	---		---	---	
	Unemployed (1 yr)	**0.09**	**[-0.59**	**0.76]**	0.24	[-0.41	0.90]
	Season (cold)	---	---		---	---	
K10 (*t* = T2)	Physical health	**-1.03****	**[-1.32**	**-0.73]**	**-1.03****	**[-1.33**	**-0.73]**
	Log_e H'hold income	**-0.31^**	**[-0.66**	**0.05]**	-0.35^	[-0.71	0.02]
	Married/Cohabiting	---	---		---	---	
	Unemployed (1 yr)	**0.29**	**[-0.32**	**0.90]**	0.36	[-0.26	0.97]
	Season (cold)	---	---		---	---	
K10 (*t* = T3)	Physical health	**-1.05****	**[-1.34**	**-0.75]**	**-1.06****	**[-1.35**	**-0.77]**
	Log_e H'hold income	**-0.21**	**[-0.54**	**0.13]**	-0.25	[-0.58	0.08]
	Married/Cohabiting	---	---		---	---	
	Unemployed (1 yr)	**0.79***	**[0.19**	**1.39]**	**0.78***	**[0.13**	**1.42]**
	Season (cold)	---	---		---	---	
Wald tests		Stat=7.90, df=8, p=0.44			N/A		

K10 = Kessler Psychological Distress Scale (total score). GMM = growth mixture model. LGCM = latent growth curve model. OR = odds ratio relative to membership in the healthful (low-stable) class. B = unstandardized regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. Baseline predictors entered at T1 values. Time-varying predictors entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion; BIC = Bayesian Information Criterion. N/A indicates wald test is not applicable because variables are being added to the model (not removed). ***^p≤0.10 *p≤0.05 **p≤0.01***

Table 29: Socio-demographic predictors of trajectories of psychological distress under GMM (class membership and within-class variation) and LGCM (variation about single population means) (3 of 3)

Unconditional class structure for comparison: LA (27%), HD (27%)		GMM: Model E *LA (27%), HD (23%)* *BIC = 16243.0*			LGCM *BIC = 16542.4*		
Between-class	Baseline covariates	OR	[95%	CI]	OR	[95%	CI]
Worsening class (LA)	Age 15-35	1.72	[0.84	3.52]	---	---	
	Age 51+	0.95	[0.51	1.79]	---	---	
	Male sex	**0.53***	**[0.28**	**0.99]**	---	---	
	Education ≥ DCS	**0.55***	**[0.32**	**0.95]**	---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	**2.00****	**[1.30**	**3.07]**	---	---	
	Population Density	1.03	[0.96	1.10]	---	---	
Chronic high-distress class (HD)	Age 15-35	1.33	[0.68	2.62]	---	---	
	Age 51+	0.76	[0.47	1.24]	---	---	
	Male sex	**0.58***	**[0.36**	**0.91]**	---	---	
	Education ≥ DCS	**0.36****	**[0.21**	**0.63]**	---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	**1.53***	**[1.09**	**2.15]**	---	---	
	Population density	**1.07***	**[1.02**	**1.12]**	---	---	
Within-class	Baseline covariates	B	[95%	CI]	B	[95%	CI]
Intercept	Age 15-35	0.42	[-0.12	0.95]	0.54	[-0.33	1.42]
	Age 51+	**-0.64***	**[-1.16**	**-0.12]**	**-1.22****	**[-2.01**	**-0.44]**
	Male sex	---	---		-0.38	[-1.04	0.28]
	Education ≥ DCS	---	---		**-1.60****	**[-2.44**	**-0.76]**
	LOR: 1-5 years	---	---		-0.18	[-0.87	0.51]
	Area SED	**-0.40****	**[-0.69**	**-0.12]**	-0.06	[-0.51	0.39]
	Population density	---	---		**0.12***	**[0.02**	**0.22]**
Slope	Age 15-35	---	---		-0.09	[-0.34	0.16]
	Age 51+	---	---		0.14	[-0.12	0.39]
	Male sex	---	---		-0.04	[-0.22	0.14]
	Education ≥ DCS	---	---		0.00	[-0.18	0.18]
	LOR: 1-5 years	---	---		0.05	[-0.14	0.25]
	Area SED	---	---		-0.01	[-0.14	0.13]
	Population density	---	---		0.00	[-0.03	0.03]
Within-class	Time-varying	B	[95%	CI]	B	[95%	CI]
K10 (*t* = T1)	Physical health	**-1.01****	**[-1.24**	**-0.78]**	**-1.28****	**[-1.60**	**-0.96]**
	Log_e H'hold income	**-0.54****	**[-0.93**	**-0.14]**	-0.44^	[-0.94	0.07]
	Married/Cohabiting	---	---		**-1.08****	**[-1.84**	**-0.32]**
	Unemployed (1 yr)	0.21	[-0.48	0.89]	0.48	[-0.37	1.33]
	Season (cold)	---	---		0.46	[-0.21	1.14]
K10 (*t* = T2)	Physical health	**-1.03****	**[-1.32**	**-0.73]**	**-1.36****	**[-1.69**	**-1.03]**
	Log_e H'hold income	**-0.38***	**[-0.74**	**-0.01]**	**-0.42***	**[-0.83**	**-0.01]**
	Married/Cohabiting	---	---		-0.68^	[-1.42	0.07]
	Unemployed (1 yr)	0.37	[-0.24	0.97]	**0.74***	**[0.04**	**1.44]**
	Season (cold)	---	---		-0.23	[-0.74	0.27]
K10 (*t* = T3)	Physical health	**-1.05****	**[-1.33**	**-0.76]**	**-1.46****	**[-1.82**	**-1.10]**
	Log_e H'hold income	-0.29^	[-0.63	0.04]	-0.39	[-0.88	0.11]
	Married/Cohabiting	---	---		**-1.02****	**[-1.78**	**-0.25]**
	Unemployed (1 yr)	**0.87****	**[0.27**	**1.47]**	0.59	[-0.13	1.32]
	Season (cold)	---	---		**0.54***	**[0.04**	**1.04]**
Wald tests		Stat=6.76, df=9, p=0.66			**N/A**		

K10 = Kessler Psychological Distress Scale (total score). GMM = growth mixture model. LGCM = latent growth curve model. OR = odds ratio relative to membership in the healthful (low-stable) class. B = unstandardized regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. Baseline predictors entered at T1 values. Time-varying predictors entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion; BIC = Bayesian Information Criterion. N/A indicates wald test is not applicable because variables are being added to the model (not removed). ***^p≤0.10 *p≤0.05 **p≤0.01***

3.2.1 Psychological distress

Table 27 to Table 29, above, present associations between covariates and trajectories of psychological distress across the five model building stages of the conditional GMM (Models A to E) and within a single population latent growth curve model (LGCM). Male gender and education were protective against membership in both adverse trajectory classes, while local-area socioeconomic deprivation and population density were risk factors for membership in those classes. Male participants were roughly half as likely as their female counterparts to fall into the worsening class (OR = 0.53, 95% CI [0.28, 0.99], p=0.047) or chronic distress class (OR = 0.58, 95% CI [0.36, 0.91], p=0.019) relative to the healthful class. Possessing a diploma of college studies or higher qualification at T1 was associated with a similar reduction in the odds of membership in the worsening class (OR = 0.55, 95% CI [0.32, 0.95], p=0.032) and even more strongly with membership in the chronic distress class (OR = 0.36, 95% CI [0.21, 0.63], p<0.00001). On the other hand, local-area socioeconomic deprivation was associated with greater odds of belonging to the worsening class (OR = 2.00, 95% CI [1.30, 3.07], p=0.002) or the chronic distress class (OR = 1.53, 95% CI [1.09, 2.15], p=0.014) while local-area population density was independently associated with membership in the chronic distress class only (OR = 1.07, 95% CI [1.02, 1.12], p=0.012).

Length of residence and age group were not associated with trajectory class membership. Within classes, however, the oldest participants (aged 51 or over) tended to report the lowest levels of psychological distress at commencement of the study, as indicated by an association with intra-class intercepts (B=-0.64, 95% CI [-1.16, -0.12], p=0.016). Similarly, holding class membership constant, better self-reported physical health (B_{T1}=-1.28, 95% CI [-1.60, -0.96], p<0.001), higher household income (B_{T1}=-0.54, 95% CI [-0.93, -0.14], p=0.016), and having some paid employment in the 12 months prior to the interview ($B_{T3(unemployed)}$ =0.87, 95% CI [0.27, 1.47], p=0.005) tended to be associated with lower levels of psychological distress at concurrent waves of the study. However, only for physical health was the relationship statistically significant at all time points. Conditional upon class membership, marital status and season of interview did not explain further variation in the level of psychological distress at any occasion.

Measures of global fit for the latent growth curve model with all covariate effects indicated acceptable fit to the observed data (RMSEA=0.05, CFI=0.94, SRMR=0.03) (Hu and Bentler, 1999, Little, 2009, McDonald and Ho, 2002). Yet, as observed in relation to the unconditional

models, the relative fit of the final conditional GMM was undoubtedly better[84] (BIC diff.=-299.4, BF≈$1.03*10^{65}$). Conclusions regarding the relationships of covariates to trajectory intercepts and time-specific levels of distress were roughly comparable between the single- and multiple-population models, taking into account the partitioning of effects into between- and within-class components in the GMM[85]. The most striking discrepancy between these models pertained to the prediction of variation in trajectory slopes. Specifically, the LGCM failed to identify any significant predictors of variation in the rate of change in psychological distress. This is particularly noteworthy given that a number of covariates influenced the relative odds of membership in the worsening distress class, compared with the healthful class, in the conditional GMM.

Holding covariates constant, the difference in trajectory intercepts between the healthful ($\alpha_{\eta 0} = 5.13$) and worsening ($\alpha_{\eta 0} = 6.37$) classes was marginally significant, both statistically (Wald statistic=3.97, df=1, p=0.046) and substantively (Figure 22, p.176). The difference in mean trajectory slopes was more pronounced in both respects, with a significant positive slope in the worsening class ($\alpha_{\eta 1} = 0.835$) contrasting against a non-significant (i.e. near-zero) slope in the healthful class ($\alpha_{\eta 1} = -0.071$) (Wald statistic=19.55, df=1. $p<0.001$). It is therefore reasonable to state that the effects of male gender, education and area socioeconomic deprivation on membership in the worsening class reflect, at least partially, differences in the propensity to experience escalating symptoms of psychological distress throughout the study. If the analyses were restricted to the LGCM, on the other hand, one would conclude that none of the baseline predictors was associated with the rate of change in psychological distress.

---

[84] This remained true if non-significant effects ($p>0.10$) were trimmed from the LGCM (BIC diff.=-231.3, BF≈$1.67*10^{50}$).

[85] Whereas the LGCM estimates the direct effects of a covariate on within-class intercepts and slopes, in the GMM these effects are (at least partially) channelled through class membership. Thus, differentials in the coefficients for direct ('within class') effects of education, area SED, and population density on trajectory intercepts is attributable to the fact that, in the GMM, these are residual effects *after* accounting for the influence of those variables on membership in the chronic high-distress class. Overall, conclusions regarding the risk or protective properties of these variables are analogous when comparing their effects on trajectory intercepts (a) indirectly via the chronic high-distress class in the GMM and (b) directly in the LGCM. One exception is the influence of male sex on the initial level of distress, which curiously is not detected in the LGCM despite being evidently protective against membership in both adverse GMM trajectory classes. Another notable discrepancy between the models is the significant relationship of marital status to time-specific levels of distress in the LGCM, but not the GMM. Again, this reflects the fact that the association in the GMM is conditional upon class membership, where a greater proportion of the healthful class (56% at T1) is married or cohabiting compared with the worsening (48% at T1) or chronic high-distress class (41% at T1). Controlling for class membership when estimating the relationship of marital status to distress therefore partially obscures the influence of this variable.

3.2.2 Life satisfaction

Table 30 to Table 32 present associations between covariates and trajectories of life satisfaction across the five model building stages of the conditional GMM (Models A to E) and compare those findings against a single population latent growth curve model (LGCM). Only local-area socioeconomic deprivation appeared to distinguish between the odds of membership in the various trajectory classes, with participants residing in a census tract at the 75th percentile of SED exhibiting 2.22 times greater odds of belonging to the worsening class relative to the healthful class. However, this relationship was not statistically significant in the final model (p=0.067). Conditional on class membership, younger participants (aged 15 to 35 at T1) and older participants (aged 51 or over at T1) tended to report greater initial levels of life satisfaction, compared to those aged between 36 and 50. Finally, better self-reported physical health, higher household income and being married or in a common law relationship were consistently associated with greater life satisfaction at concurrent waves of the study.

Measures of global fit for the latent growth curve model with all covariate effects indicated acceptable fit to the observed data (RMSEA=0.061, CFI=0.922, SRMR=0.050) (Hu and Bentler, 1999, Little, 2009, McDonald and Ho, 2002), although the relative fit of the GMM was far superior (BIC diff.=-207.3, BF≈1.03*10^{45}). Once again, results of the two models were largely analogous in relation to explaining initial status and time-specific values of the outcome. They did appear, however, to differ in relation to predicting variation in trajectory slopes. In the GMM, there was some indication that area socioeconomic deprivation influence membership in the worsening class, relative to the healthful class. These classes do not differ in terms of trajectory intercepts (Wald statistic =0.536, df=1, p=0.464) or variances (constrained to equality) in the conditional model, but they do differ in terms of trajectory slopes (Wald statistic =4.719, df=1, p=0.030). Thus, it may be reasonable to conclude that an effect of area SED on membership in the worsening class reflects its influence on the propensity to experience declining life satisfaction. As stated previously, this effect was not statistically significant, although the direction and magnitude of the observed association suggest that greater statistical power might have helped to clarify the nature of this association, particularly given the small size of the worsening class. By contrast, the LGCM revealed no indication whatsoever of an association between area SED and the rate of change in life satisfaction; in fact, the relationship between these variables was essentially zero.

Table 30: Socio-demographic predictors of trajectories of life satisfaction under GMM (class membership and within-class variation) and LGCM (variation about single population means) (1 of 3)

Unconditional class structure for comparison: HD (8%), LA (13%)		GMM: Model A *HD (15%), LA (12%) BIC = 20534.3*			GMM: Model B *HD (16%), LA (10%) BIC = 20611.3*		
Between-class	Baseline covariates	OR	[95%	CI]	OR	[95%	CI]
Worsening class (HD)	Age 15-35	0.24*	[0.07	0.85]	0.28^	[0.08	1.04]
	Age 51+	0.37^	[0.12	1.12]	0.34	[0.07	1.58]
	Male sex	0.82	[0.37	1.83]	0.80	[0.28	2.31]
	Education ≥ DCS	---	---		0.86	[0.32	2.36]
	LOR: 1-5 years	---	---		0.78	[0.23	2.60]
	Area SED	---	---		2.17*	[1.08	4.38]
	Population Density	---	---		0.95	[0.80	1.12]
Chronic low-satisfaction class (LA)	Age 15-35	1.01	[0.44	2.32]	0.82	[0.36	1.89]
	Age 51+	0.91	[0.45	1.87]	0.66	[0.32	1.37]
	Male sex	1.11	[0.64	1.94]	0.98	[0.54	1.78]
	Education ≥ DCS	---	---		0.64	[0.31	1.33]
	LOR: 1-5 years	---	---		0.91	[0.45	1.85]
	Area SED	---	---		1.01	[0.57	1.76]
	Population density	---	---		1.05	[0.94	1.18]
Within-class	Baseline covariates	B	[95%	CI]	B	[95%	CI]
Intercept	Age 15-35	---	---		---	---	
	Age 51+	---	---		---	---	
	Male sex	---	---		---	---	
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		---	---	
	Population density	---	---		---	---	
Slope	Age 15-35	---	---		---	---	
	Age 51+	---	---		---	---	
	Male sex	---	---		---	---	
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		---	---	
	Population density	---	---		---	---	
Within-class	Time-varying	B	[95%	CI]	B	[95%	CI]
SLDS (*t* = T1)	Physical health	3.39**	[2.69	4.09]	3.28**	[2.54	4.01]
	Log_e H'hold income	---	---		1.67**	[0.69	2.65]
	Married/Cohabiting	---	---		1.54*	[0.20	2.88]
	Unemployed (1 yr)	---	---		0.43	[-1.12	1.98]
	Season (cold)	---	---		-0.99*	[-1.98	0.00]
SLDS (*t* = T2)	Physical health	3.07**	[2.40	3.75]	3.06**	[2.38	3.74]
	Log_e H'hold income	---	---		0.69	[-0.20	1.58]
	Married/Cohabiting	---	---		1.28*	[0.02	2.53]
	Unemployed (1 yr)	---	---		-0.64	[-1.86	0.57]
	Season (cold)	---	---		-0.01	[-0.82	0.80]
SLDS (*t* = T3)	Physical health	3.48**	[2.85	4.11]	3.30**	[2.66	3.95]
	Log_e H'hold income	---	---		1.19*	[0.28	2.10]
	Married/Cohabiting	---	---		1.27^	[-0.05	2.60]
	Unemployed (1 yr)	---	---		-0.40	[-1.83	1.02]
	Season (cold)	---	---		-0.38	[-1.45	0.70]
Wald tests			N/A			N/A	

SLDS = Reduced Satisfaction with Life Domains Scale (total score), GMM = growth mixture model. LGCM = latent growth curve model. OR = odds ratio relative to membership in the healthful (high-stable) class. B = unstandardized regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. Baseline predictors entered at T1 values. Time-varying predictors entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion; BIC = Bayesian Information Criterion. N/A indicates wald test is not applicable because variables are being added to the model (not removed). ***^p≤0.10 *p≤0.05 **p≤0.01***

Table 31: Socio-demographic predictors of trajectories of life satisfaction under GMM (class membership and within-class variation) and LGCM (variation about single population means) (2 of 3)

Unconditional class structure for comparison: HD (8%), LA (13%)		GMM: Model C ***HD (17%), LA (10%)*** *BIC = 20556.6*			GMM: Model D *HD (11%), LA (10%)* *BIC = 20588.7*		
Between-class	Baseline covariates	OR	[95%	CI]	OR	[95%	CI]
Worsening class (HD)	Age 15-35	0.26*	0.08	0.86	0.51	[0.10	2.55]
	Age 51+	0.35	0.08	1.49	0.98	[0.25	3.73]
	Male sex	0.85	0.34	2.16	1.06	[0.35	3.19]
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	1.82^	0.96	3.44	2.35*	[1.19	4.61]
	Population Density	---	---		---	---	
Chronic low-satisfaction (LA)	Age 15-35	0.88	0.37	2.08	1.23	[0.50	3.00]
	Age 51+	0.75	0.36	1.58	1.13	[0.48	2.62]
	Male sex	1.01	0.56	1.81	1.00	[0.48	2.06]
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	1.19	0.83	1.71	1.32	[0.82	2.14]
	Population density	---	---		---	---	
Within-class	Baseline covariates	B	[95%	CI]	B	[95%	CI]
Intercept	Age 15-35	---	---		1.50	[-0.70	3.70]
	Age 51+	---	---		1.94*	[0.20	3.68]
	Male sex	---	---		-0.13	[-1.95	1.68]
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		0.41	[-0.82	1.64]
	Population density	---	---		---	---	
Slope	Age 15-35	---	---		0.13	[-0.33	0.58]
	Age 51+	---	---		0.43^	[-0.01	0.88]
	Male sex	---	---		0.17	[-0.24	0.58]
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	---	---		0.07	[-0.11	0.25]
	Population density	---	---		---	---	
Within-class	Time-varying	B	[95%	CI]	B	[95%	CI]
SLDS (*t* = T1)	Physical health	3.29**	[2.54	4.04]	3.28**	[2.51	4.05]
	Log_e H'hold income	1.54**	[0.60	2.47]	1.68**	[0.68	2.68]
	Married/Cohabiting	1.69*	[0.37	3.02]	1.72*	[0.33	3.10]
	Unemployed (1 yr)	---	---		---	---	
	Season (cold)	-0.98*	[-1.96	-0.01]	-1.08*	[-2.06	-0.10]
SLDS (*t* = T2)	Physical health	3.08**	[2.40	3.77]	3.10**	[2.43	3.77]
	Log_e H'hold income	0.80^	[-0.05	1.65]	1.02*	[0.19	1.85]
	Married/Cohabiting	1.20^	[-0.06	2.46]	1.20^	[-0.08	2.48]
	Unemployed (1 yr)	---	---		---	---	
	Season (cold)	-0.10	[-0.89	0.69]	-0.11	[-0.90	0.69]
SLDS (*t* = T3)	Physical health	3.34**	[2.70	3.97]	3.34**	[2.71	3.97]
	Log_e H'hold income	1.24**	[0.36	2.11]	1.65**	[0.79	2.51]
	Married/Cohabiting	1.31^	[-0.05	2.67]	1.37^	[-0.02	2.75]
	Unemployed (1 yr)	---	---		---	---	
	Season (cold)	-0.38	[-1.41	0.66]	-0.48	[-1.54	0.58]
Wald tests		Stat=6.58, df=9, p=0.68				N/A	

SLDS = Reduced Satisfaction with Life Domains Scale (total score), GMM = growth mixture model. LGCM = latent growth curve model. OR = odds ratio relative to membership in the healthful (high-stable) class. B = unstandardized regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. Baseline predictors entered at T1 values. Time-varying predictors entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion; BIC = Bayesian Information Criterion. N/A indicates wald test is not applicable because variables are being added to the model (not removed). ***^p≤0.10 *p≤0.05 **p≤0.01***

Table 32: Socio-demographic predictors of trajectories of life satisfaction under GMM (class membership and within-class variation) and LGCM (variation about single population means) (3 of 3)

Unconditional class structure for comparison: HD (8%), LA (13%)		GMM: Model E *HD (10%), LA (11%) BIC = 20555.7*			LGCM *BIC = 20763.0*		
Between-class	Baseline covariates	OR	[95%	CI]	OR	[95%	CI]
Worsening class (HD)	Age 15-35	0.40	[0.08	2.15]	---	---	
	Age 51+	0.63	[0.18	2.22]	---	---	
	Male sex	0.76	[0.25	2.35]	---	---	
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	2.00^	[0.95	4.18]	---	---	
	Population Density	---	---		---	---	
Chronic low-satisfaction class (LA)	Age 15-35	1.21	[0.52	2.78]	---	---	
	Age 51+	1.37	[0.61	3.08]	---	---	
	Male sex	1.04	[0.58	1.86]	---	---	
	Education ≥ DCS	---	---		---	---	
	LOR: 1-5 years	---	---		---	---	
	Area SED	1.26	[0.87	1.82]	---	---	
	Population density	---	---		---	---	
Within-class	Baseline covariates	B	[95%	CI]	B	[95%	CI]
Intercept	Age 15-35	1.73*	[0.19	3.28]	1.29	[-0.62	3.20]
	Age 51+	2.94**	[1.51	4.37]	1.72*	[0.14	3.30]
	Male sex	---	---		-0.31	[-1.97	1.35]
	Education ≥ DCS	---	---		-0.63	[-2.27	1.02]
	LOR: 1-5 years	---	---		-0.14	[-1.69	1.40]
	Area SED	---	---		0.21	[-0.87	1.30]
	Population density	---	---		-0.08	[-0.38	0.23]
Slope	Age 15-35	---	---		0.35^	[-0.06	0.77]
	Age 51+	---	---		0.54*	[0.05	1.02]
	Male sex	---	---		0.15	[-0.22	0.53]
	Education ≥ DCS	---	---		0.09	[-0.33	0.50]
	LOR: 1-5 years	---	---		0.07	[-0.35	0.49]
	Area SED	---	---		-0.01	[-0.21	0.19]
	Population density	---	---		-0.01	[-0.07	0.05]
Within-class	Time-varying	B	[95%	CI]	B	[95%	CI]
SLDS (*t* = T1)	Physical health	3.27**	[2.52	4.03]	3.77**	[2.93	4.61]
	Log_e H'hold income	1.60**	[0.67	2.53]	2.34**	[1.17	3.50]
	Married/Cohabiting	1.72*	[0.38	3.06]	2.08**	[0.55	3.61]
	Unemployed (1 yr)	---	---		-0.20	[-1.81	1.40]
	Season (cold)	-1.06*	[-2.04	-0.08]	-1.13^	[-2.39	0.13]
SLDS (*t* = T2)	Physical health	3.09**	[2.43	3.76]	3.60**	[2.89	4.30]
	Log_e H'hold income	0.92*	[0.10	1.74]	1.47**	[0.56	2.37]
	Married/Cohabiting	1.16^	[-0.08	2.41]	1.66*	[0.33	2.99]
	Unemployed (1 yr)	---	---		-1.40	[-2.68	-0.12]
	Season (cold)	-0.10	[-0.89	0.69]	0.15^	[-0.66	0.96]
SLDS (*t* = T3)	Physical health	3.35**	[2.73	3.97]	3.82**	[3.13	4.52]
	Log_e H'hold income	1.44*	[0.59	2.29]	2.04**	[1.05	3.04]
	Married/Cohabiting	1.30^	[-0.05	2.66]	1.85*	[0.36	3.35]
	Unemployed (1 yr)	---	---		-1.26	[-2.84	0.31]
	Season (cold)	-0.46	[-1.50	0.58]	-0.59	[-1.77	0.59]
Wald tests		Stat=4.86, df=6, p=0.56				N/A	

SLDS = Reduced Satisfaction with Life Domains Scale (total score). GMM = growth mixture model. LGCM = latent growth curve model. OR = odds ratio relative to membership in the healthful (high-stable) class. B = unstandardized regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. Baseline predictors entered at T1 values. Time-varying predictors entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion; BIC = Bayesian Information Criterion. N/A indicates wald test is not applicable because variables are being added to the model (not removed). ***^p≤0.10 *p≤0.05 **p≤0.01***

3.3 Cross-classification agreement between models of psychological distress and life satisfaction

Given the conceptual similarities in the number of classes and trajectory shapes ('healthful', 'worsening', 'chronic') implied by the GMMs of psychological distress and life satisfaction a significant level of cross-classification agreement might be expected between these models (See Figure 22 and Figure 23, p.176). This section examines the association between trajectories of each outcome using an unconditional parallel process GMM to estimate the joint probability distribution of class membership across the two sets of growth mixtures (Muthén and Muthén, 2000). This approach treats changes in psychological distress and life satisfaction as distinct temporal processes that are modelled concurrently in order to estimate the joint probability that an individual belongs to each possible combination of classes (3 K10 classes x 3 SLDS classes = 9 possible combinations) across the two outcomes. Importantly, analysing joint model-based probabilities (rather than indirectly assessing cross-classification agreement by first assigning individuals to their 'most likely' class under each model) helps to temper the extent to which classification uncertainty appears as strong misalignment outcomes. This is particularly relevant to 'borderline' cases that may exhibit similar probabilities of belonging to two different classes.

Importantly, the direct analysis of joint model-based probabilities precludes the attribution of classification disagreement to uncertainty in determining the 'most likely' class assignments, based on maximum posterior probabilities, for each outcome separately. Table 33 presents estimated marginal and conditional probabilities from the parallel process GMM. Conditional probabilities reflect the relationship between life satisfaction and psychological distress class membership; specifically, they convey the estimated probabilities of membership in the various K10 classes, given SLDS class membership. High diagonal values indicate a high probability of membership in the 'complementary' class and thus a high level of cross-classification agreement. For instance, a person belonging to the chronic low-satisfaction class has a 0.92 probability of also belonging to the chronic high-distress class.

The total estimated probability of belonging to any two 'complementary' classes (i.e. healthful SLDS/healthful K10, worsening SLDS/worsening K10 or chronic low SLDS/chronic high K10) was 0.68. In other words, on average, approximately twice as many individuals follow analogous trajectories of psychological distress and life satisfaction during a four-year

period than belong to discordant classes. A chi-square test of independence of the 3x3 cross-classification table rejected the null hypothesis that agreement between the models was attributable to random chance ($\chi 2$=500.6, df=4, p<0.001).

Table 33: Row-wise conditional probabilities of membership in each psychological distress trajectory class (columns) given membership in a particular life satisfaction trajectory class (rows).

		Conditional probabilities given SLDS class		
		Psychological distress (K10) class		
Life satisfaction (SLDS) class	*SLDS class probability*	Healthful	Worsening	Chronic high-distress
Healthful	*.75*	**.64**	.23	.13
Worsening	*.10*	.00	**.66**	.34
Chronic low-satisfaction	*.15*	.00	.08	**.92**
K10 class probability		*.48*	*.25*	*.27*

Membership in one of the adverse (worsening or chronic low-satisfaction) SLDS classes essentially precluded membership in the healthful K10 class, while significantly increasing the likelihood of belonging to the complementary K10 class. Odds ratios (OR) were computed to compare the likelihood of belonging to a particular K10 class among members of the complementary SLDS class, versus members of all other SLDS classes. Compared with other individuals, members of the worsening life satisfaction class were 7 times more likely to belong to the worsening distress class (OR=7.04, 95% CI 4.49 to 11.04; $\chi 2$=89.1, df=1, p<0.001) and members of the chronic low-satisfaction class were 61 times more likely than others to belong to the chronic high-distress class (OR=60.6, 95% CI 32.1 to 114.50; $\chi 2$=347.8, df=1, p<0.001).

These findings point to a strong association between concurrent patterns of psychological distress and life satisfaction. There were, however, some notable exceptions. First, it was estimated that approximately one-quarter of the members of the healthful SLDS class also belonged to the worsening K10 class (conditional probability = 0.23). Second, it was estimated that one-third of the members of the worsening SLDS class also belonged to the chronic K10 class (conditional probability = 0.34). On average, one in five individuals were partitioned into either of these class combinations (total probability = 0.21). Conditional probabilities for these pairings were roughly equivalent to the marginal probabilities of membership in the respective K10 classes, indicating that membership in the healthful (or worsening) SLDS class does little to discriminate membership in the worsening (or chronic) K10 class.

Indeed, whereas membership in the healthful SLDS class greatly decreased the odds of membership in the chronic K10 class (OR=0.07, 95% CI 0.05 to 0.10; $\chi 2$=276.7, df=1, p<0.001), its association with membership in the worsening K10 class was much weaker (OR=0.65, 95% CI 0.47 to 0.90; $\chi 2$=6.60, df=1, p=0.010). More strikingly, belonging to the worsening SLDS class essentially precluded membership in the healthful K10 class, but its association with membership in the chronic K10 class was statistically non-significant (OR=1.56, 95% CI 1.00 to 2.44; $\chi 2$=3.92, df=1, p=0.522). Altogether, the evidence suggests that these discordant pairings (healthful satisfaction and worsening distress; or worsening satisfaction and chronic high-distress) were not particularly unusual.

4 Summary of results

This chapter has demonstrated the application of growth mixture modelling to identify distinct intra-individual trajectories of change in positive and negative dimensions of mental health, within a community-based sample of persons aged 15 to 69 at commencement of the study. The findings supported the existence of multiple subpopulations of participants that differed according to the average course of changes in life satisfaction or psychological distress over an approximate four-year period. Taking into account relative statistical fit and the substantive utility of the GMM solutions, a three-class solution was identified as the optimal means of summarising observed heterogeneity in trajectories of each outcome. Each model featured three broadly analogous trajectory types, comprising a ‘healthful’ class with initially good, stable mental health; a class with initially good but worsening mental health (the ‘worsening’ class); and a class with initially poor mental health (the ‘chronic’ class). In both models, conditional on covariates, the stable and worsening classes featured roughly equivalent trajectory intercept parameters and differed primarily in relation to the rate of change in the outcome. Prediction of the relative odds of membership in these classes is therefore of particular interest, as it clearly reflects a differential propensity to experience deteriorating mental health. Predicting membership in the chronic class, on the other hand, is similar to predicting a cross-sectional effect because this class differed primarily according to initial standing on the outcome.

A number of sociodemographic factors, tested jointly, were associated with between and/or within-class variability in trajectories of each outcome. In the psychological distress model, male gender and a higher level of education at T1 were associated with decreased odds of membership in the worsening class, relative to the healthful class. Greater socioeconomic deprivation in the local residential area, on the other hand, was associated with significantly higher relative odds of belonging to the worsening class. A similar trend was evident in the life satisfaction model, where area socioeconomic deprivation was the only notable predictor of membership in the worsening class. However, the coefficient was marginally statistically non-significant, perhaps owing to the small size of this class. Accounting for the variation in trajectories attributable to class membership, notable within-class effects included an inverse age gradient in initial levels of psychological distress (K10 intercepts). Better self-rated physical health and higher income were consistently associated with better outcomes at contemporaneous (time-specific) occasions of measurement in both models. Being without employment was positively related to levels of psychological distress only, while being married or in a common law relationship was positively related to levels of life satisfaction only.

These associations are consistent with the findings of previous high quality studies, which have demonstrated that women report substantially higher levels of psychological distress than do men (Turner and Marino, 1994, Mirowsky and Ross, 1995); younger people report higher levels of distress than do older people[86] (Turner and Marino, 1994, Andrews et al., 1999, Mirowsky and Ross, 2010); and the married, on average, report higher levels of life satisfaction (Ambrey and Fleming, 2013), happiness (Gove et al., 1983), and total emotional wellbeing than do the unmarried (Westerhof and Keyes, 2010). Markers of socio-economic status including education, income, and employment, have consistently been associated with lower risk of common mental disorder (Fryers et al., 2003) and psychological distress (Gadalla, 2009). Self-rated health has been associated with a greater likelihood of 'complete' mental health, reflecting the simultaneous absence of mental illness and presence of high levels of positive emotional, social, and psychological wellbeing ('flourishing') (Westerhof and Keyes, 2010). Physical health has also been associated with psychological distress

[86] With the possible exception of the elderly, who were not included in the sample for this research (Andrews et al., 1999, Mirowsky and Ross, 2010).

(Gadalla, 2009) and life satisfaction (Ambrey and Fleming, 2013) as distinct dimensions of mental health. Finally, a number of studies indicate that residential area socioeconomic deprivation exerts a deleterious effect on mental health independently of individual socioeconomic circumstances (Truong and Ma, 2006, Kim, 2008, Mair et al., 2008, Blair et al., 2014).

Latent growth curve models applied to the same data failed to identify prospective associations (i.e. associations with variation in trajectory slopes) that were evident in the GMMs. Although global fit of the LGCMs was acceptable, the relative improvement to model fit with the addition of multiple subpopulations was striking. For instance, approximate Bayes factors suggested that the final unconditional GMMs were each at least 10^{48} times more likely to be the correct model than the corresponding LGCM. It is noteworthy that the alternative modelling approaches returned largely analogous results pertaining to prediction of trajectory intercepts and occasion-specific values of the outcomes. Thus, while LGCMs were proficient in explaining cross-sectional inter-individual variation in the level of psychological distress or life satisfaction, they failed to identify the key longitudinal change trends discussed above.

Despite the broad agreement in trajectory shapes implied by the life satisfaction and psychological distress GMMs, a cross-classification analysis estimated that only two-thirds of individuals belong to 'complementary' classes across models (e.g. chronic high-distress and chronic low-satisfaction). In absolute terms, the majority of cross-classification disagreement was attributable to temporal stability in the measures of life satisfaction; whereas the healthful SLDS class comprised over three-quarters of the sample, the healthful K10 class comprised only half. Evidently, many participants reporting high and stable levels of life satisfaction did not report similar stability in the level of psychological distress throughout the same four-year period. Looking within the life satisfaction classes, the most prominent cases of classification discordance arose between the healthful life satisfaction/worsening distress classes and worsening life satisfaction / chronic high-distress classes. Altogether, the findings are consistent with the two continua model of mental health introduced in Chapter 2 (Section 2.2, p.25), which describes positive and negative manifestations of mental health as distinct, yet interrelated, dimensions. I return to discuss this point in the final chapter of the thesis.

CHAPTER 5

Public open space ‘greenness’ as a buffer against the psychological harm of stressful life events (Study 1)

1 Research aims and conceptual model

The first substantive study undertaken for this thesis concerns whether residential public open space 'greenness' (*POS greenness*) buffers the psychological impact of stressful life events (SLE). Study 1 contributes to addressing the following research aims formulated in Chapter 2 (Table 2, p.71):

Research aims	
1	To evaluate whether POS 'greenness' exerts a protective 'stress-buffering' effect against the potential psychological harm of acutely stressful life events
4	To explore whether these findings differ according to the dimensionality (positive or negative) of the mental health outcome under consideration

The associations tested in Study 1 derive from the analytic model first depicted in Figure 3 (p.73) and reproduced in Figure 24 on the next page.

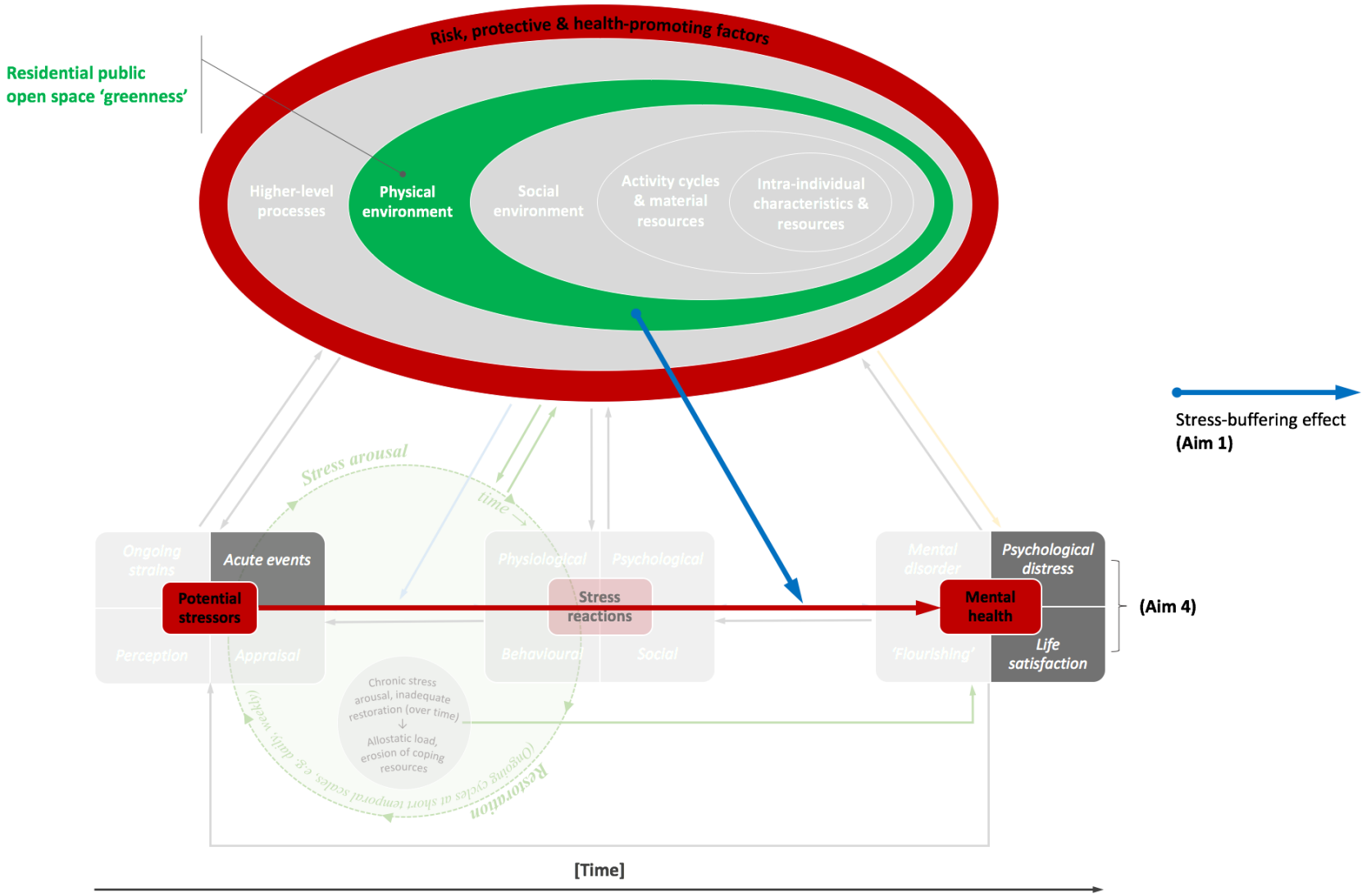


Figure 24: Analytic model to be tested in Study 1, depicting the proposed 'stress-buffering' effect of public open space 'greenness' in relation to the effects of stressful life events on positive and negative dimensions of mental health (arising from the conceptual framework presented in Chapter 2).

The analytic model presented above proposes that green POS in the residential environment might buffer against the negative psychological impact of stressful life events. This proposition reflects a moderation hypothesis, depicted in a causal model in Figure 25, suggesting that the magnitude of the relationship between one variable (*stressful life events;* Z) and another (*mental health;* Y) is conditional upon the value of a third variable (*POS greenness;* X). In this mechanism, X is not part of the causal sequence between Z and Y but affects the direction and/or strength of the relationship between those variables. The conditional nature of the relationship is reflected in a multiplicative (rather than purely additive) effect of X and Z in explaining the outcome (Wheaton, 1985).

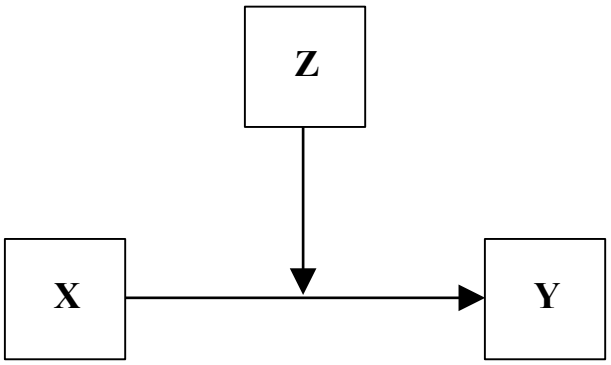


Figure 25: Causal model in which Z moderates the effect of X on Y

Mental health outcomes are assessed in relation to trajectories of intra-individual change in psychological distress or life satisfaction throughout an approximate four-year period. As detailed in Chapter 4, growth mixture models were used to define three broad classes of individuals based on distinctions in the nature of the change trajectory followed by members of each group. Because class membership succinctly summarises the range of distinct growth trajectories observed in the broader population, this is the primary outcome of interest in the present study. The moderating effect of *POS greenness* is tested in relation to the effects of stressful life events experienced between the first and last occasions of mental health measurement, such that any stress-buffering effect is presumed to unfold more or less simultaneously with the occurrence of SLE exposure. The specifics of this approach are detailed below.

2 Data analysis

Study 1 utilises individual-level data obtained from a geographically defined sample of 929 adults living in the ZEPSOM epidemiological catchment area of Montréal, Canada. This section presents a brief summary of the research method specific to the present study. A detailed methodological statement, including a description of the setting, context, measures and analytic approach for this research, was presented in Chapters 3 and 4.

The Kessler Psychological Distress Scale (K10), a reduced form of the Satisfaction with Life Domains Scale (SLDS), and a 22-item inventory of past-year stressful life events (SLE) were administered to ZEPSOM participants on three occasions (T1-T3) spaced approximately two years apart. Linear trajectories of psychological distress and life satisfaction from T1 to T3 were modelled separately, each using a three-class growth mixture model (GMM) to distinguish probabilistically between individuals following a healthful, worsening, or chronically poor course of mental health throughout this period (Chapter 4). With respect to each outcome, membership in the longitudinal trajectory classes reflects:

- *Healthful:* a low and stable level of distress / a high and stable level of satisfaction;
- *Worsening:* an initially low but increasing level of distress / an initially high but declining level of satisfaction;
- *Chronically poor:* a persistently elevated level of distress / a persistently low level of satisfaction.

As detailed in Chapter 3 (Section 6.5, p.131) past-year SLE reported at T2 and T3 were weighted by severity and summed to reflect 'new' life stressors arising after the first occasion of mental health measurement. This measure was added to the GMM as a predictor of class membership, in order to estimate the effects of accumulated SLE on trajectories of mental health while controlling for prior values of the outcome (i.e. mental health at T1). In this sense, a positive association between SLE and membership in the 'worsening' class (relative to the 'healthful' class) would be plausible, given the similarities in initial standing between these classes. To control for any lagged effects of SLE experienced prior to the first occasion of mental health measurement, particularly in relation to initial values of distress or life satisfaction, past-year SLE reported at T1 were also allowed to predict class membership.

Due to the strong aetiologic links between SLE and mental health, I then assessed whether improvements to model fit would be achieved by further allowing SLE to predict within-class trajectory variation. Specifically, SLE reported at T1 were permitted to directly influence trajectory intercepts, while SLE reported at T2 and T3 were permitted to directly influence trajectory slopes. These direct effects noticeably improved the fit of the psychological distress model (BIC difference = 7.3) but not the life satisfaction model (BIC difference = 0.82). Including direct effects in the life satisfaction model also appeared to decrease the precision of estimated trajectories in the non-healthful classes, particularly threatening the certainty with which the 'worsening' class could be differentiated substantively from the 'healthful' class. For this reason, direct effects were only retained in the psychological distress model.

The next stage of the analysis sought to determine whether *POS greenness* moderates the association between SLE and trajectories of psychological distress or life satisfaction. Egocentric neighbourhoods were defined by 500m and 1000m road network buffers around the individual's place of residence at T1, within which objective measures of the total proportion, size, and 'greenness' of POS were derived in a geographic information system (Chapter 3, Section 6.1). The final sample was restricted to individuals who did not move further than 500 meters from this location during the follow-up period, such that presiding characteristics of residential POS at T1 may reasonably be assumed to prevail for the total duration of the study (Chapter 3, Section 3.5). For each spatial scale, measures of the three POS characteristics and a multiplicative interaction term between *POS greenness* (Z) and the measure of 'new' SLE reported at T2 and T3 (X) were added to the GMMs as predictors of class membership. A significant interaction term (XZ) is indicative, then, of moderation by *POS greenness* of the effect of SLE on mental health (Wheaton, 1985, Baron and Kenny, 1986). Specifically, a negative interaction (OR < 1) would indicate a stress-buffering effect whereby *POS greenness* attenuates the association between SLE and membership in one of the adverse mental health trajectory classes (worsening or chronic) relative to the healthful class. A positive interaction (OR > 1) would indicate stress-exacerbating effects whereby *POS greenness* compounds the association between SLE and one of the adverse mental health classes (worsening or chronic) relative to the healthful class. The constitutive terms are also interpretable but must be understood within the context of the interaction model; both SLE and *POS greenness* were centred at their sample means, such that the main effects of POS reflect the influence of that attribute at mean levels of SLE, and vice versa (Brambor et al., 2006).

All analyses controlled for individual- and area-level covariates in accordance with the final conditional GMMs presented in Chapter 4. Standard errors were adjusted for spatial clustering of participants (n=929) within census tracts (n=74) using a sandwich estimator. Coefficients were considered statistically significant at alpha=0.05.

3 Results

3.1 Associations between stressful life events and trajectories of psychological distress and life satisfaction

Table 34 presents associations of between- and within-class variation in trajectories of psychological distress and life satisfaction with stressful life events experienced prior to (SLE(T1)) and during (SLE(T2+T3)) the period of mental health measurement. As described in Chapter 4, between-class effects describe how a predictor influences the trajectory of an outcome indirectly, via its effect on latent class membership. These effects were estimated using multinomial logistic regression with the healthful class as the reference group; odds ratios (OR) therefore reflect the nature of change in the odds of membership in class *k*, relative to the healthful class, for a one-unit increase in weighted SLE exposure. Within-class effects refer to the partial or residual effect of a predictor on the growth factors, conditional upon class membership; these effects reflect the average linear change in initial status (intercept) or the rate of change (slope) within a given trajectory class, for a one-unit increase in weighted SLE exposure.

Table 34: Associations between stressful life events (SLE) and trajectories of psychological distress and life satisfaction, accounting for socio-demographic characteristics

		Psychological Distress			Life satisfaction		
Between-class	Baseline predictors	OR	[95% CI]		OR	[95% CI]	
Worsening	SLE (T1)	0.89	[0.75	1.06]	1.32**	[1.10	1.58]
class	SLE (T2+T3)	1.27**	[1.11	1.45]	1.41**	[1.23	1.61]
(K10 28%)	Age 15-35	1.27	[0.61	2.65]	0.31	[0.06	1.69]
(SLDS 14%)	Age 51+	0.91	[0.46	1.81]	0.53	[0.14	1.96]
	Male gender	0.51*	[0.27	0.98]	0.76	[0.25	2.30]
	Education ≥ DCS	0.55*	[0.31	0.97]	---	---	
	Area SED	1.91**	[1.26	2.91]	1.74	[0.72	4.20]
	Population Density	1.04	[0.96	1.12]	---	---	
Chronic class	SLE (T1)	1.07	[0.94	1.21]	1.24*	[1.04	1.48]
(K10 22%)	SLE (T2+T3)	1.39**	[1.25	1.56]	1.38**	[1.22	1.57]
(SLDS 11%)	Age 15-35	1.02	[0.50	2.10]	0.98	[0.33	2.89]
	Age 51+	0.82	[0.48	1.41]	1.28	[0.46	3.54]
	Male	0.53*	[0.31	0.91]	0.88	[0.45	1.72]
	Education ≥ DCS	0.38**	[0.20	0.71]	---	---	
	Area SED	1.47*	[1.03	2.10]	1.28	[0.83	1.98]
	Population Density	1.08*	[1.01	1.15]	---	---	
Within-class	Baseline predictors	B	[95% CI]		B	[95% CI]	
Intercept	SLE (T1)	0.17*	[0.03	0.31]	---	---	
	Age 15-35	0.40	[-0.12	0.91]	1.92	[0.07	3.77]
	Age 51+	-0.53^	[-1.07	0.01]	2.30	[0.63	3.97]
	Area SED	-0.38**	[-0.66	-0.10]	---	---	
Slope	SLE (T2+T3)	0.04*	[0.00	0.08]	---	---	
Within-class	Time-varying predictors	B	[95% CI]		B	[95% CI]	
(*t* = T1)	Physical health	-0.90**	[-1.13	-0.66]	3.16**	[2.47	3.85]
	Log_e H'hold income	-0.37^	[-0.80	0.06]	1.44**	[0.52	2.36]
	Married/Cohabiting	---	---		1.44*	[0.09	2.78]
	Unemployed (1 year)	0.21	[-0.47	0.90]	---	---	
	Season of interview	---	---		-1.10*	[-2.06	-0.13]
(*t* = T2)	Physical health	-0.97**	[-1.26	-0.67]	2.99**	[2.34	3.64]
	Log_e H'hold income	-0.22	[-0.60	0.17]	0.70	[-0.14	1.54]
	Married/Cohabiting	---	---		0.91	[-0.30	2.13]
	Unemployed (1 year)	0.39	[-0.23	1.01]	---	---	
	Season of interview	---	---		-0.13	[-0.92	0.67]
(*t* = T3)	Physical health	-0.98**	[-1.25	-0.71]	3.22**	[2.61	3.83]
	Log_e H'hold income	-0.09	[-0.45	0.27]	1.08*	[0.24	1.92]
	Married/Cohabiting	---	---		1.06	[-0.33	2.45]
	Unemployed (1 year)	0.91**	[0.30	1.52]	---	---	
	Season of interview	---	---	---	-0.37	[-1.37	0.62]

Note. OR = odds ratio relative to membership in the healthful (low-stable psychological distress or high-stable life satisfaction) class. Estimate = unstandardised regression coefficient. [95% CI] = 95% confidence interval around odds ratio/estimate. N/A = not applicable. Baseline predictors are entered at T1 values, except SLE(T2+T3) which reflects stressful life events experienced after T1. Time-varying predictors are entered at Time t values. Between-class effects = predictors of class membership. Within-class effects = predictors of variation in growth parameters or time-specific outcomes, conditional upon class membership. DCS = Diploma of College Studies; LOR = length of residence at baseline address; Area SED = area-level (census tract) socioeconomic deprivation; Log(e) H'hold income = natural logarithm of household income. (%) = class proportion. ***^p≤0.10 *p≤0.05 **p≤0.01.***

Reporting a greater number of acute stressors during the mental health measurement period was associated with adverse outcomes across both negative and positive dimensions of mental health. In relation to psychological distress, each additional SLE reported at T2 or T3 increased the odds of membership in the worsening class by 27% (OR=1.27, 95% CI [1.11,1.45], p<0.0001) and the odds of membership in the chronic high-distress class by 39% (OR=1.39, 95% CI [1.25,1.56], p<0.0001) relative to the healthful distress class. Within classes, initial values of distress were positively associated with SLE reported to have been experienced prior to T1 (B=0.172, 95% CI [0.03, 0.31], p=0.015) and the rate of growth in distress was positively associated with SLE experienced during the measurement period (B=0.043, 95% CI [0.00, 0.08], p=0.028).

In relation to life satisfaction, each additional SLE reported at T2 or T3 increased the odds of membership in the worsening class by 41% (OR=1.41, 95% CI [1.23, 1.61], p<0.0001) and the odds of membership in the chronic low-satisfaction class by 38% (OR=1.38, 95% CI [1.22-1.57], p<0.0001) relative to the healthful class. In addition, whereas SLE reported to have been experienced prior to T1 did not significantly influence trajectory class membership in the psychological distress model, these SLE did exert a substantial effect on trajectories of life satisfaction. Specifically, each additional SLE reported for the twelve months prior to the first measurement occasion was associated with a 32% increase in the odds of membership in the worsening life satisfaction class (OR=1.32, 95% CI [1.10, 1.58], p=0.003) and a 24% increase in the odds of membership in the chronic low-satisfaction class (OR=1.24, 95% CI [1.04, 1.48], p=0.018) relative to the healthful class.

3.2 *POS greenness* as a moderator of the association between stressful life events and mental health

Results in the previous section indicate that, across both dimensions of mental health, exposure to a greater number of acute stressors during the measurement period increased the likelihood of membership in the adverse trajectory classes. This section explores whether those relationships were moderated by POS greenness; specifically, whether POS greenness buffered the adverse effects of stressors experienced after the first measurement occasion. Table 35 (p.202) presents the interaction of POS greenness with 'new' SLE in predicting trajectory class membership. These analyses accounted for POS size and availability as well as individual and area-level covariates, in accordance with the models presented in Table 34.

Statistically significant interaction terms indicate that POS greenness did buffer the detrimental effects of SLE, but only in relation to membership in the worsening psychological distress class. Specifically, the association between 'new' SLE and membership in the worsening distress class was attenuated at higher levels of POS Greenness, both within 1000m of the home (OR for interaction = 0.74, 95% CI [0.58, 0.96], p=0.021) and 500m of the home (OR for interaction = 0.80, 95% CI [0.66, 0.97], p=0.025). POS Greenness did not statistically significantly alter the associations of 'new' SLE with membership in the chronic high-distress class, the worsening life satisfaction class, or the chronic low-satisfaction class, at either spatial scale.

Figure 26 (p.203) depicts the marginal effect of 'new' SLE on the odds of membership in the worsening psychological distress class, relative to the healthful class, at high (1SD above the mean) versus low (1SD below the mean) values of POS greenness. This figure illustrates how, among individuals with initially low levels of psychological distress, POS greenness serves to attenuate the likelihood that SLE will result in worsening symptoms over time. At low levels of greenness, the relative odds of membership in the worsening distress class grows exponentially with greater numbers of stressful events; at high levels of greenness, the association was almost non-existent. The figure also serves to illustrate the stress exposure conditions under which POS greenness is protective against rising psychological distress. With limited exposure to acute stressors (e.g. two stressful events, or fewer, in a two-year period) there appears to be little distinction in mental health outcomes between the low and high *POS greenness* conditions. In relation to the area within 1000m of the home, high POS greenness was associated with statistically significantly better outcomes for individuals experiencing three events or more, in a two-year period. Within 500m of the home, the effects of high *POS* greenness were more dependent on exposure to stress, with differences between the groups becoming pronounced beyond the mean level of SLE exposure (roughly five or more events in a two-year period)[87].

[87] Although 95% confidence intervals for the high and low *POS greenness* conditions overlap in the 500m model, this does not imply the absence of a statistically significant difference between the groups. A requirement for non-overlapping confidence intervals is a conservative test of significance, with indications that intervals can overlap by as much as half the length of one CI arm before a corresponding p-value for the difference becomes

Table 35: Main and interactive effects of stressful life events and public open space greenness on trajectories of psychological distress and life satisfaction: estimated odds ratios of membership in the adverse mental health classes (relative to the healthful class) adjusted for physical health, socio-demographic covariates, POS availability and POS size

	Psychological distress						Life satisfaction					
	Worsening class (28%)			High distress class (22%)			Worsening class (14%)			Low satisfaction class (11%)		
1000m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness [Z]	0.33**	[0.14	0.76]	1.14	[0.73	1.76]	0.73	[0.20	2.67]	0.87	[0.35	2.13]
Stressful Life Events (T2+T3) [X]	1.18**	[1.05	1.33]	1.38**	[1.25	1.54]	1.47**	[1.24	1.73]	1.37**	[1.19	1.58]
POS Greenness x SLE (T2+T3) [XZ]	0.74*	[0.58	0.96]	0.94	[0.77	1.16]	1.21	[0.87	1.70]	0.99	[0.74	1.33]
POS Availability	1.05	[0.99	1.12]	1.04	[0.99	1.08]	0.98	[0.85	1.12]	1.01	[0.94	1.08]
POS Size (median >9.31ha)[#]	1.24	[0.63	2.44]	0.97	[0.57	1.63]	0.62	[0.19	2.04]	1.08	[0.44	2.69]
500m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness [Z]	0.63	[0.29	1.34]	0.98	[0.65	1.50]	0.88	[0.38	2.02]	0.34	[0.09	1.35]
Stressful Life Events (T2+T3) [X]	1.20**	[1.05	1.36]	1.40**	[1.25	1.56]	1.45**	[1.25	1.69]	1.42**	[1.24	1.64]
POS Greenness x SLE (T2+T3) [XZ]	0.80*	[0.66	0.97]	0.93	[0.79	1.09]	1.02	[0.80	1.29]	1.04	[0.81	1.34]
POS Availability	0.99	[0.93	1.05]	1.00	[0.96	1.05]	0.96	[0.87	1.06]	1.01	[0.95	1.07]
POS Size (median >12.4ha)[#]	0.82	[0.40	1.70]	0.83	[0.47	1.45]	1.96	[0.57	6.73]	3.02^	[0.94	9.68]

 # = binary variable. OR = odds ratio; reference group is the healthful (low-stable distress or high-stable satisfaction) class. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median. [95% CI] = 95% confidence interval around odds ratio/estimate. All models are adjusted for covariates according to the base model presented in Table 34.
^p≤0.10 *p≤0.05 **p≤0.01.

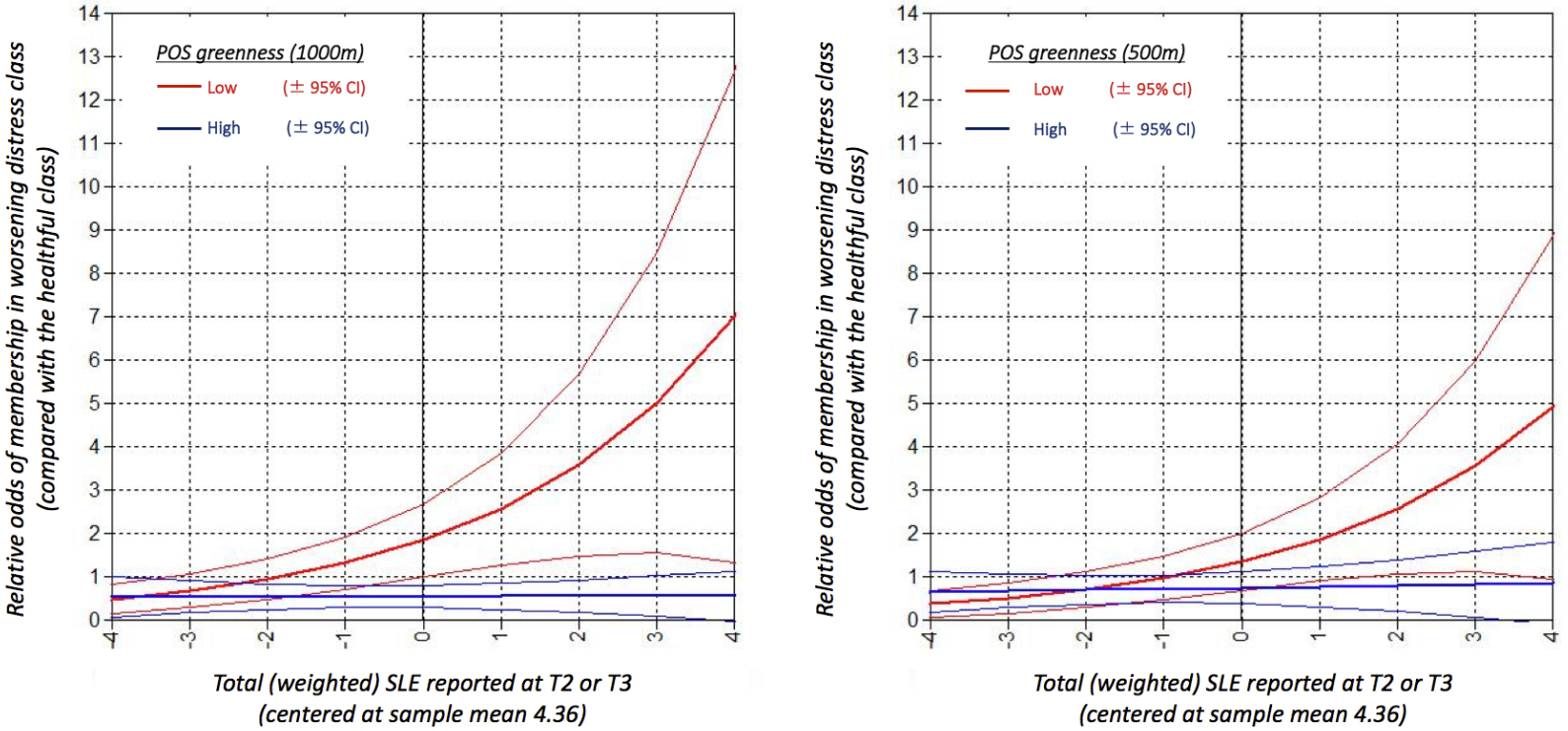


Figure 26: Relative odds of membership in the worsening psychological distress class with increasing numbers of stressful life events at high (1SD above mean) versus low (1SD below mean) levels of POS greenness within 1000m and 500m of the home.

4 Summary of results

This chapter assessed whether the characteristics of residentially accessible public open space can buffer the psychological harm of acute stressors. Specifically, it tested whether the presence of POS that are 'greener', on average, within 500m or 1000m of the home influenced the associations between accumulated stressful life events and four-year trajectories of psychological distress or life satisfaction. Analyses controlled for the total availability and median size of POS in these areas, as well as a range of individual- and area-level determinants of mental health.

Experiencing a greater number of stressful life events after baseline was associated with a greater likelihood of following a worsening or chronically poor trajectory, relative to a stable trajectory of good mental health, for both outcomes of interest. Living among greener POS statistically significantly attenuated the association of SLE with worsening trajectories of psychological distress, but did not moderate the association with chronically elevated trajectories of distress; nor did it moderate associations with the worsening or chronically low trajectories of life satisfaction. Results were consistent across both spatial scales, although POS greenness within 1000m of the home appeared to have greater potency in buffering SLE than that within 500m.

CHAPTER 6

Main effects of public open space 'greenness' on mental health and mediation by psychosocial resources (Study 2)

1 Research aims and conceptual model

The second empirical study undertaken for this thesis assesses whether residential public open space 'greenness' exerts a main effect on mental health independently of exposure to stressful life events. The study also assesses whether psychosocial resources at various levels of organisation – such as the ability to cope with stress, the availability of social support, or the extent to which an individual integrates socially into the residential neighbourhood – comprise part of an indirect causal sequence between POS 'greenness' and mental health. Study 2 contributes to addressing the following research aims formulated in Chapter 2 (Table 2, p.71):

Research aims	
2	To evaluate whether POS 'greenness' exerts a 'main' salutogenic effect independently of exposure to acutely stressful events
3	To evaluate the intermediary role of psychosocial resources at three levels – within the individual, within the neighbourhood social environment, and within broader social networks – in explaining prospective associations between POS 'greenness' and mental health
4	To explore whether these findings differ according to the dimensionality (positive or negative) of the mental health outcome under consideration

The associations tested in Study 2 derive from the conceptual model first depicted in Figure 4 (p.76) and reproduced in Figure 27 on the next page.

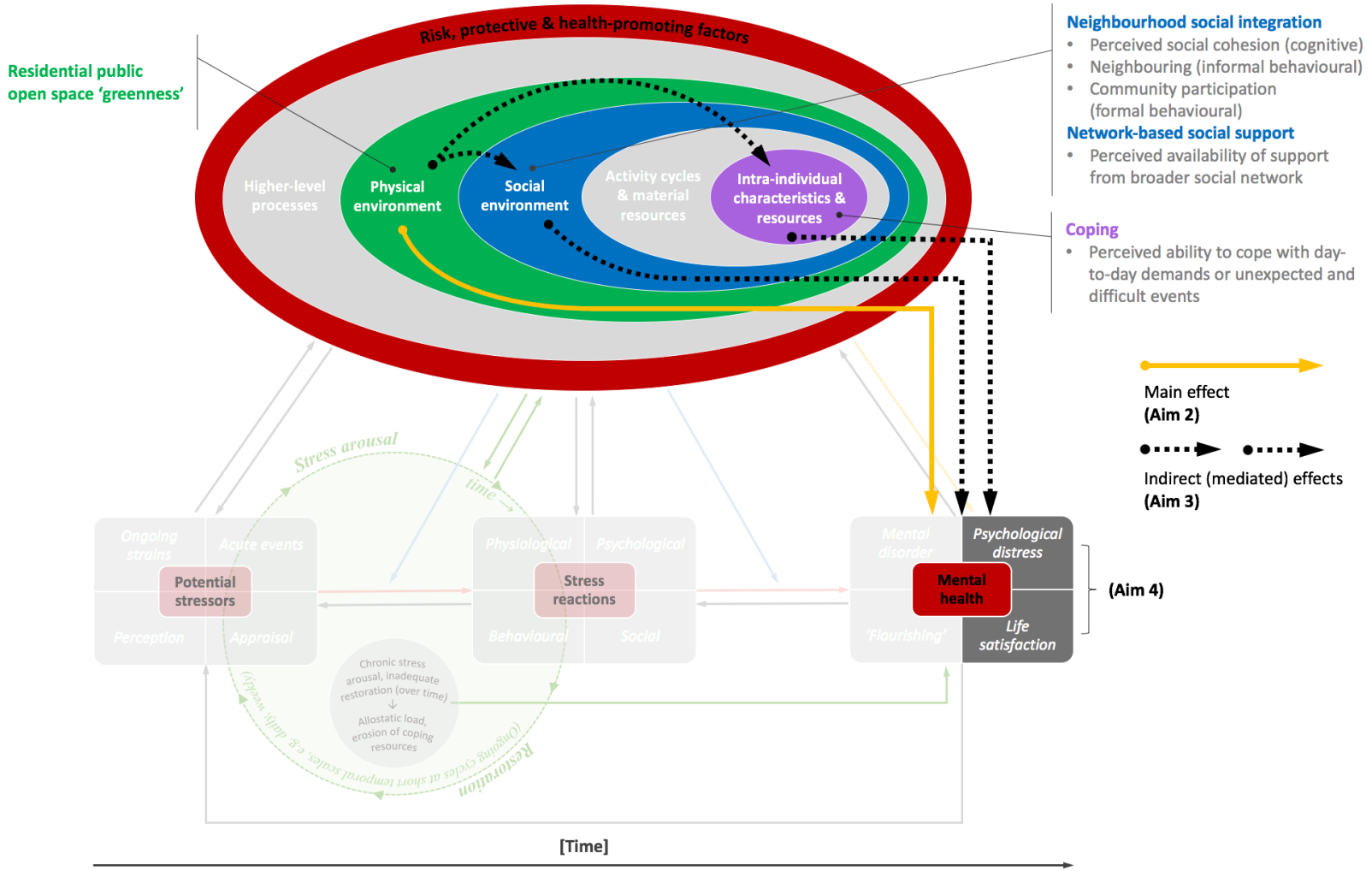


Figure 27: Analytic model to be tested in Study 2, depicting the proposed 'main' effect of residential public open space 'greenness' on positive and negative dimensions of mental health, operating independently of exposure to acute stressors and mediated through the social environment and intra-personal resources, over time (arising from the conceptual framework presented in Chapter 2).

The analytic model proposes that the availability of greener POS in an individual's residential environment may enhance (a) their cognitive or behavioural integration into the local community, including (i) perceptions of social cohesion, (ii) neighbouring behaviour, or (iii) community participation; (b) their perceived availability of support from personal social networks; and/or (c) their perceived ability to cope with daily life stress. These factors (referred to collectively as *psychosocial resources* throughout this chapter) may, in turn, be protective of mental health.

Together, these propositions reflect a series of mediation hypotheses, each suggesting a chain of relations in which an intermediary variable (a *psychosocial resource;* M) transmits – wholly or partially – the effect of an independent variable (*POS greenness;* X) onto a dependent variable (Y) (MacKinnon et al., 2007). In this mechanism, M is part of an indirect causal sequence between X and Y. A causal model of this sequence is presented in Figure 28, where *c* represents the *total main effect* of X on mental health Y, *a* represents the effect of X on M, *b* represents the effect of M on Y, and *c'* represents the *direct main effect* (or the residual effect) of X on Y after accounting for its indirect effect via M (a*b).

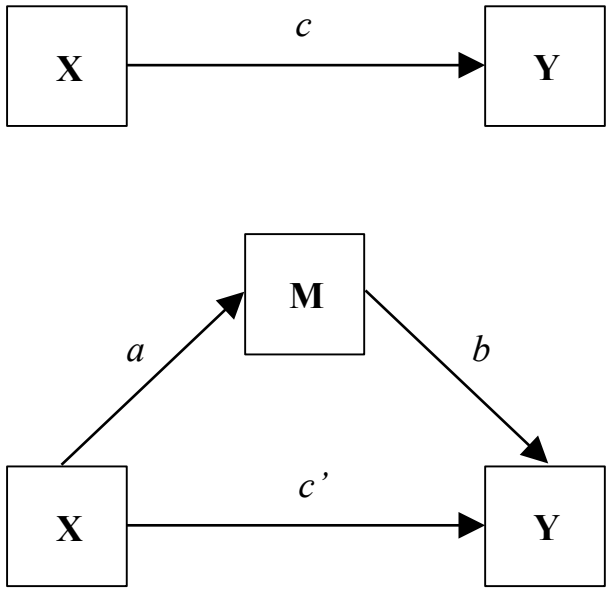


Figure 28: Causal model in which M mediates the effect of X on Y

Indirect effects of *POS greenness* via the various psychosocial resources were tested separately for each proposed intermediary variable. Both the independent variable (*POS greenness*) and the intermediary variables (*psychosocial resources*) were measured at the first wave (T1) of the ZEPSOM study. As detailed in Chapter 4, prospective changes in *mental health* were summarised using growth mixture models to describe inter-individual variation in trajectories of psychological distress and life satisfaction between the first and third waves of the ZEPSOM study (T1 to T3) while controlling for a range of potential individual- and area-level confounders. Stressful life events (SLE), which were entered into those base covariate models in Chapter 5, were retained as covariates in the present study in order to assess the 'main' salutogenic effects of POS greenness and psychosocial resources (Wheaton, 1985). In other words, consistent with the research aims of this study, associations with mental health are interpreted as arising independently of the level of exposure to acute stressors.

In addition to their interpretational relevance, SLE exert a strong effect on latent class membership in both the psychological distress and life satisfaction models, substantially improving the overall fit of both models as well as the precision of individual classifications within them. Therefore, these variables also serve to enhance the substantive utility of distinctions in trajectory class membership as a dependent variable (Lubke and Muthén, 2007).

As in previous chapters, latent trajectory class membership was the primary outcome of interest in all models assessing the influence of a particular variable on mental health. This is a half-longitudinal mediation design in which X and M are measured contemporaneously (T1) and related longitudinally to prospective changes in Y (T1-T3). The imposition of a 12-month minimum period of residence at the T1 address should strengthen inference regarding the temporal order of effects between *POS Greenness* and *psychosocial* resources, by ensuring sufficient time for the former to exert an effect on the latter. The use of latent trajectory classes as an outcome is advantageous for the analysis of mediation processes in the context of individual development. As discussed in Chapter 4, this approach specifically assesses the relationship of predictors to inter-individual differences *in intra-individual change* over time, in contrast with longitudinal panel models that elucidate these mechanisms only in terms of changes in inter-individual standing on the variables of interest (Selig and Preacher, 2009).

2 Data analysis

Mediation of the relationship between POS greenness and mental health by a given psychosocial resource was assessed with reference to Baron and Kenny's (1986) conditions for mediation – although not all of the authors' criteria were deemed necessary, as detailed shortly – followed by a direct test of the mediated effect using the Monte Carlo Method for Assessing Mediation (MCMAM) (Selig and Preacher, 2008, Preacher and Selig, 2012). Baron and Kenny's criteria state that a variable functions as a mediator of the relationship between two variables when the following conditions are satisfied:

1. The independent variable (*POS greenness*) is significantly related to the proposed mediator (*psychosocial resources*) **(path $a \neq 0$)**;
2. The independent variable (*POS greenness*) is significantly related to the dependent variable (*mental health*) **(path $c \neq 0$)**;
3. The proposed mediator (*psychosocial resources*) is significantly related to the dependent variable (*mental health*) after accounting for the independent variable (*POS greenness*) **(path $b \neq 0$)**;
4. The relationship between the independent variable and the dependent variable is eliminated (i.e. no longer significant, reflecting full mediation) or weakened (partial mediation) after accounting for the proposed mediator **(path $c' <$ path c)**.

Associations between *POS greenness* and each measure of *psychosocial resources* (path a) were estimated cross-sectionally and adjusted for age, sex, physical health, education, income, marital status, employment status and length of residence, as well as socioeconomic deprivation and population density at the level of census tracts[88]. Logistic regression (*coping* and *community participation*) and censored normal regression (*neighbouring behaviour* and *social support*) were employed as required by the scale and distribution of each outcome (see Chapter 3, Sections 6.3 and 6.4).

Associations between *POS greenness* or *psychosocial* resources and *mental health* (paths b, c, and c') were estimated prospectively by adding the relevant variable as a predictor of latent trajectory class membership to the conditional GMMs presented in Table 34 (Chapter 5, p.199). These estimates were adjusted for age, sex, physical health and additional

[88] Season of interview was excluded from the models because it was not independently associated with any measure of psychosocial resources after accounting for other covariates.

sociodemographic covariates that exhibited an independent association with trajectories of mental health[89] (see Chapter 4, Section 3.2) as well as stressful life events in accordance with the models presented in Chapter 5 (Table 34, p.199). All paths were estimated at two spatial scales (comprising a 500m and 1000m buffer) and additionally adjusted for measures of total POS availability and POS size within these areas. Standard errors account for spatial clustering of participants (n=929) within census tracts (n=74) using a sandwich estimator. Coefficients were considered statistically significant at alpha=0.05.

Baron and Kenny's (1986) criteria constitute an *informal* test of mediation, because the existence of an indirect effect is inferred logically from a set of hypothesis tests that are jointly consistent with mediation. Although widely used, this 'causal steps' approach does not directly quantify or test the indirect effect. It is particularly susceptible to the influence of type II errors, requiring the rejection of three separate null hypotheses to (in Steps 1 to 3) to support mediation, and is consequently one of the lowest powered approaches for detecting indirect effects (Preacher and Hayes, 2004, MacKinnon et al., 2007, Hayes, 2009). In this respect, the requirement for a statistically significant total effect (path $c \neq 0$ in Step 2) is particularly problematic; it is entirely plausible for mediation to exist in the absence of a total effect due to imbalances in statistical power or inconsistency in the signs of direct and indirect effects (Cerin and MacKinnon, 2009, Rucker et al., 2011). For instance, a positive effect through one intermediary variable might counteract a negative effect through another, thereby nullifying the total effect of X on Y (MacKinnon et al., 2007, Hayes, 2009, Zhao et al., 2010).

For these reasons, Baron and Kenny's causal steps were supplemented with a *formal* test of the indirect effect if conditions 1 (path $a \neq 0$) and 3 (path $b \neq 0$) were satisfied:

5. Estimate the indirect effect of POS greenness on mental health via a given psychosocial resource and obtain a corresponding **asymmetric 95% confidence interval**.

[89] Models of psychological distress were adjusted for age, sex, physical health, education, income, employment status, as well as socioeconomic deprivation and population density at the level of census tracts; marital status, length of residence, and season of interview were not independently associated with trajectories of distress. Models of life satisfaction were adjusted for age, sex, physical health, income, marital status, season of interview, and census tract socioeconomic deprivation; education, employment status, length of residence and population density were not independently associated with trajectories of life satisfaction.

The formal test of mediation was performed regardless of whether a significant total effect was evident (condition 2, path *c*). This procedure expressly quantifies and tests the significance of the indirect effect as the product of its two constituent paths (*a*b*). Significance testing was performed using a non-parametric Monte Carlo procedure to empirically approximate the sampling distribution of the indirect effect, from which an asymmetric confidence interval (CI) was computed[90] (MacKinnon et al., 2007, Preacher and Hayes, 2008, Hayes, 2009).

Asymmetric CIs are known to provide better coverage of the true value of indirect effects, more accurate type I error rates, and greater statistical power than those based on the normal distribution[91] (MacKinnon et al., 2007, Hayes, 2009). In this instance, a Monte Carlo procedure was favoured over other alternatives (such as bootstrapping) because its sole reliance on summary data makes it highly advantageous in complex modelling scenarios (Preacher and Selig, 2012). A key assumption of this method is that the path *a* and *b* parameters are normally distributed, which should be approximately satisfied for categorical outcomes (such as class membership) if coefficients are entered in the log-odds scale (Bland and Altman, 2000). The procedure was implemented using Selig and Preacher's (2008) online MCMAM tool with 20,000 samples. Finally, to maintain consistency with prior reporting in the thesis, estimates of the indirect effect and CI bounds were exponentiated to the odds scale to reflect the odds of membership in a given trajectory class relative to the healthful class. Statistical significance of the indirect effect was satisfied if the 95% CI for the odds ratio did not include one (Cerin and MacKinnon, 2009).

---

[90] Using the point estimates and asymptotic standard errors for the path *a* and *b* parameters as inputs, this procedure simulates random draws from their joint distribution and computes the product of these values (*a*b*). This process is repeated many times, and the distribution of simulated *a*b* estimates is taken as an empirical approximation of the sampling distribution for the indirect effect.

[91] The product of two normal random variables is rarely itself normally distributed. Consequently, mediated effects are often asymmetrically distributed with excess skewness and kurtosis (Hayes, 2009). Confidence intervals and significance tests based on normal theory may therefore be inaccurate and misleading in this context. Symmetric confidence intervals that assume a normally distributed indirect effect tend to underestimate its magnitude, lying to the left of the true value for positive mediated effects and to the right for negative mediated effects (MacKinnon et al., 2007). By the same token, significance tests based on the normal distribution (e.g. the Sobel test or delta method) have been demonstrated to possess low power to detect mediated effects (MacKinnon et al., 2007). For these reasons, methodologists advocate testing the significance of indirect effects using non-parametric bootstrap or Monte Carlo methods (MacKinnon et al., 2007; Preacher & Hayes, 2008; Hayes, 2009; Preacher & Selig, 2012)

3 Results

3.1 Associations between POS greenness and psychosocial resources (*path a)*

Table 36 (p.215) presents results pertaining to associations between *POS greenness* and the five psychosocial resources tested in this research. Continuous outcomes (*social cohesion*, *neighbouring behaviour*, and *network-based social support*) were standardised to enable the meaningful comparison of effect sizes, such that regression coefficients reflect the change in standard-deviation units of the outcome for a one-unit change in the predictor[92]. Logit coefficients for binary outcomes (*community participation, coping*) were exponentiated to odds ratios to reflect the relative change in the odds of reporting greater community participation, or better coping ability, with a one-unit change in the predictor. The POS exposure variables were not standardised because they were initially scaled to have meaningful values, as described in Chapter 3.

Only social cohesion was significantly associated with POS greenness after adjusting for covariates. A one-unit increase in POS greenness within 1000m of the home was associated with a 0.29 standard deviation increase in social cohesion ($p<0.0001$, 95% CI [0.15, 0.43]), accounting for the total availability and size of POS within the area as well as age, sex, physical health, education, household income, marital status, employment status, length of residence, area socioeconomic deprivation and population density. POS greenness within 500m of the home was similarly associated with greater social cohesion, although the estimated effect was smaller in magnitude than that for the broader residential area ($B = 0.18$, $p=0.006$, 95% CI [0.05, 0.31]). There is arguably no need to adjust these analyses for multiple hypothesis testing, given the theoretically derived basis upon which these associations were selected for testing (Bland and Altman, 1995, Michels and Rosner, 1996). It is worth noting, however, that associations between POS greenness and social cohesion remained statistically significant both for the 1000m buffer (adjusted $p<0.0001$) and 500m buffer (adjusted $p=0.030$) after adjustment using Holm's (1979) procedure to retain a family-wise error rate of 0.05 across the five paths tested within each spatial scale (Aickin and Gensler, 1996).

[92] Although the distributions of neighbouring behaviour and social support were censored and consequently skewed, recall that these are modelled using a censored normal regression that assumes a latent normally-distributed variable underlying the observed data.

Table 36: Cross-sectional associations between *POS greenness* in a 500m and 1000m buffer and psychosocial resources measured at T1, adjusted for physical health, length of residence and socio-demographic covariates.

	Social cohesion			Neighbouring behaviour			Community participation[#]			Network-based social support			Coping[#]		
1000m buffer (n=929)	B	[95% CI]		B	[95% CI]		OR	[95% CI]		B	[95% CI]		OR	[95% CI]	
POS Greenness	0.29**	[0.15	0.43]	0.06	[-0.11	0.24]	0.90	[0.65	1.25]	0.09	[-0.05	0.22]	1.04	[0.77	1.39]
POS Availability	0.00	[-0.01	0.01]	0.00	[-0.01	0.01]	1.02	[0.99	1.05]	0.00	[-0.01	0.02]	0.99	[0.95	1.02]
POS Size (>9.31ha)[#]	-0.04	[-0.18	0.10]	-0.14^	[-0.29	0.02]	0.86	[0.62	1.21]	-0.06	[-0.21	0.10]	0.83	[0.60	1.15]
500m buffer (n=878)	B	[95% CI]		B	[95% CI]		OR	[95% CI]		B	[95% CI]		OR	[95% CI]	
POS Greenness	0.18**	[0.05	0.31]	-0.02	[-0.18	0.14]	0.87	[0.66	1.14]	0.08	[-0.04	0.20]	1.03	[0.75	1.41]
POS Availability	-0.01	[-0.02	0.00]	0.01	[-0.01	0.02]	1.02	[0.98	1.05]	-0.01	[-0.02	0.01]	0.99	[0.96	1.02]
POS Size (>12.4ha)[#]	-0.12^	[-0.26	0.02]	-0.12	[-0.28	0.04]	0.89	[0.62	1.28]	-0.08	[-0.21	0.06]	0.89	[0.59	1.35]

 # = binary variable. B = regression coefficient for standardised continuous outcomes. OR = odds ratio for binary outcomes; reference groups reflect the lowest levels of community participation (zero of four assessed behaviours) or coping (poor/fair/good ability to cope) resulting from approximate median splits of the original scales. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median. [95% CI] = 95% confidence interval around odds ratio/estimate. Models adjust for age, sex, self-rated physical health, education, household income, marital status, employment status, length of residence at the current address, area socioeconomic deprivation and population density. Season of interview was not significantly associated with any measures of psychosocial resources and was excluded from the models. ***^p≤0.10 *p≤0.05 **p≤0.01.***

Neighbouring behaviour, community participation, network-based social support, and coping were not associated with POS greenness at either spatial scale. Sensitivity analyses indicated that these null associations were unlikely to be an artefact of the manner in which the variables were scaled (Appendix 6.1)[93]. Because these measures failed to satisfy the first condition for mediation, the remainder of this chapter focuses exclusively on indirect effects of POS greenness via social cohesion.

Table 37: Standardised regression coefficients for the association between *POS greenness* and social cohesion

	Social cohesion (T1)				Social cohesion (T1)		
1000m buffer (n=929)	β	[95% CI]		500m buffer (n=878)	β	[95% CI]	
POS Greenness	0.16**	[0.08	0.24]	POS Greenness	0.12**	[0.03	0.20]
POS Availability	-0.01	[-0.06	0.04]	POS Availability	-0.05	[-0.11	0.01]
POS Size (med. >9.31ha)#	-0.04	[-0.18	0.10]	POS Size (med. >12.4ha)#	-0.12^	[-0.26	0.02]
Age 15-35#	0.01	[-0.16	0.18]	Age 15-35#	-0.01	[-0.18	0.15]
Age 51+#	0.07	[-0.09	0.23]	Age 51+#	0.09	[-0.08	0.25]
Male#	-0.14*	[-0.25	-0.03]	Male#	-0.16**	[-0.27	-0.05]
Physical health	0.12**	[0.06	0.17]	Physical health	0.10**	[0.05	0.16]
Education ≥ DCS#	0.14*	[0.01	0.26]	Education ≥ DCS#	0.13*	[0.01	0.26]
Loge Household income	0.07^	[0.00	0.15]	Log_e Household income	0.09*	[0.01	0.17]
Married/Cohabiting#	0.07	[-0.05	0.19]	Married/Cohabiting#	0.05	[-0.08	0.19]
Unemployed (1 year)#	-0.14	[-0.31	0.03]	Unemployed (1 year)#	-0.12	[-0.29	0.06]
Length residence: 1-5yr#	-0.10	[-0.24	0.04]	Length residence: 1-5yr#	-0.09	[-0.24	0.06]
Area SED	-0.15**	[-0.24	-0.07]	Area SED	-0.19**	[-0.29	-0.10]
Population density	-0.02	[-0.10	0.05]	Population density	-0.04	[-0.13	0.04]

 # = binary variable. β = standardised regression coefficient indicating the expected change in standard deviation units of social cohesion for a standard deviation change in the independent variable (for continuous covariates) OR the expected change in standard deviation units of social cohesion when the independent variable changes from 0 to 1 (for binary covariates). All covariates are measured at T1. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median; DCS = Diploma of College Studies; Area SED = area-level (census tract) socioeconomic deprivation; Population density = area-level (census tract) population density. Log(e) H'hold income = natural logarithm of household income. [95% CI] = 95% confidence interval around odds ratio/estimate.
^p≤0.10 *p≤0.05 **p≤0.01.

[93] *Community participation* was reanalysed as a count (Poisson-distributed) variable. *Neighbouring behaviour* and *Social Support* were reanalysed as binary variables, using both the lowest and highest tertiles of scores as the cut point. *Coping* was reanalysed using an alternative binary split (poor/fair versus good/very good/excellent ability to cope) and as an ordered categorical variable. *Coping* was also reanalysed using the binary split reported in Table 36, but with the addition of a dummy covariate for language of interview to account for the distinction in questions posed to French versus English-speaking participants (i.e. coping with 'day to day demands' versus 'unexpected and difficult events'). A final analysis included an interaction term between language and POS greenness to assess whether the effects of POS greenness differed according to the type of coping being reported. None of these sensitivity analyses identified significant effects of POS greenness.

To provide further insight into the relative effect of POS greenness, Table 37 (p.215) presents fully standardised coefficients for the social cohesion models, including covariate effects adjusted for, but not reported, in Table 36. The results reported here differ from those in Table 36 because the measures of POS greenness and POS availability are also standardised[94]. These findings indicate that a one standard deviation increase in POS greenness within 1000m of the home augments perceptions of social cohesion (β=0.16, 95% CI [0.08, 0.24], p<0.0001) to an extent that offsets the negative effects of a comparable increase in area socioeconomic deprivation (β=-0.15, 95% CI [-0.24, 0.07], p<0.0001). The standardised coefficients again indicate that POS greenness within 500m of the home (β=0.16, 95% CI [0.03, 0.20], p<0.0001) had slightly less influence in determining perceptions of social cohesion.

3.2 Associations between POS greenness, social cohesion and psychological distress (*paths b, c, c′)*

Social cohesion at T1 was significantly associated with trajectories of psychological distress from T1 to T3, after accounting for POS greenness (at either spatial scale) as well as POS availability and size, age, sex, education, self-rated physical health, household income, employment status, stressful life events, area-level socioeconomic deprivation and population density (path b; Table 38, Model 2). A one-unit increase in social cohesion decreased the odds of membership in the worsening distress class by 11% (OR=0.89, 95% CI [0.80, 0.98], p=0.020) and the odds of membership in the chronic distress class by 19% (OR=0.81, 95% CI [0.74, 0.87], p<0.0001) when adjusted for POS characteristics within 1000m of the home. These associations were essentially identical when adjusted for POS within 500m of the home. Thus, social cohesion satisfies the key conditions of an intermediary variable between POS greenness and psychological distress (i.e. path $a \neq 0$ and path $b \neq 0$) at both spatial scales. The indirect effect $a*b$ is tested formally in Section 3.4.

[94] *POS Size* is not standardised, because the standard deviation change in a binary variable is not meaningful.

Table 38: Main salutogenic effects of POS greenness on trajectories of psychological distress, adjusted for physical health, socio-demographic covariates, SLE, POS availability and size (Model 1); and direct (aka residual) effects after further adjustment for social cohesion (Model 2)

	Model 1 (path c)						Model 2 (path b, path c')					
	Worsening class (28%)			High distress class (23%)			Worsening class (28%)			High distress class (23%)		
1000m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	0.40*	[0.16	0.99]	1.19	[0.76	1.87]	0.44^	[0.17	1.09]	1.42	[0.86	2.37]
POS Availability	1.04	[0.97	1.11]	1.04^	[0.99	1.08]	1.03	[0.96	1.10]	1.03	[0.98	1.09]
POS Size#	1.21	[0.60	2.44]	1.01	[0.59	1.73]	1.26	[0.60	2.65]	1.05	[0.58	1.88]
Social Cohesion	---	---	---	---	---	---	0.89*	[0.80	0.98]	0.81**	[0.74	0.87]
500m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	0.74	[0.36	1.51]	1.10	[0.72	1.92]	0.85	[0.40	1.79]	1.26	[0.77	2.06]
POS Availability	0.99	[0.93	1.05]	1.01	[0.96	1.05]	0.98	[0.92	1.05]	1.00	[0.95	1.05]
POS Size#	0.77	[0.37	1.60]	0.83	[0.46	1.49]	0.68	[0.30	1.50]	0.76	[0.38	1.53]
Social Cohesion	---	---	---	---	---	---	0.87*	[0.77	0.97]	0.80**	[0.74	0.87]

 # = binary variable. OR = odds ratio; reference group is the healthful (low-stable) distress class. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median. [95% CI] = 95% confidence interval around odds ratio/estimate. Models adjust for age, sex, education, self-rated physical health, household income, employment status, stressful life events, area socioeconomic deprivation and population density according to the base model presented in Chapter 5 (Table 34). Length of residence, marital status and season of interview were also assessed as covariates but were not significantly associated with trajectories of psychological distress. ***^p≤0.10 *p≤0.05 **p≤0.01.***

There was some evidence for a main salutogenic effect of POS greenness on trajectories of psychological distress (path c; Table 38, Model 1) but this was limited to the broader LRA buffer and specific to protection against worsening trajectories of distress. Specifically, a one-unit increase in POS greenness within 1000m of the home statistically significantly reduced the odds of membership in the worsening distress class (OR=0.40, 95% CI [0.16, 0.99], p=0.046) relative to the healthful distress class. POS greenness within 500m of the home was not associated with membership in the worsening distress class, while POS greenness was not associated with membership in the chronic distress class at either spatial scale.

With the addition of social cohesion to the model, the association between 1000m POS greenness and membership in the worsening class (path c'; Table 38, Model 2) was no longer statistically significant (OR=0.44, 95% OR [0.17, 1.09], p=0.075). In other words, the data failed to reject the null hypothesis that POS greenness exerts no direct or residual effect on the likelihood of worsening distress symptoms after accounting for its indirect effect via social cohesion. Together, these findings satisfy Baron and Kenny's criteria for full mediation. However, it should be noted that the association between POS greenness and membership in the worsening distress class was only marginally statistically significant to begin with.

3.3 Associations between POS greenness, social cohesion and life satisfaction (*paths b, c, c′)*

Social cohesion at T1 was significantly associated with life satisfaction after accounting for POS greenness (at either spatial scale) as well as POS availability and size, age, sex, self-rated physical health, household income, marital status, stressful life events, area-level socioeconomic deprivation and season of interview (path b; Table 39, Model 2). However, this relationship was largely cross-sectional in nature; relative to the healthful life satisfaction class, social cohesion protected against membership in the chronic low-satisfaction class but not the worsening (high-declining) class. A one-unit increase in *social cohesion* was associated with roughly 15% lower odds of membership in the chronic low-satisfaction class, both when controlling for POS within 1000m of the home (OR=0.84, 95% CI [0.77, 0.93], p=0.001) and 500m of the home (OR=0.85, 95% CI [0.76, 0.94], p=0.002). Because the healthful and chronic low-satisfaction classes are largely differentiated by values of the outcome at T1, these associations do not implicate social cohesion as a temporal antecedent of prospective changes in life satisfaction, and reverse causation cannot be excluded as an explanation. Consistent with this finding, *social cohesion* exerted a statistically significant direct effect on within-class variation in trajectory intercepts (B=0.39, 95% CI [0.14, 0.64], p=0.002) but not within-class trajectory slopes (B=-0.04, 95% CI [-0.09, 0.01], p=0.154])[95].

Thus, *social cohesion* satisfies the key conditions of an intermediary variable between *POS greenness* and *life satisfaction* (i.e. path $a \neq 0$ and path $b \neq 0$) at both spatial scales, but only in relation to distinctions in initial differences in satisfaction at commencement of the study. The indirect effect *a*b* is tested formally in Section 3.4.

[95] As detailed in Chapter 4, noticeable changes in the size or interpretation of the latent classes with the addition of a covariate as a predictor of class membership may indicate the need to include direct effects of the covariate to explain within-class variation in trajectory intercepts or slopes. In this instance, adding *social cohesion* as a predictor of class membership without corresponding direct effects inflated the size of the chronic low-satisfaction class by approximately 20%. Including a direct effect of *social cohesion* on within-class intercepts rectified this problem and resulted in a general improvement to model fit (BIC differences = 4.47, 3.94 in the 1000m and 500m models, respectively). Direct effects of *social cohesion* on within-class slopes were non-significant and eroded model fit, and were consequently excluded from the model.

Table 39: Main salutogenic effects of POS greenness on trajectories of life satisfaction, adjusted for socio-demographic covariates, stressful life events, POS availability and POS size (Model 1); and direct (aka residual) effects after further adjustment for social cohesion (Model 2)

	Model 1 (path c)						Model 2 (path b, path c')					
	Worsening class (14%)			Low satisfaction class (11%)			Worsening class (14%)			Low satisfaction class (11%)		
1000m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	1.01	[0.29	3.52]	0.75	[0.30	1.92]	1.18	[0.33	4.30]	0.89	[0.34	2.38]
POS Availability	0.99	[0.86	1.12]	1.01	[0.95	1.08]	0.98	[0.85	1.13]	1.01	[0.94	1.08]
POS Size#	0.68	[0.23	1.99]	1.08	[0.44	2.63]	0.64	[0.20	2.12]	1.10	[0.43	2.79]
Social Cohesion	---	---	---	---	---	---	0.91	[0.76	1.09]	0.84**	[0.77	0.93]
500m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	0.86	[0.37	1.99]	0.37^	[0.14	1.03]	1.04	[0.43	2.53]	0.42^	[0.16	1.13]
POS Availability	0.96	[0.87	1.06]	1.01	[0.95	1.07]	0.95	[0.84	1.06]	0.99	[0.93	1.06]
POS Size#	1.94	[0.57	6.57]	2.96^	[0.97	9.02]	1.50	[0.43	5.21]	2.71^	[0.89	8.29]
Social Cohesion	---	---	---	---	---	---	0.91	[0.76	1.10]	0.85**	[0.76	0.94]

 # = binary variable. OR = odds ratio; reference group is the healthful (high-stable) satisfaction class. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median. [95% CI] = 95% confidence interval around odds ratio/estimate. All models are adjusted for age, sex, self-rated physical health, household income, marital status, stressful life events, area socioeconomic deprivation and season of interview according to the base model presented in Chapter 5 (Table 34). Education, length of residence, population density and employment status were also assessed as covariates but were not significantly associated with trajectories of life satisfaction. ***Note:*** *a direct effect from social cohesion to within-class trajectory intercepts was required to stabilise the distinction in trajectory slopes between the healthful (high-stable) and worsening (high-declining) classes: 1000m buffer B=0.31, 95% CI [0.07, 0.55], p=0.012; 500m buffer B=0.31, 95% CI [0.06, 0.56], p=0.014.* ***^p≤0.10 *p≤0.05 **p≤0.01***

Main salutogenic effects of *POS greenness* on membership in the worsening or chronic low-satisfaction classes, relative to the healthful life satisfaction class, were consistently statistically non-significant (path c; Table 39, Model 1). Strictly speaking, this indicates a null global effect of *POS greenness* on trajectories of life satisfaction, after accounting for the availability and size of POS in the local area as well as physical health and sociodemographic characteristics. There was, however, some indication that green POS within 500m of the home might protect against membership in the chronic low-satisfaction class (OR=0.37, 95% CI [0.14, 1.03], p=0.057). Although this association is strictly statistically non-significant, the direction of the point estimate is consistent with indications of an indirect effect via *social cohesion*, as described above.

3.4 Indirect effects of POS greenness on psychological distress and life satisfaction via social cohesion

Sections 3.1 to 3.3 have demonstrated that social cohesion satisfies two key conditions of an intermediary variable linking POS greenness to psychological distress or life satisfaction:

1. POS greenness within 500m or 1000m of the home was related to perceptions of social cohesion at T1 (path a ≠ 0); and
2. Perceptions of social cohesion at T1 were associated with membership in the adverse mental health trajectory classes, after accounting for POS greenness (path b ≠ 0)

In relation to path b, specifically:

a) Social cohesion reduced the odds of membership in the worsening or chronic high-distress classes, relative to the healthful class;
b) Social cohesion reduced the odds of membership in the chronic low-satisfaction class, relative to the healthful class.

Table 40 (p.220) presents 95% confidence intervals for the indirect effects (*a*b*) of POS greenness, via social cohesion, on membership in the adverse psychological distress or life satisfaction trajectory classes. These associations account for covariates in both components of the mediated effect, as described in the preceding sections. Consistent with the associations described for paths *a* and *b* above, *POS greenness* exerted a statistically significant indirect effect to reduce the odds of membership in the worsening distress class, the chronic high-distress class, and the chronic low-satisfaction class, relative to the healthful class for each outcome. No indirect effect was evident in relation to the worsening life satisfaction class. In all cases, the results were consistent across both spatial scales.

Table 40: 95% confidence intervals for the indirect effects of public open space 'greenness' on trajectory class membership, via social cohesion

	Psychological distress						Life satisfaction					
	Worsening class			High distress class			Worsening class			Low satisfaction class		
	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
1000m buffer	0.88	[0.77	0.98]	0.80	[0.69	0.90]	0.91	[0.73	1.09]	0.84	[0.72	0.94]
500m buffer	0.91	[0.80	0.99]	0.87	[0.76	0.96]	0.94	[0.80	1.07]	0.90	[0.79	0.98]

*OR = odds ratio (exponentiated product of unstandardised a*b path coefficients); reference group is the healthful (low-stable distress or high-stable satisfaction) class. [95% CI] = 95% confidence interval around odds ratio. Indirect effects are computed using covariate-adjusted estimates of paths a and b, as detailed earlier in this chapter.*

4 Summary of results

This chapter assessed whether the availability of 'greener' public open space in the residential environment promotes mental health indirectly by enhancing the availability of psychosocial resources. Five measures of psychosocial resources were tested as potential intermediaries between the average 'greenness' of POS (within 500m or 1000m of the home) and prospective four-year trajectories of psychological distress or life satisfaction. These included three measures of neighbourhood social integration (social cohesion, neighbouring behaviour, and community participation), a measure of perceived support from broader social networks (not necessarily located within the neighbourhood), and a measure of perceived ability to cope with day to day demands or unexpected and difficult events. Analyses accounted for the total availability and median size of POS in these areas, as well as a range of individual- and area-level covariates.

Of the psychosocial resources tested, only social cohesion was statistically significantly associated with POS greenness. This association was consistent across spatial scales, although the presence of greener POS within 1000m of the home augmented social cohesion to a greater extent than did the presence of greener POS within 500m. Social cohesion, in turn, reduced the likelihood of following a worsening or chronically elevated trajectory of psychological distress (relative to a stable trajectory of low distress) or a chronically low trajectory of life satisfaction (relative to a stable trajectory of high satisfaction) over the ensuing four-year period. Formal tests of the indirect effect of *POS greenness*, via social cohesion, on membership in these trajectory classes revealed protective effects that were significant at an alpha level of 0.05 across both spatial scales. Social cohesion did not, however, significantly protect against a trajectory of declining life satisfaction among individuals with normal levels of life satisfaction at commencement of the study, and no corresponding indirect effect was evident. Together, these findings provide cross-sectional and prospective support for an indirect effect on psychological distress, but only cross-sectional support for an indirect effect on life satisfaction.

Despite the above, the total effect of POS greenness was statistically significant only in relation to the worsening psychological distress class, and then only within 1000m of the home. The absence of a total effect in other instances might indicate the operation of additional mechanisms that counteract the indirect protective effects detailed above. For

example, there was some evidence that benefits stemming from increased social cohesion might suppress an otherwise harmful effect of POS greenness on membership in the chronic high-distress class; although the direct effect of POS greenness (path c') was not statistically significant at either spatial scale, it was directionally opposite to the indirect effect and somewhat larger in magnitude than the total effect (path c) in both cases.

CHAPTER 7
Discussion and conclusion

1 Introduction

This thesis sought to explore the notion that the provision of 'greener' public open space (POS) in urban residential environments, by virtue of enabling incidental access to nature, may help to create an environment that is supportive of mental health. Four research aims were devised to elucidate the mechanisms by which such effects might accrue and the dimensions of mental health they are likely to influence. This final chapter begins with a summary of the key findings of the thesis (Section 2) then presents an interpretation and discussion of those findings (Section 3) in relation to the research aims. Because the discussion of results was withheld from preceding chapters, these sections present an opportunity to reflect on the specific contributions, limitations, and insights of individual research questions addressed within the thesis. Attention then turns towards the findings of the thesis as a whole, beginning with a detailed exploration of potential threats to the validity of the research (Section 4). Remaining sections describe the key contributions of the thesis as a whole (Section 5), its implications for public health practice (Section 6), and recommendations for future research (Section 7). The final section concludes the thesis.

2 Key findings in relation to the research aims

This section outlines the key findings of this thesis in relation to its four key research aims. Pertinent associations are summarised in Table 41 (p.225) as well as Figure 29 (p.228) and Figure 30 (p.229) according to the research question and mental health outcome being tested. Results are presented as estimated odds ratios for membership in the adverse psychological distress or life satisfaction classes, relative to the healthful class, per one-unit increase in *POS greenness.* These summaries help to illustrate the extent to which protective effects of POS greenness were consistently observed according to outcome dimensionality, spatial scale, and psychosocial explanatory mechanisms. Table 41 highlights statistically significant associations in green. Figure 29 and Figure 30 present the same associations graphically, where confidence intervals that do not cross 1.0 are indicative of statistically significant associations. Finally, Figure 31 (p.230) presents supplementary data illustrating cross-sectional relationships of POS greenness with each of the five psychosocial resources tested as possible mediators of an

association with mental health. This assists illustrating the broad pattern of results across domains of neighbourhood social integration, social support, and coping.

All associations were adjusted for total POS availability, size, physical health, length of residence, and socio-demographic covariates. As described in Chapter 3, *POS greenness* was scaled such that a one-unit increase (equivalent to an increase of 0.1 in mean NDVI values) corresponds to meaningful variations in land cover for POS in urban settings; for instance, from a barren square with little vegetation to a playground with moderate greenness, or from a grassy oval to a park with lush vegetation (Bell et al., 2008). Statistically significant associations therefore indicate that distinctions in vegetative cover contribute to variation in mental health outcomes over and above the total quantity or size of POS available to residents.

Table 41: Summary of thesis results. Odds ratios for membership in a given class, relative to the healthful class for that outcome, with a one-unit change in POS greenness

	Aim 1 Stress-buffering effects (interaction with SLE)		Aim 2 Main effects (holding SLE constant)		Aim 3 Indirect effects (via social cohesion)	
Psychological distress	500m	1000m	500m	1000m	500m	1000m
Worsening distress	**0.80 [0.66, 0.97]**	**0.74 [0.58, 0.96]**	0.74 [0.36, 1.51]	**0.40 [0.16, 0.99]**	**0.91 [0.80, 0.99]**	**0.88 [0.77, 0.98]**
Chronic high-distress	0.93 [0.79, 1.09]	0.94 [0.77, 1.16]	1.10 [0.72, 1.92]	1.19 [0.76, 1.87]	**0.87 [0.76, 0.96]**	**0.80 [0.69, 0.90]**
Life satisfaction	500m	1000m	500m	1000m	500m	1000m
Worsening life satisfaction	1.02 [0.80, 1.29]	1.21 [0.87, 1.70]	0.86 [0.37, 1.99]	1.01 [0.29, 3.52]	0.94 [0.80, 1.07]	0.91 [0.73, 1.09]
Chronic low-satisfaction	1.04 [0.81, 1.34]	0.99 [0.74, 1.33]	0.37 [0.14, 1.03]	0.75 [0.30, 1.92]	**0.90 [0.79, 0.98]**	**0.84 [0.72, 0.94]**

2.1 Research Aim 1: To evaluate whether POS 'greenness' exerts a protective 'stress-buffering' effect against the potential psychological harm of acutely stressful life events

In Study 1 (Chapter 5), *POS greenness* significantly attenuated the association of stressful life events with worsening trajectories of psychological distress, but did not moderate the

association with chronically elevated trajectories of distress; nor did it moderate the association with worsening or chronically low trajectories of life satisfaction.

2.2 Research Aim 2: To evaluate whether POS 'greenness' exerts a 'main' salutogenic effect independently of exposure to acutely stressful life events

In Study 2 (Chapter 6), exposure to acutely stressful life events was held constant at the sample mean in order to determine the total mental health-promoting effect of *POS greenness*. A statistically significant inverse association was observed with membership in the worsening psychological distress class, but only when *POS greenness* was measured within one kilometre of the home. The effect of *POS greenness* within 500m of the home was directionally consistent with that observed for the wider buffer but was not statistically significant. The main effects of *POS greenness* were also not statistically significant in relation to membership in the classes of chronic high-distress, worsening life satisfaction, and chronic low-satisfaction.

2.3 Research Aim 3: To evaluate the intermediary role of psychosocial factors at three levels – within the individual, within the neighbourhood social environment, and within broader social networks – in explaining prospective associations between POS 'greenness' and mental health

Study 2 (Chapter 6) tested cross-sectional associations between *POS greenness* and social cohesion; neighbouring behaviour; community participation; social support; and coping. Of these, only social cohesion was statistically significantly associated with *POS greenness*. This association was consistent across both spatial scales, although the presence of greener POS within 1000m of the home augmented social cohesion to a greater extent than that within 500m. Social cohesion, in turn, reduced the likelihood of following a worsening or chronically elevated trajectory of psychological distress (relative to a stable trajectory of low distress) or a chronically low trajectory of life satisfaction (relative to a stable trajectory of high satisfaction) over the ensuing four-year period. Formal tests of the indirect effect of *POS greenness*, via social cohesion, on membership in these trajectory classes revealed protective effects that were statistically significant across both spatial scales. Social cohesion did not,

however, protect against a trajectory of declining life satisfaction among individuals with normal levels of life satisfaction at commencement of the study, and no corresponding indirect effect was evident.

2.4 Research Aim 4: To explore whether findings differ according to the dimensionality (positive or negative) of the mental health outcome under consideration

Across Studies 1 and 2, the evidence for a protective or health-promoting effect of *POS greenness* was much stronger in relation to the negative dimension of mental health (psychological distress) than the positive dimension (life satisfaction). Whereas *POS greenness* exhibited consistent and statistically significant stress-buffering and health promoting effects in relation to the likelihood of experiencing worsening psychological distress symptoms throughout the follow-up period, considered both in the total effect and indirect component operating via augmented social cohesion, there was no such evidence for a prospective association with trajectories of life satisfaction. There was some, albeit limited, evidence that *POS greenness* was associated with lower odds of reporting a substantially diminished sense of life satisfaction at commencement of the study, with a statistically significant indirect effect via social cohesion. However, the total main effect was not statistically significant.

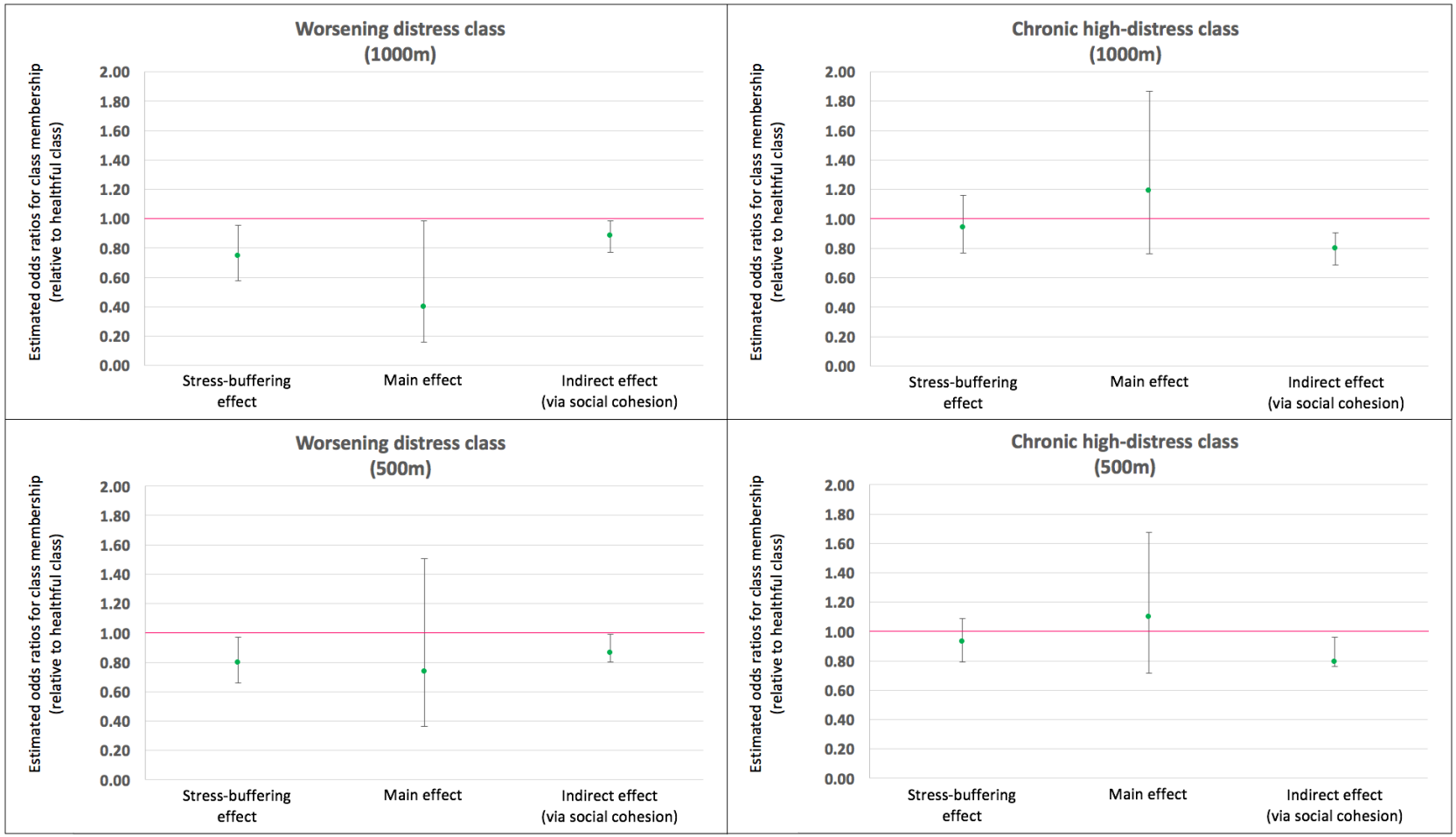


Figure 29: Summary of relationships between POS 'greenness' within 1000m (top row) and 500m (bottom row) and psychological distress via stress-buffering, main effect and indirect effect mechanisms (±95% CI)

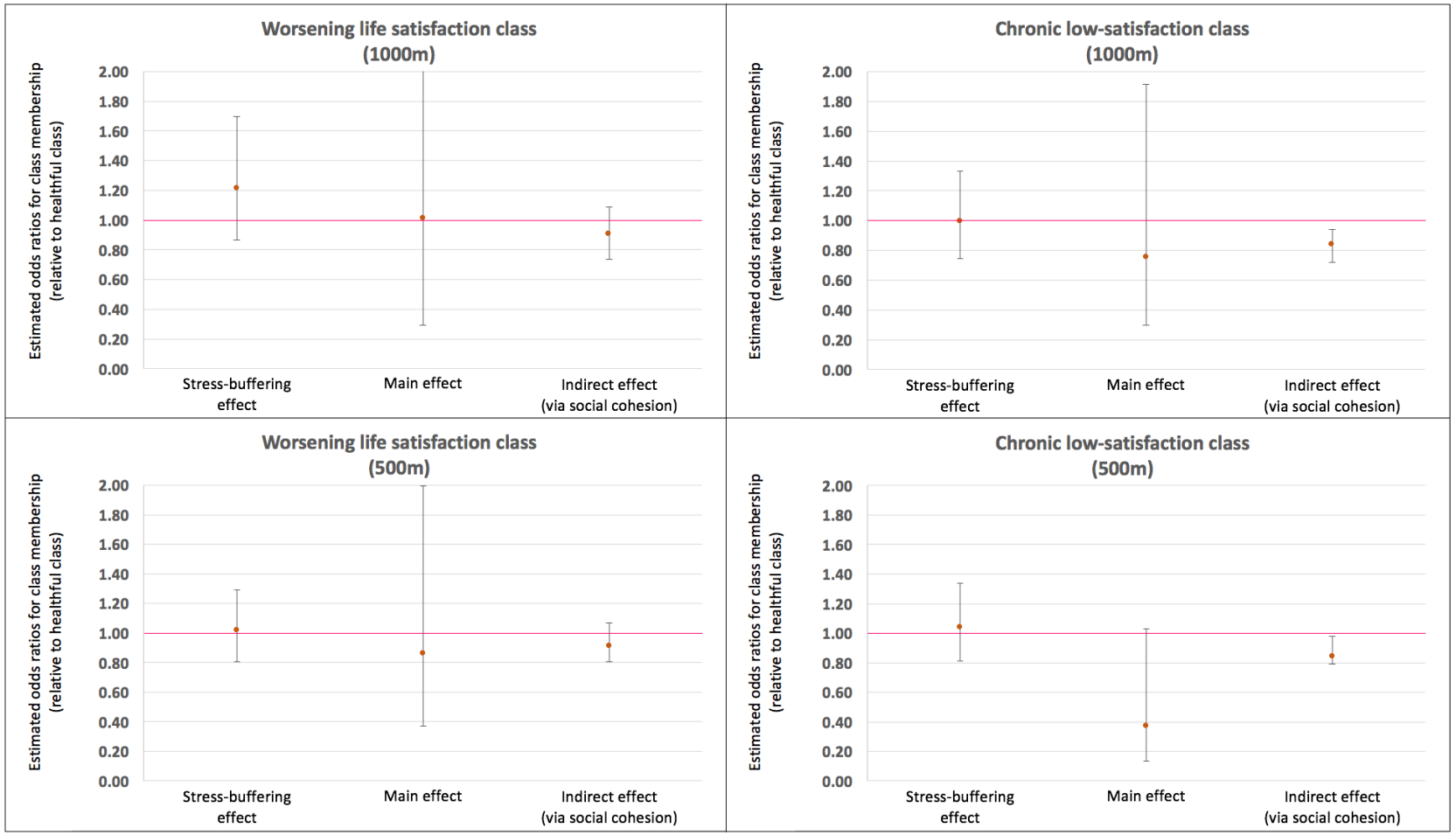


Figure 30: Summary of relationships between POS 'greenness' within 1000m (top row) and 500m (bottom row) and life satisfaction via stress-buffering, main effect and indirect effect mechanisms (±95% CI)

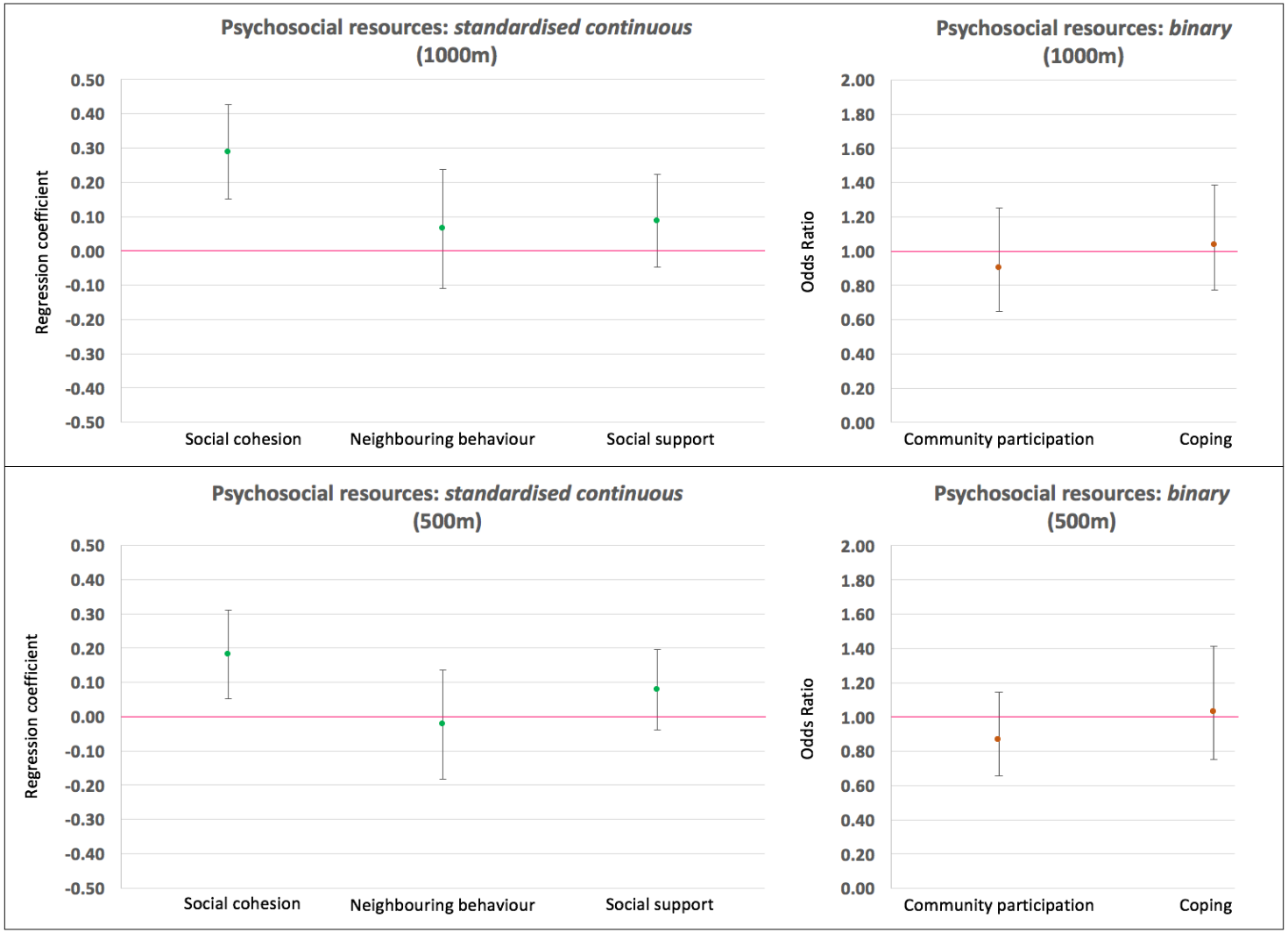


Figure 31: Summary of cross-sectional associations (±95% CI) between POS 'greenness' within 1000m (top row) or 500m (bottom row) of the home and psychosocial resources

3 Interpretation and discussion

3.1 An innovative approach to modelling trajectories of change in psychological distress and life satisfaction

This thesis employed a growth mixture modelling (GMM) framework to derive a latent classification scheme that succinctly summarised inter-individual variability in four-year trajectories of psychological distress and life satisfaction, using membership in the various classes as the primary outcome against which the effects of POS greenness, stressful life events, and psychosocial resources were assessed. During the past decade, longitudinal psychological research has increasingly employed GMM to empirically identify groups of individuals that follow qualitatively distinct symptomatic trajectories over time. However, studies applying this method have focused almost exclusively on child and adolescent development, ageing (in the later stages of life), and other transitional contexts such as changes following experiences of trauma, mental or physical illness, or childbirth. The method remains underutilised in general population samples, despite the fact that heterogeneity in psychological trajectories is equally plausible in these settings.

GMM permits a complex specification of inter-individual variability in the course of change that can be useful for identifying extreme or uncommon trajectories, and unique aetiologies, that might otherwise be overlooked (Nagin and Tremblay, 2005, Costello et al., 2008, Berlin et al., 2013a). This might be especially beneficial in observational population-based cohort studies, where the anticipated normative experience is one of a stable and healthful mental state but it is also known that this experience does not characterise the entire population. Under these circumstances, single-population analytical methods might mask deviations from the norm, making it difficult to identify the pathways leading to declining or improving mental health. This was demonstrated in Chapter 4, where single-population latent growth curve models (LGCM) fit the mental health data much worse than the growth mixtures and also failed to identify theoretically relevant predictors of variation in trajectory slopes that were evident in the latter models.

Because this is a rather novel approach in the place-health literature, I preface discussion of the research aims with a brief commentary on characteristics of the latent classes that are pertinent to the interpretation of results in this thesis.

3.1.1 Empirical evidence to support validity of the latent classes

The analyses presented in Chapter 4 and Chapter 5 provide a basis on which to assess whether the observed trajectory classes possess distinct characteristics that are consistent with theory, and are thus meaningful and practically useful as outcomes by which to address the substantive research questions of this thesis (Muthén, 2003). Support for the validity of the subpopulations will naturally be greater if the results are inconsistent with population homogeneity (Bauer and Curran, 2003b). Importantly, as described in the summaries of results within those chapters, membership in the 'adverse' trajectory classes under each model was predicted by known determinants of mental health including gender, education and residential area socio-economic deprivation (psychological distress model) as well as stressful life events (both models). These associations support the presumptive validity of the classification schemes (Muthén, 2003), while contemporaneous associations of the outcomes with self-rated health, income, employment and marital status provide more general support for the correctness of the model.

In guiding the discussion of findings within this thesis, a deeper interpretation of associations with stressful life events may be warranted. Overall, the results presented in Chapter 5 were consistent with the expectation that SLE are detrimental to mental health. What was not anticipated, however, was the extent to which membership in the chronically poor class (under both outcomes) would be tied to 'new' SLE (reported at T2 or T3) moreso than SLE in the lead up to the study (reported at T1). This finding seems counterintuitive at first, given that the initial level of mental health is central to the definition of this class. Yet, because the measure of 'new' events counts the number of stressors occurring within two years of the four-year mental health measurement period, higher scores presumably reflect either chronicity of stressful exposures throughout follow-up, or a very high incidence of stressors during a particular year. From this perspective, it is understandable that higher scores on this measure are strongly associated with chronically poor mental health; whereas a single-year measure (SLE reported at T1) is disposed to the occurrence of chance events, a split two-year measure (SLE reported at T2 or T3) might more closely reflect a set of structural conditions leading to heightened and sustained exposure to stressors and enduring strains (Baum et al., 1999, Aneshensel, 2010, Ross and Mirowsky, 2013). Alternatively, it is possible that this association reflects reverse causation, whereby individuals with initially poor mental health subsequently experience the proliferation of stressors as a result of this condition (Pearlin, 1999).

Before continuing, it might be helpful to elaborate on this point through a brief post-hoc exposition of the characteristics of the chronic high-distress class, in comparison with the healthful and worsening classes. Partitioning individuals into their 'most likely' class, a number of highly statistically significant differences (Chi-Square test, p-values <0.0001) existed between groups with respect to the prevalence of lifetime and past-year mental disorders; individuals under a low income cut-off; individuals with some university education; and individuals reporting some paid employment in the past year (Table 42).

Table 42: Prevalence of mental disorders and sociodemographic characteristics by psychological distress class membership

	Most likely class membership		
Variable (measured at T1)	Healthful (%)	Worsening (%)	Chronic high (%)
Any lifetime mental or substance use disorder[a]	20	38	61
Any past-year mental or substance use disorder[a]	5	11	39
Under Statistics Canada low income measure[b]	11	30	24
Some university education	41	20	23
Engaged in paid employment (past twelve months)	81	72	66

a. *Any lifetime disorder includes major depression, mania, panic attacks, social phobia, agoraphobia, and alcohol or drug dependence, measured using the Canada Community Health Survey (CCHS) 1.2 version of the Composite International Diagnostic Interview as reported by Caron et al. (2012b).* ***b.*** *The Statistics Canada (2010) low income measure (LIM) identifies households with a combined household income of less than 50% of the population median, after adjusting for household size.* ***Global between-group differences were statistically significant for all outcomes variables (p<0.0001).***

The classes also differed to a highly statistically significant degree (Kruskal-Wallis test, p-values <0.0001) in relation to the number of (weighted) SLE reported at each wave of the study (Table 43).

Table 43: Mean weighted stressful life event scores by psychological distress class membership

	Most likely class membership (Psychological distress GMM)		
Variable (reported at time T)	Healthful (mean)	Worsening (mean)	Chronic high (mean)
Weighted stressful life events (T1)	2.4	2.7	3.9
Weighted stressful life events (T2)	1.9	2.6	3.6
Weighted stressful life events (T3)	1.6	2.8	3.2

Weighted SLE measured as described in Chapter 3 (Section 6.5). ***Global between-group differences were statistically significant across all waves (p<0.0001).***

It is evident from the above analysis that members of the adverse (worsening or chronic) distress classes differ significantly from individuals in the healthful class along the lines of: past mental health problems; various indicators of socioeconomic status; and

exposure to acute stressors. Differences between the adverse classes themselves are more subtle, and relate primarily to a substantial elevation in (i) lifetime and past year prevalence of mental disorders, and (ii) exposure to stressful life events, within the chronic distress class[96]. Thus, the chronic high-distress class appears to partition a subpopulation facing a much greater propensity to mental illness, as well as a prolonged pattern of elevated exposure to stressful events. These characteristics are consistent with subpopulation heterogeneity, providing further evidence for the validity of the latent class structure, and are relevant to the interpretation of findings in ways I will detail throughout this chapter.

3.1.2 Cross-classification and the two-continua model of mental health

As detailed in Chapter 2, mental health is commonly understood to constitute two distinct yet interrelated dimensions that combine to determine an overall state of wellbeing. A 'complete state' of mental health is marked by a lack of psychopathology (negative dimension) as well as high levels of emotional, psychological, and social wellbeing (positive dimension) (Keyes and Michalec, 2010, Headey et al., 1993, Keyes, 2005b, Westerhof and Keyes, 2010). For this reason, it is instructive to consider the distribution of individuals across latent trajectory classes in the psychological distress (negative) and life satisfaction (positive) models.

Overall, healthful trajectories of life satisfaction (79%) were far more prevalent than healthful trajectories of psychological distress (46%). This is consistent with previous cross-sectional evidence that suggests many individuals with clinical-range mental disorder are able to maintain a moderate level of positive mental health that protects against impairments in employment, health and psychosocial functioning (Keyes, 2002, 2005b, a, Keyes and Grzywacz, 2005, Weich et al., 2011, Keyes et al., 2012). The relative stability of high life satisfaction scores might therefore reflect a certain robustness of subjective wellbeing to fluctuations in the level of psychological distress. There was certainly evidence that these outcomes follow distinct temporal processes. In particular, the rates at which (a) a worsening trajectory of psychological distress was accompanied by a healthful trajectory of life satisfaction, or (b) a chronically elevated trajectory of distress was accompanied by a trajectory of declining life satisfaction, suggest that the reverberations of

[96] Post-hoc tests comparing prevalence of mental disorder (logistic models) and stressful life events (Poisson models) between the worsening and chronic high-distress conducted using generalized estimating equations adjusting for clustering by census tract indicated highly statistically significant differences in relation to the prevalence of lifetime or past-year mental disorder (p-values <0.0001) and stressful life events at T1 and T2 (p-values <0.0001) and at T3 (p-values =0.044).

anxiety and depressive symptoms into other domains of life might take some time to unfold.

Although the association between these processes is correlational and cannot confirm the temporal hierarchy of these processes, the noted discrepancies in trajectory class membership are consistent with findings in relation to the differential effects of stressful life events on the two dimensions of mental health. Specifically, in the wake of stressful events, the arousal of psychological distress appears to be more immediate and transitory in nature than the consequences for subjective wellbeing. SLE reported to have occurred prior to T1 displayed only a small intra-class association with levels of psychological distress at commencement of the study, indicating that the ramifications of those events had largely settled prior to the first occasion of measurement. By contrast, SLE prior to T1 continued to influence the likelihood that life satisfaction would begin to deteriorate after the first occasion of measurement, as evidenced by their association with membership in the worsening satisfaction class. Altogether, these findings accord with the premise that positive and negative dimensions of mental health are not mutually deterministic but may follow different developmental trajectories and relate differentially to attributes of the individual and the environment (Greenspoon and Saklofske, 2001, Keyes, 2007, Westerhof and Keyes, 2010, p.110). Implications for the findings of this thesis are discussed throughout the remainder of this chapter.

3.2 Research Aims 1 and 2: Stress-buffering and main salutogenic effects of POS 'greenness'

3.2.1 Evidence for a 'stress-buffering' effect

Research Aim 1 of this thesis was to evaluate whether POS 'greenness' exerts a protective 'buffering' effect against the potential psychological harm of acutely stressful life events. The conceptual framework presented in Chapter 2 (Figure 2, p.16) highlighted the stress process as a potentially fruitful avenue for understanding the benefits of access to natural open spaces in urban residential environments. Specifically, it proposed that residential POS greenness, by virtue of enabling relatively frequent, easy, or incidental access to nature, might support processes of psychological restoration and/or the accumulation of psychosocial resources that, in turn, serve to moderate the consequences of stressful experiences. The findings in relation to Research Aim 1, reported in Chapter 5, lend plausibility to this perspective, illustrating how the level of 'greenness' in residentially accessible POS interacts with the experience of acute stressors to determine

mental health outcomes (Cutrona et al., 2006). Specifically, the findings indicate that the availability of greener POS, on average, within 500m or 1000m of the home, is protective against rising levels of psychological distress in the wake of typically stressful life events. This relationship was evident as the attenuation of the effects of 'new' SLE (reported after the first measurement occasion) on the odds membership in the 'worsening' psychological distress class, relative to the 'healthful' class, by POS greenness. By contrast, POS greenness did not buffer the effects of 'new' SLE on membership in the chronic high-distress class, or either of the adverse life satisfaction classes, relative to the healthful class for each outcome. I return to discuss those null associations later in the chapter.

Individuals in 'worsening' and 'healthful' psychological distress classes reported similarly low levels of distress symptomology at the first measurement occasion. Thus, the results of in relation to Research Aim 1 provide support for the notion that POS greenness buffers against the arousal of detrimental psychological stress sequelae among individuals with relatively low levels of distress prior to those events. This relationship is consistent with a short-term restorative mechanism in which POS greenness protects against the onset of psychological distress by promoting intermittent periods of cognitive and emotional restoration that might halt spirals of psychosocial resource loss before they gain momentum, and enable the maintenance of a healthy mental state over time (Hobfoll, 2001). As detailed in Chapter 2, 'greener' settings (with a greater quantity and diversity of natural elements) were hypothesised to be more beneficial for restoration from stress and mental fatigue because they constitute a richer, more coherent environment with greater scope to evoke involuntary fascination and a feeling of 'being away' (Kaplan, 1995, Fuller et al., 2007, Grahn and Stigsdotter, 2010, Carrus et al., 2013). Importantly, the effect was robust to adjustment for other POS characteristics likely to influence restorative potential (total availability and median size of POS in the residential area) as well as a broad range of individual and area-level sociodemographic characteristics, physical health status, and length of residence.

3.2.1.1 Expanding knowledge beyond the bounds of immediate restoration

These results are consistent with a substantial body of experimental evidence demonstrating the relatively immediate physiological, affective, and cognitive effects of restoration following real or simulated 'nature experience'. As detailed in Chapter 2, these studies have typically demonstrated that, following a period of mental stress, exposure to natural settings rapidly regulates the autonomic nervous system; promotes positive affect; diminishes negative affective states such as anxiety, fear, frustration and anger; inhibits

rumination; and improves the performance of executive attention, working memory, and impulse inhibition (Ulrich et al., 1991, Cackowski and Nasar, 2003, Hartig et al., 2003a, Bowler et al., 2010, Berman et al., 2012, Brown et al., 2013, Bratman et al., 2015a, van den Berg et al., 2014, Berman et al., 2008, Bratman et al., 2012). By contrast, these effects are typically evident to a much lesser extent, or not at all, following a comparable exposure to manmade urban scenery (Velarde et al., 2007). There are, however, three primary limitations to this evidence that hamper its utility for the promotion of population health through urban planning. First, experimental designs assessing the restorative effects of nature typically induce only a mild form of stress or cognitive fatigue by using, for example, a stressful film, a social stress test (e.g. mock job interview), or a cognitive ability test. Of course, ethical requirements rightly constrain the manipulation of stress in experimental settings; but this does limit the extent to which the restorative effects of nature experience can, at present, be generalised to the case of more severe or enduring stressors and strains, arising in life domains tied implicitly to self-concept and which might also disrupt the broader availability of material and interpersonal coping resources. Second, these experiments, by design, force the individual to submit to nature experience. This raises questions about the ecological validity of the findings and reservations as to what extent the mere provision of natural environments – without prescribed usage – will benefit the general population. Moreover, attention is rarely paid to variation in the type or characteristics of the natural environment being experienced, and whether this influences restoration (see e.g. van den Berg et al., 2014, Jiang et al., 2014a for exceptions). Third, due to the short-term assessment of stress and restoration in these studies, the extent to which such immediate effects might accumulate to shape longer term outcomes in relation to mental health and wellbeing remain unclear.

Altogether, the body of experimental research into restoration is unable to answer whether the mere availability of natural stimuli in a residential setting leads to longer term stress attenuating benefits among the general population. The present study addresses each of these limitations by (1) measuring exposure to potentially severe acute stressors in key life domains such as employment, relationships, housing, and finances; (2) measuring the relative naturalness of public open spaces as an enduring attribute of the individual's living environment; and (3) assessing how these characteristics interact to determine prospective changes in the level of distress symptomology over a period of roughly four years. Finally, it does so in context, using a community-based sample of adults across a broad spectrum of age groups and relative socioeconomic status, whereas the generalisability of experimental

findings is often hampered by the use of student samples in a controlled environment wholly removed from the residential context (see e.g. Velarde et al., 2007).

3.2.1.2 Comparison with existing population-based research

The findings in relation to Research Aim 1 represent a significant contribution to the literature, adding to a small number of studies that have utilised population-based samples to address the limitations described above. The results are largely consistent with prior research, but extend it in a number of ways. Roe et al. (2013) and Ward Thompson et al. (2012) linked a lower proportion of green space in the living environment to dysregulation in circadian cortisol cycles among unemployed adults residing in a socioeconomically deprived area[97]. These studies presented promising physiological evidence to support the notion that better access to natural POS might enhance resilience against chronic stress associated with socioeconomic deprivation, but did not directly assess exposure to stressors or mental health outcomes. Mitchell et al. (2015) found that deficits in positive mental wellbeing associated with socioeconomic inequality were diminished among individuals with better perceived ease of access to POS, but similarly did not directly assess exposure to stressors. Finally, Van den Berg et al. (2010) identified a weak and statistically non-significant (p=0.10) buffering effect of POS availability within three kilometres of the home, among individuals who had experienced a stressful life event within the past three months. No stress-buffering effect was evident in relation to POS availability within one kilometre of the home. The authors of that study did not distinguish between respondents who had experienced one SLE or several, nor between events that might be more or less threatening to mental health, which might have hampered their ability to identify a stress-buffering effect (Gill, 2009, Kessler, 1997). The findings of the present study illustrate that the benefits of POS greenness were more relevant to individuals who had experienced a greater number of stressful events, when weighted for their relative severity. Moreover, the findings indicate that the inherent characteristics of residential POS are important to its potential role as a stress-buffering resource. Despite the frequently espoused role of biophilia and psychological restoration as theoretical foundations for the salutogenic effects of POS, this is the first study to empirically ascertain the contribution of POS 'greenness' – as distinct from POS availability – to this mechanism.

The corollary of a stress buffering effect is that one anticipates heterogeneity in the effects of otherwise equivalent neighbourhood exposures, according to the level of stress to

[97] Ward Thompson et al. (2012) served as an exploratory study for Roe et al. (2013). The two samples were merged in the latter analysis, which confirmed the findings of the exploratory study.

which the individual is exposed (Wheaton, 1985, Cohen, 2004, Cutrona et al., 2006). Specifically, the findings from in relation to Research Aim 1 suggest that POS greenness is especially beneficial to people under heightened stress (Cobb, 1976, Pearlin et al., 1981, Thoits, 1995). Comparing the expected influence of POS greenness within 1000m of the home on the relative likelihood of membership in the worsening psychological distress class (compared with the healthful class), there appeared to be little distinction in mental health outcomes between low (1SD below the mean) and high (1SD above the mean) POS greenness conditions if one or fewer stressful events were reported, on average, per year[98] (Figure 26, p.203). The effects of POS greenness within 500m of the home were more dependent on exposure to stress, with differences between the high and low greenness conditions becoming pronounced beyond the mean level of SLE exposure (roughly 2.5 events, on average, per year).

3.2.2 Evidence for a 'main' salutogenic effect

The dependency of these effects on the level of acute stress raises the question of whether POS greenness also exerts a homogeneous salutogenic effect. As detailed in Chapter 2, the health-related effects of intra-personal and environmental resources are commonly delineated based on the extent to which they act through an interaction with stress. A health-promoting effect would be evidenced by a beneficial association with psychological distress or life satisfaction that operates independently of the stress process (Wheaton, 1985, Cohen, 2004). Thus Research Aim 2 was to evaluate whether POS 'greenness' exerts a health promoting effect independently of exposure to acutely stressful events. Analyses reported in Chapter 6, estimated the total health-promoting effects of POS greenness conditional upon the number of acute stressors reported, effectively cancelling out the influence of differing levels of eventful experience. Here, the results indicated that a higher level of POS greenness within 1000m of the home was protective against membership in the worsening psychological distress class (relative to the healthful class) after adjusting for a broad range of individual and area-level sociodemographic characteristics, physical health status, and length of residence. Since POS greenness was measured contemporaneously with the first occasion of data collection, this indicates that the presence of greener public open spaces was protective against prospective rises in psychological distress across the ensuing four-year period.

[98] In other words, if a combined total of two or fewer stressful events was reported at T2 and T3 (each of which administered a one-year retrospective report of stressful life events).

3.2.2.1 Comparison with existing population-based research

In this respect, the research makes a novel and important contribution to the limited body of evidence linking the quality of POS and natural stimuli in urban residential areas to mental health. As detailed in Chapter 2, only one longitudinal study to date has addressed this question, identifying null associations ($p<0.10$) between 'green qualities' in the residential landscape and psychological distress over a ten-year period (Weimann et al., 2015). The limitations of this research in relation to the assessment of associations specific to POS greenness in urban environments were explored in depth in Section 4.1.2.2 of that chapter, and are not repeated here. Otherwise, prior research has identified cross-sectional associations between psychological distress and the quality of tangible POS attributes (e.g. paths, lighting, playgrounds, shade, irrigated lawn, sporting facilities; Francis et al., 2012b) as well as the quantity ('green impression') or quality (variation, maintenance, orderly arrangement, general impression, and absence of litter) of greenery visible from the street (van Dillen et al., 2012, De Vries et al., 2013). While Kardan et al. (2015) did not identify an association between the proportion of tree canopy cover in parks and private gardens and the number of mental disorders reported by individual residents, findings from the present study (discussed below) suggest that the spatial scale employed therein may have been too small to identify a general health-promoting effect. To my knowledge, this thesis is the first piece of research to specifically assess the effects of objectively quantified POS greenness in relation to mental health, without conflating this exposure with other dimensions of POS quality or other sources of neighbourhood greenness. For instance, the measures of 'greenness' employed in previous studies do not differentiate between public (e.g. parks) and private open space (e.g. gardens), although the latter may contribute significantly to the aesthetic value of the neighbourhood, provide more immediate green views from the home, and influence wellbeing independently of the characteristics of public land (De Vries et al., 2003, Stigsdotter and Grahn, 2004, Nielsen and Hansen, 2007). That distinction is important for the guidance of appropriate public health interventions, particularly in inner-city areas where private open space might be less prevalent. Crucially, this thesis is only the second longitudinal study in an urban setting to employ any measure of POS quality or greenness as the primary exposure of interest.

However, the health-promoting association with membership in the worsening distress class was not statistically significant in relation to POS greenness within 500m of the home. Moreover, reminiscent of the results in relation to Research Aim 1, there was no evidence of a statistically significant association between POS greenness at either spatial

scale and membership in the chronic high-distress class, or either of the adverse life satisfaction classes, relative to the healthful class for each outcome.

3.2.3 Summary of findings: stress-buffering and main salutogenic effects

Taken together, the results in relation to Research Aims 1 and 2 suggest that the salutogenic benefits of POS greenness within the rather immediate vicinity of the home (500m) accrue primarily via a stress-buffering mechanism, endowing little protection against rising psychological distress unless the individual reported experiencing a substantial number of acutely stressful life events. Considering POS within a somewhat broader environment (1000m), there was evidence for both a stress-buffering and a health-promoting effect, such that POS greenness protected against rising distress under normative levels of stressful exposure within the study sample. This combination of mechanisms is plausible (Wheaton, 1985) and might reflect the contributions of multiple psychosocial explanatory factors. Understanding these mechanisms has important implications for the efficiency of interventions aimed at improving population mental health. For instance, a stress-buffering mechanism implies that the benefits of POS greenness are primarily applicable to individuals under heightened stress, suggesting that improvements to POS greenness should be targeted towards neighbourhoods at the highest risk of socio-environmental stressors; for instance, areas characterised by socioeconomic deprivation or high proportions of minority groups. By contrast, a main-effect mechanism implies that all individuals are likely to benefit from POS greenness to a similar extent, providing support for a more widespread allocation of resources. A number of possible psychosocial mediators were evaluated in this research (Research Aim 3) and the findings of those investigations are discussed shortly.

In relation to Research Aims 1 and 2, the effects of POS greenness were only evident in relation to the odds of membership in the worsening psychological distress class, relative to the healthful class. There was no evidence for a stress-buffering or health-promoting effect of *POS greenness* on membership in the chronic high-distress class, relative to the healthful class. POS greenness also did not appear to inhibit the adverse effects of stressful events on life satisfaction, nor did it appear to promote life satisfaction independently of exposure to stressors, possibly signifying a specificity of the effects of POS greenness to negative dimensions of mental health. The lack of statistically significant protective associations with life satisfaction was a common thread throughout the analyses in the thesis, and is addressed in depth at the end of this section. For now, I focus on the finding that POS greenness appears to lack potency in preventing a more substantial and enduring

elevation of psychological distress, characterised by membership in the chronic high-distress class, through either a stress-buffering or salutogenic mechanism.

This is not the first piece of evidence to suggest that a predisposition to elevated psychological distress might abate the stress-buffering or health-promoting characteristics of POS greenness. Gariepy et al. (2015) analysed 10-year trajectories of depressive symptom episodes using a growth mixture analysis similar to that employed in this thesis, but assessed the effects of POS availability on within-class (rather than between-class) trajectory variation. The authors found that having any POS within 500m of the home was associated with a lower likelihood of experiencing a depressive symptom episode, but only among individuals with a low-to-moderate long-term probability of such episodes. A protective effect was not evident among individuals with a high long-term probability of depressive episodes. In other words, similar to the findings of Research Aims 1 and 2, the presence of POS was associated with better mental health but only among individuals with reasonably good mental health to begin with. Taken together, these findings appear to suggest a threshold of individual risk beyond which the provision of POS resources is ineffective in preventing psychological distress.

The following sections explore possible interpretations of these null findings from the perspective of non-conscious (direct) and conscious (indirect-cognitive) mechanisms linking POS to mental health (see Chapter 2, Sections 2.1.4 and 3.7). Specifically, returning to the two key limitations of experimental 'nature experience' research introduced earlier, I explore this question from two perspectives pertaining to potential idiosyncrasies in stress exposure and activity cycles that might differentiate this group of participants from the rest of the population. The first (non-conscious) interpretation is primarily relevant to a stress-buffering effect, while the latter interpretation (pertaining to conscious POS usage) is more broadly applicable to both stress-buffering and main salutogenic effects of POS greenness.

3.2.4 Interpretation of null findings: non-conscious (direct-contextual) mechanisms

Because close to one-third of Montréal residents reported that they never use a park perceived to be within walking distance of the home (Moore et al., 2010), null associations in relation to the chronic high-distress class are first interpreted with respect to a non-conscious mechanism of restoration that does not necessitate the assumption of POS usage, but could operate through the mere visibility of nature in daily life. Specifically, this

interpretation considers whether individuals in the chronic high-distress class experience a type of stress that is beyond the bounds of effective 'nature restoration'.

Compared with members of the healthful class, these individuals typically reported 1.5 additional (weighted) stressful life events in each year preceding the three waves of data collection, at an average of three to four events per year (Table 43, p.233). This is noteworthy because: only a relatively severe set of negative life events was measured; acute stressors in one role domain might "carry over" to exacerbate the negative psychological effects of those in other domains, such that their effects are not merely additive (Thoits, 1995); acute stressors may beget enduring strains, which were unmeasured in this research but can be equally stressful and serve to shape the meaning (and effects) of SLE (Pearlin, 1989); and individuals in this class also appear to have the worst access to socio-economic resources (and potential stress moderators) including income, education, and employment (Table 42, p.233). Altogether, it is reasonable to assume that these individuals face a considerably greater risk of chronic stress.

Chronic stress refers to "stress that persists 'abnormally' or that lasts for a long time, either because it occurs repeatedly or episodically, continuously, or because it poses severe threats that are not easily adapted or overcome" (Baum et al., 1999, p.132). Thus, repeated acute stressors (reflected in this research by high SLE scores) are not necessarily indicative of chronic stress but might precipitate this condition by exposing the individual to frequent 'hits' of stressors that demand adaptation without permitting sufficient time for recovery (McEwen, 1998a). The persistence of stress over time is accompanied by a decline in the performance of neuroendocrine stress responses, which gradually become overloaded, exhausted and under-reactive to subsequent environmental demands (O'Dea and Daniel, 2001, Guilliams and Edwards, 2010). This suggests that the 'metabolic machinery' of the stress process may be poorly adapted to the persistent and recurrent nature of stressors in modern life; indeed, while physiological stress reactions are protective in the short term, "too much of a good thing" (McEwen, 1998a, p.317) has been implicated in the modern epidemic of chronic disease (Daniel et al., 2008, Guilliams and Edwards, 2010).

Considering this, it is equally plausible that the restorative effects of nature are not optimally adapted to modern conditions. Hunter-gatherer societies in the environment of evolutionary adaptedness are thought to have been relatively egalitarian, with few resource constraints and a small proportion of time devoted to economic survival tasks (Charlton, 1996). Nature restoration could well be efficacious under the patterns of stressful exposure that arise in those conditions, but much less potent as a buffer against the chronic stressors

to which many populations are now vulnerable. Present day society is characterised by structural inequalities that perpetuate the demands faced by certain groups and exacerbate the likelihood that those stressors proliferate throughout various role domains (Turner, 2010). In the present research, there was clear evidence to support the relevance of this assertion to the chronic high-distress class. Although enduring strains were not measured directly, it is broadly recognised that these converge within a broader temporal context with the experience of stressful events (Pearlin, 1989). For example, the breakdown of a relationship is likely to follow a period of interpersonal strain, while a loss of employment is likely to precipitate a period of financial strain. This knowledge, combined with the observed chronicity of stressful events and history of mental health problems within the high-distress class, suggests that these individuals could face a much more intractable constellation of stressors than do other residents of the catchment area.

It is therefore possible that the restorative effects of natural environments are not potent enough to break into the spirals of resource loss precipitated under these conditions (Hobfoll, 2001). Moreover, restoration theory primarily posits that salutogenic environments could assist the individual in returning to a state of adaptive homeostasis following the arousal of stress; i.e. that the effect is preventive rather than one stimulating recovery from a state of ill health. This is the model upon which the vast majority of experimental research supporting restoration theory is predicated, begging the question as to how this theory applies to people already in a maladaptive state marked by chronic stress and dysregulation of stress processes. For these individuals, it is possible that restorative environments will do little to influence the impact of life stressors in the absence of more focused treatments. This might explain the inefficacy of stress-buffering effects in relation to this class.

Some research has attempted to address this issue by purposefully recruiting individuals diagnosed with a clinically diagnosed mental disorder, and appears to indicate that the cognitive and affective benefits of exposure to a natural environment are indeed generalisable to this condition (Berman et al., 2012, Roe and Aspinall, 2011). In fact, these studies provide some evidence that the gains from nature experience may even be superior for individuals with poor mental health, or those under greater stress, possibly because their initial deficits in mood or attentional states provide greater scope for recovery. For instance, Roe and Aspinall (2011) found that, following a one-hour rural walk through woods and open countryside, individuals with a clinically diagnosed mental disorder experienced greater improvements in mood than those in good mental health, as well as

greater improvements in levels of perceived stress and mastery related to their current personal projects. Interestingly, however, a follow-up study reported in the same article indicated that adults in poor mental health obtained very similar benefits from a walk through an urban area as they did from a walk through a rural area; by contrast, and consistent with most other evidence of restorative effects, adults in good mental health obtained limited benefits from the urban walk but responded markedly to the rural walk. It is possible that, for those with a mental disorder, the mere opportunity to take a walk with others – regardless of the setting – brought substantial affective and cognitive benefits, but did not satisfy a similar need in those free of mental disorder. This could possibly indicate a broader deficiency in the extent to which these individuals engage in opportunities for recreation and restoration in the urban environment generally (Staats et al., 2016).

3.2.5 Interpretation of null findings: conscious (indirect-cognitive) mechanisms

The discussion above infers a second possible explanation for a lack of stress-buffering and 'main' salutogenic effects in relation to the chronic high-distress class, which is that individuals at greater risk of psychological distress interact with their environment in a way that insulates them from the potential benefits of urban nature. The notion of activity cycles was a key component of the conceptual framework for this study, which described how regular patterns of activity interact with attributes of the environment to shape opportunities for stress and restoration (Hartig et al., 2003b). Neighbourhoods are not merely containers of resources and passive individuals; rather, they constitute spatially defined distribution networks through which active agents access opportunities to protect or improve their health (Bernard et al., 2007). Returning to prior research introduced in Section 3.2.3, it is noteworthy that Gariepy et al. (2015) did not identify protective effects of numerous neighbourhood resources – including POS, healthy food stores, healthcare services, or fast food restaurants – among individuals with a high long-term probability of depressive symptomology, despite evidence that these were beneficial for individuals following a low probability symptom trajectory. Although analyses did not account for potential confounders at the neighbourhood level (e.g. socioeconomic deprivation), the findings support the notion that individuals at risk of chronically elevated depressive symptoms utilise neighbourhood resources in a manner different to those with a lower risk profile.

Residents are heterogeneous agents who move through the neighbourhood for a variety of reasons, both self-determined and externally demanded, and attach varying significance

to different places depending on subjective meanings and experiences accumulated over time (Hartig and Evans, 1993, Cattell et al., 2008, Korpela et al., 2009). In some instances, the significance of a certain place and the motivation to visit might reflect the salient ways in which it satisfies needs and desires that arise in other environments (Hartig and Evans, 1993). For instance, a desire to visit a natural environment might be motivated by the recognition of a need for restoration from stress or attentional fatigue that manifests itself in the built environment (e.g. at work, in transit, or at home) but is less effectively alleviated there. Here, dominant theories of human attraction to nature assume an implicit awareness of the deleterious, constraining or unsatisfying qualities of the built environment and the extent to which a natural environment could contrast or complement them. In the previous example, agentic interaction with a natural environment would reflect an acknowledgement of some state of psychological disequilibrium that the individual actively seeks to remedy. Similarly, other commonly cited incentives for visitation – a desire for social interaction or exercise – represent active approaches to the self-regulation of psychosocial and physiological resources. This begs the question of how the usage (and health-promoting potential) of neighbourhood POS resources might be influenced by the salience of individual needs, the salience of potential solutions, and the extent to which the individual is willing or able to act upon them.

3.2.5.1 The role of individual agency in accessing restorative opportunities

Characteristics of the physical environment are but one determinant of opportunities for restoration, and may be insufficient in the absence of appropriate social and behavioural conditions (Staats et al., 2010). As described previously in Chapter 2, individual activity cycles are constrained by social roles and higher order processes that shape the frequency, mode, and character of movements between settings (Hartig et al., 2003b). To take a simple example, research has shown that working single parents and dual-worker parents spend substantially less time in parks than do parents in two-parent, single-worker families (Fan et al., 2012). Another study found that although residents in more deprived neighbourhoods of Bristol, England, lived objectively closer to green spaces than those in more affluent areas, they perceived their accessibility to be worse and used the spaces less (Jones et al., 2009). Similarly, Annerstedt et al. (2012) failed to identify direct protective effects of access to various green qualities, but did find that these synergised the protective effects of regular physical activity to further reduce the risk of psychological distress. While Annerstedt et al. (2012) found that this synergy was dependent on the gender of the individual, Ambrey (2016) further found that it depended on the population of the

neighbourhood, indicating that the marginal utility of green space might be greater in more populated areas. This study alludes to the potentially intricate nature of interactions between elements of the individual and environment that might augment or limit the effectiveness of green POS.

Despite this, studies of POS and mental health typically ignore individual agency, seeking a generic human response to the availability of natural environments and sidelining important factors associated with how people live their lives, cope with stress, and are inclined and able to avail themselves of local POS resources (Hitchings, 2013). As Curtis states, (1998) "policies targeted at areas rather than individuals are 'blunt instruments' which will not necessarily reach the individuals who are most in need of intervention to improve their health". The findings of this research, taken in the context of prior knowledge and the conceptual framework for the thesis, suggest that individuals benefit from increased interaction (indirect or direct) with natural POS during times of heightened stress. The scope of these effects could, however, rely on the extent to which individuals are able to demonstrate 'adaptive' agency by reordering their choices and actions to overcome the influence of emerging environmental constraints and take advantage of these resources (Bell et al., 2014). Despite this, little is known about how significant life events and transitions influence green space use. For example, accessing a natural setting may require forward planning that, paradoxically, requires the individual to draw upon depleted cognitive resources; while access to nature may be perceived as 'ideal' when the need for restoration arises, the practical complications in achieving this may reduce the perceived desirability of visiting nature (Staats et al., 2010). As Hitchings (2013 , p.98) states, "perhaps the question to pose is less one of whether green space experience can be good for people and more one of how best to tempt them there".

3.2.5.2 Possible influence of chronic stress on the use of green POS

The factors governing the use of green POS may be relatively enduring, such as the level of inherent connectedness to nature (discussed later in this chapter), or else differ over time according to situational influences. While evidence exists that individuals seek out nature in times of stress, a more nuanced understanding of how, when and why different people utilise urban nature in these situations is required (Staats et al., 2010). For instance, it would be interesting to understand whether the tendency to seek out nature only applies up to a certain threshold of stress. Prevailing evidence tends to elicit recall of states that are well known to most individuals, such as feeling tired and drained, but does not

provide insight into actual behaviour under the kinds of stress that would be associated with repeated exposure to relatively severe acute socio-environmental stressors.

Interestingly, Korpela et al. (2010 , p.200) found inconsistent evidence of mediation in the relationship between environmental stressors and the effectiveness of restoration in favourite places, with the frequency of visiting those places playing a significant regulatory role. “The more worries about money and work (during the last month) a person had, the more stressed a person had felt during the last year, the less energetic s/he had felt, the lower was the number of visits to the favourite place (during the last 6 months) and the lower the typical level of restorative experiences. Inconsistently, the direct path suggested that the more worries about money and work, the higher the typical level of restorative experiences” (Korpela et al., 2010). Thus, while restorative effects appear to be enhanced by a greater precipitating level of stress or attentional fatigue when the individual is exposed to a natural setting, those conditions also reduce the extent to which the individual accesses ‘favourite places’ of their own accord for self- and emotional regulation. This is particularly pertinent given that depressive symptoms, a key component of psychological distress, may be marked by fatigue and feelings of hopelessness as well as a tendency to engage in pleasant activities less frequently (Cuijpers et al., 2007).

In this respect, it is worthwhile to return to the therapeutic landscapes framework introduced in Chapter 2 (Section 2.3.3), which highlighted the possible contingency of place-health relationships on individually specific interactions between individuals and their environment. Specifically, research in this field suggests that human responses to natural settings (and, in turn, their therapeutic properties for mental health) are not universally similar but may depend upon individual perception, and particularly the sociocultural experiences and value systems that shape preference (Curtis, 2010). The point was raised that some individuals may be fearful of natural landscapes characterised by dense or visually impenetrable vegetation, particularly if they have limited lifetime experience of these spaces (Milligan and Bingley, 2007), and that seemingly ‘beneficial’ attributes could even produce negative psychological responses under these conditions (Curtis, 2010). Yet, beyond adverse reactions to the experience of nature itself, the framework also allows for the possibility that unrelated individual experiences and sociocultural expectations could impact on the extent to which individuals perceive benefit from, and engage in, POS use. A fear of judgment on the basis of how one should look or behave in public spaces, for example, may lead to avoidance among individuals who feel they do not conform to these norms (Thomas, 2015).

In the context of the present research, this could be applicable to individuals with a high propensity for psychological distress, who are anxious or wary about the possibility of engaging in social interactions with unknown persons. Moreover, heightened exposure to stress among members of the chronic high-distress class could be associated with a disruption to personal circumstances that limits opportunities to avail oneself of green space use during times of stress. This disruption could relate, for example, to changes in interpersonal relationships or employment circumstances induced by stressful events. It is also worth noting the history of mental health problems and high levels of distress reported by these individuals at commencement of the study. A realistic consideration of the role of individual agency in determining the extent to which people reap the benefits of neighbourhood-based resources should refer to the structural constraints on individual choice and actions, as well as the manner in which accumulated experience of stressful circumstances might influence the exertion of agency. I explore this question through consideration of a personal coping resource that facilitates the exercise of individual agency and may be sensitive to prolonged or repeated exposure to stress; namely, a sense of control or mastery over life (Pearlin and Schooler, 1978, Pearlin et al., 1981, Thoits, 2010). More specifically, I attend to the phenomenon of learned helplessness precipitated by a perceived loss of control.

3.2.5.2.1 Learned helplessness and its intersection with coping responses

Learned helplessness (LH) refers to the motivational, cognitive and affective deficits that may follow repeated exposure to uncontrollable stressors and influence the manner in which the individual responds to future adversity (Abramson et al., 1978). This network of deficits inhibits the performance of tasks that require the selection, organisation and implementation of voluntary responses to solve a problem, as demonstrated experimentally in animal and human subjects who, following exposure to recurrent uncontrollable events, fail to learn or implement appropriate responses to avoid failure in subsequent tests.

The primary mechanism underlying these performance deficits is thought to stem from a cognitive representation of the contingency (or independence) of actions and outcomes, based on the causes to which the individual attributes prior failures to effect a desired outcome (experiences of helplessness) (Abramson et al., 1978). Repeated exposure to uncontrollable outcomes is liable to reduce the expectancy of control over future circumstances, such that the individual anticipates that future responses would be futile in achieving a desired result. This expectancy, conceptually similar to a diminished sense of personal control or mastery (Pearlin et al., 1981, Ross and Mirowsky, 2013), can inhibit

motivation to initiate instrumental actions to alleviate sources of stress; interfere with the ability to learn about response-outcome dependency in subsequent situations; and trigger negative affect (Isaacowitz and Seligman, 2007). As Pearlin et al. (1981 , p.340) state, eventful experience and persistent hardship "can confront people with dogged evidence of their own failures – or lack of success – and with inescapable proof of their inability to alter the unwanted circumstances of their lives". The attribution of prior failures to causes that are stable (cf. temporary), global (cf. specific), or internal (cf. external) engenders a greater perceived loss of control and is likely to result, respectively, in deficits that are more lasting, generalised across domains, and accompanied by a loss of self-esteem. Thus, symptoms of learned helplessness are attributable not only to an objective non-contingency between prior responses and outcomes, but to the perception and attribution of those occurrences and, ultimately, the extent to which non-contingency is expected in future.

Mikulincer (1994) expanded Abramson et al.'s (1978) formulation of learned helplessness theory (described above), integrating the body of empirical evidence and theoretical perspectives amassed since its publication into a framework that situates helplessness deficits as the evolving consequence of active coping in an uncontrollable environment. Specifically, the theory draws upon Lazarus & Folkman's (1984) model of coping and adaptation to describe how the mobilisation of coping strategies following a perceived threat changes in response to recurrent failure, and mediates the relationship between control expectancies and helplessness deficits. Following a small amount of failure, people ordinarily hold a reasonably high expectancy of control and employ alloplastic adaptation strategies aimed at overcoming an obstacle (problem solving) or modifying the perceived threat associated with it (reappraisal). These coping strategies preserve self-concept and existing cognitive schemas by focusing adaptation efforts outwards towards the environment; their aim is to maintain the baseline adaptive state of the individual in its broadest sense. Following a large number of failures, people typically lower their expectancy of control, leading to off-task autoplastic or escapist coping strategies, such as adjusting mental structures, goals and priorities to align with the events experienced (reorganisation) or simply disengaging cognitively and behaviourally from the problem (avoidance). In a similar fashion, Thoits (2006) argues that the frequently documented stress-buffering effects of a perceived sense of control over one's life may be explained by the unmeasured agentic behaviour facilitated by this personal resource.

These variations in coping responses presumably reflect changing perceptions of the efficacy (and cost) of problem-focused actions or the individual's sense of self-efficacy in

deploying them, and appear to follow an 'invigoration-deterioration' cycle; whereas the initial response to a perceived threat or obstacle may be heightened arousal and motivation to deal with the situation, with increasing exposure to stressors this appears to give way to passivity and 'giving up' (Mikulincer, 1994).

3.2.5.2.2 Possible linkages between coping responses and POS usage

In the context of this thesis, research on learned helplessness indicates that the individual's history of exposure to acute stressors, and the resources available to control the outcomes of those events, might shape the organisation of behaviour in response to recently experienced or potentially forthcoming stressors. For instance, individuals with a proactive coping orientation may be more likely to take preventive steps and develop habits that will reduce the impact of unavoidable problems on their wellbeing (Ross and Mirowsky, 2013). They should also be better equipped to compensate for stressful situations by seeking out positive or satisfying experiences by redirecting the investment of time and energy towards new or existing activity domains (such as outdoor recreation and exercise) that cultivate gratification and counterbalance uncontrollable hardship arising in other areas of life (Thoits, 2006 p.313). Hitchings (2013) describes how sheer force of habit and personal routine might lead individuals to forget or neglect the idea of spending time outside. As detailed in Section 3.2.4, individuals in the high-distress class are presumably at greater risk of chronic stress and 'burnout' marked by emotional exhaustion, physical fatigue, and cognitive weariness (Melamed et al., 1999). Habits and routines might therefore be strongly ingrained, and unreactive to novel environmental triggers such as stressful events. On the other hand, activity cycles might be more malleable for individuals with initially good mental health, who are better placed to "actively construct their lives in order to eliminate or dampen the effects of stressors" (Thoits, 2006 p.313, p.316). This could explain why the availability of green POS, as a resource for active coping strategies, is only amenable to stress-buffering among the latter group.

Altogether, it is plausible that historical differences in stress exposure and (possibly related) distinctions in coping styles could influence the manner in which the individual accesses neighbourhood resources such as green POS for the purposes of restoration. Individuals with a strong sense of control might actively seek opportunities for restoration to fortify themselves against potentially forthcoming stressors, or to enhance the efficacy of problem-solving and emotion-regulation efforts following a stressor. By contrast, a tendency to employ avoidance coping strategies – which might include behavioural avoidance of social situations, new activities, or leaving the house, as well as cognitive

avoidance of thoughts about the future or how to improve in areas of deficiency (Holahan and Moos, 1987, Ottenbreit and Dobson, 2004) – could redefine the salient aspects of POS to the extent that they support these inclinations. Korpela et al. (2001) describe how the attribution of identities and formation of attachment to places with restorative potential are reciprocally influential with processes of self- and emotion regulation. Here, compatibility with the inclinations and purposes of the individual appears to be more important than the inherently engaging or interesting properties of the environment, per se, in determining the difference between 'favourite' and 'unpleasant' places. Although natural settings are typically a dominant 'favourite place' at the aggregate level, there is also evidence that 'favourite places' exist in the built domain (Korpela et al., 2009). For an individual seeking the opportunity to reflect on personal problems in non-distracting circumstances, green POS may be an ideally supportive environment. By contrast, for those seeking distraction and avoidance from their problems, this may be less appealing.

A tendency towards avoidance strategies might therefore limit the extent to which individuals use green POS, both purposefully and incidentally. It is possible, then, that the observed lack of a stress buffering effect in the chronic high-distress class reflects the influence of distinctions in coping styles and, subsequently, activity cycles due to a reduced sense of personal control among members of the chronic high-distress class. Ross and Mirowsky (2013) have previously described how a perceived lack of control could interact with threatening conditions in the neighbourhood, such as crime and disorder, to amplify their effects on mistrust and further compound the sense of powerlessness. In a similar manner, by compromising individual agency, it is possible that a low expectancy of control might hinder the use of positive neighbourhood resources (such as green POS) and, in turn, prevent the individual from accessing the benefits of restoration and reflection that could enable a more proactive approach to meeting life challenges (Herzog et al., 1997, Roe and Aspinall, 2011).

3.2.5.2.3 Structural forces shaping individual learned helplessness

I take this opportunity to clarify that the discussion outlined across the preceding sections does not intend to attribute learned helplessness effects to the complacency or failings of the individual, per se. Rather, this framework is adopted in order to encourage consideration of the full context of the individual's life, and how broader structural conditions might play out through individual behaviours to influence the efficacy with which the community-level provision of resources results in improvements to population health (Thoits, 1995). The conceptual framework presented in Chapter 2 described a social

ecological structure in which physical, social, economic, and cultural contexts have the potential to pervade the daily lives and experiences of individuals, such that the differential placement of individuals within these larger systems may generate inequalities in health and wellbeing over time (Stokols et al., 1996, Pearlin, 1999). It also explicitly linked the influence of social roles and higher-order structural processes to the performance of activity cycles and, in turn, opportunities for restoration (Hartig et al., 2003b). Consistent with the hypothesis that lower control expectancies might relate to reduced POS usage, previous studies have found that structurally disadvantaged groups (e.g. older adults, racial or ethnic minorities, females and lower-income families) are also more likely to be infrequent or nonusers of parks, citing a lack of time, money, personal health, information and transportation among reasons for not engaging in park-related activities (Bedimo-Rung et al., 2005).

Endowment with optimal coping resources is not attributable to individual efforts alone, but also to one's place in society (Hobfoll, 2001). The availability of material resources and opportunity, in the sense of possessing education, employment, and social status, shapes and interacts with psychosocial resources to determine coping responses (Hobfoll, 2002). Thus, beliefs about personal control are also often realistic perceptions of objective conditions, and vary systematically with structural positions indicative of powerlessness. "People's positions in the social structure equip them (or not) with resources that enhance (or inhibit) the exercise of agency, and they are able to act (or not) in their own best interests only within social and cultural constraints that are themselves unequally distributed by social status" (Thoits, 2006 p.318, see also Williams, 2003). For instance, resource and opportunity barriers to the achievement of socially desirable goals or the satisfaction of the demands and expectations implicit in social roles might predispose the individual to failure in the face of effort and, eventually, fatalism and helplessness (Ross and Mirowsky, 2013).

The protection, recovery, and acquisition of coping resources itself requires some initial investment of resources from the existing reservoir; for instance, time, money, cognitive effort, social support, or favours might be expended in pursuit of these goals. For this reason, individuals less endowed with resources to begin with are also less capable of resource gain and more vulnerable to spiralling resource losses. These individuals often adopt a defensive (avoidant) strategy of coping with stressors, either because they do not have appropriate resources available to invest or because they choose to conserve their limited reserves rather than investing them in the current situation (Holahan and Moos,

1987, Hobfoll, 2001). In other words, active coping is avoided at the risk of exacting a major resource cost. Yet, these responses are less likely to result in successful adaptation, leaving the individual at risk of further resource losses and a subsequently weakened resource pool. Because resources tend to aggregate in caravans, both at a given point in time and across the life span, shortages of resources are usually apparent in a general (rather than resource-specific) sense. Thus, for individuals with depleted resource reservoirs, "intervention will have to be broad-based and multifaceted. In contrast, for those who are well endowed with resources, intervention may only need to allow them respite in order that they remobilise their resource armamentaria" (Hobfoll, 2001 , p.363). Once again, this indicates why POS greenness might be more beneficial to individuals at lower risk of psychological distress.

3.2.6 Summary

Findings of Research Aims 1 and 2 suggest that POS greenness is protective against rising levels of psychological distress throughout a four-year period, and could exert its effect through both stress-buffering and main effect mechanisms. However, if ecological interventions directed towards elements of urban residential design are to succeed in promoting population health, further attention must be paid to the factors that influence the reach, incidental benefit, and utilisation of neighbourhood resources. The notion that prolonged or heightened stress could influence activity cycles (e.g. if individuals withdraw from social interaction or physical activity) indicates that these conditions might alter individuals' movement through the neighbourhood, thereby influencing the scope for indirect exposure to POS as well as purposeful usage. Under these circumstances, the mere provision of greener POS may be ineffective in protecting against acute stressors in the populations most vulnerable to the processes of stress proliferation and cumulative disadvantage that cause increasingly widening inequalities in mental health outcomes (Thoits, 2010).

3.3 Research Aim 3: Assessing the indirect effects of POS greenness on mental health, via psychosocial resources

Research Aim 3 sought to evaluate the intermediary role of psychosocial resources at three levels – within the individual, within the neighbourhood social environment, and within broader social networks – in explaining prospective associations between POS 'greenness' and mental health. This analysis, reported in Chapter 6, began by investigating cross-sectional associations between POS greenness and five psychosocial resources

covering a spectrum of intra-personal, interpersonal, cognitive, and behavioural dimensions – social cohesion, neighbouring behaviour, community participation, social support, and coping. As in the assessment of Research Aim 2, these relationships were estimated conditional upon the number of acute stressors reported, to reflect a generalised health-promoting role mechanism (Wheaton, 1985). Throughout this section, I allude to some limitations of the study design employed in this thesis, as they are pertinent to a discussion of the results. A more detailed exposition of the study limitations is presented later in this chapter.

3.3.1 Evidence for cross-sectional associations with psychosocial resources

Of the five psychosocial resources tested, only social cohesion exhibited a statistically significant association with POS greenness. The positive association between these variables was statistically significant at both spatial scales after adjusting for multiple testing (see Section 4.3.1 of this chapter) and was directionally consistent with the point estimates of associations with neighbouring behaviour, perceived social support, and coping (Figure 31, p.230). This provides a degree of evidence for a broad association between POS greenness and a constellation of intra-individual and interpersonal psychosocial resources, lending plausibility to the conclusion that the association with social cohesion was not merely a chance observation. Possible theoretical explanations for the observed differences in effect sizes, particularly between social cohesion and the measures of neighbouring and social support, are discussed further shortly. However, the pattern of results also raises the possibility that social cohesion was the only intermediary variable measured with enough precision to detect a statistically significant effect. The subsections below attend in further detail to the observed cross-sectional associations between POS greenness and coping, community participation, and social cohesion. The following sections (3.3.2 to 3.3.4) discuss evidence for an indirect effect of POS greenness on mental health, via social cohesion.

3.3.1.1 Coping

The lack of a statistically significant association with coping was counterintuitive, given the stress-buffering effects identified in Chapter 5. However, this could be attributable to a lack of reliability in the single-item instrument employed to measure this construct. Single-item measures generally permit only broad-brushed distinctions between individuals (here, the coping item distinguished only five levels of the construct) and often possess considerable measurement error because a given individual is unlikely to select exactly the same response in successive administrations of the instrument (Churchill Jr, 1979). These

measures may be particularly problematic for abstract or multidimensional constructs, such as coping, where ambiguity in interpretation of the item between individuals introduces additional random error to the responses (Fuchs and Diamantopoulos, 2009). In the present study, the general nature of these limitations was compounded by the fact that roughly one-third of the sample (English-speaking participants) responded to a different coping item than did the rest (French-speaking participants). As detailed in Chapter 3, the two items reflected different requirements and applications of the coping process. The French item related to managing ambient day-to-day stressors, and the English item to managing acute stressors. While it is plausible that both questions tap into the participant's latent ability to deal with stress, and inter-item correlations at later waves of the study were good (Spearman's ρ=0.58, 0.62 at T2, T3), this oversight directly introduced an additional element of interpretational ambiguity and, consequently, measurement error. Finally, a skip pattern in the questionnaire directly resulted in a significant amount of missing data (12.7%) on the coping measure. Although the MAR assumption was satisfied, permitting multiple imputation of the missing data to preserve sample size, this procedure does introduce additional (between-imputation) variance to the measures (Rubin, 1987). Taken together, these factors are likely to have eroded the statistical power of the present study to detect a true effect of POS greenness on coping. Importantly, despite these limitations, the point estimate for the association between POS greenness and coping was directionally consistent with the hypothesised effect, indicating that this may be a fruitful avenue for future research.

As a final note, it is possible that a lack of specificity in the measure of coping could obscure associations with POS greenness if effects vary across different dimensions of the outcome. For instance, POS greenness might support problem-focused coping in a different manner to emotion-focused coping or, as alluded to earlier, active coping in a different manner to avoidance coping (Taylor and Stanton, 2007). Existing self-report measures could be employed to explore these relationships in greater detail. For example, the Ways of Coping questionnaire (Folkman and Lazarus, 1988) could be used to evaluate whether POS greenness supports specific coping strategies such as planful problem-solving or positive reappraisal, which might be supported by the replenishment of directed attention resources. However, such an approach does not circumvent the broader problems inherent in attempting to measure internal processes indirectly via self-reports. Specifically, these assessments require the conscious appraisal and verbalisation of internal processes by the participant, in response to a set of criteria elicited by the researcher, and

might inadequately capture the full range of relevant processes and conditions that support successful coping (Young, 1980). More direct measurement techniques, for instance via physiological markers of stress, might therefore also be employed to enable the identification of non-conscious mechanisms of stress reduction and restoration that could operate below the level of individual awareness.

3.3.1.2 Community participation

One psychosocial resource – community participation – was inversely associated with POS greenness, although this relationship was not statistically significant. Although directionally inconsistent with associations of POS greenness to the other psychosocial resources, this finding is not inconsistent with prior research. The instrumental acts captured by the community participation measure – such as participation in a neighbourhood association or contacting an elected public official – are frequently motivated by functional or political concerns in relation to the neighbourhood. These acts seek to achieve collective goals; change the neighbourhood's physical, economic, and institutional environments; and redress inequality within and between neighbourhoods (Swaroop and Morenoff, 2006). In this sense, community participation is a conceptually distinct type of network relations when compared with the informal exchanges of sociability, information, and support that might be captured by measures of social cohesion or neighbouring behaviour (Bernard et al., 2007). The observed association might indicate that low levels of POS greenness motivate residential activism because the quality of open space resources is perceived to be inadequate (Peters et al., 2010). However, community participation tends to be more prevalent in areas of socioeconomic disadvantage, or where residents perceive greater disorder (Swaroop and Morenoff, 2006), and in this sense the observed association might simply reflect a broader state of under-investment or under-resourcing throughout the neighbourhood. Considering that the analyses were adjusted for area socioeconomic deprivation, the relative discrepancy between prevailing conditions and the type of opportunity structure 'expected' in a neighbourhood of a certain social status could be the driver of instrumental participation. Evidently, this raises some concern about residual confounding, which I return to later in this chapter.

3.3.1.3 Social cohesion

The statistically significant association of social cohesion to POS greenness observed in the present study is consistent with several pieces of prior research that have demonstrated positive cross-sectional relationships between cognitive dimensions of neighbourhood social integration and perceptions of neighbourhood greenness ('social coherence' in

Sugiyama et al., 2008); the quantity and quality of vegetation visible from the street ('social cohesion' in De Vries et al., 2013); and the perceived quality of public open space reflected in general impressions such as atmosphere, comfort, attractiveness and maintenance ('sense of community' in Francis et al., 2012a). Importantly, the absence of statistically significant associations with neighbouring behaviour and social support also has precedence in prior research. As detailed in Chapter 2, several studies have not found associations between the total availability of residential POS and the perceived availability of functional network-based social support (Triguero-Mas et al., 2015) or the frequency of social contact with other individuals and groups in the neighbourhood (Astell-Burt et al., 2013b). Others found that POS availability was protective against feelings of loneliness and a perceived shortage of social support, but had no bearing on the frequency of contact with neighbours or friends in the area, nor on the number of supportive interactions received (Maas et al., 2009b). The authors of that study suggested that POS resources might promote social wellbeing – and subsequently, mental health – by strengthening place attachment rather than supporting actual interactions between neighbours. Similarly, Völker et al. (2007) demonstrated that an association between the availability of neighbourhood 'meeting places' and social wellbeing was not reflected in the proportion of neighbours included in personal social networks.

Consistent with this notion, other studies found that the protective effects of perceived neighbourhood greenness or objective POS quality were not explained by measures of local social interaction (Sugiyama et al., 2008) or network-based social support (Francis et al., 2012b), respectively[99]. Meanwhile, both Sugiyama et al. (2008) and De Vries et al. (2013) concluded that protective effects of 'neighbourhood greenness' were partially mediated by perceptions of local social cohesion. Measures of the exposure in both those studies tapped into general impressions of 'greenness' as perceived by residents or

[99] Although prior research found that higher levels of vegetation in the courtyards of public housing developments predicted stronger neighbourhood social ties among adjacent residents (Kuo et al., 1998b, Kweon et al., 1998), the generalisability of those findings to other neighbourhood contexts is uncertain. The studies took place in impoverished, high density public housing developments with dramatic variation in POS greenness; while some common spaces consisted of grass and trees, others were barren concrete and devoid of vegetation. Thus, the relative contribution of 'extra' greenness in other settings, where most open spaces are likely to contain some amount of vegetation, may be far less influential. Perhaps more importantly, prior studies have shown that persons with low household income are more likely to have core neighbourhood ties, and that "rootedness" or stability within a neighbourhood influences the likelihood of engaging in neighbouring behaviour (Farrell et al., 2004). Furthermore, measures of POS greenness were derived for the common space directly attached to the building in which the individual lived, greatly increasing the likelihood that interactions within those spaces would occur among familiar neighbours. Together, these factors might explain why POS greenness was more conducive to the development of social ties in those studies.

independent raters. Thus, whereas the data in Francis et al.'s (2012b) study were not consistent with mediation by a sense of community or sense of place, this could reflect the focus on objective measurement of tangible quality attributes. By contrast, perceived quality reflected in general impressions of public open space (e.g. atmosphere, comfort, attractiveness and maintenance) has been linked to a sense of community (Francis et al., 2012a).

3.3.2 Indirect effects of POS greenness via social cohesion

The results in relation to Research Aim 3 indicated that social cohesion reduced the likelihood of following a worsening or chronically elevated trajectory of psychological distress (relative to a healthful trajectory of low distress) or a chronically low trajectory of life satisfaction (relative to a healthful trajectory of high satisfaction) over the ensuing four-year period. Formal tests of the indirect effect of POS greenness, via social cohesion, on membership in these trajectory classes revealed protective effects that were statistically significant across both spatial scales. Social cohesion did not, however, exhibit a statistically significant protective effect against trajectories of declining life satisfaction, and no corresponding indirect effect was evident. Because the chronic high-distress and chronic low-satisfaction classes are largely differentiated from their healthful counterparts by values of the outcome at T1, the observed associations do not implicate social cohesion as a temporal antecedent of these states of wellbeing and reverse causation cannot be excluded as an explanation. Similar to the interpretation of results in relation to Research Aims 1 and 2, however, evidence for an indirect effect of POS greenness on membership in the *worsening* psychological distress class suggests that the apparent ability of this physical resource to protect against prospective rises in distress occurs, at least partly, through its association with perceptions of social cohesion.

This study makes a significant and novel contribution to the body of existing literature by assessing mechanisms of mediation in relation to *prospective changes* in psychological distress. In particular, the temporal configuration of perceived social cohesion (measured at T1) and trajectories of psychological distress (from T1 to T3) makes alternative explanations of the association between these variables (e.g. that people with heightened distress perceive lower cohesion as a result, rather than a cause of their distress) less plausible. The cross-sectional nature of the association between POS greenness and social cohesion remains problematic, however, and I return to discuss this issue shortly. Altogether, the results across Research Aims 1 to 3 were broadly consistent across the

500m and 1000m spatial scales, indicating a certain robustness to the researcher assumptions of what constitutes the 'local' residential area.

3.3.3 Relevance of cognitive vs. behavioural dimensions of social integration

The consistency with which social cohesion is identified as a mediator of associations between POS greenness and mental health, but measures of behavioural integration or network capital and support are found to be unrelated to POS availability, is interesting from a conceptual standpoint. While there are noteworthy differences between POS availability and greenness, I explore these findings collectively from two perspectives. Once again, the first interpretation relates to a non-conscious (direct-contextual) mechanism and suggests that if the effects of natural stimuli and aesthetically pleasing environments operate largely through innate biological and psychological pathways, then outcomes pertaining to cognitive dimensions of neighbourhood social integration may be more proximal to these exposures than behavioural dimensions. The second interpretation relates to a conscious (indirect-cognitive) mechanism whereby the effects of green POS usage on cognitive dimensions of integration are hypothesised to transmit more readily throughout the community, and thus become more widespread, when compared with behavioural social correlates.

3.3.3.1 Interpretation of the relation between POS greenness and social cohesion: non-conscious (direct-contextual) mechanisms

In relation to possible non-conscious pathways describing the relevance of POS greenness to social cohesion, I return to theoretical discussion presented in Chapter 2 (Section 2.3.2) that described how biophilia might contribute to positive social perceptions and behaviours in communities with greater access to natural settings. In essence, that discussion proposed that an indirect path might exist from nature experience, via cognition and affect, to social outcomes. Specifically, it was hypothesised that if natural environments support enhanced self-regulation through restoration from stress or the replenishment of directed attention resources, then they may serve to inhibit socially inappropriate behaviours that lead to negative social interactions (Kaplan, 1995, von Hippel and Gonsalkorale, 2005, Kaplan and Berman, 2010). This perspective is consistent with the pattern of observed effects, where the influence of POS greenness on positive social behaviours (i.e. neighbouring) was directionally consistent but weaker than the influence on positive social cognitions (i.e. social cohesion).

I also discussed the fact that natural settings – even within urban environments – have been found to evoke a sense of belonging, order and purpose to the existence of oneself

and others (Chiesura, 2004). This is thought to reflect a psychological architecture that has evolved to respond to nature with feelings of kinship, affiliation and identity within the broader ecology of living beings. These feelings of emotional connection and stability can derive from an attachment to nature, and its seeming permanence, which can provide a powerful source of emotional bonding, attachment and nurturance (Kellert, 1997, Kellert, 2004, Terhaar, 2009). As Kellert (2004 , p.13) describes:

> "Nature is deeply significant to people as a source of moral and spiritual inspiration…The unity and connection [between living creatures] offers people a sense of underlying meaning and a cornerstone of spiritual belief. Perceiving universal pattern in creation provides a foundation for morality that gives definition and shape to our existence. Through the shared conviction in life's underlying relation, we achieve a sense of cohesion and mutual commitment. These sentiments encourage the belief that at the core of our existence may lie a fundamental logic, harmony, and even goodness. We derive faith and confidence through discerning a unity in creation that transcends our individual aloneness and separation."

It could therefore be argued that natural environments are especially conducive to a sense of confidence in the constancy of both one's self-identity and one's environment, supporting a feeling of ontological security; "of feeling at ease, or at home in a world which can appear external and threatening" (Dupuis and Thorns, 1998 , p.30). Evidence suggests that POS and natural features contribute particularly strongly to neighbourhood attachment (Korpela et al., 2001, Bow and Buys, 2003, Kim and Kaplan, 2004, Peters et al., 2010, Arnberger and Eder, 2012, van Herzele and de Vries, 2012) and that these affective person-place bonds are reflected in a greater sense of social coherence, integration, and actualisation (Rollero and De Piccoli, 2010) as well as better mental health (Theodori, 2001). The internalisation of group membership shapes the psychology of individuals through its influence on social identity, providing a sense of stability, meaning, purpose and belonging that is central to health and wellbeing as well as productive social interaction including cooperation, helping, trust, and organisation (Haslam et al., 2009).

This discussion brings to bear the distinction drawn by Carrasco and Bilal (2016) between social cohesion as a state of "being" and social capital as a state of "having". The former perspective understands social relationships as a normative framework of social organisation characterised by attributes such as trust, reciprocity, and solidarity, which are rather universally beneficial (Fulkerson and Thompson, 2008). The latter often emphasises the social interactions and investments of the individual within networks of relationships that provide access to resources important for one's social position. In this sense, it is

conceptually plausible that access to nature – although a 'capital resource' in its own right (Bernard et al., 2007) – should, through the arousal of a perception of belonging, primarily influence social cohesion. Empirically, this argument finds support in an experimental study by Mayer et al. (2009), who found that a sense of connectedness to nature (a sense of oneness with the natural world; kinship with animals and plants; and equality between the self and nature) mediated the association between nature experience and positive affect. The authors argued that researchers and practitioners "may want to think of more than simply how nature can restore depleted attentional capacity and reduce stress [but also] of how people need to feel a sense of belonging to something larger than themselves, and that this need may be fulfilled through a sense of connectedness to the natural world" (Mayer et al., 2009, p.635). Consistent with this viewpoint, Shanahan et al. (2016) very recently identified a positive association between self-reported connection to nature and social cohesion among a broadly representative sample of adults in Brisbane, Australia, adjusted for age, sex, income, education, days of employment per week, presence of children in the home, and area socio-economic deprivation.

3.3.3.2 Interpretation of the relation between POS greenness and social cohesion: conscious (indirect-cognitive) mechanisms

The second point that I prefaced earlier relates to a conscious (indirect-cognitive) mechanism by which POS greenness was hypothesised to influence neighbourhood social integration; specifically, that by providing a more pleasing aesthetic environment and open space resources that are attractive to residents, POS greenness might encourage greater POS use and/or neighbourhood walkability (Ulrich, 1993, Coley et al., 1997, Kuo et al., 1998b 102, Sullivan et al., 2004, Sugiyama et al., 2010) and thereby present more opportunities for individuals to interact with one another. In this respect, the findings of the present study might be indicative of the nature of the ties supported by such a mechanism. Here, the measure of neighbouring behaviour assessed interactions that might be initiated in the presence of moderately strong neighbourhood ties, such as discussing a personal problem with a neighbour or asking them to watch over one's house while away. The measure of social cohesion, on the other hand, might reflect broader networks of weak ties and a general sense of trust and familiarity among residents of the neighbourhood.

Considering the differential associations between social cohesion and neighbouring behaviour, this interpretation would indicate a more pronounced effect of POS greenness on weak rather than strong neighbourhood ties. Again, this is consistent with prior evidence. As already described, several population-based studies have not found an

association between the availability of POS or other meeting places and either the number of neighbours in personal social networks or the frequency of purposeful contact with others in the neighbourhood. Sugiyama et al. (2008) did find that perceived neighbourhood greenness was associated with a greater frequency of casual social interactions, including waving, saying hello, or stopping to talk with a neighbour, but it is possible that this study was confounded by same-source bias. Perceived greenness does not necessarily reflect objective reality and may be influenced by the cognitive and behavioural characteristics of the individual (Leslie et al., 2010). For instance, people who undertake a greater amount of walking or socialising in their neighbourhood might be more aware of nearby POS and therefore perceive their neighbourhood to be 'greener'.

In a study of well-known parks in three Dutch cities, Peters et al. (2010) described how culturally diverse groups of residents valued the opportunity for social interaction with others (known and unknown) but rarely visited with a primary motivation to meet strangers. Incidental interactions were infrequent, short, and typically amounted to little more than small talk, but were held favourably by POS visitors. In fact, weak neighbourhood ties – which tend to be more plentiful than strong ties and may be as insignificant as a nodding acquaintance – can endow residents with a feeling of familiarity and security that supports wellbeing, particularly when these casual encounters occur routinely or continuously over time (Henning and Lieberg, 1996, Forrest and Kearns, 2001, Cattell et al., 2008). In Peters et al.'s (2010) study, although people tended to visit POS to 'do their own thing', they felt at ease sitting very close to others when the size of the space demanded it. Interestingly, another study indicated that POS greenness might have a relatively greater attracting power for lone visitors than for groups (Sullivan et al., 2004), which is consistent with evidence that people desire refuge and solitude when seeking restoration (Korpela et al., 2001, Staats et al., 2003, Grahn and Stigsdotter, 2010, Nordh and Østby, 2013, Staats and Hartig, 2004, Staats et al., 2010). In addition to the processes described below, this might also explain the weak association between POS greenness and social support.

Although passing encounters may form the basis for stronger ties, these connections may be slow to develop and appear to require more frequent and routine use of POS resources (Cattell et al., 2008). As such, the present findings could also be indicative of a difference in the extent to which the associations of POS greenness with cognitive versus behavioural dimensions of neighbourhood social integration transmit throughout the neighbourhood beyond POS users. By its very nature, a mechanism whereby POS

greenness promotes social integration through greater numbers of incidental interactions would likely be most evident among individuals who visit POS. Moore et al. (2010) analysed associations between park use and social participation, using data collected from a sample of Montréal residents in 2008. In addition to parallels in the setting and timeframe of data collection, the sample in Moore et al.'s research was remarkably similar to the final sample the present study, both in relation to its size and composition along the lines of age, gender, education, marital status, and income, making it an interesting point of comparison for the findings described above. The authors found that among adults aged 25 or over who self-identified as having a park within walking distance of the home, 30% reported that they did not use the park, even occasionally. Interestingly, a statistically significant positive association was evident between park usage and informal neighbouring behaviour, akin to that measured in this study, controlling for a range of individual and area-level characteristics. Kaźmierczak (2013) identified a similar correlation between the frequency and duration of POS visits and the number of friends in the neighbourhood, although this was unadjusted for potential confounders. Contrasted against numerous studies, including this thesis, that have not found evidence of an association between residential POS *as a feature of the built environment* and local social ties or behaviours, the findings of Moore et al. (2010) and Kaźmierczak (2013) suggest that POS *usage* may be an important factor in the development of these outcomes. Consistent with this notion, Kuo et al. (1998b) found that the frequency of POS usage partially mediated an association between POS greenness and neighbourhood social ties. By contrast, frequency of POS usage could not explain a positive association between subjective POS quality and sense of community (Francis et al., 2012a) or between objective POS quality and mental health (Francis et al., 2012b) in studies of new housing developments of Perth, Western Australia.

3.3.3.2.1 Dyadic versus open-ended systems of local sociability

Although the pattern of relations described above is by no means conclusive, it raises the possibility that the effects of POS resources on cognitive dimensions of neighbourhood social integration might diffuse further throughout the neighbourhood than effects on behavioural dimensions, which appear to be more heavily localised among POS users. To clarify this viewpoint, I draw attention to the relatively dyadic versus open-ended nature of local sociability reflected in neighbouring behaviour (and/or social ties) versus social cohesion. Positive chance encounters with a variety of individuals, however fleeting or mundane, may be conducive to building a sense of trust and belonging that underlies broader systems of informal reciprocity throughout the neighbourhood as a whole, more so

than strengthening specific dyadic relationships. In this respect, POS may contribute toward strengthening open-ended systems of giving and receiving under the expectation that these acts will be reciprocated some time, somewhere, to or from some other person in the community (Bernard et al., 2007). The notion of trust is central to such systems of informal reciprocity, which distribute resources according to culturally determined and often unspoken rules in a manner far less systematic than their distribution by markets and institutions; in particular, the nature of the counterpart in these systems is much less specific, and the act of giving is based on trust in receiving some reciprocal action in future but not necessarily from the party of the initial transaction. The imbalanced and open-ended manner in which such systems regulate access to resources is a benefit of belonging to a broader collective ('being') that emanates beyond one's network of dyadic relationships (Felton and Shinn, 1992, Carrasco and Bilal, 2016). As such, the benefits of POS to local sociability may diffuse more broadly, beyond the individual and in a less systematic manner than that captured by the exchange of functional support among immediate neighbours; an orientation towards open ended provision of sociability, information, and support underpinned by trust that these favours may be returned, is not restricted to one's strong or proximal social ties. Interestingly, and consistent with this notion, Forrest and Kearns (2001, p.2132) note that "it appears that you can have good neighbours in places where people are [perceived as] not generally very friendly"; this point emphasises the distinction in the spatial diffusion of neighbouring behaviour in contrast with broader perceptions of social cohesion.

In relation to this point, it is noteworthy that, whereas the stress buffering effects of POS greenness were influential only in relation to the worsening distress class, the indirect effect via social cohesion was protective against membership in both the chronic high-distress class and chronic low-satisfaction class[100]. On a theoretical level, this may be

[100] In relation to the chronic distress class, consideration of the residual direct effect of POS greenness may be instructive. This configuration of effects accords with an 'inconsistent mediation' model (MacKinnon et al., 2000; Rucker et al., 2011) in which POS greenness increases the propensity for chronically elevated distress, either directly or through unmeasured intermediary variables, while also decreasing this propensity via its influence on social cohesion. However, the lack of a significant direct effect in this instance renders this conclusion somewhat speculative and open to further research. By contrast, there was no evidence to support the notion that the statistically non-significant total effects of POS greenness on membership in the worsening distress class or the chronic low-satisfaction class were attributable to inconsistent mediation. Specifically, the direct effects (path c') of POS greenness were always directionally consistent with the indirect effect and also smaller in magnitude than the total effect (path c) in these models. In these instances, it is possible that the study was simply underpowered to detect total effects; the precision with which effects on class membership were estimated was much greater for *social cohesion* than for *POS greenness*, which might render the indirect effect easier to detect than the total effect for a given sample size (Rucker et al., 2011).

attributable to the pervasive nature of social cohesion; if neighbourhoods with green POS are characterised by social cohesion, the ability of the individual to benefit might depend less on POS usage than, say, achieving restoration from stress (Grahn and Stigsdotter, 2003). Rather, all members of the community benefit from belonging to a cohesive community. As described previously, notions of trust, reciprocity, cohesion, and solidarity as attributes of social organisation are conceived to have a broad protective influence throughout society. The sense of belonging to a social group might combat the sense of normlessness and bondlessness associated with feelings of anomie and provide a source of resilience against the stressors experienced by this group (Curtis, 2010). In fact, Greenaway et al. (2015) demonstrated across a series of five studies that shared social identity is a powerful source of personal agency and control, potentially explaining why social cohesion was able to protect against membership in the chronically poor mental health classes.

3.3.4 Limitations attributable to a (half) cross-sectional mediation design

Despite the compelling findings presented throughout this discussion, analytical limitations in the body of research pertaining to mediation of POS effects, including this thesis, must be acknowledged. In this regard, the comparison presented earlier between the present research and Moore et al.'s (2010) paper is instructive. Whereas Moore et al. (2010) hypothesised that greater behavioural social integration would lead to increased POS usage, studies linking objective characteristics of the distribution or quality of POS to the same constructs typically propose a relationship that runs in the opposite direction. This distinction succinctly highlights the limitations of cross-sectional research, particularly in the analysis of mediated effects (described previously in Chapter 2, Sections 4.1.1.3 and 4.2.1). Although this research sought to establish whether POS greenness influences neighbourhood social integration, an association between these constructs could also plausibly indicate that individuals seeking greater social integration move to areas with nicer POS, or that neighbourhoods characterised by greater social integration prioritise investment into the quality of communal spaces.

The half-longitudinal design employed in present study has extended the evidence base by linking social cohesion to prospective changes in psychological distress, indicating that the relationship between mediator and outcome does not reflect reverse causation (i.e. where people perceive less cohesion as a result, rather than a cause, of the distress they are

experiencing) (Mair et al., 2008)[101]. This is an important contribution in its own right, and a substantial improvement over previously published mediation designs in this field of research. Yet, the analysis remains limited by the assessment of a cross-sectional association between POS greenness and social cohesion. The consistency with which aspects of residential 'greenness' have been linked to social cohesion, from studies in the Netherlands (De Vries et al., 2013), to Australia (Sugiyama et al., 2008), and now Canada, lends weight to the inference of a causal effect. But, these studies routinely fail to delineate the temporal relationship between constructs; that is, "which is the cart and which is the horse" (Hill, 1965, p.9). Although there is some evidence to indicate that the perceived importance of living near POS does not discriminate between individuals in areas with high versus low POS availability (Kaczynski and Mowen, 2011), suggesting self-selection might not confound associations between POS and neighbourhood social integration, further work is required to unravel the way in which these relationships develop. Possible directions for future research in relation to this issue are discussed in Section 7.4 of this chapter.

3.4 Effects of POS 'greenness' on positive versus negative dimensions of mental health

Overall, whereas the 'greenness' of POS within walking distance of the home appeared to be protective against prospective rises in psychological distress through stress-buffering, health-promoting, and indirect mechanisms, it was of very little relevance to inter-individual variation in trajectories of life satisfaction. There are a number of potential explanations for this. I discuss these first from a theoretical standpoint, before addressing the potential methodological causes of this discrepancy.

First, the results could indicate a specificity of the protective effects of POS greenness to negative dimensions of mental health. As described previously, wellbeing and distress are not opposite ends of a single continuum, nor are they mutually deterministic; rather, they constitute two related but distinct dimensions that may follow different developmental trajectories and relate differentially to attributes of the individual and the environment (Greenspoon and Saklofske, 2001, Keyes, 2007, Westerhof and Keyes, 2010, p.110). Indeed, prior qualitative research has demonstrated that residents attribute differing

[101] As noted earlier in Section 3.3.2, this interpretation is not applicable to indirect effects on membership in the chronic high-distress and chronic low-satisfaction classes because these are largely differentiated from their healthful counterparts by values of the outcome at T1. Those findings might more appropriately be interpreted as arising from a fully cross-sectional mediation design, with implicit limitations in relation to the possibility of reverse causation between social cohesion and mental health.

importance to neighbourhood characteristics in relation to their effects on positive versus negative dimensions of mental health (O'Campo et al., 2009). Interestingly, however, that research suggested that urban residents consider natural environments highly beneficial for the promotion of positive mental health but much less important for preventing psychological distress (O'Campo et al., 2009). Considering those findings in conjunction with longitudinal quantitative studies that have identified associations between the total availability of residential green space and life satisfaction (White et al., 2013, Krekel et al., 2016), as well as the (admittedly weak) evidence for a cross-sectional association with POS greenness in the present study, I am hesitant to conclude that POS greenness is irrelevant to positive dimensions of mental health.

Rather, I suggest it is possible that the absence of prospective associations with regard to life satisfaction indicates a stronger affective rather than cognitive component to the effects of POS greenness. Unlike prior studies, which have measured life satisfaction using a single evaluative item (E.g. "How satisfied are you with your life, all things considered?") the present research measured life satisfaction using the multiple-item Satisfaction with Life Domains Scale (SLDS). This scale called upon the participant to evaluate their satisfaction with 17 specific aspects of life, from their food and clothing to their friends, free time and responsibilities. The externally-focused evaluations in this instrument lend themselves more heavily to a cognitive assessment of subjective wellbeing, whereas single-item measures might draw to a greater extent on feelings or emotions as a source of information for evaluative judgments (Suh et al., 1998). Perhaps as a result of this, multiple-item life satisfaction scales are known to be substantially more stable than single-item scales, particularly across periods of less than five years (Schimmack and Oishi, 2005). Yet, importantly, SLDS did identify prospective declines in life satisfaction, which frequently overlapped with prospective rises in psychological distress, indicating that the scale was capable of detecting change throughout the study period.

On the other hand, although it might be plausible to suggest that differential access to natural environments could play a role in shaping the 'reality' of key life domains across the life course – if, for instance, restorative effects help to alleviate allostatic load and/or prevent problematic psychosocial functioning arising from chronic activation of stress responses (Marin et al., 2011) – one would not expect to observe these effects across a handful of years. The notion of an external 'life reality' is particularly pertinent to the estimation of stress-buffering effects in this thesis, where stressful exposures were

measured in relation to events that would impact precisely the domains being evaluated within the life satisfaction scale. It is therefore possible that POS greenness buffered against the emotional fall-out from these events, as evidenced in the protective effect against rising psychological distress, but did not influence the cognitive appraisal of ensuing changes in life circumstances.

In this sense, the SLDS measure was not particularly well suited to the research objectives; however, the data had already been collected prior to the commencement of candidature, to suit the broader objectives of the ZEPSOM catchment area study. Future studies could employ alternative measures of subjective psychological wellbeing, such as the 8-item Flourishing Scale (Diener et al., 2010). This scale places much less emphasis on satisfaction with specific material circumstances or social relationships, assessing instead the extent to which the individual feels that their universal psychological needs are satisfied. Measures include the level of agreement with statements such as, "I lead a purposeful and meaningful life"; "I am optimistic about my future"; and "I am competent and capable in the activities that are important to me". Alternatively, as alluded to in the last paragraph, it is also possible that a failure to detect associations between POS greenness and life satisfaction in the study was caused by an inappropriate match between measure and temporal design, rather than an inherent unsuitability of the measure, per se. For example, the Satisfaction with Life Domains scale employed in this thesis would probably provide informative results if employed in a life course approach to the study of place and health, as described in relation to the findings of Research Aim 3.

It should be noted that investigating psychological distress and life satisfaction separately likely resulted in a loss of important information about how these dimensions interact with one another. For instance, the analysis of cross-classification probabilities identified noteworthy clusters of participants who were concurrently following (1) a healthful trajectory of life satisfaction and a worsening trajectory of distress symptoms; or (2) a chronically elevated trajectory of distress symptoms and a worsening trajectory of life satisfaction. In both cases, isolating either outcome as the target of analysis fails to fully appreciate the overall mental health consequences of the individual's personal, social and environmental circumstances (Aneshensel, 2005). In the first case, the individual is classified unreservedly as being 'well' in the life satisfaction model but 'unwell' in the distress model. Yet, the two-continua model of mental health implies that wellness is graded; these individuals appear neither to be 'languishing' or 'flourishing', but merely 'moderately mentally healthy' (Keyes, 2007). Analysing the outcomes separately fails to

fully appreciate the neighbourhood attributes that contribute to the extreme states of total wellbeing. Similarly, in the second case, differentiating those individuals for whom a chronically elevated trajectory of distress is, or is not, accompanied by declining satisfaction with domains of life is clearly of interest from a health promotion standpoint. Future analyses might consider this using a parallel process model to derive latent classifications based on inter-individual variation across both outcomes simultaneously.

4 Threats to validity

This section describes possible threats to the validity of findings from this research, in relation to construct validity, internal validity, statistical conclusion validity, and external validity.

4.1 Construct validity

4.1.1 Latent trajectory classes of psychological distress and life satisfaction

Growth mixture modelling offers many attractive features to analysts seeking to describe and explain heterogeneity in the development of an outcome over time, and has accordingly enjoyed increasing popularity in recent years, particularly in the psychological and behavioural sciences (Bauer, 2007). However, it is important to note an ongoing debate about the ontological validity of developmental typologies implied by this method. Above all, the root of philosophical debate in this sphere stems from the fact that a *k*-class GMM is manufactured on an assumption that *k* classes actually exist within the population. The number and nature of trajectory classes are not fixed properties of a sample, and it is possible to encounter situations in which competing models cannot be distinguished on the basis of statistical fit alone (Muthén, 2004) or individual classifications are sensitive to the 'slice' of time that is analysed (Sher et al., 2011). This section summarises the essence of these discussions in order to contextualise the interpretation of GMM results in this thesis.

4.1.1.1 Direct versus indirect applications of GMM

It is helpful to foreshadow this discussion by highlighting the distinction between 'indirect' and 'direct' applications of GMM, which differ in purpose and interpretation with respect to the extraction of latent classes (Bauer and Curran, 2003a, Muthén, 2004, Petras and Masyn, 2010, Masyn, 2013). As detailed in Chapter 4, GMM relaxes the requirement for multivariate normality at the overall population level such that residuals on the growth factors and observed outcomes need only be normally distributed *within* each

class. This method can therefore be useful as an analytical device to indirectly approximate a complex (e.g. highly skewed or bimodal) unitary population distribution by mixing a small number of normal component distributions (Bauer and Curran, 2003a). In these 'indirect' applications, there is no intention to interpret the classes as distinct latent subpopulations[102]. The number and characteristics of the component distributions are therefore of little intrinsic interest and are relatively inconsequential as long as the mixture solution approximates the population sampling distribution reasonably well (Masyn, 2013). In 'direct' applications, on the other hand, the primary aim is to identify a "true" developmental taxonomy of qualitatively distinct subgroups and the number and characteristics of the extracted latent class distributions are of primary concern. For instance, criminologists often seek to identify and explain typologies in the pattern of criminal behaviour or recidivism across the life course (Petras and Masyn, 2010).

4.1.1.2 The true structure of the population is unknown

As I foreshadowed at the beginning of this section, the problem facing users of GMM is that the true structure of the population – whether unitary or comprising multiple subpopulations – is unknown and often cannot be deduced empirically. Direct and indirect applications are analytically equivalent, and simply identifying some optimal number of classes does not infer true population heterogeneity. Multiple trajectory classes can easily be extracted from a single population characterised by a non-normal sampling distribution, with common mixture model fit statistics (e.g. BIC) failing to adequately differentiate between the potential sources of this apparent heterogeneity (Bauer and Curran, 2003a). Novel tests of fit comparing model-implied and observed quantities of skewness and kurtosis can assist in the rejection of multiple-class solutions from highly non-normal single population distributions, although they may lack the power to do so in cases of mild non-normality (Muthén, 2003, Rindskopf, 2003). Moreover, some argue that these procedures might only encourage the over extraction of latent classes to better approximate the observed data without shedding any real light on the "true" nature of the population distribution (Bauer and Curran, 2003b). While this might appear to be an issue of semantics, erroneously dividing a homogenous population into subgroups has the potential to obscure genuine relationships or generate spurious relationships by dissecting the total sample size and artificially partitioning inter-individual variability into between- and

[102] In fact, prior to reporting results, class-specific parameter estimates may be combined to obtain valid estimates for the aggregate distribution, which is of principal interest (Bauer, 2007).

within-class components (Bauer and Curran, 2003a, Muthén, 2003, Bauer and Curran, 2003b).

4.1.1.3 Taking caution in the reification of latent classes

For the reasons outlined above, some authors caution strongly against the reification of statistically derived classes of individuals (Bauer and Curran, 2003a, Sher et al., 2011, Nagin and Odgers, 2010, Nagin and Tremblay, 2005, Sampson and Laub, 2005). For instance, Bauer (2007 p.777) argues that individual trajectories of outcomes with complex systems of multiple influences will most often differ by degrees, without clear cut points to separate distinct types of individuals and that "latent trajectory classes are, in most cases, nothing more than artificial categories rendered from the true continuum of change". Nagin and Odgers (2010 p.118) echo these sentiments, cautioning against interpreting trajectory groups as "literally distinct entities" and describing them instead as mere "approximations of a more complex reality".

This does not, however, inherently disqualify the practical utility of discretely categorising what may be dimensionally distributed traits (Maughan, 2005). GMM is advocated for the identification of distinct patterns of change even if the veracity of latent subpopulations cannot be confirmed, provided appropriate interpretational caution is applied (Cudeck and Henly, 2003, Muthén, 2004, Petras and Masyn, 2010, Sher et al., 2011). For instance, taxonomies of change may assist in identifying the causes and consequences of differential trajectories even if the various groups should not be interpreted as 'literally distinct' (Masyn, 2013). Moreover, it is generally acknowledged that evidence for the substantive validity of latent classes may be built by mapping trajectory typologies onto auxiliary variables (antecedents, consequences, or events concurrent with the developmental pattern of interest) that provide conceptual support for statistically derived groupings (Muthén, 2003, Bauer and Curran, 2003b, Petras and Masyn, 2010, Nagin and Odgers, 2010). This was discussed at the beginning of this chapter (Section 3.1.1), which illustrated that the 'worsening' and 'chronic high-distress' classes were not clearly demarcated by gradations in socioeconomic status, but did exhibit distinct patterns of aetiologically significant antecedent conditions including the number of stressful life events and prevalence of lifetime mental disorder. This lends weight to the interpretation of these classes as clinically distinct subpopulation.

It is, however, important to clarify that the thesis did not explicitly attempt to detect and describe a 'true' typology of distinct trajectory forms. The statistical extraction of latent classes was adopted primarily as a vehicle to approximate the observed inter-

individual heterogeneity in mental health trajectories more closely than less flexible single-group statistical methods, regardless of whether these discrete mixture components simply approximated a continuum of variability.

4.1.1.4 Relevance of the number of manifest observations

A limitation of this thesis, related to the points presented above, pertains to the fact that only three waves of data were available for the analysis. Specifically, Sher et al. (2011, p.327) caution against a presumption of longitudinal consistency in trajectory shapes and classifications from shorter to longer observation periods, noting the "parochial" nature of time-bounded trajectories depending on which "slice" of the time-course is analysed. Splitting eight waves (four years) of alcohol use data into two adjacent four-wave periods, the authors noted that only a minority of individuals classified in a non-stable (i.e. increasing or decreasing) class with reference to one of the four-wave periods were similarly classified across the full eight-wave period. In fact, striking logical inconsistencies were sometimes evident in trajectory classifications (and the implied pattern of alcohol use) when compared (a) between the two four-wave periods, and (b) between the full eight-wave period and the amalgamation of its four-wave components. The authors raise the possibility that such inconsistencies arise from the forced extraction of linear trajectories (occasionally with a quadratic component) from what might, in reality, be a highly non-linear process, resulting in fragmented and oversimplified picture of complex patterns of change.

This raises potential limitations relating to the specification of the GMMs themselves. For example, although the suitability of the growth factor covariance structure for the unconditional GMMs was probed thoroughly, it is possible that other parameters (e.g. residual outcome variances or within-class covariate effects) were misspecified by constraining them to equality across classes (Enders and Tofighi, 2008). It is also possible that the size of the sample was insufficient to identify additional classes of substantive interest that exist within the broader population, particularly because only three indicators were available to define each trajectory (Kim, 2012). This limited the analyses to a strictly linear growth function and is likely to have obscured a more complex array of trajectory shapes underlying the generic 'healthful' / 'worsening' / 'chronic' classification schemes. Ideally, a larger number of observations would be available to allow for the estimation of polynomial or piecewise trajectory shapes (e.g. to distinguish between 'gradually' and 'rapidly' worsening cases) and to reduce dependence of individual classifications on a

chance alignment between observation timing and fluctuations in mental health status (Hunter et al., 2010, Tan et al., 2011).

4.1.2 Measurement of residential POS 'greenness'

The availability of objective POS measures is an asset for this research. Self-reported proximity to POS and perceived neighbourhood 'greenness' are often discordant with objective measures of those environmental attributes, and can be influenced by the personal characteristics, behaviours and preferences of the persons reporting them, or by other features of the neighbourhood environment (Lackey and Kaczynski, 2009, Macintyre et al., 2008, Gebel et al., 2009, Leslie et al., 2010, Moore and Kestens, 2011). For instance, people who undertake a greater amount of walking or socialising in their neighbourhood might be more aware of nearby POS, or perceive it to be closer. This introduces an element of same-source bias that may confound the true relationships between POS and mental health. Furthermore, participants' subjective interpretations of where the bounds of a 'neighbourhood' lie may not match the assumptions of the researcher, and this could lead to variability in the spatial scales that are analysed between participants. While perceived and objective measures of environmental attributes are each unique and important contributors to the understanding of neighbourhood effects on health and health-related behaviours, objective measures are likely to be more useful than residents' perceptions for informing policy decisions relating to land use and development (Leslie et al., 2010). There do remain, however, some potential threats to the validity of this measure, ranging from the definitions of POS and residential accessibility employed in the study, to the measure of 'greenness' itself. The lack of information pertaining to POS usage is also discussed.

4.1.2.1 Definition of public open space

Public open space data were extracted specifically for this project from the MEGAPHONE GIS and validated by the candidate. For the purposes of this thesis, POS includes 'spaces within the urban environment that are readily and freely accessible to the wider community, regardless of size, design or physical features and are intended primarily for amenity or recreation purposes – whether active or passive' (adapted from Kellett, 2009). Included in this definition were parks, ovals, playgrounds, public squares, and community gardens; excluded were sidewalk nature strips and street greenery, cemeteries, golf courses, semi-private open space (e.g. in the immediate vicinity of apartment buildings) and vacant house blocks. These distinctions largely accord with those drawn by other researchers in recent studies of public open space (e.g. Krekel et al., 2016). While some of these distinctions are obviously defensible, given the research questions, others are

less clear-cut. Part of the difficulty in defining open spaces arose in determining (1) what was 'readily and freely' accessible and (2) how this criterion should be balanced against the potential amenity value of spaces that might not have been freely accessible. For instance, a golf course is not freely accessible to the community for their recreational purposes, but does provide a vast source of ambient greenness, viewable for some, but not all.

In the end, decisions about what constitutes POS and what does not tended to favour the truly *public* character of these spaces – i.e. their usable recreation value – over their inaccessible but visible amenity value. While this is likely to be a sound conceptualisation in relation to the effects of POS on interpersonal resources, it might be less suitable in relation to effects on coping. Having said that, the present study was one of few in the mental health literature to purposefully compile and validate a map layer of POS with a specific focus on analysing spaces that are *accessible* to the public and *plausibly useful for recreation*. I believe this is an important step forward in assessing the value of parks and open spaces as they are conceived of by residents and policy makers, in comparison with other common indicators of 'green space' that might be liable to present unusable space as a 'neighbourhood resource'. However, qualitative or mixed methods research would be beneficial to guide the field in understanding how residents draw a distinction between 'public' and 'private' land, and how this distinction plays into the value of open spaces.

4.1.2.2 Definition of residential POS accessibility

Choosing the most appropriate boundary for the 'local residential area' (LRA) is a key methodological challenge when studying relationships between residential exposures and health (Lebel et al., 2007). This challenge stems from the absence of natural geographic entities within the urban environment, where instead, the borders of possible spatial units are indistinct and almost infinitely modifiable; i.e. the 'modifiable areal unit problem' (MAUP) (Openshaw, 1996). The principal characteristics of a spatial unit, and their observed associations with health outcomes, are likely to differ depending on its geographic scale, its shape, and overall, the extent to which it adequately captures the individual's residential milieu and the spatial mechanism of interest (Diez Roux, 2001, Green, 2012). Thus, the choice of geographic scale should be explicitly defined and driven by reasoned etiologic considerations (Kaplan, 2004).

The use of multiple spatial scales in this thesis reflects best practice in place-health research, permitting assessment of the sensitivity of findings to the choice of areal unit and exploration of the spatial scale most relevant to the mechanisms of interest (Diez Roux,

2001). Importantly, the spatial scales were chosen a priori to suit the objectives of this research and were broadly consistent with accepted guidelines for POS provision. However, the scales selected were still rather small, and did not capture in POS in the broader environment. Thus, the definition of the residential area assumes that people are willing or able to walk 1000m, but no further, to access POS. However, prior evidence suggests that people may be willing to travel further to access large and aesthetically pleasing POS (Sugiyama et al., 2010). In the Montréal context, it is worth noting the existence of Mont Royal Park; a small mountain in the middle of Montréal Island, and home to a park designed by Frederik Law Olmsted, the eminent landscape architect behind Central Park in New York City (see Murray, 1967). The park comprises a large wooded area, and is located only 5km from Saint Henri, one of the neighbourhoods in the study region characterised by typically smaller and more barren POS. Thus, it is possible that individuals residing in this area, or elsewhere in the study region, would travel outside their 'local residential area' to avail themselves of this space on a weekend.

This raises another potential limitation of the manner in which accessibility to POS was defined. The study implicitly assumes that the area around the home provides the best representation of the individual's physical environment in relation to the ease with which they are able to access POS resources. Yet, the theoretical framework for this study was predicated around activity cycles as a central determinant of the individual's ability to avail themselves of restorative experiences. Activity cycles, in turn, are shaped by various social roles that are likely to be spatially bounded both within (e.g. at home) and outside (e.g. at work) of the residential area. Thus, the delineation of broader activity spaces – for instance, including several primary activity sites and the typical paths travelled between them – might increase power to detect the effects of neighbourhood exposures by more fully representing the lived daily experience of the individual (van Heeswijck et al., 2015).

Finally, the study assumed that POS were openly accessible at all points along their boundaries, when in actual fact, residents may need to travel out of their way to reach a point of entry due to fencing or other impediments.

4.1.2.3 Measure of POS greenness (NDVI)

There is, of course, a question of whether a blunt instrument such as NDVI might violate the consistency assumption; that is, whether this measure satisfies the requirement that there are 'no versions of treatments' (Rehkopf et al., 2016). If NDVI is intended to capture the aesthetic value and restorative potential of POS, then a high value should

always be indicative of greater aesthetic value and restorative potential, across all POS in which it is recorded.

One way in which the consistency assumption might be violated is if a high value of NDVI were to result from an overgrown and neglected space that is perceptually overly complex and liable to threaten feelings of safety. Aesthetic preference is related to complexity (the number of independently perceived elements in a scene) in an inverted-U-shaped manner, such that that settings of moderate complexity will be most restorative (Ulrich, 1983). However, the fact that this study took place in a metropolitan region means that very few, if any, settings that would be described as high in complexity (this might characterise a dense forest), while the well maintained system of parks in Montréal is unlikely to contain spaces for which vegetation represents a disamenity. Perhaps a greater risk to the consistency assumption is the fact that NDVI might be insensitive to other aspects of spatial aesthetics, such as the level of variation in the types of vegetation present. For instance, the level of biodiversity or species richness is hypothesised to be relevant to mental health, but is not captured directly by NDVI (Dean et al., 2011).

Finally, the measure did not take into account other sources of natural aesthetic attraction, such as large bodies of water. This applies within POS (although there very were few lakes present) but also alongside POS. The study area is characterised by two sets of long, linear parks running alongside the Lachine canal and the St Laurent River. The river, in particular, provides attractive scenery and might contribute significantly to the restorative potential of adjacent spaces (Korpela et al., 2014). Indeed, prior research on therapeutic landscapes has indicated that waterscapes (‘blue space’) may have a special symbolic, spiritual and social significance for health (Curtis, 2010, Windhorst and Williams, 2015, Thomas, 2015). The fact that these waterscapes were not measured means it is possible that effects on mental health attributed to the adjacent ‘green’ space were actually attributable to this ‘blue’ space, which may have reduced the precision of estimated relationships therefore biasing them towards the null.

An additional limitation is the fact that POS availability and greenness were measured only once (contemporaneously with T1) and assumed to remain stable throughout the ensuing four year period. Theoretically, it is possible that the ‘greenness’ of some spaces changed during this time, either due to the death of original vegetation or the planting of new vegetation. Similarly, it is possible that existing POS sites could have been built up, or that developed land could have been reclaimed and turned into POS. Although I am unaware of any major changes to the distribution and greenness of POS in the study area

(e.g. major 'greening' programs or allocation of new POS) I cannot rule out that these changes may have occurred (this is discussed further in Section 4.2.3.2).

4.1.2.4 Unmeasured aspects of POS quality

In addition, I acknowledge that there are other important aspects of POS quality, such as the availability, variety, or condition of amenities including seating areas, play equipment, and lighting, that were not measured in this study (Broomhall et al., 2004, McCormack et al., 2010, Ward et al., 2014, Byrne and Sipe, 2010). Spatial measures of these features are, "rarely readily available; are inconsistently collected and collated across local government authorities; are extremely difficult to source both regionally and nationally; and are […] prone to temporality issues" (Villanueva et al., 2015, p.116). Collecting them for large geographical areas is time-consuming and expensive, and because the presence and condition of amenities is liable to change in a relatively short space of time (e.g. by the addition of a playground; natural weathering of picnic benches; or graffiti and vandalism) it is problematic to do so retrospectively. Remote image-based methods do not provide an infallible solution to these problems; constraints on image resolution and viewpoint hinder the observation of some POS attributes, and readily available omnidirectional imagery (e.g. Google Street View) is not time-stamped (Wilson and Kelly, 2011). For these reasons, more refined indicators of POS quality were unavailable for the study region and could not be collected to correspond temporally with the other baseline POS measures.

4.1.2.5 Assumptions in relation to POS usage

It is worth reiterating that the data in this thesis did not contain information on actual usage of POS by members of the cohort. On the one hand, numerous authors have demonstrated strong associations between residential proximity to POS and usage (Grahn and Stigsdotter, 2003, Moore et al., 2010, Lee and Maheswaran, 2011), indicating that the identification of locally accessible POS is a reasonable proxy for usage opportunities. On the other, as noted throughout this thesis, usage is not the sole pathway by which POS greenness is hypothesised to augment population health. Psychological benefits might also accrue from the mere visibility of public open spaces, providing everyday 'micro restorative' experiences (Tennessen and Cimprich, 1995, Kaplan, 2001). Methodologies predicated on POS usage are likely to underrepresent this pathway, whereas the approach taken in this thesis could reasonably be assumed to capture the full range of POS effects as relevant to urban planning policy. Despite this, it must be noted that the interpretation of results premised upon patterns of POS usage (i.e. described in relation to indirect-cognitive pathways) are merely presumptive and were not supported by supplementary data.

4.1.3 Measurement of stress and psychosocial resources

4.1.3.1 Stressful life events

Life event inventories continue to dominate stress research, perhaps due to the existence of well established instruments that are easy to collect, in combination with a widespread belief that scores on these inventories serve as an objective marker for the likelihood of stress arousal (Young, 1980, Pearlin et al., 1981, Turner, 2010). However, there are some notable shortcomings to measuring discrete events as a proxy for stress arousal. In one sense, it is self-evident that SLE inventories are blunt instruments that ignore a range of potentially important determinants of the consequences of those events for health. As Antonovsky (1996 , p.11) states, "none of our graduate students today is so naive as to think that scores on a list of events per se can predict illness with any power. They know that one must distinguish between negative and positive life events, consider whether the events were controllable, explore the coping mechanisms used, and so on." For instance, one potentially important characteristic of a stressor is whether it occurs at a particular time in the life course (Elliott and Eisdorfer, 1982), a commonly cited example being the expected difference in reaction to losing one's partner in mid-life rather than in old age. More generally, but related to this point, is the fact that SLE inventories largely ignore the role of appraisal in determining whether an event is, in fact, stressful for the individual who experiences it (Lazarus and Folkman, 1984). In keeping with the characterisation of SLE as 'objective events', this thesis weighted the severity of SLE by an 'agreed' (i.e. sample average) rating of stressfulness to avoid potential issues of reverse causation (whereby, for example, depressed individuals might rate the stressors to which they were exposed as more severe). This may have diminished the discriminatory power of the measure by ignoring individual specificity in processes of appraisal, and could therefore have biased estimates of relationships between stress and mental health toward the null.

Yet, there is a broader deficiency to the SLE approach that subsumes the issues just raised. Those comments imply a deficiency in the way SLE inventories are operationalised, possibly lending themselves to the interpretation that what is needed is a better means of measuring and quantifying eventful experiences. In fact, a much more pressing concern is the extent to which a focus on SLE ignores the significant role of enduring strains in precipitating stress processes and adverse health outcomes (Gadalla, 2009). Evidence suggests that even seemingly minor daily hassles could influence health (Elliott and Eisdorfer, 1982, van Eck et al., 1996), while Pearlin (1981, 1989) has highlighted the ways in which acute events converge with enduring strains to determine health outcomes. In the

course of stress research, SLE are standardised and decontextualised to such an extent that they become detached from the broader hierarchies of determinants within which they are nested, while the legitimacy of a focus on this particular set of determinants becomes reified through research practice (Young, 1980). Yet stressors arise "in the organisation of lives and the structure of experience" (Pearlin, 1989, p.254) where discrete events are dynamically intertwined with enduring conditions that exist beyond the level of individuals and may precipitate stress through conscious and non-conscious processes (Daniel et al., 2008). Because stressors gather in 'constellations', within which events and strains precipitate and shape the meaning of one another, ignoring either set of exposures risks underestimating the true extent of variation in the experience of stress within or between populations.

Thus, it is particularly important to note the specificity of 'stress arousal' in this thesis to the experience of stressful events. A failure to identify enduring strains may have resulted in a significant underestimation of actual stress arousal, most prominently among individuals with lower socioeconomic status, who tend to experience a greater number of enduring strains (Turner, 2010). This is problematic, because unmeasured differences in stress exposure could masquerade as differential vulnerability (or adaptational ability) to stress, potentially confounding relationships between other hypothesised causal factors and mental health (Turner et al., 1995). Adjustment of the analyses for socioeconomic status at both the individual- and area-levels is likely to have minimised this risk. Additionally, from a conceptual standpoint, it is possible that the restorative benefits of nature – which were situated in the conceptual framework for this study within short term (e.g. daily or weekly) cycles of stress and restoration – could be more influential in buffering against enduring strains and daily hassles than acute events, because the temporal alignment in the operation of both stressor and stress-buffer is closer.

4.1.3.2 Coping

Specific limitations pertaining to the measure of coping were discussed in detail earlier in this chapter in relation to the findings of Research Aim 3 (p.254). Briefly, it is possible that the lack of a statistically significant association between POS greenness and coping, despite evidence for stress-buffering effects of POS greenness, is attributable to a combination of imprecision in the single-item instrument, a lack of specificity in the domain of the construct being measured, and a loss of power due to administrative errors in the collection of the data (Churchill Jr, 1979, Fuchs and Diamantopoulos, 2009). In relation to the construct validity of the measure, one of those administrative errors – the

fact that English and French-speaking participants were inadvertently asked to answer two different items – is particularly concerning. Given that the issues with the coping instrument have been detailed above, and were also described in Chapter 3 (Section 6.4.2), they are not reiterated further here.

4.1.3.3 Neighbourhood social integration

Two key limitations could be raised in relation to the measurement of neighbourhood social integration in this thesis. First, although POS exposures were measured in relation to objectively defined local areas, social cohesion, neighbouring behaviour, and community participation were measured using participant self-reports in relation what they perceive to be 'the neighbourhood'. The size of the perceived neighbourhood is likely to differ between individuals, possibly in a systematic manner according to prevailing environmental conditions (Vallée et al., 2015), and may not map particularly well onto objectively defined areas used to assess neighbourhood exposures. In the present study, buffer sizes for the local residential area within which POS greenness was measured were selected to match the region in which psychosocial functions of neighbourhood are expected to be strongest. Typically, this is considered to fall within a 5 to 10 minute walk from the home (Kearns and Parkinson, 2001), and so it was encouraging to see this reflected in relative effect sizes for relationships between social cohesion and POS greenness within the 500m and 1000m buffers.

Second, neighbourhood social integration was measured in relation to individual behaviours and cognitions, as a reflection of what some might argue should be conceptualised as a collective phenomenon. There is a conceptual distinction between the integration of an individual into the neighbourhood social environment, and social integration as a collective attribute of the neighbourhood. The effect of the construct could easily differ depending on the level at which it is measured, and the individual and collective manifestations might even interact to determine health outcomes (Poortinga, 2006). While this is not to say that an individual approach to the measurement of social phenomena is wrong – indeed, the individual's social cognitions and behaviours reflect their lived experience and are likely to be strongly implicated in the aetiology of health – it is certainly important to be clear about what one has measured. This may be particularly relevant to the present study, where I have proposed that POS greenness might influence perceptions of social cohesion via a cognitive pathway linked to the feelings of kinship and affiliation stirred by nature experience.

4.2 Internal validity

4.2.1 Ambiguous temporal precedence

Only Research Aim 2 ('To evaluate whether POS 'greenness' exerts a health promoting effect independently of exposure to acutely stressful events') was assessed using a fully prospective study design. The first occasion of measurement in the longitudinal analysis of mental health outcomes (T1) corresponded temporally with the measurement of POS greenness, such that estimated trajectories of mental health outcomes from T1 to T3 reflect prospective changes in mental health status over the ensuing four-year period. The same approach was taken to estimate prospective changes in mental health in relation to social cohesion (Research Aim 3). As detailed in Chapter 4, associations between these variables and membership in the 'worsening' class for either outcome, relative to the 'healthful' class, were reasonably interpreted as reflecting a prospective deterioration in mental health. Specifically, because initial standing on the outcome was so similar between groups, this indicates that variation in the exposure (POS greenness or social cohesion) at T1 was associated with *later changes* in mental health. By contrast, associations with membership in the chronically poor class for either outcome, relative to the healthful class, primarily reflect a cross-sectional association with initial standing at T1. These associations do not permit delineation of the temporal order between exposure and outcome, casting doubt on the exchangeability of individuals between environmental exposure conditions (Oakes, 2004, 2006) and leaving these relationships particularly vulnerable to residual confounding and self-selection effects (Gollob and Reichardt, 1987, Cole and Maxwell, 2003). Here, mental health prior to T1 is an unmeasured exogenous factor that embodies a constellation of direct and indirect influences liable to induce a non-causal association between exposure and outcome (Selig and Preacher, 2009, Selig and Little, 2012). Possible sources of confounding are described in the following section.

As discussed earlier in this chapter, in relation to Research Aim 3 ('To evaluate the intermediary role of psychosocial factors in explaining prospective associations between POS 'greenness' and mental health'), the associations between POS 'greenness' and the psychosocial resources was also assessed cross-sectionally. The same concerns just described are equally applicable to the estimation of these relationships. However, I note that although POS greenness and psychosocial resources were measured contemporaneously, sample exclusion criteria requiring that the participant had resided at the address for a minimum of one year does at least satisfy the assumption of an induction period during which relationships between these variables may have developed. That is,

the data do not erroneously imply that these effects are instantaneous (Gollob and Reichardt, 1987, Selig and Preacher, 2009). The objective derivation of POS attributes also circumvents bias due to shared method variance that might otherwise spuriously inflate correlations with psychosocial resources (Cole and Maxwell, 2003). Considering this point in relation to that made in the previous paragraph, it is evident that the benefits of the half-longitudinal mediation design employed in this thesis are not entirely applicable to mediated effects describing the odds of membership in the chronically poor mental health classes, relative to the healthful classes. Essentially, the three variables are all assessed contemporaneously, despite the caveats just mentioned. Cross-sectional designs are known to be particularly problematic in the assessment of mediation hypotheses (Selig and Preacher, 2009, Cole and Maxwell, 2003, Maxwell and Cole, 2007, Maxwell et al., 2011). For instance, Maxwell et al. (2011) have demonstrated that cross-sectional correlations can imply the existence of a substantial mediated effect even when the longitudinal effect is zero, or else fail to distinguish between very different sets of underlying longitudinal parameter values. For this reason, evidence in relation to the indirect effects of POS greenness, via social cohesion, on membership in the chronic high-distress and low-satisfaction classes should be treated with caution.

Finally, Research Aim 1 ('To evaluate whether POS 'greenness' exerts a protective 'buffering' effect against the potential psychological harm of acutely stressful life events') was addressed using a study design conceptually similar to a parallel process model, to evaluate how POS 'greenness' moderates the unfolding association between SLE reported after T1 and changes in mental health from T1 to T3. I describe the model in this sense because a parallel process model would assess the correlation between concurrent longitudinal trajectories of exposure and outcome to evaluate how the exposure and outcome unfold contemporaneously, using latent variables to represent initial status and rate of change over time. In this study, a similar approach is adopted to model trajectories of mental health, whereas SLE were measured using two manifest variables reflecting reported exposure prior to T1 (≈ initial status) and the number of 'new' events reported after T1 (whose effects are conditional upon the initial level of SLE; ≈ rate of change, whose effects are conditional upon the initial status or level of SLE).

Generally speaking, the relationship between two longitudinal processes measured simultaneously over the same period is correlational and does not satisfy the temporal hierarchy required for causal inference, despite explicitly modelling change in both constructs (Cheong et al., 2003). This is an important consideration, given the potentially

bidirectional causal nature of the relationship between stressful events and mental disorder (Elliott and Eisdorfer, 1982). The present study does, however, differ from this situation to some extent; although measures of SLE and mental health were collected at the same measurement occasions, the twelve-month retrospective nature of the SLE measure introduces a slight chronological lag between stress exposures and psychological outcomes that supports the hypothesised direction of influence.

4.2.2 Further limitations in temporal design

In addition to the primary concern about ambiguity in the temporal precedence of causes to effects, two other aspects of temporal design may have influenced the extent to which relationships between the constructs of interest were observed in this thesis. These relate to the influence of residential history (i.e. how long the participant had resided at their baseline address) and the total length of the study period.

4.2.2.1 Influence of the length of residence at baseline

Models of neighbourhood influences on health should ideally take into account temporal as well as spatial dimensions of exposure (Macintyre and Ellaway, 2003, Wheaton and Clarke, 2003). Yet, little remains known about the time intervals during which neighbourhood characteristics are likely to manifest themselves in health outcomes. Only one study has attempted to identify how long it might take for POS to exert a beneficial effect on mental health (the induction period required) and if or when these benefits might cease to accrue (Alcock et al., 2014). In that study, the authors found support for a 'shifting baseline' hypothesis whereby mental health improves directly after moving to a greener area (i.e.. within one year) and remains stable at this heightened level thereafter. Alcock et al.'s (2014) findings highlight a possible limitation in the temporal design of this research.

Firstly, 116 (9%) participants who completed all three interviews were excluded from the analysis because they had lived at their current address for less than one year on recruitment. These participants were excluded from the research because, as just discussed, it was important to ensure that the spacing of constructs allowed time for effects of POS on psychosocial resources to accrue. However, in light of the findings above, this approach will have obscured significant effects of POS greenness on wellbeing that might accrue in the first year of residence. While this is important for noting, the broader implication of evidence for a 'shifting baseline' process is that isolating the analyses in this research to a

residentially immobile cohort[103] may have suppressed estimates of the salutary benefits of POS, because wellbeing benefits accumulated prior to the first interview were not observable as longitudinal changes throughout the study period. That is, if one assumes that a ceiling effect exists over time, and that this ceiling effect is reached well prior to T1, one would not anticipate any further changes to accrue. In this respect, the fact that I am unable to comment on *changes* in mental health following *changes* in residential POS exposure, and do not possess information about prior residential exposures for participants who had more recently moved (i.e. whether they have moved to a 'greener', less 'green', or equally 'green' neighbourhood), may be a noteworthy limitation of the research. As already noted, however, the possibility that Alcock et al.'s (2014) 'shifting baseline' effect was confounded by other factors related to residential relocation should be revisited in future research.

Recruitment of a cohort of residents from established neighbourhoods drew a sample in which length of residence at the baseline address varied from several months up to 39 years. In relation to the history between resident and neighbourhood, the point at which we began to observe these individuals was determined somewhat arbitrarily, secondary to concerns about the ability to efficiently recruit a sample that was representative in relation to geographic location and socioeconomic characteristics. Yet, the length of residence upon recruitment reflects both the length of exposure to a particular neighbourhood opportunity structure and the recency of exposure to other neighbourhoods, with similar or different configurations of resource opportunities. Although I controlled broadly for length of residence in the analyses, I did not account for the fact that this variable could moderate or alter the strength of the relationships observed between POS and prospective changes in mental health. Thus, the relationships reported simply reflect the mean level of the response among participants within broadly categorised exposure periods (1 to 5 years versus 6+ years). Note, however, that such a limitation is not peculiar to this thesis. The review of literature (Chapter 2) identified only one study, referred to above, that had attempted to explore the temporal progression of relationships between POS and mental health, and many studies do not even account for length of residence.

[103] Because POS exposures were only measured at commencement of the study, a residentially stable sample was purposefully selected to ensure that these measures remained representative of each participant's local residential area across the life of the study.

4.2.2.2 Total time-span of the study

Finally, as has already been discussed in relation to the findings of Research Aim 4, The substantial size of the 'healthful' life satisfaction class indicated that the overall length of our study may have been insufficient to identify notable changes in these fairly stable life domains. Although the choice of time lags is generally considered less critical in a trajectory modelling context (compared with, say, longitudinal panel modelling) there is a requirement that outcomes are measured frequently enough to capture the true shape of the trajectory and that the overall span of the study allows sufficient time for causal changes to occur (Gollob and Reichardt, 1987, Selig and Preacher, 2009). Adjusting the timing of measurements and increasing the overall length of the study would likely have revealed greater complexity in these change processes and improved statistical power via increased class sizes and classification certainty. However, as is commonly the case in epidemiological studies, feasibility of funding and human resources did not allow for this.

4.2.3 Confounding

As outlined in Section 4.2.1, the longitudinal elements of this experimental design satisfied a number of conditions required for causal inference, including the appropriate temporal ordering of causes and effects, spacing of measurements that allows time for effects to unfold, and the ability to control for participants' prior mental health status (Zapf et al., 1996, Cole and Maxwell, 2003, MacKinnon et al., 2007, Selig and Little, 2012). Despite this, a lack of experimental control precludes definitive causal statements from this research. The study design was necessarily observational, and participants could not be randomly assigned to different treatment conditions (levels of POS greenness) in order to ensure an even distribution of confounders between those conditions. In reality, individuals presumably have been sorted into different residential areas through complex, unobserved spatial selection processes (Verheij, 1996) such that factors relating to these processes could confound associations between POS greenness and mental health.

A range of individual- and area-level covariates were included in the analyses in order to control for confounding influences and account for potential selection effects that might occur when a third variable influences both the likelihood that a person lives in an area with certain POS exposures and also their mental health (MacKinnon et al., 2000). The inclusion of these variables permits the investigation of contextual area effects on health while accounting for self-selection effects (due to the characteristics of the individual being studied) and compositional effects (due to the makeup of population in their residential area). Individual-level covariates included age, sex, annual household income, highest

education level, marital status, self-reported physical health, employment during the past 12 months, season of interview, and length of residence. Area-level covariates included population density and a composite measure of area socioeconomic deprivation, both measured at the level of census tracts. There remain, however, several possible sources of residual confounding unadjusted in the analyses.

4.2.3.1 Self-selection effects

First, self-selection into neighbourhoods with greener POS on the basis of personality or attitudes towards nature cannot be ruled out. In particular, it is possible that persons who place greater personal importance on neighbourhood social integration, or who perceive utility in natural settings for the maintenance of wellbeing, might move to areas with resources and characteristics conducive to these sentiments (Bonnes et al., 2011, Bell et al., 2014). Although some research suggests that objectively measured individual differences in the residential availability of POS are not explained by the perceived importance of living near POS (Kaczynski and Mowen, 2011), that research did not evaluate differences in the inherent characteristics (e.g. 'greenness') of those spaces. There remain compelling theoretical reasons to consider self-selection effects, particularly in relation to natural open spaces. As discussed earlier, a sense of connectedness with nature predicts the perceived importance of green POS for wellbeing (Bell et al., 2014) as well as the overall strength of restorative outcomes in favourite places (Korpela et al., 2010) and improvements in mood following green exercise (Rogerson et al., 2016). Thus, nature connectedness might sort individuals for whom POS greenness is (both subjectively and objectively) more important into areas with greener POS. Taken to an extreme, this selection effect could violate the assumption of exchangeability between individuals in areas with POS of varying 'greenness' because those residing in less green areas might not obtain the benefits of exposure to natural stimuli even if they were more accessible. In this respect, it is worth considering life course influences on nature connectedness and how, across generations, these could propagate spatial inequalities in the prevalence of nature connectedness across neighbourhoods. As described earlier, frequent use of natural outdoor spaces in childhood appears to predict both nature connectedness (Ward Thompson, 2007) and frequency of use in adulthood (Ward Thompson et al., 2008, Asah et al., 2012). These adults might weight the availability of green POS somewhat more heavily in their choice of neighbourhood and, in turn, take their children to visit green POS more frequently, potentially leading to a gradual ongoing spatial selection effect. For this reason, a measure of nature connectedness should ideally be included as a covariate in future analyses of POS

greenness and health, if not as central component of the mechanism being investigated. In relation to the present research, the previous comment about the potential limits to exchangeability of residents between neighbourhoods is pertinent.

4.2.3.2 History effects

As already mentioned (see Section 4.1.2.3), POS greenness was measured contemporaneously with the first measurement occasion (in the year 2007) and assumed to remain stable thereafter. Consistent with this approach, the sample was restricted to residentially immobile participants who remained living within 500m of their baseline address throughout the remainder of the study period. For these reasons, it is important to note the possible influence of gentrification taking place within one parts of the ZEPSOM region during this time.

From the period 1996 to 2006, a period of 'standard' and 'new-build' gentrification was documented in the neighbourhood of Saint-Henri, reflecting both the upgrading of existing housing stock and the adaptive reuse of former industrial sites for housing targeted towards higher-income groups than those in the surrounding neighbourhood (Twigge-Molecey, 2009). This gentrification, precipitated by the proposal of a new mega-hospital project on the site of a former railroad in area (the project was completed in 2014), was marked by increases in: the proportion of owner-occupied households; dwelling values and average rents; average household and average personal incomes; the proportion of the population aged 15+ with a university degree or certificate; and the proportion of professionals and seniors managers in the neighbourhood (Twigge-Molecey, 2009). Saint-Henri is one of Canada's oldest working-class neighbourhoods, previously characterised by, "a sense of neighbourhood belonging developed more on a cultural than socio-professional bases… and a frame of reference of belonging to a very well-defined neighbourhood, where the neighbourhood unit dominates" (Falardeau, 1989, Favreau, 1989 in Twigge-Molecey, 2009 , p.3). Towards the end of the study period, in 2012, it was described in the media as "eccentric and artsy" (Collette, 2012).

Thus, while the availability and characteristics of parks may have remained stable (we have no evidence, for example, that previously existing POS was developed on) the character of the neighbourhood may have changed substantially. Importantly, this is also an area of the ZEPSOM characterised by relatively barren parks; POS greenness scores for residents in the borough of Saint-Henri / Pointe St Charles were significantly lower than those of residents in other neighbourhoods both within 500m (mean diff.=0.77; $t=21.01$, $df=507$, $p<0.0001$) and 1000m (mean diff. 0.82; $t=35.75$, $df=800$, $p<0.0001$) of the home.

Thus, it is possible that to some extent, POS greenness is acting as a proxy for other historic processes that may be detrimental to perceptions of social cohesion or mental health. I alluded to this point earlier, when discussing the association between POS greenness and community participation.

4.2.3.3 Other potential confounders

Finally, it is possible that unmeasured aspects of POS quality could confound associations between POS 'greenness' and mental health, if 'greenness' is merely a marker of a generally higher level of investment or maintenance bestowed upon POS in a particular area. Francis et al. (2012b) found that objective quality of POS was related to lower levels of distress when measured in relation to the quality of tangible amenities such as paths, lighting, playgrounds, shade, irrigated lawn, and sporting facilities, but it was unclear to what extent the 'green' components of quality were responsible for this relationship.

4.2.4 Selection bias

Despite the best efforts of researchers, the process of recruitment and follow-up to a longitudinal study rarely delivers a completely random sample of the parent population. Those individuals who can be contacted, agree to participate in the research, and continue to participate across multiple waves of a longitudinal study often differ systematically from those who do not. For instance, the likelihood of recruitment and/or dropout may be affected by social, educational, health or environmental conditions (Nohr et al., 2006). If those influences include (or themselves determine) both the exposure and outcome of interest, then study participation is a 'collider' on the causal path between exposure and outcome (Cole et al., 2010). In these circumstances, restricting analysis of the exposure-outcome relationship to individuals with complete participation amounts to conditioning on a common effect of both variables, and may generate a spurious or biased association between them (Hernán et al., 2004, Chaix et al., 2011). Essentially, the fact of selection induces dependence between exposure and outcome within the pool of participants by artificially excluding cases in which neither participatory influence operates. This may occur even if the exposure and outcome are marginally independent in the population, and regardless of whether the relationship between exposure/outcome and participation is mediated by several variables or attributable to some exogenous common cause (Rothman et al., 2008). Importantly, in the context of spatial health research, selection bias may arise through systematic variations in participation associated with neighbourhood conditions as well as individual characteristics (Chaix et al., 2011). This section discusses potential

sources of selection bias arising from differential likelihoods of recruitment or attrition/exclusion from the final sample according to the characteristics of individuals or neighbourhoods. The analysis referred to herein was detailed in Chapter 3 (Section 4).

The door-to-door recruiting campaign achieved a cooperation rate of 42% among individuals who were contacted and eligible to participate. This is similar to cooperation rates reported in other epidemiological studies during the early 21st century, following an average decline in cohort study participation rates of 0.87% per year between 1970 and 2003 (Morton et al., 2006, Galea and Tracy, 2007, Nohr et al., 2006). Among other factors, this decline has been attributed to the proliferation in research studies and appeals for participation, the increasingly demanding nature of those studies (e.g. requests for ongoing follow-up), and a general decrease in 'volunteerism' and social participation (Galea and Tracy, 2007).

It was more difficult to reach potential participants in areas characterised by higher average income and educational attainment, as well as those that were home to the highest proportions of couples with children and lowest proportions of sole parents. However, once contact was made with an eligible person, there were no statistically significant differences in the propensity to participate between areas that differed in terms of income, educational attainment, family composition, residential mobility, or voter participation rates. The SES differential in door-to-door absence rates is pertinent to the present study because lower SES neighbourhoods have frequently been observed to suffer from inferior accessibility and quality of public open spaces (Estabrooks et al., 2003, Powell et al., 2004, Wolch et al., 2005, Cradock et al., 2005, Crawford et al., 2008, Mitchell et al., 2011, Astell-Burt et al., 2014a) and also appear to have a detrimental effect on mental health (Truong and Ma, 2006, Kim, 2008, Mair et al., 2008, Blair et al., 2014). The differential in relation to family composition is also pertinent, because sole parents might spend less time in POS than individuals in two-parent families (Fan et al., 2012). A bias towards the selection of sole parents in less affluent areas could therefore theoretically result in an overrepresentation of individuals with poor POS resources and less opportunity to use those resources. If selection is also biased towards those with better mental health, as one might anticipate, then those processes could artificially inflate estimates of the benefits of POS greenness. Importantly, however, the associated threat to internal validity was minimised by elements of the stratified sampling procedure employed in this research, including the use of targeted address ranges and enforcement of recruitment quotas relative to the size of the dissemination area population. Together, these approaches help to increase the probability

of recruitment from a pre-specified geographic area (even if absence rates are elevated within the address range) such that selective absence rates did not disproportionately skew the sample towards low SES dissemination areas. Moreover, by preserving the geographic integrity of the sample, selective absence rates did not influence the distribution of POS characteristics.

Of the 2433 individuals recruited, 1129 (46%) did not complete all three interviews and were dropped from the sample. This is a clear limitation of the research; by discarding real data from the first wave(s) of research, casewise deletion reduces statistical power and can bias the estimation of regression parameters if the data are missing in a systematic way (Newman, 2003). The rates of attrition from T1 to T2 (25%) and T2 to T3 (28%) were slightly elevated compared to other prospective psychiatric epidemiological studies with one-to-three year follow-up intervals, which have typically lost around 20% of the sample at each wave (Eaton et al., 1992, de Graaf et al., 2000, de Graaf et al., 2013). This was largely attributable to the relocation of participants outside the study region. In addition to those who did not complete all three interviews, a further 375 (29%) were excluded from the final sample because they had not resided at their T1 address for a full twelve months at commencement of the study, or moved further than 250m from their T1 address during the study.

Overall, residential mobility proved to be a significant hindrance to the retention of participants in this study. In total, 29% (n=717) of the initial baseline sample was lost due to residential relocation within or outside the ZEPSOM region during the study. A further 5% of otherwise eligible participants (n=122) were lost because they had changed residence within a one-year period prior to commencement of the study, while 15% (n=368) could not be recontacted; many of whom, presumably, had also moved house. This is noteworthy for future research that measures residential exposures at a single point in time, and suggests paying close attention to the potential for residential mobility to erode sample sizes and statistical power. Of the participants excluded for moving within the study zone, half (n=130, 52%) had already moved more than 500m by the second wave of data collection. Generally speaking, this corresponded with the participant moving into a new census tract (91%), indicating that this issue would equally plague studies that measure residential exposures within the bounds of statistical local areas rather than buffers. In future, a more appropriate method of dealing with residential mobility would be to generate an ‘average exposure’ measure that summarises ‘time in place’ across the

various residential contexts to which the individual is exposed, rather than excluding from the study any participants who have relocated.

Altogether, the odds of attrition or exclusion from the sample were elevated among people who were younger, possessed lower educational qualifications, reported lower household income, and had been living at their T1 address for a shorter period of time. Age, education and paid employment are often inversely related to rates of attrition in psychiatric epidemiological catchment area studies (Eaton et al., 1992, de Graaf et al., 2000, Lamers et al., 2012, de Graaf et al., 2013) as well as many other population studies with different foci. There was some evidence of selective sample losses (from the combined sources of attrition and exclusion) among individuals reporting higher levels of psychological distress at the first occasion of data collection. This association was, however, largely explained by the number of acute stressors experienced in the twelve months prior to T1, which had a pronounced effect on the likelihood of attrition or exclusion. Life satisfaction at T1 was not associated with subsequent sample losses. These findings are consistent with previous studies that have identified a weak-to-moderate effect of baseline psychopathology on attrition, after accounting for sociodemographic characteristics (Eaton et al., 1992, de Graaf et al., 2000, de Graaf et al., 2013) but indicate the systematic loss of individuals reporting greater exposure to stress. Sample losses were also elevated to a statistically significant degree among participants reporting lower levels of social cohesion, neighbouring behaviour, or community participation[104] at T1. In addition, sample losses tended to be lower among individuals with access to greener POS, on average, within 500m or 1000m of the home, although the practical significance of the difference in mean levels of greenness between lost and retained participants was negligible.

Under these conditions, restricting the analysis to individuals retained in the sample could have attenuated the associations between POS greenness and social cohesion, neighbouring behaviour, and community participation. Thus, the possibility should be considered that a failure to identify a statistically significant association between POS greenness and neighbouring behaviour was attributable to selective sample losses. Given that the mean difference in *POS Greenness*, for either buffer size, was only equivalent to roughly one-tenth of the T1 sample standard deviation between lost and retained

104 The association with community participation was strictly marginally non-significant (p=0.058)

participants, and noting that a statistically significant effect was identified with social cohesion despite similar selection processes, this seems implausible.

Secondly, if a variable that lies in the causal pathway from POS greenness to mental health (e.g. social cohesion) is associated with selective sample losses, then restricting analyses to participants who completed the study could bias estimates of POS-MH relations towards the null by 'blocking' the flow of information along the causal path (Pearl, 2009, Schisterman et al., 2009, Elwert and Winship, 2014). In this instance, it should be considered whether the lack of a statistically significant health-promoting association between POS greenness and membership in the worsening psychological distress, in relation to the 500m buffer size, was attributable to such a bias. However, considering that a statistically significant effect was still observed in relation to the 1000m buffer area, and that POS greenness in that area was in fact more strongly related to social cohesion than it was in the 500m buffer, this again seems implausible.

Finally, potentially unobservable influences on attrition from the sample must be considered. Specifically, selected losses attributable to unobserved declines in mental health or psychosocial functioning may result in informative censoring whereby participants remaining in the study are less likely to experience declining mental health than those lost from the sample. In this respect, it is worth reconsidering prior discussion of individuals as active agents in accessing POS greenness. For example, it is possible that individuals with initially good mental health who did not utilise POS to deal with stress (and consequently experienced rising levels of distress) dropped out of the study at a higher rate than individuals who had access to the same resources, but actively engaged with them. This could artificially inflate the observed protective association between residential POS greenness as a neighbourhood resource and membership in the worsening distress class, because individuals who actively use these resources are overrepresented in the final sample compared with those who do not.

In summary, the present study suffered from a low cooperation rate and reasonably high attrition rates, although these were not unusual in relation to other longitudinal cohort studies. However, the study did lose additional participants due to the imposition of additional exclusion criteria, retaining just under 40% of the T1 sample for the final analysis. Discarding real data from the first wave(s) of research is a limitation of the study, as it reduces statistical power and has the potential to bias regression estimation estimates if the data are missing in a systematic way (Newman, 2003). There was no strong evidence for selection bias arising from observed determinants of participation or sample losses.

However, I cannot rule out that part of the association between POS greenness and membership in the worsening distress class is due to selective dropout attributable to unobserved values of the outcome.

4.2.5 Regression to the mean

Given that the present study analyses its primary outcomes of psychological distress and life satisfaction using linear trajectories estimated from only three waves of data, the extent to which observed changes might be explained by regression to the mean (RTM) was quantitatively assessed in relation to the mean trajectories for the two adverse trajectory classes under each outcome (Appendix 4.4). The primary aim of this analysis was to determine the extent to which the mean trajectory slopes used to describe these classes reflected true change over time, or were merely statistical artefacts of the manner in which participants were partitioned across the spectrum of baseline mental health scores.

The analysis concluded that RTM was likely to account fully for what appeared to be an 'improving' trend among those entering the study with very high levels of psychological distress. Similarly, RTM accounted for most of what appeared to be an 'improving' trend among those entering the study with very low levels of life satisfaction. Conversely, RTM was unlikely to account for a significant portion of the change in these outcomes among the 'worsening' distress or 'worsening' life satisfaction classes. This lends confidence to the interpretation of membership in the 'worsening' classes as reflecting a true state of deteriorating mental health.

4.3 Statistical conclusion validity

Inferential research involves the application of statistical criteria in order to ascertain the degree to which any co-variation apparent between a presumed cause and effect could reflect chance (i.e. random) variation. Thus, statistical conclusion validity concerns the risk of drawing false conclusions about co-variation due to the stochastic nature of observations or the inappropriate use or misuse of statistical techniques and procedures.

4.3.1 Possibility of type I error

In statistical hypothesis testing, convention dictates that the null hypothesis be rejected when the possibility of erroneously concluding the existence of an association between exposure and outcome is 5% (or alpha = 0.05, expressed as a probability). Thus, one threat to statistical conclusion validity is the possibility that a true null hypothesis is incorrectly rejected and thus the inferred effect is a 'false positive' (type I error). Formally, alpha reflects the individual error rate, or the probability of type I error arising from a single

hypothesis test. Invoking multiple or sequential hypothesis tests increases the likelihood of committing a type I error somewhere within the family of *k* tests. Thus, the family-wise error rate reflects the probability of incorrectly rejecting the 'complete' null hypothesis, i.e. rejecting at least one of *k* null hypotheses when in fact all null hypotheses in the family are true (Bender and Lange, 2001).

For example, in Chapter 6, the somewhat exploratory approach of independently testing associations between POS greenness and five psychosocial resources inflated the possibility that an association was observed due to random chance. To reduce this risk, p-values for these associations were adjusted post-hoc using Holm's (1979) procedure to retain a family-wise error rate of 0.05 across the five paths tested within each spatial scale (Aickin and Gensler, 1996). Associations between *POS greenness* and *social cohesion* remained statistically significant both for the 1000m buffer (adjusted $p<0.0001$) and 500m buffer (adjusted $p=0.030$) after adjustment, indicating that the statistical significance of these associations was not an artefact of multiple testing. Adding weight to this conclusion was the consistency in the direction of associations between POS greenness and social cohesion, neighbouring behaviour, social support, and coping; despite the fact that associations with the latter three resources were not statistically significant, this pattern of results accords with the notion that POS greenness supports psychosocial wellbeing in a general sense. In fact, the adjustment of p-values for multiple hypothesis testing is arguably too conservative, given the theoretically derived basis for testing these associations, and may simply serve to inflate the risk of type II error (Bland and Altman, 1995, Michels and Rosner, 1996).

In broader terms, it might be considered whether the sequential mode of model development in this thesis has inflated the possibility of type I error. In relation to the model building stages described in Chapter 4, which sought to develop base covariate models for use throughout the thesis, this would not be particularly concerning; type I errors (incorrectly retaining covariates with null associations to mental health) could exact a cost on degrees of freedom, but it is most important that pertinent socio-demographic covariates were not incorrectly excluded from further analyses. Considering the adaptation of these models to achieve the substantive research aims of the thesis, Chapters 5 and 6 also presented multiple hypothesis tests relating to multiple theoretical mechanisms, mental health outcomes, and latent class comparisons. This does not, however, necessarily invoke the problem of 'multiple testing' as described above. Bender et al. (2001, p.344) state that, in general, the problem of multiple testing should be controlled "when the results

of a well-defined family of multiple tests should be summarised in one conclusion for the whole experiment". I would argue that this does not characterise the analyses of mental health outcomes in this thesis, where the multiplicity of hypothesis tests primarily reflects an attempt to answer distinct research questions, rather than a series of interconnected tests intended to answer a single question. Taking this into consideration, and acknowledging that the cost of adjustment for multiple testing is an increased type II error rate (discussed below), I take the rationalist position that such action could in fact be detrimental to the validity of conclusions from this research (Rothman, 1990, Feise, 2002).

4.3.2 Possibility of type II error (statistical power)

A second and related threat to statistical conclusion validity is the possibility of an erroneous decision to accept (or, more specifically, to not reject) the null hypothesis. This is referred to as a type II error, and is a function of statistical power. Currently, little is known about the sample size requirements for growth mixture modelling, although it is apparent that these differ may differ widely depending on the true number of classes in the population, the separation between those classes, and the number of manifest observations (i.e. time points) that are available. Under realistic conditions of low class separation within the population, and using four manifest indicators, Kim's (2012) simulation study suggested a minimum sample size of 700 individuals if two classes (75%, 25%) exist in the population and 2,400 if there are six classes (30%, 20%, 15%, 15%, 10%, 10%). Thus, the sample size of 929 individuals in the present study seems reasonable for a three-class growth mixture. It should also be noted that all classes exceeded the recommended minimum recommended cut-off of 25 participants or 1% of the sample (Jung and Wickrama, 2008, Berlin et al., 2013b). However, as alluded to in Section 4.1.1 of this chapter, Kim's (2012) simulation suggests that the sample size was probably insufficient to identify additional trajectory classes that might exist in the population.

It should be considered whether the thesis was underpowered to detect statistically significant effects of POS greenness on trajectories of life satisfaction, particularly in relation to estimates of the main effects, which were consistently in the hypothesised direction of a protective effect[105] but suffered from poor precision (Figure 30, p.229). The relatively small sizes of the worsening and chronic low-satisfaction classes, as well as the lack of statistically significant associations between time-invariant sociodemographic

[105] With the exception of the main effect of POS greenness in a 1000m buffer on membership in the worsening life satisfaction class, for which the point estimate which was essentially null.

covariates and trajectory class membership (Table 32, p.186) would be consistent with a conclusion that the study was underpowered. However, it is important to note that associations between stressful life events and class membership were highly statistically significant (Table 34, p.199), indicating that the life satisfaction model was not entirely insensitive to the detection of strong covariate effects on longitudinal trajectories. By contrast, while the unadjusted correlations between life satisfaction and POS greenness at T1 were statistically significant, they were very weak at both spatial scales (1000m: Pearson's r=0.088, p=0.007; 500m: Pearson's r=0.073, p=0.03). A recent study utilising panel data from roughly 22,000 individuals also indicated that contemporaneous associations between the availability of POS and life satisfaction could be very weak (Krekel et al., 2016). Taken together, these findings suggest that very large samples may be needed to further an understanding of these relationships in future. However, as discussed earlier in this chapter (Section 3.4), I would contend that the selection of measures and the short time frame of the study may hold greater responsibility for the findings than low statistical power, as such.

4.4 External validity

4.4.1 Generalisability to the source population

Evidently, the final sample is not entirely representative of the population from which it was drawn. Broadly speaking, participants are more likely to be female, older, better educated, and have higher income than the general population of the catchment area; characteristics frequently associated with recruitment (e.g. Sonne-Holm et al., 1989, Galea and Tracy, 2007, Hara et al., 2010) and retention (Eaton et al., 1992, de Graaf et al., 2000, Lamers et al., 2012, de Graaf et al., 2013) in population health studies. In some respects, a skew away from the characteristics of the larger source population may have been anticipated given the pursuit of a geographically representative cohort with equal numbers of participants in each of the four unequally populated (and sociodemographically diverse) boroughs. Moreover, all cohorts are expected to become less representative of the source population over time, due to selective attrition processes such as those detailed earlier in this chapter.

Despite this, the lack of precise alignment to the regional population is not inherently problematic in the context of this research, considering that the sample is not wildly unrepresentative on any key sociodemographic criteria. Our objective is not to make descriptive statistical inferences about the prevalence of psychiatric disorders among the

catchment area population[106], but to make scientific inferences about longitudinal associations between public open space, psychosocial resources, and mental health. This does not require that our sample is representative of the population from which it was drawn (Rothman et al., 2013, Nohr and Olsen, 2013, Elwood, 2013, Richiardi et al., 2013). In fact, the geographically robust and exhaustive sample satisfies a more pressing concern to achieve sufficient variation in the exposures (and outcomes) of interest in order to enable comparisons across different levels of these variables (Szklo, 1998, Lacey et al., 2013). Moreover, it allows examination of the effect across a representative distribution of other pertinent environmental variables, such as area socioeconomic status and population density (Chong et al., 2013, Ambrey, 2016). As long as groups of participants under comparison are 'equally unrepresentative', then unbiased and generalisable estimates of exposure-outcome associations should be obtained (Szklo, 1998). Thus, compositional discrepancies between a sample and its source population are unlikely to impede causal inference provided they do not reflect the operation of uncontrolled selection biases in study participation and retention (Richiardi et al., 2013).

Some key attributes of the sample composition do, however, limit the generalisability of conclusions to certain groups. For instance, the study entirely excludes children under 15 and the elderly, and to a notable extent underrepresents the most disadvantaged residents of the catchment area. This is pertinent given that factors such as age, gender and socioeconomic factors influence physical abilities and the adoption of social roles, which, in turn, shape the extent to which activity cycles are tied to the residential milieu (Hartig et al., 2003b). Elderly individuals and children, for instance, tend to leave their neighbourhoods less frequently and regularly than other individuals and might therefore be influenced to a greater extent by attributes of the residential environment (Massey, 1998, Pearlin, 1999). Moreover, barriers to mobility modify the real accessibility of resources for these groups, such that proximity becomes increasingly important (van Herzele and Wiedemann, 2003). Numerous studies have indicated that the proximity and total availability of POS have a greater effect on the wellbeing of certain subpopulations, such as children and older adults (Maas et al., 2006) or individuals with lower socioeconomic status (De Vries et al., 2003, Maas et al., 2006, Mitchell and Popham, 2008, Ambrey and Fleming, 2013, Mitchell et al., 2015). As such, generalisation of the present findings to

[106] This task has been undertaken by Caron et al. (2012) using appropriate weighting procedures.

those populations at the extremes of the age range included here, and not accounted for in this study, should be treated with caution.

4.4.2 Generalisability to other contexts

A key attribute of the study region in this thesis, which may limit its generalisability to other contexts, was the relatively high level of accessibility to POS. Among the final sample, the maximum road network distance from a participant's home to the nearest POS was 885m, while just over three-quarters (78%) of the sample had access to POS within 250m. This could be compared against a study in Bryan, Texas, for example, where only 55% of the population lived within an 800m straight-line radius of POS (Nicholls, 2001). Anecdotally speaking, POS in the study region tend to be well maintained and are quite green across the board (mean NDVI of POS in the region = 0.20, SD = 0.09). High levels of POS accessibility and greenness may hamper the generalizability of findings from this study to other contexts, since relations between POS and mental health may not be linear across all exposure levels (Szklo, 1998). That is, a relatively high level of ambient exposure to POS may have limited the consequences of variation in this exposure to POS greenness.

Few data exist to shed light on the nature of the dose-response curve relating POS greenness to mental health. However, a small body of laboratory-based experimental evidence suggests non-linear effects of streetscape tree density on both stated preference and the efficacy of physiological restoration following the arousal of stress. In relation to stated preference, Jiang et al. (2015) identified very steep returns from slight increases in tree density within relatively barren settings, with positive but diminishing returns to further increases in tree density. This relationship suggests that adding more trees to the streetscape will always increase preference, but that the amount of change will be most pronounced in areas with fewer trees to begin with. By contrast, the relationship of tree density to physiological restoration appears to be less straightforward. In a separate study, Jiang et al. (2014a) induced stress by engaging participants in a Trier Social Stress Test, then randomly assigned each individual to a six-minute, three-dimensional video of neighbourhood streets characterised by a particular level of tree density. The effectiveness of restoration across these treatments was measured as the relative reduction in salivary cortisol and skin conductance after viewing these scenes. Streetscape tree density was associated with the effectiveness of restoration, but only among men. Moreover, the relationship appeared to follow an inverted u-shaped dose response curve with an optimal tree density occupying between 24% to 34% of pixels in the imagery. Below 24% the

efficacy of restoration was positively associated with tree density, but above 34% restoration was inversely associated with tree density. Other studies have demonstrated non-linear effects between the overall availability or accessibility of urban green space with life satisfaction (Astell-Burt et al., 2014b, Bertram and Rehdanz, 2015 1068, Krekel et al., 2016) and psychological distress (Astell-Burt et al., 2014b) indicating declining marginal returns from increasing quantities of public open space. Together, these studies suggest that the associations between POS greenness and mental health are likely to be stronger in contexts with less POS or more barren POS.

Issues related to climate must also be considered, given that the cold Montréal winter will have radical implications for the appearance, and possibly usage, of POS at different times of the year. It is possible that the extremes of the climate could limit the overall effectiveness of POS as a resource for mental health. Research on the restorative effects of POS in winter ('white space') are lacking (Korpela et al., 2014). Theoretically, although POS may no longer appear 'green', it remains aesthetically pleasing during the winter and could continue to provide natural scenery with restorative potential (Kaplan, 1992b). However, a pilot study failed to identify any attentional benefits of a wintertime walk in a wooded setting, compared with the effects of walking in a neighbourhood or a parking lot (Perkins et al., 2011). Although this provides limited and speculative evidence, it suggests the possibility that the actual restorative functions of POS greenness might differ according to the seasons; perhaps because leaves have fallen from the trees, or because reduced thermal comfort conditions make it more difficult to 'relax'. In relation to POS usage, it should be noted that residents of Montréal still utilise POS during the winter for activities such as hiking, snowshoeing and ice skating. Although warm conditions and the presence of sunlight are important factors in the use of outdoor spaces in cooler climates (Nikolopoulou et al., 2001), there is increasing evidence that people can tolerate wide changes of the physical environment, provided they are produced naturally. That is, expectations and experience of what the environment 'should be like' greatly influence perceptions of the thermal comfort of outdoor spaces, and people adapt psychologically as well as physiologically to changing conditions across the seasons (Nikolopoulou et al., 2001, Nikolopoulou and Steemers, 2003).

4.4.3 Generalisability to the candidate's home country of Australia

The analytical opportunities afforded by the ZEPSOM would not be possible to my knowledge with any current collection of data in Australia. However, the demographic and economic characteristics of Montréal as a modern urban centre support the relevance of the

proposed work to other developed contexts. The populations of Montréal, Québec and Melbourne, Victoria, for instance, are closely aligned on several demographic markers including total population size, age structure, and median household income (Table 44). Moreover, the 12-month prevalence of mental disorders within the ZEPSOM catchment area (16.7%) is similar to that in major urban areas of Australia (20.4%) (Australian Bureau of Statistics, 2007, Caron, 2012b).

Table 44: Selected demographic characteristics of Montréal, Canada and Melbourne, Australia

	Greater Montréal: Census Metropolitan Area (2011)	Greater Melbourne: Greater Capital City Statistical Area (2011)
Total population	3,824,221	3,999,982
Population aged under 15	16.5%	18.5%
Population aged 65 and over	14.6%	13.1%
Median age	39.7	36
Median household income	$69,150 CAD	$69,316 AUD
Population density (people/square km)	898	430
Number of occupied private dwellings	1,613,260	1,430,655
Average people per household	2.3	2.6
% households with registered motor		90.9%

(Sources: Statistics Canada, 2012a, b, 2013, Australian Bureau of Statistics, 2013a, b).

Importantly, there is a distinct overarching similarity in the health systems of Canada and Australia, both of which are regionally administered under a universal public insurance program (Medicare), but in Australia upwards of half the population purchase additional private insurance for benefits not covered by Medicare (Thomson et al., 2013).

Of course, there are noteworthy differences between Australia and Canada in relation to both climate and the characteristics of remnant vegetation. Whereas Canadians endure long, cold winters, Australians swelter through long, hot summers. The benefits of POS greenness for minimising urban heat island effects are likely to be particularly relevant to liveability in the latter case, as well as providing much needed shade for users of POS in the warmer months. The presence of evergreen (versus deciduous) trees means that Australian 'green space' may be more likely to remain 'green' all year round, although there is variation in the prevalence of deciduous tree cover throughout Montréal. On the other hand, vegetation in Montréal tends to be a much brighter, more vivid shade of green than that characterising predominant vegetation (e.g. gum trees) in Australia. In relation to the comparability of NDVI values between contexts, it is possible that this could indicate

distinctions in the leaf optical properties from which the vegetation index is derived (Huemmrich and Goward, 1997). While there is little evidence to guide hypotheses about how these factors might influence the generalisability of results across contexts, the point of this discussion is to highlight that 'POS greenness' does not necessarily mean the same thing in one place, as it does in another.

In terms of practical considerations in the translation of knowledge between contexts, it is noteworthy that a Public Health Partnership Agreement has been in place between Québec and South Australia since 2008 (South Australian Department of Health, 2010). This partnership provides a solid foundation for informational exchange, aiming to strengthen and deepen the mutual understanding of public health issues of common concern to both jurisdictions. In this manner, it provides an opportunity for policy makers in Australia to identify relevant initiatives from the Canadian province that can be adapted to the South Australian context for the advancement of public health.

5 Relevance, timeliness and contribution

Throughout the past decade, there has been a proliferation of research interest into the salutogenic benefits of nature experience and POS in urban residential environments. Across the same period, the understanding of these benefits appears to have found renewed interest in the consciousness of policy makers as evidenced, for example, by the prevalence of POS policy indicators across Australia (Badland et al., 2014) as well as recent government publications pertaining to 'creating liveable open space' (e.g.State Government of Victoria, 2013) and metropolitan green space funding programs (e.g. New South Wales Government, 2015). In fact, as recently as this year the journal *Nature* published a series of articles on urban health and wellbeing, of which two pieces pertained to the benefits of POS in relation to happiness (Gilbert, 2016) and protection from stress (Maxmen, 2016).

In the relevant scientific literature, attention has turned, over time, from the effects of these resources on negative dimensions of mental health, such as psychological distress and disorder, to positive dimensions of mental health, such as life satisfaction. Research has also begun to disentangle the effects of POS accessibility from POS quality, and to elucidate the psychosocial mechanisms by which observed associations with mental health might accrue. Yet, many of these avenues of inquiry remain in their infancy. Chapter 2

presented a thorough narrative review of the literature in relation to urban residential POS and mental health, pertinent aspects of which may be summarised as follows:

- Prior to the commencement of this study in 2012, relationships between urban POS and mental health had (1) relied exclusively on cross-sectional research designs; (2) failed to assess the effects of POS on positive dimensions of mental health, such as life satisfaction; and (3) primarily assessed the total availability or accessibility of POS, rather than its inherent attributes or qualities (for a contextual review, see Lee and Maheswaran, 2011, Park et al., 2011).
- More recently, a handful of longitudinal research studies have demonstrated compelling evidence for associations between the total availability or accessibility of urban POS and symptoms of psychological distress or life satisfaction, but attention to POS quality remains lacking.
- Despite the frequently espoused role of biophilia and psychological restoration as theoretical foundations for the salutogenic effects of POS, no research to date has specifically assessed the effects of POS 'greenness' – as distinct from neighbourhood 'greenness' arising in public and private space – on mental health.
- A small number of studies have tested potential explanatory mechanisms linking POS to mental health, such as its potential to buffer against life stress, or the extent to which its effects are mediated via neighbourhood social integration. However, these mechanisms remained to be tested using a longitudinal research design.

A more detailed explication of these issues was presented in Chapter 2. This thesis addressed each of the key limitations identified above and makes a novel contributions to the state of knowledge linking urban POS to mental health, by providing empirical support for the contentions that:

- The 'greenness' of public open space is an important quality attribute in the promotion of mental health, over and above the total availability or size of POS in the residential area.
- POS 'greenness' buffers against the arousal of psychological distress following the accumulation of stressful life events over a number of years, indicating that a greater focus on mechanisms involved in the stress process may be beneficial in advancing the body of knowledge related to the enduring (rather than immediate) benefits of exposure to natural environments.

- POS ‘greenness’ also appears to exert a main salutogenic effect in relation to the arousal of psychological distress, with indications that this effect may be transmitted through its association with perceptions of social cohesion.
- Each of these findings is consistent with the biophilia hypothesis, providing broad support for the importance of easily accessible nature in supporting psychosocial functioning. Moreover, this thesis illustrates the potential importance of providing natural stimuli in the purely public realm, indicating the relevance of its findings to public policy.

The first major strengths of this study derive from its access to a psychiatric epidemiological catchment area (ECA) study – the *Zone d’Épidémiologie Psychiatrique du Sud-Ouest de Montréal* (ZEPSOM) study – in an exclusively urban setting in the south-western region of Montréal, Québec, Canada. The ZEPSOM is home to over a quarter of a million people and comprises a diverse collection of neighbourhoods that exhibit significant variation along sociodemographic factors such as income and ethnic composition. Importantly, the stratified sampling plan for the study yielded a sample that was representative of the study region with regards to the geographic distribution of the population and, accordingly, exposure to different environmental living conditions including population density and area socioeconomic status (SES) (Caron, 2012b). Although there were substantial losses from the sample across the life of the study, the geographical distribution of the sample remained unchanged. This is a strength of the study, because the area-level conditions just mentioned could moderate relationships between POS greeenness, psychosocial resources, and mental health (Chong et al., 2013, Ambrey, 2016). Thus, we can be confident that the relationships identified are broadly translatable to other large and diverse metropolitan contexts.

The ZEPSOM research program is the first longitudinal epidemiological catchment area study of mental health in Canada, and the first epidemiological catchment area study in North America to utilise a geographic information system (GIS) that allows the linkage of individual-level health measures to detailed information on residential environmental risk conditions and accessibility to resources (Caron et al., 2007, Caron, 2012b). Combining geo-coded individual surveys with a GIS is an optimal strategy to situate mental health in an ecological system with multidimensional influences, permitting investigation of the contribution of environmental living conditions to mental health outcomes while controlling for individual-level risk and protective factors. Importantly, the MEGAPHONE GIS (Daniel and Kestens, 2007) permitted the purposeful extraction of POS indicators to

suit the specific objectives of this research, rather than the use of less finely granulated (but commonly used) secondary data. For instance, using the GIS, I was able to: (i) ascertain spatial variation in the quantity and condition of vegetation within public open spaces, rather than using a more crude measure of generic 'green space' availability (Richardson et al., 2012); (ii) generate egocentric representations of the local residential environment for individual participants; and (iii) assess the stability of the results to small-scale variations in the assumed spatial scale of that area.

Moreover, the measure of POS greenness was scaled to reflect meaningful variations in land cover for POS in urban settings. For instance, a one-unit increase (equivalent to an increase of 0.1 in mean NDVI values) reflects the change from a barren square with little vegetation to a playground with moderate greenness, or from a grassy oval to a park with lush vegetation (Bell et al., 2008). Consistent with restoration theory, the findings in this thesis indicate that such distinctions do contribute in a meaningful way to the protection and promotion of mental health, and are associated with greater social cohesion, over and above the total quantity or size of POS available to residents. This is a significant contribution to the field, given that studies to date have almost exclusively assessed the total availability of 'green space' without distinguishing more refined qualities of the type of 'green' being provided; for instance, whether 'neighbourhood greenness' resides in public versus private space, or whether public 'green space' comprises monotonous lawn versus urban forest (Richardson et al., 2012).

With the exception of the coping measure (which had obvious fallibilities) all measures of mental health, psychosocial resources, and stressful events employed in this thesis used validated, multiple-item scales with good psychometric properties. This lends confidence to the knowledge that the study has measured what it purported to, and did so with reasonable precision for the sample size available. The research investigated a range of potential psychosocial mediators that were purposefully selected for their potential to reflect, to differing degrees, prevailing notions of the manner in which POS greenness might influence health (e.g. via restoration, social interaction or place attachment). This approach builds on prior research to enable a more controlled comparison of potential pathways within a single study, rather than attempting to infer these differences across multiple investigations with varied samples and contexts. In addition, the assessment of outcomes across both positive and negative dimensions of mental health is an asset to the thesis. This is a rarity in place-health research, despite a growing understanding that the development of these outcomes could follow distinct aetiologies (Westerhof and Keyes,

2010). Although findings in relation to effects of POS greenness on life satisfaction may be interpreted with caution, they do provide an interesting stimulus for future investigations to explore this question further.

In addition to strengths in the setting, sample, and measures, the thesis employed a longitudinal design – also still relatively rare in place-health research – that assessed the prospective effects of POS greenness or social cohesion on mental health, minimising concerns of self-selection and reverse causation in relation to these pathways. To do so, it employed a novel statistical approach (growth mixture modelling) yet to experience wide uptake in community-based cohort studies. This thesis demonstrates that the ability to isolate atypical trajectories using GMM can be especially beneficial in observational studies where the anticipated normative experience is one of good, stable mental health. Under these circumstances, single-population analytical methods might mask deviations from the norm, making it difficult to identify the pathways leading to declining or improving mental health. This is especially pertinent to social epidemiological investigations where experimental manipulation of exposures is difficult or impossible and subjects have been embedded in the context of interest for quite some time. In this manner, the thesis contributes to the pursuit of methodological innovation and versatility that is necessary for the discipline to overcome these challenges (Galea and Link, 2013).

Finally, from a research translation perspective, the ZEPSOM research program is being undertaken in partnership with all institutions and community organisations that offer mental health services in the study region, and brings together a committee of researchers, policy makers, and stakeholders to guide the development and transfer of knowledge from the catchment area to aid policy development and program planning for mental health promotion. The province of Québec is viewed as a world leader in public health policy, and has adopted a Health in All Policies approach at the highest level of government {Lazzari, 2015 #1127}. The guiding principle of this approach is that decisions in an array of diverse policy areas – including housing, transport, and urban planning – have important repercussions for the determinants of health and wellbeing (Puska, 2007, Kickbusch et al., 2008, Lazzari et al., 2015). The implication of this is that when deciding between competing policy or implementation options, the impact on health should always be considered. Thus, Health in All Policies represents a purposeful and coordinated approach to innovative, integrative solutions that cross the traditional barriers of policy portfolio or organisational silos in order to manipulate the social determinants of health. This is fertile ground for the translation of interdisciplinary research on population health into action.

6 Implications for public health practice

The analyses in this thesis were guided by a theoretical framework in which POS greenness, as a component of the physical residential environment, was situated within a socio-spatial ecology of risk, protective, and health-promoting factors that influence the mental health of individuals either interactively or independently of the stress process. In the framework, the physical environment is nested between one 'upstream' domain ('higher level processes', such as urban planning policy) and several 'downstream' domains (including the social environment; activity cycles and material resources; and intra-individual characteristics and resources). To maintain consistency with the theoretical framework, implications of the findings for public health practice are considered from the standpoint of a social ecological approach to health promotion. This approach emphasises the degree of fit between people's biological, behavioural, and sociocultural needs, and the environmental resources available to them, as a key determinant of health and illness (Stokols, 1996). As such, it does not implicitly favour interventions targeted at individuals (e.g. modifying health-related attitudes, beliefs and behaviour) over those targeted at the environment (e.g. improving the availability and quality of physical and social resources), or vice versa. Rather, health promotion efforts under a social ecological approach should ideally integrate strategies aimed at both the individual and the environment, combining active and passive interventions across individual, organisational, and community levels (Green and Kreuter, 1993, Stokols, 1996). In accordance with this model, I first address the implications of this work first in relation to the interventions targeted at the environment, before turning my attention to interventions targeted at the individual.

Following from the key findings of this thesis, the discussion focuses upon the utility of urban nature, localised within residential public open spaces, as a salutogenic resource with the potential to reduce the incidence or severity of anxiety and depressive symptoms within the community at large (Antonovsky, 1996). In this sense, urban nature experience is treated as a 'preventive innovation'; a relatively novel idea that requires action at one point in time in order to avoid consequences at some future time (Rogers, 2002). Reference is therefore made to Rogers' (2002) model for the diffusion of preventive interventions, which enables the identification of appropriate strategies to speed up the spread and implementation of such ideas. The model describes five conditions that determine the rate at which an innovation is adopted: (1) its perceived *relative advantage* over ideas it supersedes; (2) its *compatibility* with the existing values, past experiences, and needs of

potential adopters; (3) its *complexity*, or the extent to which it is difficult to understand or use; (4) its *trialability* on a limited basis; and (5) its *observability* to others. Increasing the relative advantage, compatibility, trialability, and observability of an innovation, and decreasing its complexity, will lead to more rapid diffusion.

In relation to the adoption of nature experience, the conditions governing diffusion might include: (1) the extent to which individuals are aware of the restorative benefits of nature and believe that nature experience could lead to better outcomes than other relaxing activities, such as watching television; (2) the extent to which the individual feels a sense of connectedness to nature or has prior experience with nature interaction (e.g. as a child); (3) the extent to which nature experience is easily accessible and requires only minor adjustments to existing activity cycles; (4) the existence of opportunities to trial nature experience, possibly as a secondary benefit to other activities; and (5) the visibility of natural areas throughout the neighbourhood as well as prevailing norms in relation to their usage. These might be summarised more succinctly as factors that *predispose* (relative advantage, compatibility), *enable* (complexity, trialability) and *reinforce* (observability) the target behaviour. The relative importance of each set of factors to the uptake of an innovation is likely to differ depending on relative position along the diffusion curve, i.e. the time to adoption, since this is indicative of the extent to which behaviours are resistant to change. For example, predisposing factors might be sufficient to encourage early adoption among individuals who are well placed to take up the behaviour (e.g. have access to motorised transportation, plenty of free time, feel comfortable in nature due to past experience, and are in reasonably good health). Enabling factors are likely to become more important towards the middle of the diffusion curve, while reinforcement by widespread visibility and prevailing social norms will be particularly important in encouraging the last segments of the population to take up the behaviour.

Because preventive innovations generally diffuse fairly slowly, attention to the full range of these conditions might help to promote the uptake of nature experience as a salutogenic resource over time. Thus, across the interventions targeted towards the individual and the environment, I attempt to suggest viable ways to promote both predisposing, enabling, and reinforcing factors.

6.1 Interventions targeting the environment

6.1.1 Interventions targeting the physical environment

The concept of *enabling* factors described above suggests that nature experience will be more readily adopted by urban residents if supportive environments, i.e. public open spaces with a large diversity of healthy vegetation, are readily accessible through small adjustments to existing activity cycles. Here, the concept of accessibility as the ease with which a person can reach an activity site, or their relative level of opportunity to interact or come into contact with those sites, is applicable (Hansen, 1959, Nicholls, 2001, Gregory et al., 2009). In a residential context, high accessibility will generally manifest as a greater number of activity sites located near the home, a lower degree of spatial separation from those sites, and/or a lower cost of overcoming that separation, for instance due to greater choice in transportation modes (Gregory et al., 2009). In this respect, enabling nature experience could mean that an individual is able to pass through green POS as they move between the home and other routine destinations, such as work, or that they are able to quickly and easily access green POS during leisure time without needing access to a vehicle. The present research was consistent with the purported benefits of these conditions, indicating that access to greener public open spaces within walking distance of the home was protective against prospective rises in psychological distress.

Recognition of the structural constraints that urban environments impose on healthful behaviour and opportunities has, since the turn of the 21st century, led to an "explosion of demands from public health authorities for knowledge exchange and for effective contact between the health and [urban] planning sectors" (Barton, 2009 , p.S116). On a positive note, there is evidence that the practice of undertaking health impact assessments in relation to policies situated outside the health sector is becoming more prevalent, and is particularly common in the sectors of transport, housing, and urban planning (Ståhl et al., 2006). On a less positive note, recent evidence suggests that the public "open space standards used in Australia have never had, and continue not to have, any publicly documented rational basis" (Veal, 2013 , p.225). It is outside the scope of this thesis to comment on the credibility of existing POS standards in relation to the distribution of public open space, however the implications of fallibilities in those spatial indicators for population health do not go unnoticed (see e.g. Villanueva et al., 2015). More relevant to the present research is an apparent lack of attention, globally, to the standards of quality required of POS.

Since urban planning policy directly influences the distribution and characteristics of POS in residential areas, the first recommendation from this research pertains to the manner in which the importance of 'greenness' is recognised within this sector. Although it is outside the scope of this thesis to embark on a review of policy standards in relation to public open space, it is worth stating that the indicators adopted in this domain are typically availability- or accessibility-centric. Thus, a broad typology of the most commonly applied POS standards would include population-ratio (a prescribed quantity of open space per unit of population in a given area), area-percentage (a specified percentage of land to be reserved for open space) or catchment area specifications (the maximum distance residents should have to travel to gain access to open space) (Veal, 2013)[107]. The findings of the present research indicate that the development of planning standards into the future might consider dictating the manner in which vegetation, and not merely open space, is distributed throughout cities. Others have made a similar call for greater attention to POS quality in the selection of spatially attributable indicators, recognising the potential importance of the internal attributes of POS for its attractiveness and amenity to residents (Villanueva et al., 2015). While those authors note the difficulty of large scale spatial measurement of certain POS quality attributes, such as the presence of walking paths and play equipment, the present study has illustrated that the spatial distribution of POS 'greenness' can be measured quickly and easily using readily available satellite imagery with fine scale resolution and relevance to population health outcomes.

Using these tools, geographic information systems permit assessment of the extent to which the existing spatial distribution of POS greenness meets resource need (Byrne and Sipe, 2010). This is of practical relevance to 'healthy' urban planning for a number of reasons. First, whereas the spatial distribution of POS availability will generally remain static over the long term, the quantity and condition of vegetation therein could deteriorate across a shorter time frame. For example, Martin (2004) found that small city parks in Phoenix, Arizona, tended to be more abundant in vegetation if they were situated in newer neighbourhoods. This pattern could reflect either evolving trends in city planning (such that more vegetation is installed in newer parks) or a failure to initiate revegetation at a rate sufficient to keep up with vegetation mortality in the older neighbourhoods of this 'urban desert'. In either case, the findings indicate that there may be a need for ongoing

[107] In some instances, these may be further supplemented by facility specifications pertaining to the size or recreational opportunities (typically the presence of play equipment or sports fields) that should be afforded by open spaces within catchment areas of a particular size (National Recreation and Park Association, 1983, American Planning Association, 2006).

monitoring in relation to POS greenness to ensure equitable provision of open space quality across neighbourhoods and over time. Second, the findings of the present study suggest that 'greening' POS may present a promising avenue for health promotion in residential contexts where there is little prospect to provide additional green space, such as in high density neighbourhoods where there is no land available. Finally, since the findings of this study indicate that 'greener' POS are particularly beneficial to individuals under heightened exposure to stress, a 'needs-based' approach to the distribution of vegetation could be devised to weigh more heavily the needs of populations at risk of stress; for instance, those residing in deprived low SES neighbourhoods (Byrne and Sipe, 2010). Access to green POS could be especially important in these neighbourhoods, where individuals might not possess the land or resources to cultivate and maintain vegetation-rich yards that contribute the small-scale patterning of vegetation in more affluent neighbourhoods (Martin et al., 2004).

The observed association between POS greenness and social cohesion presents even greater incentive to consider the wellbeing potential of interventions targeting this resource. Area-based interventions may be employed as a means to address spatially concentrated problems arising from the composition of personal circumstances, the contextual attributes of place, and the social dynamics that take place within them. These are often complex programs comprising a number of components working interactively or independently to address a variety of social health determinants (e.g. Droomers et al., 2014) and frequently aim to improve social cohesion (Browne et al., 2015). However, there is still only a limited understanding of the type of activities that may be responsible for the health impact of these initiatives (Droomers et al., 2016). Packages of interventions are typically designed to target both 'people' and 'places', but the often intensive, laborious and expensive nature of interventions targeting 'people' can limit their reach and, ultimately, it may only be participants who benefit (Droomers et al., 2016). By contrast, interventions targeting 'places' have the potential to benefit all members of the community. The findings of the present research indicate that POS greenness might be a viable, tangible target for interventions seeking to ameliorate an intangible social determinant of health in social cohesion. This may be especially important for individuals with mental health problems, since mental health services rarely actively work towards augmenting the individual's social cohesion and social capital within the broader community, despite an understanding that this could be integral to promotion of mental health in an increasingly fragmented society (Priebe et al., 2013).

As a final point, I note that the benefits associated with POS greenness cut across several other policy areas, and are therefore particularly relevant to a Health in All Policies approach. Urban biodiversity supported by green POS facilitates a broad range of ecosystem services, including a number of 'regulating services' such as improvements in urban hydrology, air quality, temperature regulation, and carbon sequestration (Tzoulas et al., 2007, Dean et al., 2011, Shanahan et al., 2015). For example, the canopies of 'urban forests' both reduce the urban heat island effect (Barton, 2009, Bush et al., 2015) and provide a temporary water storage system that is able to reduce the rate and volume of runoff in times of rain[108] (Xiao and McPherson, 2002). This reduces flooding hazards as well as pollutant loading in the runoff, incurring cost-saving benefits in relation to both stormwater treatment and flood damage control. Indeed, when McPherson et al. (2002) estimated the net cost benefits of public trees in cities of Washington and Oregon, USA – subtracting the direct costs of trees (e.g. planting, irrigation, pruning and other maintenance) from cost savings related to reductions in energy expenditure, atmospheric carbon dioxide and stormwater runoff, as well as improvements to air quality – they concluded that a single large (e.g. Red Oak) tree in a park or on the street would return net benefits worth $48 per annum to the city over 40 years. Aggregated across the scale of whole cities, these cost savings can run into hundreds of millions of dollars (Wolf, 2004). Moreover, the regulating and cultural ecosystem benefits of green POS influence the liveability of neighbourhoods and cities (Badland et al., 2014) and could therefore be relevant to policies relating to economic growth and development. For instance, there are indications that these resources might attract residential migration into the city (Wu and Plantinga, 2003) which is thought to be important for urban vitality and economic prosperity. In sum, the protective mental health effect of POS greenness is just one of several reasons to invest in urban vegetation.

6.1.2 Interventions targeting the social environment

At the beginning of this section, I related the *observability* of nature experience to the visibility of natural areas throughout the neighbourhood, as well as prevailing norms in relation to the usage of these spaces. In addition, I described how these *reinforcing* factors might be particularly important in the latter stages of diffusion of this preventive intervention. 'Laggards', the final 16% of the population to adopt an innovation, "will only accept a new idea when they are surrounded by peers who have already adopted and are

108 Notably, this effect is enhanced when trees have broader canopies, such as those found to be optimal for restoration.

satisfied with the new idea" (Rogers, 2002 , p.991). In other words, *predisposing* and *enabling* factors such as information about the benefits of nature experience and provision of green POS are likely to be insufficient to encourage this behaviour in the absence of widespread social reinforcement. As stated earlier, preventive innovations tend to diffuse slowly, and it is likely to take some time before the adoption of nature experience has spread this far. It might therefore be fruitful to employ a longer-term strategy targeting the social environment, by promoting nature experience and nature connectedness among children.

As detailed earlier in this chapter, interaction with natural environments in childhood predicts the frequency of visits in adulthood (Ward Thompson et al., 2008, Asah et al., 2012) and is also likely to contribute to a sense of connectedness to nature (Ward Thompson, 2007, Mayer et al., 2009, Nisbet and Zelenski, 2011). Nature connectedness, in turn, is associated with wellbeing (Capaldi et al., 2014) and augments the efficacy of restoration in natural environments (Korpela et al., 2010, Tang et al., 2015, Rogerson et al., 2016). Finally, the accumulation of positive experiences in natural environments is likely to build a sense of attachment to these settings and guide individuals toward these 'favourite places' (Hartig and Evans, 1993, Cattell et al., 2008, Korpela et al., 2009). In respect to the latter point, it is beneficial to clarify that place attachments are not necessarily directed towards a specific geographically defined context, but could relate the identity of a person trans-spatially to *types* of places with similar characteristics (Daniel et al., 2011). In this sense, interventions that build nature-oriented values and behavioural dispositions in childhood are liable to have lasting implications for the ways in which the individual relates to and benefits from nature experience across the life span. Of course, in one respect, this could be classified as an individual-level intervention that seeks to *predispose* children to nature experience later in life by cultivating values and experiences that are *consistent* with the behaviour. Thus, it is likely to have a multifaceted influence on the diffusion of this behaviour. I discuss it here as an environmental intervention, however, because I believe it is important to highlight how the accumulation of these individual effects should, in later years, help to cultivate a more positive (and more visible) perception of the value of parks throughout the community, thereby indirectly promoting the target behaviour within harder to reach segments of society.

With appropriate governmental support, children in schools and pre-schools are relatively easy to reach with "Nature Play" initiatives, which facilitate child-initiated and child-directed play in natural settings (Burdette and Whitaker, 2005, Erickson and Ernst,

2011). Importantly, the aims of such programs are consistent with the first action listed in the 'Prevention and Early Intervention' priority area of Australia's Fourth National Mental Health Plan; namely, to "work with schools, workplaces and communities to deliver programs to improve mental health literacy and enhance resilience" (Commonwealth of Australia, 2009). A key benefit of these programs is that they take the impetus away from parents to engage in the planning and execution of trips to natural POS, potentially alleviating inequalities in childhood exposure that might arise, for instance, between the children of working single parents and those in two-parent, single-worker families (Fan et al., 2012). Again, this is imperative in ensuring the widespread diffusion of nature experience by ensuring that social norms of POS usage are distributed evenly across neighbourhoods and do not become clustered primarily within affluent areas. Although they need not be involved in the program, communication with parents will assist them to understand the benefits of nature play for their child's wellbeing and could also be a valuable opportunity to disseminate information about how nature experience can be beneficial to adults and children alike. Finally, if parents are to be encouraged to engage their child in nature play during their own time, physical environmental supports such access to green POS with safe playgrounds are likely to be important (Burdette and Whitaker, 2005).

A recent initiative took a more individualistic approach to encouraging nature experience among children by "prescribing" physical activity, in a specific park identified for its safety and accessibility, to child patients at a health clinic in Washington, DC (Martin, 2013). More than 300 parks in the city were mapped and rated by volunteers, with one-page summaries linked to the patient's medical records to create a searchable database of nearby places to play (Wahowiack, 2016). Initial evaluations of the "Park Rx" initiative revealed positive feedback from both healthcare providers and parents, indicating that this could be an effective way of encouraging nature play in the absence of funding for broadly implemented programs. Indeed, a source from the National Recreation and Park Association stated in 2015 that there were "at least 75-100" park prescription efforts for children ongoing throughout the United States (Seltenrich, 2015, p.255). As alluded to earlier, however, some parents participating in the initial Park Rx initiative did cite time constraints as a barrier to carrying out the prescribed nature-based activities (Martin, 2013), which might limit their effectiveness in some families.

6.2 Interventions targeting the individual

A central tenet of a social ecological approach to health promotion is that interventions should seek to enhance the fit between people and their surroundings (Green and Kreuter, 1993, Stokols, 1996). While the interventions outlined in the previous section are intended to provide environmental supports for interaction with nature in urban residential environments, this section discusses how health promotion efforts might overcome potential barriers to nature experience imposed by individual behaviours and beliefs. In other words, these interventions seek to *predispose* and *enable* nature experience by altering constraints at the individual level that might otherwise limit the efficacy of green POS resources created through higher-level policies.

6.2.1 Interventions in primary healthcare settings

The previous section discussed the use of "park prescriptions" to encourage nature-based physical activity among children, and it is plausible that a similar approach could be implemented among the adult population. One benefit of such an approach is that information disseminated by general practitioners is likely to be perceived as reliable, and might thereby *predispose* the individual to nature experience by increasing its perceived relative advantage. Although, as has long been evidenced in the field of smoking prevention, this knowledge is unlikely to constitute a sufficient stimulus for the behaviour in many cases, it does represent a crucial first step in the innovation-decision process that is particularly important for novel innovations (Rogers, 2002). By providing the individual with specific instructions of where to visit, and what to do, a "park prescription" could also reduce the complexity of nature experience by effectively assuming responsibility for key aspects of decision-making related to the activity (Staats et al., 2010). In effect, this intervention can bypass the stages of attitude formation and decision-making that would usually precede implementation of the new idea (Rogers, 2002). As discussed earlier in this chapter, this is likely to be especially beneficial for individuals who may be stuck in a maladaptive cycle of learned helplessness marked by avoidant coping behaviours.

Importantly, there is evidence that these initiatives could yield positive outcomes, which makes confirmation and reinforcement of the prescribed behaviour more likely. For example, Korpela and Ylén (2009) found that a prescription to visit favourite places every day for five weekdays achieved a higher total daily level of restorative experiences (covering relaxation, attention restoration, clearing one's thoughts, vitality and self-confidence) among the treatment group, compared with a randomised control group. Although the authors note that these results may only be generalizable to volunteers

willing to follow place-visit instructions, there is strong evidence for the effectiveness of behavioural activation (BA) approaches, considered more generally, in the treatment of depression. While BA treatment packages can include a range of tools, activity scheduling is a hallmark of this approach and has received clear empirical support as a stand-alone procedure (Cuijpers et al., 2007, Kanter et al., 2010). Similar to a 'park prescription', activity scheduling uses specific 'homework assignments' to engage the client in behaviours that increase contact with sources of positive reinforcement in the environment. This might include engagement in mood-enhancing pleasant activities as well as functionally important activities that increase mastery, provide alternatives to avoidance and rumination, and build routine. Engagement with natural spaces would be ideal for inclusion in such a plan; not only are the mood-enhancing properties of nature experience well documented, but natural environments also inhibit rumination (Bratman et al., 2015b) and are conducive to personal reflection (Herzog et al., 1997). Moreover, natural spaces are able to host activities of varying difficulty (e.g. from simply 'being' in the space to going for a run), in social and non-social forms, as well as activities that might enhance a sense of mastery, such as engagement in community gardening or volunteer conservation efforts.

This makes nature experience a flexible resource for BA treatments, and the similarity in these approaches presents a promising avenue by which to encourage general practitioners and psychologists to adopt the idea of "park prescriptions" for adults. This is important, since medical practitioners themselves do not readily adopt innovative psychosocial interventions (Backer et al., 1986) but may be more likely to do so if the new approach is similar to one that is already employed (i.e. it possesses high *compatibility*). Although "park prescriptions" have been adopted quite rapidly among healthcare providers working with children (Seltenrich, 2015), diffusion in relation to the treatment of adults may be hampered by a focus on "playful" activities. In fact, programs for adults need not emphasise physical activity components at all, particularly if the practitioner feels that this will simply be a barrier to adoption of the treatment. Rather, green POS could simply be utilised as a setting for mood-enhancing pleasant activities and passive restoration.

General practitioners and psychologists could prescribe this intervention to individuals presenting with stress-related symptoms of anxiety or depression, but there is an obvious limitation to this strategy; specifically, it fails to reach the majority of the population who do not self-identify as experiencing heightened levels of distress or are not seeking treatment. In this respect, 'piggybacking' on BA treatments is likely to be of little use in

preventing incident psychological distress, since the approach is employed in the treatment of people who are already depressed. Similarly, the dissemination of knowledge about nature experience through community mental health organisations is unlikely to reach the majority of healthy individuals. To some extent, these points highlight a broader deficiency in the way the health system acts to prevent cases of mental ill health before they occur. Despite the widely accepted relationship between stress and mental health, the demands faced by an individual are largely ignored until they manifest in some form of dysfunction. Ideally, general practitioners could use patient visits for any ailment as an opportunity to gather an appraisal of the individual's current stress levels – Cohen et al.'s (1983) four-item perceived stress scale, for instance, could be implemented in little more than the time it takes to measure the patient's blood pressure – and provide them with a fact sheet about simple stress reduction techniques, if necessary.

7 Directions for future research

Throughout the discussion in this chapter, a number of important directions for future research have emerged. This section briefly describes five areas in which subsequent studies could address the limitations both of this thesis and the broader body of literature pertaining to public open space. These include a need for: (i) innovative approaches to the measurement of stress; (ii) innovative approaches to the measurement of residential public open space attributes and usage; (iii) greater attention to the delineation of conscious and non-conscious mechanisms in explaining relationships between POS and mental health; (iv) increasing temporal complexity in the analysis of socio-physical aspects of place and mental health; (v) longitudinal studies with longer time frames and a greater number of observations; and (vi) new perspectives on the nature of associations between POS and the neighbourhood social environment.

7.1 Pursuing innovation in the measurement of stress arousal

Section 4.1.3.1 detailed the limitations of employing a stressful life events inventory as a proxy for stress arousal, and suggested that restorative benefits of nature might be particularly relevant to buffering against more enduring strains or 'daily hassles' due to the closer temporal alignment between stressor and stress-buffer. To date, the stress-buffering effects of POS have only been analysed in relation to stressful life events (Wells and Evans, 2003, van Den Berg et al., 2010) or perceived financial strain (Mitchell et al., 2015) (see Chapter 2, section 4.3). In this respect, there is scope for future research to employ

more comprehensive and sensitive measures of stress arousal in order to adequately portray the full effects of the constellations of stressors and strains to which individuals are exposed, and thereby assess the full stress-buffering potential of POS. Here, the emphasis on the measurement of stress arousal – rather than exposure to stressors – is important. Throughout this thesis, attention has been drawn to the non-conscious pathways by which environmental conditions 'get under the skin' to influence health outcomes. This is relevant not only to the salutogenic benefits of POS greenness, as it has been framed to this point, but also to the measurement of stress, where "conscious outer resignation to unfavourable conditions of living may conceal subconscious biological arousal" (Daniel et al., 2008, p.125). The measurement of stress in this thesis, as in the studies cited above, fails to address this important mechanism because it captures only consciously perceived stressors and weights those stressors according to conscious appraisals of severity (Young, 1980).

Thus, novel methodologies are needed. As was raised earlier in this chapter in relation to possible approaches to the measurement of coping, more direct measurement techniques, for instance via physiological markers of stress or allostatic load, could fruitfully be employed to enable the identification of non-conscious mechanisms of stress and restoration operating below the level of individual awareness. Others have noted the potential utility of this approach given that allostatic load can summarise 'weathering' effects that might not yet register clinically (Turner, 2010). While physiological markers of stress responses are commonly measured in experimental studies instead of (or in addition to) self reported stress and restoration, the application of these procedures in-situ remains limited. Yet, research in recent years has indicated promising results in relation to compliance with a salivary cortisol testing protocol within neighbourhood effects research (Ward Thompson et al., 2012, Roe et al., 2013). These protocols do not rely upon the development of increasingly complex inventories of stressful events and role strains intended to capture the 'full range' of stress, but that might only result in an unwieldy number of sociological variables that serve merely to fragment structural determinants of the stress process into smaller and smaller slices with little theoretical guidance as to how the influence of these factors should be configured or summarised (Young, 1980).

7.2 Pursuing innovation in the measurement of POS exposure

Very briefly, qualitative or mixed methods research would be beneficial to guide the field in conceptualising and measuring POS exposures into the future. The validity of spatial constructs employed in POS research has received insufficient attention,

particularly when one considers the effort taken to deconstruct the validity of outcome measures in the same pieces of research. For example, little is known about how residents draw a distinction between 'public' and 'private' land, how this distinction plays into the value of open spaces, and how this differs depending on characteristics of the neighbourhood or the explanatory mechanisms of interest; whereas non-accessible spaces will be less relevant to local social interaction, the visible amenity of these areas could remain highly relevant to restoration. Moreover, although opportunities for restoration arise across the full spectrum of daily activity cycles, POS research typically remains planted in one locale (e.g. the area of residence or employment) rather than assessing the combination of environments that make up a more representative activity space (van Heeswijck et al., 2015). There is substantial scope for the integration of modern technology – such as GPS monitors, mobile phones, and fitness trackers – into research designs that collect real-time locational, physiological, and/or self-report data within the everyday routines of their participants.

7.3 Distinguishing between conscious and non-conscious pathways

Future research should focus attention more purposefully on distinguishing the relative contribution of non-conscious (e.g. incidental restoration) and conscious (e.g. purposeful use) mechanisms in explaining the effects of POS on mental health. This is a fairly fundamental question concerning the conditions required for health promotion, and could help to clarify the extent to which individuals need to actively engage with green POS in order to reap its benefits. It is well documented that the mere provision of POS does not engender usage among large segments of the population (Moore et al., 2010, Kaźmierczak, 2013, Ward et al., 2014). However, the notion that this negates the possibility of wellbeing experience for non-users may be an equally faulty assumption that risks unduly diverting knowledge development towards "the generation of more nuanced insights into when and why different people do or do not use green space" (Bell et al., 2014, p.287) without appreciating the broader salutogenic function of POS. Prior research indicates that effects on mental health (e.g. Nielsen and Hansen, 2007, Sturm and Cohen, 2014) and cognitive social integration (Francis et al., 2012a) may not be solely attributable to usage, although this question appears mostly as an afterthought rather than a stated research aim. This thesis did not have access to POS usage data and was therefore unable to contribute to knowledge in this respect. However, in attempting to interpret findings relating POS greenness to mental health, the distinction between these mechanisms emerged as an

important framework underpinning the implications for design and targeting of relevant interventions; specifically, because the two pathways imply a distinct emphasis on the purposeful versus merely incidental assimilation of nature experience into residents' activity cycles.

7.4 Moving beyond cross-sectional associations between the physical and social attributes of places

As foreshadowed in Section 3.3.4 of this chapter, the vast majority of research seeking to understand the relationships between physical and social attributes of places (including the research presented in this thesis) is limited by a reliance on cross-sectional design. Of course, in practice, there are considerable hurdles to identifying temporal precedence in associations between physical and social neighbourhood characteristics. When approached to participate in a study of neighbourhood effects, most people have been embedded in the context of interest for some time; for instance, the median length of residence in the present study was 8 years, with a maximum of 39 years. This makes it incredibly difficult to establish the temporal basis for contextual effects on social cohesion, because even if one were to adjust for 'baseline' levels of the construct, this is really just an arbitrary cut point determined by the coincidental timing of the study. While a longitudinal trajectory design might be suitable for assessing prospective changes in mental health, perceptions of social cohesion are likely to be reasonably well established after a number of years in the neighbourhood. One could attempt to recruit only 'recent arrivals' to the neighbourhood in order to track their perceptions of cohesion over the ensuing years, but this too has its drawbacks. Firstly, the process of identifying and recruiting these individuals is likely to be time-consuming and costly. Secondly, this approach would result in a residentially mobile sample of individuals that is unlikely to be representative of the broader population (e.g. single young adults might be overrepresented relative to families or the elderly). Finally, as evidenced by the rate of attrition attributable to residential relocation in the present study, this approach may be particularly prone to bias and a loss of power due to selective sample losses.

Beyond these practical issues, there are deeper conceptual issues that will need to be addressed if we are to progress our understanding of the interrelationship between physical and social neighbourhood contexts. At both the individual and neighbourhood levels, associations between these dimensions at any given time are likely to reflect the culmination of complex and unobserved historical processes. Among individuals, variability in perceptions of social cohesion might partially reflect differences in physical

characteristics of the current neighbourhood, but could also reflect the lagged effects of previous places of residence; lives are not influenced by static conditions but by an ever-changing historical and biographical context (Elder Jr et al., 2003). As such, it is possible that the effects of current context cannot be interpreted independently of past contexts, and that the differences in exposure one should truly take interest in are vastly more complex spatio-temporal patterns of variability representing the accumulation of neighbourhood contexts across the life course (Wheaton and Clarke, 2003 931).

7.4.1 Addressing the influence of individual life course

To elucidate the spatio-temporal complexity of neighbourhood effects in relation to the present research, it is worthwhile to consider how childhood exposure to POS greenness might moderate the effects of POS greenness on mental and social wellbeing across the rest of life course. Ward Thompson et al. (2008) argue that the physical and emotional benefits of access to green space are strongly reflected in childhood experience, demonstrating that the frequency of visiting woodlands or green space as a child was a highly significant predictor of the frequency of visiting as an adult after adjusting for age, sex, occupation and distance to green space. This relationship was most pronounced in relation to a lack of use, such that not visiting green space as a child exhibited a particularly strong relationship with not visiting as an adult (cf. the relationship between frequent childhood and frequent adult visitation). Asah et al. (2012) reached a similar conclusion, and described how the relationship between childhood and adult participation in nature-based activities is partially explained by increased motivation to participate and improved efforts to negotiate constraints blocking participation. Importantly, there are also indications that "only frequent childhood users of green space are likely to feel energetic in green spaces as adults, or to think of such places as potentially 'magical' or with some transcendental quality" (Ward Thompson, 2007, p.29).

In a similar vein, other research showed that exposure to natural environments increased the individual's sense of connectedness to nature (Nisbet and Zelenski, 2011) and that this, in turn, mediated the effects of nature experience on positive mood (Mayer et al., 2009). Nature connectedness (a concept described earlier in this chapter) has also been linked to the overall strength of restorative outcomes in favourite places (Korpela et al., 2010) and of improvements in mood following green exercise (Rogerson et al., 2016). In a broader sense, a recent meta-analysis identified a small but significant overall association between nature connectedness and happiness (Capaldi et al., 2014). Finally, there is evidence to indicate that the promotion of nature connectedness might be more sustainable in children

under the age of 11 years, compared with children who are slightly older (Liefländer et al., 2013). These relationships suggest that exposure to green POS in the early years of childhood might play an incredibly important role in the extent to which the individual access the psychosocial benefits of nature experience throughout the life course, both by encouraging greater usage of green spaces and by augmenting the benefits of restoration accrued therein. Moreover, outdoor play in childhood is thought to be especially conducive to early psychosocial development because the unstructured nature of the environment generates opportunities for problem solving and creative thinking that are not apparent in indoor spaces (Burdette and Whitaker, 2005).

For these reasons, life course study designs represent a promising direction for future research into the relationships between POS greenness, neighbourhood social integration, and mental health. Life course approaches attempt to identify the cumulative effects of environmental exposures across the life span of the individual as well as the critical periods in which these exposures might be particularly pertinent. For instance, a life course approach could investigate the influence of POS greenness on the development of social cohesion, or related outcomes, at key transitional periods such as when the individual enters adolescence, first leaves the family home, purchases their first home, moves into a retirement home, etc. Recently, Pearce et al. (2016) demonstrated how secondary data sources could successfully be combined to assess long-term historical changes in POS availability for individuals and neighbourhoods, allowing linkage of these data to retrospective information on residential location. Astell-Burt et al. (2014b) took a different approach, employing an accelerated longitudinal design to pool several years' worth of observations across individuals in a wide range of age groups, to determine whether the influence of POS availability was more important at particular stages of the life course.

7.4.2 Addressing the social evolution of a neighbourhood

Perhaps of greater difficulty to address is the social history of the neighbourhoods themselves, which have typically existed well beyond the lifetimes of current residents. Much as neighbourhoods are not a passive container of resources, nor are their social or physical characteristics immutable and unchanging. Bernard et al. (2007) describe how the contextual and compositional characteristics of a neighbourhood might mutually shape one another, changing over time in a related, and sometimes almost synergistic manner. The acts of individual and organisational agents (manifested in, for example, selective migration or political mobilisation) influence the environment, but are themselves motivated, supported or constrained by the broader structural conditions that define a

neighbourhood. In this respect, neighbourhood actors reproduce and transform their context, such that the practices and resources of individuals shape the opportunity structure of a neighbourhood over time (Macintyre et al., 2002). In other words, "specific neighbourhood structures have strong influence over residents' behaviours, but on the other hand, it is through their practices that residents reify structure" (Bernard et al., 2007, p.1841).

Thus, it is quite possible that cross-sectional associations between POS greenness and social cohesion do not obscure the one 'true' direction of their relationship, but reflect a long history of mutually reciprocal processes by which physical and social environments develop together. For instance, a reciprocal causal cycle between these constructs might occur if accessible natural open spaces breeds a cohesive community, which is then better placed to mobilise and improve the quality of public spaces. There is, of course, also the possibility of confounding by other historical trends. For example, Walks and Maaranen (2008) found that neighbourhood gentrification in major Canadian cities (including Montreal) from 1976-2001 led to increasing levels of intra-neighbourhood income polarisation and inequality and the displacement of low-income populations to whom these areas were traditionally home. The turnover of residents in these areas is almost certainly relevant to the structure of social capital and social integration in these neighbourhoods (Kleinhans et al., 2007), while gentrification in the guise of 'neighbourhood revitalisation' could also involve the greening of open spaces and streetscapes. Complex interrelationships between the physical and social contexts of neighbourhoods, and their interactions in shaping mental health, might best be understood using mixed methods research that employs the 'knowledgeable narratives' of residents to explore both historical and unfolding processes embodied within the current state of the neighbourhood (Williams, 2003).

7.4.3 The utility of natural experiments

Another approach to overcome some of the difficulties inherent in the estimation of associations between POS greenness and neighbourhood social integration is the use of neighbourhood interventions or natural experiments, although the conditions of these experiments should be carefully considered in the interpretation of results. For example, Branas et al. (2011) investigated the effects of a vacant lot 'greening' program in Philadelphia, comparing before-after differences in crime rates and self-reported health around approximately 4,400 'greened' lots and 13,300 randomly selected and matched control lots. They found that converting vacant lots into park-like, tended public spaces –

by removing trash and debris, installing low wooden perimeter fences, and planting grass and trees – was associated with a citywide reduction in gun assaults, and a reduction in vandalism in one section of the city. Furthermore, in select sections of the city, individuals residing around 'greened' lots reported less stress and more exercise than those residing near control lots. However, one limitation of this approach is that it fails to distinguish between the introduction of an amenity (additional 'green space') and the removal of a disamenity (vacant lots), making it difficult to isolate the mechanism responsible for these positive changes.

7.5 Increasing the number and length of observations in longitudinal research

This thesis has demonstrated that growth mixture modelling may be a promising addition to the toolbox of epidemiologists seeking to explain inter-individual variability in prospective trajectories of change among the general population. However, as discussed in Section 4.1.1 of this chapter, the extent to which the full benefits of such an approach could be exploited may have been hampered by the relatively short length of the study, small number of observation points, and limited sample size. For studies seeking to apply GMM, data should ideally be collected as frequently as possible and also over as long a time frame as possible (Kim, 2012). Study designs with these characteristics assist in the identification of a greater number of substantively unique trajectory classes, permit complex non-linear growth functions, and reduce the likelihood that potentially complex and volatile trajectories of change are fragmented into 'parochial' classifications depending on the slice of time that is captured (Hunter et al., 2010, Sher et al., 2011, Tan et al., 2011). Resultant improvements in classification certainty lend themselves to greater statistical power, and importantly, investments in a greater number of observations and/or a longer observation period are offset by substantial decreases in the sample size required (Muthén, 2004, Loughran and Nagin, 2006, Kim, 2012). The implication is that the suggested direction is not necessarily impractical or unrealistic, but one that could require forward planning.

7.6 Widening the scope of investigations into psychosocial resources

As detailed in Chapter 2 (Section 4.2), most investigations into the role of psychosocial resources as explanatory factors underlying relations between POS and mental health have tested for the existence of indirect effects via the perceptions of the social environment or,

less frequently, social contacts. There has been a lack of attention to the role of coping abilities, which is seemingly at odds with a widespread emphasis on the role of attention restoration and stress reduction as potential explanatory constructs. Although the present research did not identify a statistically significant association with coping, the direction of the association was consistent with expectation despite a number of weaknesses in the measure employed. This remains a worthwhile question for future investigations, which could improve upon the limitations of the present study by placing greater emphasis on the delineation of dimensions of coping in order to unpack the ways in which this may or may not be facilitated by POS greenness; for instance, to separate dimensions of coping that might relate to interpersonal functions of support from strictly intrapersonal resources such as directed attention.

This research could not account for the role of 'nature connectedness' in determining the relationship between urban POS greenness and mental health, and this merits further attention. As well as dealing more explicitly with the potential for confounding by spatial selection effects related to nature connectedness (see Section 4.2.3.1 of this chapter), future research might also consider placing a greater focus on the conceptualisation of this construct as a mutable psychosocial resource in its own right. For example, Section 6.1.2 described the possible implementation of interventions (e.g. 'Nature Play') that seek to develop this orientation in children in order to shape norms of nature utilisation as well as perceived and actual benefits of nature experience across future generations. The efficacy of these interventions in developing a lasting sense of connectedness to nature deserves greater scrutiny, as does the role of nature connectedness as a central explanatory component (versus covariate in) mechanisms linking POS to mental health.

Besides devoting more attention to these types of resources, POS researchers might consider stepping outside the bounds of simple mediation analyses to broaden the scope of mechanisms by which psychosocial resources are implicated in relations with mental health. Numerous studies, including this thesis, have now yielded cross-sectional evidence for an association between aspects of POS in the residential environment and perceptions of local social cohesion. The convergence of these findings across varied contexts and in relation to varied measures of 'urban nature' is consistent with the existence of a relationship between these broadly defined constructs. Future research might now be better placed to explore the subtleties of this association. For example, prevailing approaches (including that employed in this thesis) assume that all individuals are equally sensitive to the influence of social cohesion, but this assumption is questionable and requires further

testing. Just as POS appears to have a greater influence among individuals under heightened stress, the effects of social cohesion might also differ depending on stressful exposure. Thus, the two analytic models employed in this thesis could be amalgamated into a mediated moderation (where social cohesion mediates the extent to which POS greenness buffers against stress) or a moderated mediation (where stress moderates the extent to which indirect effects of POS greenness operate through social cohesion) in an attempt to disentangle how these mechanisms work together, or separately, to determine health outcomes.

As a final remark, it is worth noting that characteristics of the broader neighbourhood are likely to influence the perceived accessibility and value of POS, and ultimately its usage. POS availability is one of many features of physical and social neighbourhood contexts such that interactive, coincident perceptions of incivility, disorder, or a lack of safety and social cohesion may discourage people from visiting POS (Jones et al., 2009, Seaman et al., 2010). Research has recently begun to address the question of how characteristics of surrounding neighbourhoods could moderate effects of POS on health. For instance, Chong et al. (2013) found that in very disadvantaged neighbourhoods perceived as unsafe by their residents, a greater accessibility of POS can be associated with heightened levels of psychological distress. Yet, no research to date has assessed how positive social characteristics at the level of neighbourhoods might moderate the effects of POS. Most studies that have evaluated causal pathways in relation to dimensions of neighbourhood social integration have, like this thesis, assumed that these dimensions mediate associations between POS and wellbeing. However, it is also possible that neighbourhood social integration acts as an effect modifier. For instance, if POS represents a resource for social gatherings, then it may be particularly beneficial to mental health in areas with strong social structures already in place. Thus, a question for future research, is whether POS *builds* community, *facilitates* the function of community that already exists, or both. This question links back to previous discussion of the difficulties in disentangling oft-cited cross sectional associations between POS and social cohesion, and might fruitfully be explored through qualitative research.

8 Conclusion

This thesis has presented a comprehensive exploration of prospective associations between public open space ‘greenness’ and mental health within a metropolitan

epidemiological catchment area. The original research reported herein assessed evidence for three distinct psychosocial mechanisms by which POS greenness might generate salutogenic effects, including a stress-buffering mechanism, a main-effect mechanism, and an indirect mechanism by which effects of POS greenness are channelled through the accumulation of psychosocial resources. Each mechanism was assessed in relation to trajectories of change in positive (life satisfaction) and negative (psychological distress) dimensions of mental health throughout roughly a four-year period.

Prior studies had investigated these mechanisms to varying degrees but (a) typically focused on the total availability of POS rather than its inherent characteristics, (b) were largely limited by cross-sectional research designs, and (c) had generally neglected to assess both positive and negative dimensions of mental health outcomes. This thesis makes a number of important and novel contributions to the literature, demonstrating that:

- The 'greenness' of public open space is an important quality attribute in the promotion of mental health, over and above the total availability or size of POS in the residential area;
- POS 'greenness' buffers against the arousal of psychological distress following the accumulation of stressful life events over a number of years, indicating that a greater focus on mechanisms involved in the stress process may be beneficial in advancing the body of knowledge related to the enduring (rather than immediate) benefits of exposure to natural environments;
- POS 'greenness' also appears to exert a main salutogenic effect in relation to the arousal of psychological distress, with indications that this effect may be transmitted through its association with perceptions of social cohesion.

Together, these findings provide broad support for the importance of easily accessible nature in supporting psychosocial functioning and mental health. Threats to validity were extensively reviewed and are not considered to pose a significant risk to the conclusions of this research. The findings have clear relevance to public policy at the intersection of urban planning and public health. With reference to a social ecological framework of health promotion, the thesis devised a number of possible interventions targeting both individuals and the social and physical environment in order to maximise the psychological benefits of public open space in the urban milieu. Finally, the thesis presented five key areas within

which future research could continue to take large strides in furthering our understanding of these relationships.

References

Abraham, A., Sommerhalder, K. & Abel, T. 2010. Landscape and well-being: a scoping study on the health-promoting impact of outdoor environments. *International Journal of Public Health,* 55(1)**,** pp.59-69.

Abramson, J. H. 2011. WINPEPI updated: computer programs for epidemiologists, and their teaching potential. *Epidemiologic Perspectives & Innovations,* 8(1)**,** pp.1-9.

Abramson, L. Y., Seligman, M. E. & Teasdale, J. D. 1978. Learned helplessness in humans: critique and reformulation. *Journal of Abnormal Psychology,* 87(1)**,** pp.49-74.

Adams, R. E. 1992. Is happiness a home in the suburbs? The influence of urban versus suburban neighborhoods on psychological health. *Journal of Community Psychology,* 20(4)**,** pp.353-372.

Aickin, M. & Gensler, H. 1996. Adjusting for multiple testing when reporting research results: the Bonferroni vs Holm methods. *American Journal of Public Health,* 86(5)**,** pp.726-728.

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E. & Depledge, M. H. 2014. Longitudinal effects on mental health of moving to greener and less green urban areas. *Environmental Science & Technology,* 48(2)**,** pp.1247-1255.

Allison, P. D. 2009. Missing data. *In:* Millsap, R. E. & Maydeu-Olivares, A. (eds.) *The SAGE Handbook of Quantitative Methods in Psychology.* London: Sage Publications.

Almanza, E., Jerrett, M., Dunton, G., Seto, E. & Ann Pentz, M. 2012. A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data. *Health & Place,* 18(1)**,** pp.46-54.

Ambrey, C. L. 2016. Greenspace, physical activity and well-being in Australian capital cities: how does population size moderate the relationship? *Public Health,* 133**,** pp.38-44.

Ambrey, C. L. & Fleming, C. M. 2013. Public greenspace and life satisfaction in urban Australia. *Urban Studies,* 51(6)**,** pp.1290-1321.

American Association for Public Opinion Research: AAPOR 2011. Standard definitions: Final dispositions of case codes and outcome rates for surveys. 7th edition. *In:* Aapor (ed.). AAPOR.

American Planning Association 2006. *Planning and urban design standards,* Hoboken, NJ, John Wiley & Sons.

Andrews, G., Hall, W., Teesson, M. & Henderson, S. 1999. The mental health of Australians. Canberra, ACT: Mental Health Branch, Commonwealth Department of Health and Aged Care.

Andrews, G. & Slade, T. 2001. Interpreting scores on the Kessler psychological distress scale (K10). *Australian and New Zealand Journal of Public Health,* 25(6)**,** pp.494-497.

Aneshensel, C. S. 2005. Research in mental health: Social etiology versus social consequences. *Journal of Health and Social Behavior,* 46(3)**,** pp.221-228.

Aneshensel, C. S. 2009. Toward explaining mental health disparities. *Journal of Health and Social Behavior,* 50(4)**,** pp.377-394.

Aneshensel, C. S. 2010. Neighborhood as a social context of the stress process. *In:* Avison, W. R., Aneshensel, C. S., Schieman, S. & Wheaton, B. (eds.) *Advances in the conceptualisation of the stress process: Essays in honor of Leonard I. Pearlin.* New York: Springer.

Annerstedt, M., Östergren, P. O., Björk, J., Grahn, P., Skärbäck, E. & Währborg, P. 2012. Green qualities in the neighbourhood and mental health: results from a longitudinal cohort study in southern Sweden. *BMC Public Health,* 12(1)**,** pp.337-348.

Antonovsky, A. 1996. The salutogenic model as a theory to guide health promotion. *Health Promotion International,* 11(1)**,** pp.11-18.

Arnberger, A. & Eder, R. 2012. The influence of green space on community attachment of urban and suburban residents. *Urban Forestry & Urban Greening,* 11(1)**,** pp.41-49.

Asah, S. T., Bengston, D. N. & Westphal, L. M. 2012. The Influence of Childhood Operational Pathways to Adulthood Participation in Nature-Based Activities. *Environment and Behavior,* 44(4)**,** pp.545-569.

Asparouhov, T. & Muthén, B. 2010a. Chi-square statistics with multiple imputation (Version 2). *Mplus technical appendices.* Los Angeles, CA: Muthén & Muthén.

Asparouhov, T. & Muthén, B. 2010b. Computing the strictly positive Satorra-Bentler chi-square test in Mplus. *MPlus Web Notes.* Los Angeles, CA: Muthén & Muthén.

Asparouhov, T. & Muthén, B. 2010c. Multiple imputation with Mplus. *MPlus Web Notes.* Los Angeles, CA: Muthén & Muthén.

Asparouhov, T. & Muthén, B. 2014. Auxiliary Variables in Mixture Modeling: Three-Step Approaches Using Mplus. *Structural Equation Modeling,* 21(3)**,** pp.329-341.

Asparouhov, T. & Muthén, B. O. 2012. Saddle Points. *MPlus Web Notes.* Los Angeles, CA: Muthén & Muthén.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2013a. Does access to neighbourhood green space promote a healthy duration of sleep? Novel findings from a cross-sectional study of 259 319 Australians. *BMJ Open,* 3(8)**,** pp.e003094.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2013b. Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: evidence from 260,061 Australians. *Preventive Medicine,* 57(5)**,** pp.601-606.

Astell-Burt, T., Feng, X., Mavoa, S., Badland, H. M. & Giles-Corti, B. 2014a. Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health,* 14(1)**,** pp.292-303.

Astell-Burt, T., Mitchell, R. & Hartig, T. 2014b. The association between green space and mental health varies across the lifecourse. A longitudinal study. *Journal of Epidemiology and Community Health,* 68(6)**,** pp.578-583.

Australian Bureau of Statistics 2007. National Survey of Mental Health and Wellbeing: Summary of Results. Canberra, ACT: ABS.

Australian Bureau of Statistics 2012. Information paper: Use of the Kessler Psychological Distress Scale in ABS health surveys, Australia 2007-2008. Canberra, ACT: ABS.

Australian Bureau of Statistics. 2013a. *2011 Census QuickStats: Greater Melbourne* [Online]. Canberra, ACT: Australian Bureau of Statistics. Last updated March 28, 2013. Available: http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/2GMEL [Accessed 26 February 2014].

Australian Bureau of Statistics. 2013b. *Regional Population Growth, Australia, 2011-12* [Online]. Canberra, ACT: Australian Bureau of Statistics. Last updated April 30, 2013. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Products/3218.0~2011-12~Main+Features~Victoria#PARALINK2 [Accessed 26 February 2014].

Australian Institute of Health and Welfare 2004. Results of second field testing of core questions for inclusion in a nation-wide preventable chronic disease and behavioural risk factor survey module manual. *Population health monitoring and surveillance: question development field testing.* Canberra, Act: AIHW.

Ayers, J. W., Althouse, B. M., Allem, J.-P., Rosenquist, J. N. & Ford, D. E. 2013. Seasonality in seeking mental health information on Google. *American Journal of Preventive Medicine,* 44(5)**,** pp.520-525.

Backer, T. E., Liberman, R. P. & Kuehnel, T. G. 1986. Dissemination and adoption of innovative psychosocial interventions. *Journal of Consulting and Clinical Psychology,* 54(1)**,** pp.111-118.

Badland, H., Whitzman, C., Lowe, M., Davern, M., Aye, L., Butterworth, I., Hes, D. & Giles-Corti, B. 2014. Urban liveability: emerging lessons from Australia for exploring the potential for indicators to measure the social determinants of health. *Social Science & Medicine,* 111**,** pp.64-73.

Baker, F. & Intagliata, J. 1982. Quality of life in the evaluation of community support systems. *Evaluation and Program Planning,* 5(1)**,** pp.69-79.

Bakk, Z., Tekle, F. B. & Vermunt, J. K. 2013. Estimating the association between latent class membership and external variables using bias-adjusted three-step approaches. *Sociological Methodology,* 43(1)**,** pp.272-311.

Barnett, A. G., van der Pols, J. C. & Dobson, A. J. 2005. Regression to the mean: what it is and how to deal with it. *International Journal of Epidemiology,* 34(1)**,** pp.215-220.

Baron, R. M. & Kenny, D. A. 1986. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology,* 51(6)**,** pp.1173-1182.

Barton, H. 2009. Land use planning and health and well-being. *Land Use Policy,* 26S**,** pp.S115-S123.

Barton, J. & Pretty, J. 2010. What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environmental Science & Technology,* 44(10)**,** pp.3947-3955.

Bauer, D. J. 2007. Observations on the use of growth mixture models in psychological research. *Multivariate Behavioral Research,* 42(4)**,** pp.757-786.

Bauer, D. J. & Curran, P. J. 2003a. Distributional assumptions of growth mixture models: implications for overextraction of latent trajectory classes. *Psychological Methods,* 8(3)**,** pp.338-363.

Bauer, D. J. & Curran, P. J. 2003b. Overextraction of Latent Trajectory Classes: Much Ado About Nothing? Reply to Rindskopf (2003), Muthén (2003), and Cudeck and Henly (2003). *Psychological Methods,* 8(3)**,** pp.384-393.

Bauer, D. J. & Curran, P. J. 2004. The integration of continuous and discrete latent variable models: potential problems and promising opportunities. *Psychological Methods,* 9(1)**,** pp.3-29.

Baum, A., Garofalo, J. & YALI, A. 1999. Socioeconomic status and chronic stress: does stress account for SES effects on health? *Annals of the New York Academy of Sciences,* 896(1)**,** pp.131-144.

Beck, P. S., Atzberger, C., Høgda, K. A., Johansen, B. & Skidmore, A. K. 2006. Improved monitoring of vegetation dynamics at very high latitudes: A new method using MODIS NDVI. *Remote Sensing of Environment,* 100(3)**,** pp.321-334.

Bedimo-Rung, A. L., Mowen, A. J. & Cohen, D. A. 2005. The significance of parks to physical activity and public health: a conceptual model. *American Journal of Preventive Medicine,* 28(2)**,** pp.159-168.

Bell, J. F., Wilson, J. S. & Liu, G. C. 2008. Neighborhood greenness and 2-year changes in body mass index of children and youth. *American Journal of Preventive Medicine,* 35(6)**,** pp.547-553.

Bell, S. L., Phoenix, C., Lovell, R. & Wheeler, B. W. 2014. Green space, health and wellbeing: Making space for individual agency. *Health & Place,* 30**,** pp.287-292.

Bender, R. & Lange, S. 2001. Adjusting for multiple testing—when and how? *Journal of Clinical Epidemiology,* 54(4)**,** pp.343-349.

Berlin, K. S., Parra, G. R. & Williams, N. A. 2013a. An Introduction to Latent Variable Mixture Modeling (Part 2): Longitudinal Latent Class Growth Analysis and Growth Mixture Models. *Journal of Pediatric Psychology,* 39(2)**,** pp.188-203.

Berlin, K. S., Williams, N. A. & Parra, G. R. 2013b. An Introduction to Latent Variable Mixture Modeling (Part 1): Overview and Cross-Sectional Latent Class and Latent Profile Analyses. *Journal of Pediatric Psychology,* 39(2)**,** pp.174-187.

Berman, M. G., Jonides, J. & Kaplan, S. 2008. The cognitive benefits of interacting with nature. *Psychological Science,* 19(12)**,** pp.1207-1212.

Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., Kaplan, S., Sherdell, L., Gotlib, I. H. & Jonides, J. 2012. Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders,* 140(3)**,** pp.300-305.

Bernard, P., Charafeddine, R., Frohlich, K. L., Daniel, M., Kestens, Y. & Potvin, L. 2007. Health inequalities and place: a theoretical conception of neighbourhood. *Social Science & Medicine,* 65(9)**,** pp.1839-1852.

Berry, H. L. 2008. 'Crowded suburbs' and 'killer cities': a brief review of the relationship between urban environments and mental health. *New South Wales Public Health Bulletin,* 18(12)**,** pp.222-227.

Bertram, C. & Rehdanz, K. 2015. The role of urban green space for human well-being. *Ecological Economics,* 120**,** pp.139-152.

Beyer, K., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F. & Malecki, K. 2014. Exposure to Neighborhood Green Space and Mental Health: Evidence from the Survey of the Health of Wisconsin. *International Journal of Environmental Research and Public Health,* 11(3)**,** pp.3453-3472.

Blair, A., Ross, N. A., Gariepy, G. & Schmitz, N. 2014. How do neighborhoods affect depression outcomes? A realist review and a call for the examination of causal pathways. *Social Psychiatry and Psychiatric Epidemiology,* 49(6)**,** pp.873-887.

Blanchflower, D. G. & Oswald, A. J. 2008. Is well-being U-shaped over the life cycle? *Social Science & Medicine,* 66(8)**,** pp.1733-1749.

Bland, J. M. & Altman, D. G. 1995. Multiple significance tests: the Bonferroni method. *BMJ,* 310(6973)**,** pp.170.

Bland, J. M. & Altman, D. G. 2000. The odds ratio. *BMJ,* 320**,** pp.1468.

Bodner, T. E. 2008. What improves with increased missing data imputations? *Structural Equation Modeling,* 15(4)**,** pp.651-675.

Bolck, A., Croon, M. & Hagenaars, J. 2004. Estimating latent structure models with categorical variables: One-step versus three-step estimators. *Political Analysis,* 12(1)**,** pp.3-27.

Bonnes, M., Passafaro, P. & Carrus, G. 2011. The ambivalence of attitudes toward urban green areas: between proenvironmental worldviews and daily residential experience. *Environment and Behavior,* 43(2)**,** pp.207-232.

Bono, C., Ried, L. D., Kimberlin, C. & Vogel, B. 2007. Missing data on the Center for Epidemiologic Studies Depression Scale: a comparison of 4 imputation techniques. *Research in Social and Administrative Pharmacy,* 3(1)**,** pp.1-27.

Boone, C. G., Buckley, G. L., Grove, J. M. & Sister, C. 2009. Parks and people: An environmental justice inquiry in Baltimore, Maryland. *Annals of the Association of American Geographers,* 99(4)**,** pp.767-787.

Bow, V. & Buys, L. 2003. Sense of community and place attachment: The natural environment plays a vital role in developing a sense of community. *Social Change in the 21st Century.* Brisbane, Australia.

Bowler, D., Buyung-Ali, L., Knight, T. & Pullin, A. 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health,* 10(1)**,** pp.456-466.

Bradley, B. A., Jacob, R. W., Hermance, J. F. & Mustard, J. F. 2007. A curve fitting procedure to derive inter-annual phenologies from time series of noisy satellite NDVI data. *Remote Sensing of Environment,* 106(2)**,** pp.137-145.

Brambor, T., Clark, W. R. & Golder, M. 2006. Understanding interaction models: Improving empirical analyses. *Political Analysis,* 14(1)**,** pp.63-82.

Branas, C. C., Cheney, R. A., MacDonald, J. M., Tam, V. W., Jackson, T. D. & Ten Have, T. R. 2011. A difference-in-differences analysis of health, safety, and greening vacant urban space. *American Journal of Epidemiology,* 174(11)**,** pp.1296-1306.

Brander, L. M. & Koetse, M. J. 2011. The value of urban open space: Meta-analyses of contingent valuation and hedonic pricing results. *Journal of Environmental Management,* 92(10)**,** pp.2763-2773.

Bratman, G. N., Daily, G. C., Levy, B. J. & Gross, J. J. 2015a. The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning,* 138**,** pp.41-50.

Bratman, G. N., Hamilton, J. P. & Daily, G. C. 2012. The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences,* 1249**,** pp.118-136.

Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C. & Gross, J. J. 2015b. Nature experience reduces rumination and subgenual prefrontal cortex activation. *Proceedings of the National Academy of Sciences,* 112(28)**,** pp.8567-8572.

Brooks, R. T., Beard, J. & Steel, Z. 2006. Factor structure and interpretation of the K10. *Psychological Assessment,* 18(1)**,** pp.62-70.

Broomhall, M., Giles-Corti, B. & Lange, A. 2004. Quality of public open space tool (POST). Perth, WA: School of Population Health, University of Western Australia.

Brown, D. K., Barton, J. L. & Gladwell, V. F. 2013. Viewing nature scenes positively affects recovery of autonomic function following acute-mental stress. *Environmental Science & Technology,* 47(11)**,** pp.5562-5569.

Browne, G. R., Davern, M. T. & Giles‐Corti, B. 2015. An analysis of local government health policy against state priorities and a social determinants framework. *Australian and New Zealand Journal of Public Health,* 40(2)**,** pp.126-131.

Burdette, H. L. & Whitaker, R. C. 2005. Resurrecting free play in young children: looking beyond fitness and fatness to attention, affiliation, and affect. *Archives of Pediatrics & Adolescent Medicine,* 159(1)**,** pp.46-50.

Bush, J., Aye, L. & Hes, D. 2015. Cooling cities with green space: a policy analysis framework. *State of Australian Cities Conference.* Gold Coast, Queensland.

Byrne, J. & Sipe, N. 2010. Green and open space planning for urban consolidation–A review of the literature and best practice. *Urban Research Program: Issues Paper 11.* Griffith, QLD: Griffith University.

Cackowski, J. M. & Nasar, J. L. 2003. The restorative effects of roadside vegetation implications for automobile driver anger and frustration. *Environment and Behavior,* 35(6)**,** pp.736-751.

Capaldi, C. A., Dopko, R. L. & Zelenski, J. M. 2014. The relationship between nature connectedness and happiness: a meta-analysis. *Frontiers in Psychology,* 5**,** pp.976-991.

Caplow, T., Stryker, S. & Wallace, S. E. 1964. *The urban ambience:: a study of San Juan, Puerto Rico,* Totowa, NJ, Bedminster Press.

Caron, J. 1996. L'échelle de provisions sociales: une validation québécoise. *Santé Mentale au Québec,* 21(2)**,** pp.158-180.

Caron, J. 2012a. Predictors of quality of life in economically disadvantaged populations in Montreal. *Social Indicators Research,* 107**,** pp.411-427.

Caron, J., Fleury, M-J., Perreault, M., Crocker, A., Tremblay, J., Tousignant, M., Kestens, Y., Cargo, M., Daniel, M. 2012b. Prevalence of psychological distress and mental disorders, and use of mental health services in the epidemiological catchment area of Montreal South-West. *BMC Psychiatry,* 12**,** pp.183-195.

Caron, J. & Liu, A. 2011. Factors associated with psychological distress in the Canadian population: a comparison of low-income and non low-income sub-groups. *Community Mental Health Journal,* 47(3)**,** pp.318-330.

Caron, J., Mercier, C. & Tempier, R. 1997. Une validation québécoise du Satisfaction with Life Domains Scale. *Santé Mentale au Québec,* 22(2)**,** pp.195-217.

Caron, J., Tousignant, M., Pedersen, D., Fleury, M.-J., Cargo, M., Daniel, M., Kestens, Y., Crocker, A., Perreault, M. & Brunet, A. 2007. La création d'une nouvelle génération d'études épidémiologiques en santé mentale. *Santé Mentale au Québec,* 32(2)**,** pp.225-238.

Carrasco, M. A. & Bilal, U. 2016. A sign of the times: To have or to be? Social capital or social cohesion? *Social Science & Medicine,* 159**,** pp.127-131.

Carrus, G., Lafortezza, R., Colangelo, G., Dentamaro, I., Scopelliti, M. & Sanesi, G. 2013. Relations between naturalness and perceived restorativeness of different urban green spaces. *Psyecology,* 4(3)**,** pp.227-244.

Cattell, V., Dines, N., Gesler, W. & Curtis, S. 2008. Mingling, observing, and lingering: Everyday public spaces and their implications for well-being and social relations. *Health & Place,* 14(3)**,** pp.544-561.

Celeux, G. & Soromenho, G. 1996. An entropy criterion for assessing the number of clusters in a mixture model. *Journal of Classification,* 13(2)**,** pp.195-212.

Cerin, E. & MacKinnon, D. P. 2009. A commentary on current practice in mediating variable analyses in behavioural nutrition and physical activity. *Public Health Nutrition,* 12(8)**,** pp.1182-1188.

Chaix, B., Billaudeau, N., Thomas, F., Havard, S., Evans, D., Kestens, Y. & Bean, K. 2011. Neighborhood effects on health: correcting bias from neighborhood effects on participation. *Epidemiology,* 22(1)**,** pp.18-26.

Charlton, B. 1996. A new science of health: salutology and the evolutionary perspective. *QJM: An International Journal of Medicine,* 89(3)**,** pp.233-236.

Chavis, D. M., Hogge, J. H., McMillan, D. W. & Wandersman, A. 1986. Sense of community through Brunswik's lens: A first look. *Journal of Community Psychology,* 14(1)**,** pp.24-40.

Chen, L. & Ng, E. 2012. Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities,* 29(2)**,** pp.118-125.

Cheng, V. 2010. Understanding density and high density. *In:* Ng, E. (ed.) *Designing high-density cities for social and environmental sustainability.* London: Earthscan.

Cheong, J., MacKinnon, D. P. & Khoo, S. T. 2003. Investigation of mediational processes using parallel process latent growth curve modeling. *Structural Equation Modeling,* 10(2)**,** pp.238-262.

Chiesura, A. 2004. The role of urban parks for the sustainable city. *Landscape and Urban Planning,* 68(1)**,** pp.129-138.

Chong, S., Lobb, E., Khan, R., Abu-Rayya, H., Byun, R. & Jalaludin, B. 2013. Neighbourhood safety and area deprivation modify the associations between parkland and psychological distress in Sydney, Australia. *BMC Public Health,* 13(1)**,** pp.422.

Chrousos, G. P. 2009. Stress and disorders of the stress system. *Nature Reviews Endocrinology,* 5(7)**,** pp.374-381.

Churchill Jr, G. A. 1979. A paradigm for developing better measures of marketing constructs. *Journal of Marketing Research,* 16**,** pp.64-73.

Clark, C., Myron, R., Stansfeld, S. A. & Candy, B. 2007. A systematic review of the evidence on the effect of the built and physical environment on mental health. *Journal of Public Mental Health,* 6(2)**,** pp.14-27.

Clark, S. L. & Muthén, B. 2009. Relating latent class analysis results to variables not included in the analysis. *Submitted for publication.*

Clarke, K. C. 1990. *Analytical and computer cartography,* Englewood Cliffs, NJ, Prentice Hall.

Cobb, S. 1976. Social support as a moderator of life stress (Presidential address). *Psychosomatic Medicine,* 38(5)**,** pp.300-314.

Cohen, D. A., Inagami, S. & Finch, B. 2008. The built environment and collective efficacy. *Health & Place,* 14(2)**,** pp.198-208.

Cohen, D. A., Marsh, T., Williamson, S., Derose, K. P., Martinez, H., Setodji, C. & McKenzie, T. L. 2010. Parks and physical activity: Why are some parks used more than others? *Preventive Medicine,* 50**,** pp.S9-S12.

Cohen, S. 2004. Social relationships and health. *American Psychologist,* 59(8)**,** pp.676-684.

Cohen, S., Kamarck, T. & Mermelstein, R. 1983. A global measure of perceived stress. *Journal of Health and Social Behavior,* 24(4)**,** pp.385-396.

Cole, D. A. & Maxwell, S. E. 2003. Testing mediational models with longitudinal data: questions and tips in the use of structural equation modeling. *Journal of Abnormal Psychology,* 112(4)**,** pp.558-577.

Cole, S. R. & Frangakis, C. E. 2009. The consistency statement in causal inference: a definition or an assumption? *Epidemiology,* 20(1)**,** pp.3-5.

Cole, S. R., Platt, R. W., Schisterman, E. F., Chu, H., Westreich, D., Richardson, D. & Poole, C. 2010. Illustrating bias due to conditioning on a collider. *International Journal of Epidemiology,* 39(2)**,** pp.417-420.

Coley, R. L., Sullivan, W. C. & Kuo, F. E. 1997. Where does community grow? The social context created by nature in urban public housing. *Environment and Behavior,* 29(4)**,** pp.468-494.

Collette, O. 2012. Urban Villages: St-Henri eccentric, artsy. *Montreal Gazette*, 11 August 2012.

Collins, L. M., Schafer, J. L. & Kam, C.-M. 2001. A comparison of inclusive and restrictive strategies in modern missing data procedures. *Psychological Methods,* 6(4)**,** pp.330-351.

Commonwealth of Australia 2009. Fourth National Mental Health Plan: An agenda for collaborative government action in mental health, 2009-2014. Canberra, ACT: Commonwealth of Australia.

Conradson, D. 2005. Landscape, care and the relational self: Therapeutic encounters in rural England. *Health & Place,* 11(4)**,** pp.337-348.

Coombs, T. 2005. Australian Mental Health Outcomes and Classification Network Kessler-10 training manual. Canberra, ACT: Commonwealth of Australia.

Corten, P., Mercier, C. & Pelc, I. 1994. "Subjective quality of life": clinical model for assessment of rehabilitation treatment in psychiatry. *Social Psychiatry and Psychiatric Epidemiology,* 29(4)**,** pp.178-183.

Corti, B., Donovan, R. J. & Holman, C. 1996. Factors influencing the use of physical activity facilities: results from qualitative research. *Health Promotion Journal of Australia,* 6(1)**,** pp.16-21.

Cosmides, L. & Tooby, J. 1992. Cognitive adaptations for social exchange. *In:* Barkow, J. H., Cosmides, L. & Tooby, J. (eds.) *The adapted mind: evolutionary psychology and the generation of culture.* New York: Oxford University Press.

Costello, D. M., Swendsen, J., Rose, J. S. & Dierker, L. C. 2008. Risk and protective factors associated with trajectories of depressed mood from adolescence to early adulthood. *Journal of Consulting and Clinical Psychology,* 76(2)**,** pp.173-183.

Cotten, S. R. 1999. Marital status and mental health revisited: Examining the importance of risk factors and resources. *Family Relations,* 48(3)**,** pp.225-233.

Council of Australian Governments 2006. National Action Plan on Mental Health 2006-2011. Canberra, ACT: Commonwealth of Australia.

Cradock, A. L., Kawachi, I., Colditz, G. A., Hannon, C., Melly, S. J., Wiecha, J. L. & Gortmaker, S. L. 2005. Playground safety and access in Boston neighborhoods. *American Journal of Preventive Medicine,* 28(4)**,** pp.357-363.

Crawford, D., Timperio, A., Giles-Corti, B., Ball, K., Hume, C., Roberts, R., Andrianopoulos, N. & Salmon, J. 2008. Do features of public open spaces vary according to neighbourhood socio-economic status? *Health & Place,* 14(4)**,** pp.889-893.

Crompton, J. L. 2005. The impact of parks on property values: empirical evidence from the past two decades in the United States. *Managing Leisure,* 10(4)**,** pp.203-218.

Cronbach, L. J. 1951. Coefficient alpha and the internal structure of tests. *Psychometrika,* 16(3)**,** pp.297-334.

Cuba, L. & Hummon, D. M. 1993. A place to call home: Identification with dwelling, community, and region. *The Sociological Quarterly,* 34(1)**,** pp.111-131.

Cudeck, R. & Henly, S. J. 2003. A realistic perspective on pattern representation in growth data: comment on Bauer and Curran (2003). *Psychological Methods,* 8(3)**,** pp.378-383.

Cuijpers, P., Van Straten, A. & Warmerdam, L. 2007. Behavioral activation treatments of depression: A meta-analysis. *Clinical Psychology Review,* 27(3)**,** pp.318-326.

Curran, P. J. & Hussong, A. M. 2002. Structural equation modeling of repeated measures data: latent curve analysis. *In:* Moskowitz, D. S. & Hershberger, S. L. (eds.) *Modeling intraindividual variability with repeated measures data.* Mahwah, NJ: Lawrence Erlbaum Associates.

Curtis, S. 2010. *Space, place and mental health,* Farnham, England, Ashgate Publishing, Ltd.

Curtis, S. & Rees Jones, I. 1998. Is there a place for geography in the analysis of health inequality? *Sociology of Health & Illness,* 20(5)**,** pp.645-672.

Cutrona, C. E. & Russell, D. W. 1987. The provisions of social relationships and adaptation to stress. *Advances in Personal Relationships,* 1**,** pp.37-67.

Cutrona, C. E., Wallace, G. & Wesner, K. A. 2006. Neighborhood characteristics and depression: an examination of stress processes. *Current Directions in Psychological Science,* 15(4)**,** pp.188-192.

Daniel, M. & Kestens, Y. 2007. Montreal Epidemiological & Geographic Analysis of Population Health Outcomes & Neighbourhood Effects: MEGAPHONE (Copyright ® 1046898). Montreal, Canada: Centre de Recherche du Centre Hospitalier de l'Université de Montréal.

Daniel, M., Lekkas, P., Cargo, M., Stankov, I. & Brown, A. 2011. Environmental risk conditions and pathways to cardiometabolic diseases in indigenous populations. *Annual Review of Public Health,* 32**,** pp.327-347.

Daniel, M., Moore, S. & Kestens, Y. 2008. Framing the biosocial pathways underlying associations between place and cardiometabolic disease. *Health & Place,* 14(2)**,** pp.117-132.

de Graaf, R., Bijl, R. V., Smit, F., Ravelli, A. & Vollebergh, W. A. 2000. Psychiatric and sociodemographic predictors of attrition in a longitudinal study The Netherlands Mental Health Survey and Incidence Study (NEMESIS). *American Journal of Epidemiology,* 152(11)**,** pp.1039-1047.

de Graaf, R., van Dorsselaer, S., Tuithof, M. & ten Have, M. 2013. Sociodemographic and psychiatric predictors of attrition in a prospective psychiatric epidemiological study among the general population. Result of the Netherlands Mental Health Survey and Incidence Study-2. *Comprehensive Psychiatry,* 54**,** pp.1131-1139.

De Jong, K., Albin, M., Skärbäck, E., Grahn, P. & Björk, J. 2012. Perceived green qualities were associated with neighborhood satisfaction, physical activity, and general health: results from a cross-sectional study in suburban and rural Scania, southern Sweden. *Health & Place,* 18**,** pp.1374-1380.

De Silva, M. J., McKenzie, K., Harpham, T. & Huttly, S. R. A. 2005. Social capital and mental illness: a systematic review. *Journal of Epidemiology and Community Health,* 59(8)**,** pp.619-627.

De Vries, S., Van Dillen, S. M., Groenewegen, P. P. & Spreeuwenberg, P. 2013. Streetscape greenery and health: stress, social cohesion and physical activity as mediators. *Social Science & Medicine,* 94**,** pp.26-33.

De Vries, S., Verheij, R. A., Groenewegen, P. P. & Spreeuwenberg, P. 2003. Natural environments-healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A,* 35(10)**,** pp.1717-1732.

Dean, J., Van Dooren, K. & Weinstein, P. 2011. Does biodiversity improve mental health in urban settings? *Medical Hypotheses,* 76**,** pp.877-880.

DeFries, R. & Townshend, J. 1994. NDVI-derived land cover classifications at a global scale. *International Journal of Remote Sensing,* 15(17)**,** pp.3567-3586.

Dekker, M. C., Ferdinand, R. F., Van Lang, N. D., Bongers, I. L., Van Der Ende, J. & Verhulst, F. C. 2007. Developmental trajectories of depressive symptoms from early childhood to late adolescence: gender differences and adult outcome. *Journal of Child Psychology and Psychiatry,* 48(7)**,** pp.657-666.

Diener, E. & Lucas, R. E. 1999. Personality and subjective well-being. *In:* Kahneman, D., Diener, E. & Schwarz, N. (eds.) *Well-being: The foundations of hedonic psychology.* New York: Russell Sage.

Diener, E., Wirtz, D., Tov, W., Kim-Prieto, C., Choi, D.-w., Oishi, S. & Biswas-Diener, R. 2010. New well-being measures: Short scales to assess flourishing and positive and negative feelings. *Social Indicators Research,* 97(2)**,** pp.143-156.

Diez-Roux, A. V. 2007. Neighborhoods and health: where are we and where do we go from here?: Environnement résidentiel et santé: état de la question et perspectives pour le futur. *Revue d'Epidemiologie et de Santé Publique,* 55(1)**,** pp.13-21.

Diez Roux, A. V. 2001. Investigating neighborhood and area effects on health. *American Journal of Public Health,* 91(11)**,** pp.1783-1789.

Dolan, P., Peasgood, T. & White, M. 2008. Do we really know what makes us happy? A review of the economic literature on the factors associated with subjective well-being. *Journal of Economic Psychology,* 29(1)**,** pp.94-122.

Dong, Y. & Peng, C.-Y. J. 2013. Principled missing data methods for researchers. *SpringerPlus,* 2**,** pp.222-239.

Downey, R. G. & King, C. V. 1998. Missing data in Likert ratings: A comparison of replacement methods. *The Journal of General Psychology,* 125(2)**,** pp.175-191.

Droomers, M., Harting, J., Jongeneel-Grimen, B., Rutten, L., van Kats, J. & Stronks, K. 2014. Area-based interventions to ameliorate deprived Dutch neighborhoods in practice: Does the Dutch District Approach address the social determinants of health to such an extent that future health impacts may be expected? *Preventive Medicine,* 61**,** pp.122-127.

Droomers, M., Jongeneel-Grimen, B., Bruggink, J.-W., Kunst, A. & Stronks, K. 2016. Is it better to invest in place or people to maximize population health? Evaluation of the general health impact of urban regeneration in Dutch deprived neighbourhoods. *Health & Place,* 41**,** pp.50-57.

Dupuis, A. & Thorns, D. C. 1998. Home, home ownership and the search for ontological security. *The Sociological Review,* 46(1)**,** pp.24-47.

Durlak, J. A. & Wells, A. M. 1997. Primary prevention mental health programs for children and adolescents: A meta-analytic review. *American Journal of Community Psychology,* 25(2)**,** pp.115-152.

Dziak, J. J., Coffman, D. L., Lanza, S. T. & Li, R. 2012. Sensitivity and specificity of information criteria. Pennsylvania, PA: The Methodology Center, Pennsylvania State University.

Eaton, W. W., Anthony, J. C., Tepper, S. & Dryman, A. 1992. Psychopathology and attrition in the epidemiologic catchment area surveys. *American Journal of Epidemiology,* 135(9)**,** pp.1051-1059.

Echeverria, S. E., Diez-Roux, A. V. & Link, B. G. 2004. Reliability of self-reported neighborhood characteristics. *Journal of Urban Health,* 81(4)**,** pp.682-701.

Edwards, J. R. 2011. The fallacy of formative measurement. *Organizational Research Methods,* 14(2)**,** pp.370-388.

Edwards, N., Hooper, P., Trapp, G. S., Bull, F., Boruff, B. & Giles-Corti, B. 2013. Development of a Public Open Space Desktop Auditing Tool (POSDAT): A remote sensing approach. *Applied Geography,* 38**,** pp.22-30.

Elder Jr, G. H., Johnson, M. K. & Crosnoe, R. 2003. The emergence and development of life course theory. *In:* Mortimer, J. T. & Shanahan, M. J. (eds.) *Handbook of the Life Course.* Boston, MA: Springer.

Elliott, G. R. & Eisdorfer, C. 1982. *Stress and human health: analysis and implications of research,* New York, Springer Publishing Company.

Elwert, F. & Winship, C. 2014. Endogenous selection bias: the problem of conditioning on a collider variable. *Annual Review of Sociology,* 40**,** pp.31-53.

Elwood, J. M. 2013. Commentary: on representativeness. *International Journal of Epidemiology,* 42(4)**,** pp.1014-1015.

Enders, C. K. 2010. *Applied missing data analysis*, Guilford Publications.

Enders, C. K. & Tofighi, D. 2008. The impact of misspecifying class-specific residual variances in growth mixture models. *Structural Equation Modeling,* 15(1)**,** pp.75-95.

Erickson, D. M. & Ernst, J. A. 2011. The real benefits of nature play every day. *Exchange,* 33(4)**,** pp.97-99.

Esch, T., Stefano, G. B., Fricchione, G. L. & Benson, H. 2002. The role of stress in neurodegenerative diseases and mental disorders. *Neuroendocrinology Letters,* 23(3)**,** pp.199-208.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, California: Environmental Systems Research Institute.

Estabrooks, P. A., Lee, R. E. & Gyurcsik, N. C. 2003. Resources for physical activity participation: does availability and accessibility differ by neighborhood socioeconomic status? *Annals of Behavioral Medicine,* 25(2)**,** pp.100-104.

Falardeau, R. 1989. Mouvement populaire et intervention communautaire de 1960 à nos jours, Continuités et ruptures, par Louis Favreau, Montréal, le Centre de formation populaire et les Éditions du Fleuve, Alternatives, 1989, 307 pages. Mouvement populaire et intervention communautaire de 1960 à nos jours, Continuités et ruptures, par Louis Favreau, Montréal, le Centre de formation populaire et les Éditions du Fleuve, Alternatives, 1989, 307 pages. *Service Social,* 38(2-3)**,** pp.321-322.

Fan, Y., Das, K. V. & Chen, Q. 2011. Neighborhood green, social support, physical activity, and stress: assessing the cumulative impact. *Health & Place,* 17**,** pp.1202-1211.

Fan, Y., French, S. A. & Das, K. V. 2012. Family structure and park use among parents. *American Journal of Preventive Medicine,* 43(5)**,** pp.520-526.

Farrell, S. J., Aubry, T. & Coulombe, D. 2004. Neighborhoods and neighbors: Do they contribute to personal well‐being? *Journal of Community Psychology,* 32(1)**,** pp.9-25.

Feeney, B. C. & Collins, N. L. 2015. A new look at social support A theoretical perspective on thriving through relationships. *Personality and Social Psychology Review,* 19(2)**,** pp.113-147.

Feise, R. J. 2002. Do multiple outcome measures require p-value adjustment? *BMC Medical Research Methodology,* 2**,** pp.8-11.

Feldman, B. J., Masyn, K. E. & Conger, R. D. 2009. New approaches to studying problem behaviors: a comparison of methods for modeling longitudinal, categorical adolescent drinking data. *Developmental Psychology,* 45(3)**,** pp.652-676.

Felton, B. J. & Shinn, M. 1992. Social integration and social support: Moving "social support" beyond the individual level. *Journal of Community Psychology,* 20(2)**,** pp.103-115.

Fitzmaurice, G. M., Laird, N. M. & Ware, J. H. 2012. *Applied longitudinal analysis,* Hoboken, NJ, John Wiley & Sons.

Fleury, M.-J., Grenier, G., Bamvita, J.-M. & Perreault, M. 2011. Typology of adults diagnosed with mental disorders based on socio-demographics and clinical and service use characteristics. *BMC Psychiatry,* 11(1)**,** pp.67-78.

Folkman, S. & Lazarus, R. S. 1988. *Manual for the ways of coping questionnaire*, Consulting Psychologists Press.

Forrest, R. & Kearns, A. 2001. Social cohesion, social capital and the neighbourhood. *Urban Studies,* 38(12)**,** pp.2125-2143.

Fox‐Wasylyshyn, S. M. & El‐Masri, M. M. 2005. Handling missing data in self‐report measures. *Research in Nursing & Health,* 28(6)**,** pp.488-495.

Fox, K. R. 1999. The influence of physical activity on mental well-being. *Public Health Nutrition,* 2(3a)**,** pp.411-418.

Francis, J., Giles-Corti, B., Wood, L. & Knuiman, M. 2012a. Creating sense of community: The role of public space. *Journal of Environmental Psychology,* 32(4)**,** pp.401-409.

Francis, J., Wood, L. J., Knuiman, M. & Giles-Corti, B. 2012b. Quality or quantity? Exploring the relationship between Public Open Space attributes and mental health in Perth, Western Australia. *Social Science & Medicine,* 74**,** pp.1570-1577.

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J. & Saelens, B. E. 2005. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *American Journal of Preventive Medicine,* 28(2)**,** pp.117-125.

Fryers, T., Melzer, D. & Jenkins, R. 2003. Social inequalities and the common mental disorders. *Social Psychiatry and Psychiatric Epidemiology,* 38(5)**,** pp.229-237.

Fuchs, C. & Diamantopoulos, A. 2009. Using single-item measures for construct measurement in management research. *Die Betriebswirtschaft,* 69(2)**,** pp.195.

Fujita, F. & Diener, E. 2005. Life satisfaction set point: stability and change. *Journal of Personality and Social Psychology,* 88(1)**,** pp.158.

Fulkerson, G. M. & Thompson, G. H. 2008. The Evolution of a contested concept: a meta‐analysis of social capital definitions and trends (1988‐2006). *Sociological Inquiry,* 78(4)**,** pp.536-557.

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H. & Gaston, K. J. 2007. Psychological benefits of greenspace increase with biodiversity. *Biology letters,* 3(4)**,** pp.390-394.

Furukawa, T. A., Kessler, R. C., Slade, T. & Andrews, G. 2003. The performance of the K6 and K10 screening scales for psychological distress in the Australian National Survey of Mental Health and Well-Being. *Psychological Medicine,* 33(2)**,** pp.357.

Gadalla, T. M. 2009. Determinants, correlates and mediators of psychological distress: A longitudinal study. *Social Science & Medicine,* 68(12)**,** pp.2199-2205.

Gaitani, N., Mihalakakou, G. & Santamouris, M. 2007. On the use of bioclimatic architecture principles in order to improve thermal comfort conditions in outdoor spaces. *Building and Environment,* 42(1)**,** pp.317-324.

Galea, S. 2011. The urban brain: new directions in research exploring the relation between cities and mood–anxiety disorders. *Depression and Anxiety,* 28(10)**,** pp.857-862.

Galea, S., Freudenberg, N. & Vlahov, D. 2005. Cities and population health. *Social Science & Medicine,* 60(5)**,** pp.1017-1033.

Galea, S. & Link, B. G. 2013. Six paths for the future of social epidemiology. *American Journal of Epidemiology,* 178(6)**,** pp.843-849.

Galea, S. & Tracy, M. 2007. Participation rates in epidemiologic studies. *Annals of Epidemiology,* 17(9)**,** pp.643-653.

Galea, S., Uddin, M. & Koenen, K. 2011. The urban environment and mental disorders: Epigenetic links. *Epigenetics,* 6(4)**,** pp.400-404.

Gariepy, G., Thombs, B. D., Kestens, Y., Kaufman, J. S., Blair, A. & Schmitz, N. 2015. The Neighbourhood Built Environment and Trajectories of Depression Symptom Episodes in Adults: A Latent Class Growth Analysis. *PloS one,* 10(7)**,** pp.e0133603.

Gebel, K., Bauman, A. & Owen, N. 2009. Correlates of non-concordance between perceived and objective measures of walkability. *Annals of Behavioral Medicine,* 37(2)**,** pp.228-238.

Gesler, W. 2005. Therapeutic landscapes: An evolving theme. *Health & Place,* 11(4)**,** pp.295-297.

Gidlöf-Gunnarsson, A. & Öhrström, E. 2007. Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. *Landscape and Urban Planning,* 83(2)**,** pp.115-126.

Gilbert, N. 2016. Green space: A natural high. *Nature,* 531(7594)**,** pp.S56-S57.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A. & Donovan, R. J. 2005. Increasing walking: how important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine,* 28(2S2)**,** pp.169-176.

Gill, T. 2009. *Determinants of psychological distress in South Australia: final report for the Assessment of the Determinants and Epidemiology of Psychological Distress (ADEPD) study,* Adelaide, SA, University of Adelaide.

Gilljam, M. & Granberg, D. 1993. Should we take don't know for an answer? *Public Opinion Quarterly,* 57(3)**,** pp.348-357.

Gollob, H. F. & Reichardt, C. S. 1987. Taking account of time lags in causal models. *Child Development,* 58(1)**,** pp.80-92.

Google Maps 2013. Street View. *In:* Inc., G. (ed.).

Gove, W. R., Hughes, M. & Style, C. B. 1983. Does marriage have positive effects on the psychological well-being of the individual? *Journal of Health and Social Behavior,* 24(2)**,** pp.122-131.

Graham, J. W. 2009. Missing data analysis: Making it work in the real world. *Annual Review of Psychology,* 60**,** pp.549-576.

Graham, J. W., Olchowski, A. E. & Gilreath, T. D. 2007. How many imputations are really needed? Some practical clarifications of multiple imputation theory. *Prevention Science,* 8(3)**,** pp.206-213.

Graham, J. W. & Schafer, J. L. 1999. On the performance of multiple imputation for multivariate data with small sample size. *Statistical Strategies for Small Sample Research,* 50**,** pp.1-27.

Grahn, P. & Stigsdotter, U. A. 2003. Landscape planning and stress. *Urban Forestry & Urban Greening,* 2(1)**,** pp.1-18.

Grahn, P. & Stigsdotter, U. K. 2010. The relation between perceived sensory dimensions of urban green space and stress restoration. *Landscape and Urban Planning,* 94(3)**,** pp.264-275.

Green, C. 2012. Geographic information systems and public health: benefits and challenges. *Purple paper.* Winnipeg, Manitoba: National Collaborating Centre for Infectious Diseases.

Green, L. W. & Kreuter, M. W. 1993. *Health promotion planning: An educational and ecological approach,* New York, McGraw-Hill.

Greenaway, K. H., Haslam, S. A., Cruwys, T., Branscombe, N. R., Ysseldyk, R. & Heldreth, C. 2015. From "we" to "me": Group identification enhances perceived personal control with consequences for health and well-being. *Journal of Personality and Social Psychology,* 109(1)**,** pp.53-74.

Greenspoon, P. J. & Saklofske, D. H. 2001. Toward an integration of subjective well-being and psychopathology. *Social Indicators Research,* 54(1)**,** pp.81-108.

Gregory, D., Johnston, R., Pratt, G., Watts, M. & Whatmore, S. 2009. *The dictionary of human geography,* Chichester, UK, John Wiley & Sons.

Grigsby-Toussaint, D. S., Chi, S.-H. & Fiese, B. H. 2011. Where they live, how they play: Neighborhood greenness and outdoor physical activity among preschoolers. *International Journal of Health Geographics,* 10**,** pp.66-76.

Groenewegen, P., van den Berg, A., De Vries, S. & Verheij, R. 2006. Vitamin G: effects of green space on health, well-being, and social safety. *BMC Public Health,* 6**,** pp.149-157.

Groenewegen, P. P., van den Berg, A. E., Maas, J., Verheij, R. A. & de Vries, S. 2012. Is a Green Residential Environment Better for Health? If So, Why? *Annals of the Association of American Geographers,* 102(5)**,** pp.996-1003.

Groom, G., Hickie, I. & Davenport, T. 2003. Out of hospital, out of mind. Canberra, ACT: Mental Health Council of Australia.

Guilliams, T. G. & Edwards, L. 2010. Chronic stress and the HPA axis. *The Standard,* 9(2)**,** pp.1-12.

Hansen, W. G. 1959. How accessibility shapes land use. *Journal of the American Institute of Planners,* 25(2)**,** pp.73-76.

Hara, M., Higaki, Y., Imaizumi, T., Taguchi, N., Nakamura, K., Nanri, H., Sakamoto, T., Horita, M., Shinchi, K. & Tanaka, K. 2010. Factors influencing participation rate in a baseline survey of a genetic cohort in Japan. *Journal of Epidemiology,* 20(1)**,** pp.40.

Hartig, T. & Evans, G. W. 1993. Psychological foundations of nature experience. *Advances in Psychology,* 96**,** pp.427-427.

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S. & Gärling, T. 2003a. Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology,* 23(2)**,** pp.109-123.

Hartig, T., Johansson, G. & Kylin, C. 2003b. Residence in the social ecology of stress and restoration. *Journal of Social Issues,* 59(3)**,** pp.611-636.

Hartig, T., Mitchell, R., de Vries, S. & Frumkin, H. 2014. Nature and Health. *Annual Review of Public Health,* 35**,** pp.21.1–21.22.

Hartig, T. & Staats, H. 2006. The need for psychological restoration as a determinant of environmental preferences. *Journal of Environmental Psychology,* 26(3)**,** pp.215-226.

Haslam, S. A., Jetten, J., Postmes, T. & Haslam, C. 2009. Social identity, health and wellbeing: an emerging agenda for applied psychology. *Applied Psychology,* 58(1)**,** pp.1-23.

Hawthorne, G. & Elliott, P. 2005. Imputing cross-sectional missing data: comparison of common techniques. *Australian and New Zealand Journal of Psychiatry,* 39(7)**,** pp.583-590.

Hayes, A. F. 2009. Beyond Baron and Kenny: statistical mediation analysis in the new millennium. *Communication Monographs,* 76(4)**,** pp.408-420.

Headey, B., Kelley, J. & Wearing, A. 1993. Dimensions of mental health: life satisfaction, positive affect, anxiety and depression. *Social Indicators Research,* 29(1)**,** pp.63-82.

Henning, C. & Lieberg, M. 1996. Strong ties or weak ties? Neighbourhood networks in a new perspective. *Scandinavian Housing and Planning Research,* 13(1)**,** pp.3-26.

Henry, J. & Stephens, P. 1977. *Stress, Health, And The Social Environment: A Sociobiologic Approach To Medicine,* New York, Springer.

Henson, J. M., Reise, S. P. & Kim, K. H. 2007. Detecting mixtures from structural model differences using latent variable mixture modeling: A comparison of relative model fit statistics. *Structural Equation Modeling,* 14(2)**,** pp.202-226.

Hernán, M. A., Hernandez-Diaz, S. & Robins, J. M. 2004. A structural approach to selection bias. *Epidemiology,* 15(5)**,** pp.615-625.

Herzog, T. R., Black, A. M., Fountaine, K. A. & Knotts, D. J. 1997. Reflection and attentional recovery as distinctive benefits of restorative environments. *Journal of Environmental Psychology,* 17(2)**,** pp.165-170.

Herzog, T. R., Maguire, P. & Nebel, M. B. 2003. Assessing the restorative components of environments. *Journal of Environmental Psychology,* 23(2)**,** pp.159-170.

Hill, A. B. 1965. The environment and disease: association or causation? *Proceedings of the Royal Society of Medicine,* 58(5)**,** pp.295.

Hipp, J. R. & Bauer, D. J. 2006. Local solutions in the estimation of growth mixture models. *Psychological Methods,* 11(1)**,** pp.36.

Hird, J. N. & McDermid, G. J. 2009. Noise reduction of NDVI time series: An empirical comparison of selected techniques. *Remote Sensing of Environment,* 113(1)**,** pp.248-258.

Hitchings, R. 2013. Studying the preoccupations that prevent people from going into green space. *Landscape and Urban Planning,* 118**,** pp.98-102.

Hobfoll, S. E. 2001. The influence of culture, community, and the nested‐self in the stress process: advancing conservation of resources theory. *Applied Psychology,* 50(3)**,** pp.337-421.

Hobfoll, S. E. 2002. Social and psychological resources and adaptation. *Review of General Psychology,* 6(4)**,** pp.307.

Holahan, C. J. & Moos, R. H. 1987. Personal and contextual determinants of coping strategies. *Journal of Personality and Social Psychology,* 52(5)**,** pp.946.

Holahan, C. J., Moos, R. H., Holahan, C. K. & Cronkite, R. C. 1999. Resource loss, resource gain, and depressive symptoms: A 10-year model. *Journal of Personality and Social Psychology,* 77(3)**,** pp.620.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics,* 6(2)**,** pp.65-70.

Honold, J., Lakes, T., Beyer, R. & van der Meer, E. 2016. Restoration in urban spaces: nature views from home, greenways, and public parks. *Environment and Behavior,* 48(6)**,** pp.796-825.

Hordyk, S. R., Hanley, J. & Richard, É. 2015. "Nature is there; its free": Urban greenspace and the social determinants of health of immigrant families. *Health & Place,* 34**,** pp.74-82.

Horwitz, A. V. 2007. Distinguishing distress from disorder as psychological outcomes of stressful social arrangements. *Health,* 11(3)**,** pp.273-289.

Hu, L. t. & Bentler, P. M. 1999. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal,* 6(1)**,** pp.1-55.

Huang, D., Brecht, M.-L., Hara, M. & Hser, Y.-I. 2010. Influences of covariates on growth mixture modeling. *Journal of Drug Issues,* 40(1)**,** pp.173-194.

Huang, G.-H. & Bandeen-Roche, K. 2004. Building an identifiable latent class model with covariate effects on underlying and measured variables. *Psychometrika,* 69(1)**,** pp.5-32.

Huemmrich, K. & Goward, S. 1997. Vegetation canopy PAR absorptance and NDVI: an assessment for ten tree species with the SAIL model. *Remote Sensing of Environment,* 61(2)**,** pp.254-269.

Hummon, D. M. 1992. Community attachment: local sentiment and sense of place. *In:* Altman, I. & Low, S. M. (eds.) *Place Attachment.* New York: Plenum Press.

Hunter, A. M., Muthén, B. O., Cook, I. A. & Leuchter, A. F. 2010. Antidepressant response trajectories and quantitative electroencephalography (QEEG) biomarkers in major depressive disorder. *Journal of Psychiatric Research,* 44(2)**,** pp.90-98.

Iacobucci, D., Saldanha, N. & Deng, X. 2007. A meditation on mediation: evidence that structural equations models perform better than rRegressions. *Journal of Consumer Psychology,* 17(2)**,** pp.139-153.

Irvine, K. N., Devine-Wright, P., Payne, S. R., Fuller, R. A., Painter, B. & Gaston, K. J. 2009. Green space, soundscape and urban sustainability: an interdisciplinary, empirical study. *Local Environment,* 14(2)**,** pp.155-172.

Irvine, K. N., Warber, S. L., Devine-Wright, P. & Gaston, K. J. 2013. Understanding urban green space as a health resource: A qualitative comparison of visit motivation and derived effects among park users in Sheffield, UK. *International Journal of Environmental Research and Public Health,* 10(1)**,** pp.417-442.

Isaacowitz, D. M. & Seligman, M. E. P. 2007. Learned helplessness. *Encyclopedia of Stress (Second Edition)*. New York: Academic Press.

Jackson, L. E. 2003. The relationship of urban design to human health and condition. *Landscape and Urban Planning,* 64(4)**,** pp.191-200.

James, P., Banay, R., Hart, J. & Laden, F. 2015. A review of the health benefits of greenness. *Current Epidemiology Reports,* 2(2)**,** pp.131-142.

Jenks, M. & Dempsey, N. 2007. Defining the neighbourhood: challenges for empirical research. *Town Planning Review,* 78(2)**,** pp.153-177.

Jennings, V., Larson, L. & Yun, J. 2016. Advancing sustainability through urban green space: cultural ecosystem services, equity, and social determinants of health. *International Journal of Environmental Research and Public Health,* 13(2)**,** pp.196.

Jiang, B., Chang, C.-Y. & Sullivan, W. C. 2014a. A dose of nature: tree cover, stress reduction, and gender differences. *Landscape and Urban Planning,* 132**,** pp.26-36.

Jiang, B., Larsen, L., Deal, B. & Sullivan, W. C. 2015. A dose–response curve describing the relationship between tree cover density and landscape preference. *Landscape and Urban Planning,* 139**,** pp.16-25.

Jiang, B., Li, D., Larsen, L. & Sullivan, W. C. 2014b. A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. *Environment and Behavior***,** pp.0013916514552321.

Jones, A., Hillsdon, M. & Coombes, E. 2009. Greenspace access, use, and physical activity: Understanding the effects of area deprivation. *Preventive Medicine,* 49(6)**,** pp.500-505.

Judd, L. L., Akiskal, H. S., Maser, J. D., Zeller, P. J., Endicott, J., Coryell, W., Paulus, M. P., Kunovac, J. L., Leon, A. C. & Mueller, T. I. 1998. A prospective 12-year study of subsyndromal and syndromal depressive symptoms in unipolar major depressive disorders. *Archives of General Psychiatry,* 55(8)**,** pp.694-700.

Jung, T. & Wickrama, K. 2008. An introduction to latent class growth analysis and growth mixture modeling. *Social and Personality Psychology Compass,* 2(1)**,** pp.302-317.

Kaczynski, A. T. & Henderson, K. A. 2007. Environmental correlates of physical activity: a review of evidence about parks and recreation. *Leisure Sciences,* 29(4)**,** pp.315-354.

Kaczynski, A. T. & Mowen, A. J. 2011. Does self-selection influence the relationship between park availability and physical activity? *Preventive Medicine,* 52(1)**,** pp.23-25.

Kaczynski, A. T., Potwarka, L. R. & Saelens, B. E. 2008. Association of park size, distance, and features with physical activity in neighborhood parks. *American Journal of Public Health,* 98(8)**,** pp.1451.

Kahneman, D. 1999. Objective happiness. *In:* Kahneman, D., Diener, E. & Schwarz, N. (eds.) *Well-being: The foundations of hedonic psychology.* New York: Russell Sage.

Kang, N. & Kwak, N. 2003. A multilevel approach to civic participation, individual length of residence, neighborhood residential stability, and their interactive effects with media use. *Communication Research,* 30(1)**,** pp.80-106.

Kanter, J. W., Manos, R. C., Bowe, W. M., Baruch, D. E., Busch, A. M. & Rusch, L. C. 2010. What is behavioral activation?: A review of the empirical literature. *Clinical Psychology Review,* 30(6)**,** pp.608-620.

Kaplan, G. A. 2004. What's wrong with social epidemiology, and how can we make it better? *Epidemiologic Reviews,* 26(1)**,** pp.124-135.

Kaplan, R. 2001. The nature of the view from home. *Environment and Behavior,* 33(4)**,** pp.507-542.

Kaplan, R. & Kaplan, S. 1989. *The experience of nature: A psychological perspective,* Cambridge, UK, Cambridge University Press.

Kaplan, S. 1992a. Environmental preference in a knowledge-seeking, knowledge-using organism. *In:* Barkow, J. H., Cosmides, L. & Tooby, J. (eds.) *The adapted mind: evolutionary psychology and the generation of culture.* New York: Oxford University Press.

Kaplan, S. The restorative environment: nature and human experience. Role of Horticulture in Human Well-being and Social Development: A National Symposium. Timber Press, Arlington, Virginia, 1992b. 134-142.

Kaplan, S. 1995. The restorative benefits of nature: toward an integrative framework. *Journal of Environmental Psychology,* 15(3)**,** pp.169.

Kaplan, S. & Berman, M. G. 2010. Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science,* 5(1)**,** pp.43-57.

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L. J., Paus, T. & Berman, M. G. 2015. Neighborhood greenspace and health in a large urban center. *Scientific Reports,* 5.

Kasarda, J. D. & Janowitz, M. 1974. Community attachment in mass society. *American Sociological Review,* 39(3)**,** pp.328-339.

Kass, R. E. & Raftery, A. E. 1995. Bayes factors. *Journal of the American Statistical Association,* 90(430)**,** pp.773-795.

Kawachi, I. & Berkman, L. F. 2001. Social ties and mental health. *Journal of Urban Health,* 78(3)**,** pp.458-467.

Kaźmierczak, A. 2013. The contribution of local parks to neighbourhood social ties. *Landscape and Urban Planning,* 109(1)**,** pp.31-44.

Kearns, A. & Parkinson, M. 2001. The significance of neighbourhood. *Urban Studies,* 38(12)**,** pp.2103-2110.

Kegan, R. 1994. *In over our heads: The mental demands of modern life,* Cambridge, MA, Harvard University Press.

Keller, M. B., Lavori, P. W., Mueller, T. I., Endicott, J., Coryell, W., Hirschfeld, R. M. & Shea, T. 1992. Time to recovery, chronicity, and levels of psychopathology in major depression: a 5-year prospective follow-up of 431 subjects. *Archives of General Psychiatry,* 49(10)**,** pp.809-816.

Kellert, S. Ordinary nature: the value of exploring and restoring nature in everyday life. *In:* Shaw, W., Harris, L. & Vandruff, L., eds. 4th International Urban Wildlife Symposium, 2004 Tucson, AZ.

Kellert, S. R. 1993. The biological basis for human values of nature. *In:* Kellert, S. R. & Wilson, E. O. (eds.) *The biophilia hypothesis.* Washington, D.C.: Island Press.

Kellert, S. R. 1997. *Kinship to mastery: Biophilia in human evolution and development,* Washington, D.C., Island Press.

Kellett, J. E. 2009. Creating Active Communities: how Can Open and Public Spaces in Urban and Suburban Environments Support Active Living? A Literature Review. Adelaide, SA: Institute for Sustainable Systems and Technologies, University of South Australia.

Kelly, C. M., Wilson, J. S., Baker, E. A., Miller, D. K. & Schootman, M. 2013. Using Google Street View to audit the built environment: inter-rater reliability results. *Annals of Behavioral Medicine,* 45(1)**,** pp.108-112.

Kendler, K. S., Karkowski, L. M. & Prescott, C. A. 1999. Causal relationship between stressful life events and the onset of major depression. *American Journal of Psychiatry,* 156(6)**,** pp.837-841.

Kessler, R. C. 1997. The effects of stressful life events on depression. *Annual Review of Psychology,* 48(1)**,** pp.191-214.

Kessler, R. C., Aguilar-Gaxiola, S., Alonso, J., Chatterji, S., Lee, S., Ormel, J., Üstün, T. B. & Wang, P. S. 2009. The global burden of mental disorders: an update from the WHO World Mental Health (WMH) surveys. *Epidemiologia e Psichiatria Sociale,* 18(01)**,** pp.23-33.

Kessler, R. C., Amminger, G. P., Aguilar‐Gaxiola, S., Alonso, J., Lee, S. & Ustun, T. B. 2007a. Age of onset of mental disorders: a review of recent literature. *Current Opinion in Psychiatry,* 20(4)**,** pp.359.

Kessler, R. C., Andrews, G., Colpe, L. J., Hiripi, E., Mroczek, D. K., Normand, S. L. T., Walters, E. E. & Zaslavsky, A. M. 2002. Short screening scales to monitor population prevalences and trends in non-specific psychological distress. *Psychological Medicine,* 32(6)**,** pp.959-976.

Kessler, R. C., Angermeyer, M., Anthony, J. C., De Graaf, R., Demyttenaere, K., Gasquet, I., De Girolamo, G., Gluzman, S., Gureje, O. & Haro, J. M. 2007b. Lifetime prevalence

and age-of-onset distributions of mental disorders in the World Health Organization's World Mental Health Survey Initiative. *World Psychiatry,* 6(3)**,** pp.168.

Kessler, R. C., Barker, P. R., Colpe, L. J., Epstein, J. F., Gfroerer, J. C., Hiripi, E., Howes, M. J., Normand, S. L. T., Manderscheid, R. W. & Walters, E. E. 2003. Screening for serious mental illness in the general population. *Archives of General Psychiatry,* 60(2)**,** pp.184.

Kessler, R. C. & Greenberg, P. E. 2002. The economic burden of anxiety and stress disorders. *In:* Davis, K., Charney, D., Coyle, J. T. & Nemeroff, C. (eds.) *Neuropsychopharmacology: The fifth generation of progress.* Philadelphia, PA: Lippincott, Williams & Wilkins.

Kestens, Y., Routhier, D., Beaulieu, S., Brunet, A., Cargo, M., Crocker, A., Daniel, M., Fleury, M.-J., Pederson, D., Perreault, M., Tousignant, M., Tremblay, J., Turecki, G. & Caron, J. 2012. (Working paper) Neighbourhood factors associated with recruitment and attrition in a populational mental health epidemiological catchment area cohort. Montreal, Canada: Centre de recherche de l'Hôpital Douglas, McGill University.

Keyes, C. L. 2002. The mental health continuum: From languishing to flourishing in life. *Journal of Health and Social Behavior,* 43(2)**,** pp.207-222.

Keyes, C. L. 2005a. Chronic physical conditions and aging: Is mental health a potential protective factor? *Ageing International,* 30(1)**,** pp.88-104.

Keyes, C. L. 2005b. Mental illness and/or mental health? Investigating axioms of the complete state model of health. *Journal of Consulting and Clinical Psychology,* 73(3)**,** pp.539.

Keyes, C. L. 2007. Promoting and protecting mental health as flourishing: a complementary strategy for improving national mental health. *American Psychologist,* 62(2)**,** pp.95.

Keyes, C. L., Eisenberg, D., Perry, G. S., Dube, S. R., Kroenke, K. & Dhingra, S. S. 2012. The relationship of level of positive mental health with current mental disorders in predicting suicidal behavior and academic impairment in college students. *Journal of American College Health,* 60(2)**,** pp.126-133.

Keyes, C. L. & Grzywacz, J. G. 2005. Health as a complete state: The added value in work performance and healthcare costs. *Journal of Occupational and Environmental Medicine,* 47(5)**,** pp.523-532.

Keyes, C. L. & Michalec, B. 2010. Viewing mental health from the complete state paradigm. *In:* Scheid, T. L. B., Tony N. (ed.) *A Handbook for the Study of Mental Health.* 2nd ed. New York: Cambridge University Press.

Kickbusch, I., McCann, W. & Sherbon, T. 2008. Adelaide revisited: from healthy public policy to Health in All Policies. *Health Promotion International,* 23(1)**,** pp.1-4.

Kim, D. 2008. Blues from the neighborhood? Neighborhood characteristics and depression. *Epidemiologic Reviews,* 30(1)**,** pp.101-117.

Kim, J. & Kaplan, R. 2004. Physical and psychological factors in sense of community new urbanist Kentlands and nearby Orchard Village. *Environment and Behavior,* 36(3)**,** pp.313-340.

Kim, S.-Y. 2012. Sample size requirements in single-and multiphase growth mixture models: A Monte Carlo simulation study. *Structural Equation Modeling,* 19(3)**,** pp.457-476.

Kiviruusu, O., Huurre, T., Haukkala, A. & Aro, H. 2012. Changes in Psychological Resources Moderate the Effect of Socioeconomic Status on Distress Symptoms: A 10-Year Follow-Up Among Young Adults. *Health Psychology,* 32(6)**,** pp.627-636.

Kleinhans, R., Priemus, H. & Engbersen, G. 2007. Understanding social capital in recently restructured urban neighbourhoods: two case studies in Rotterdam. *Urban Studies,* 44(5-6)**,** pp.1069-1091.

Koohsari, M. J., Mavoa, S., Villanueva, K., Sugiyama, T., Badland, H., Kaczynski, A. T., Owen, N. & Giles-Corti, B. 2015. Public open space, physical activity, urban design and public health: Concepts, methods and research agenda. *Health & Place,* 33(0)**,** pp.75-82.

Korpela, K., Borodulin, K., Neuvonen, M., Paronen, O. & Tyrväinen, L. 2014. Analyzing the mediators between nature-based outdoor recreation and emotional well-being. *Journal of Environmental Psychology,* 37**,** pp.1-7.

Korpela, K. M., Hartig, T., Kaiser, F. G. & Fuhrer, U. 2001. Restorative experience and self-regulation in favorite places. *Environment and Behavior,* 33(4)**,** pp.572-589.

Korpela, K. M., Ylén, M., Tyrväinen, L. & Silvennoinen, H. 2009. Stability of self-reported favourite places and place attachment over a 10-month period. *Journal of Environmental Psychology,* 29(1)**,** pp.95-100.

Korpela, K. M., Ylén, M., Tyrväinen, L. & Silvennoinen, H. 2010. Favorite green, waterside and urban environments, restorative experiences and perceived health in Finland. *Health Promotion International,* 25(2)**,** pp.200-209.

Korpela, K. M. & Ylén, M. P. 2009. Effectiveness of favorite-place prescriptions: A field experiment. *American Journal of Preventive Medicine,* 36(5)**,** pp.435-438.

Korten, A. & Henderson, S. 2000. The Australian National Survey of Mental Health and Well-Being Common psychological symptoms and disablement. *The British Journal of Psychiatry,* 177(4)**,** pp.325-330.

Kovess, V. & Fournier, L. 1990. The DISSA: an abridged self-administered version of the DIS. *Social Psychiatry and Psychiatric Epidemiology,* 25(4)**,** pp.179-186.

Krause, M. S. 2009. Reversion Toward the Mean Independently of Regression Toward the Mean. *Methodology,* 5(1)**,** pp.3-6.

Krekel, C., Kolbe, J. & Wüstemann, H. 2016. The greener, the happier? The effect of urban land use on residential well-being. *Ecological Economics,* 121**,** pp.117-127.

Krosnick, J. A., Holbrook, A. L., Berent, M. K., Carson, R. T., Hanemann, W. M., Kopp, R. J., Mitchell, R. C., Presser, S., Ruud, P. A. & Smith, V. K. 2002. The impact of "no

opinion" response options on data quality: non-attitude reduction or an invitation to satisfice? *Public Opinion Quarterly,* 66(3)**,** pp.371-403.

Kuo, F. E. 2001. Coping with poverty: impacts of environment and attention in the inner city. *Environment and Behavior,* 33(1)**,** pp.5-34.

Kuo, F. E., Bacaicoa, M. & Sullivan, W. C. 1998a. Transforming inner-city landscapes trees, sense of safety, and preference. *Environment and Behavior,* 30(1)**,** pp.28-59.

Kuo, F. E. & Sullivan, W. C. 2001a. Aggression and violence in the inner city: effects of environment via mental fatigue. *Environment and Behavior,* 33(4)**,** pp.543-571.

Kuo, F. E. & Sullivan, W. C. 2001b. Environment and crime in the inner city does vegetation reduce crime? *Environment and Behavior,* 33(3)**,** pp.343-367.

Kuo, F. E., Sullivan, W. C., Coley, R. L. & Brunson, L. 1998b. Fertile ground for community: Inner-city neighborhood common spaces. *American Journal of Community Psychology,* 26(6)**,** pp.823-851.

Kweon, B. S., Sullivan, W. C. & Wiley, A. R. 1998. Green common spaces and the social integration of inner-city older adults. *Environment and Behavior,* 30(6)**,** pp.832-858.

La Rosa, D. 2014. Accessibility to greenspaces: GIS based indicators for sustainable planning in a dense urban context. *Ecological Indicators,* 42**,** pp.122-134.

Lacey, R. J., Jordan, K. P. & Croft, P. R. 2013. Does Attrition during follow-up of a population cohort study inevitably lead to biased estimates of health status? *PloS one,* 8(12)**,** pp.e83948.

Lackey, K. J. & Kaczynski, A. T. 2009. Correspondence of perceived vs. objective proximity to parks and their relationship to park-based physical activity. *International Journal of Behavioral Nutrition and Physical Activity,* 6(1)**,** pp.53-61.

Lamers, F., Hoogendoorn, A. W., Smit, J. H., van Dyck, R., Zitman, F. G., Nolen, W. A. & Penninx, B. W. 2012. Sociodemographic and psychiatric determinants of attrition in the Netherlands Study of Depression and Anxiety (NESDA). *Comprehensive Psychiatry,* 53(1)**,** pp.63-70.

Larsen, J., El-Geneidy, A. & Yasmin, F. 2010. Beyond the quarter mile: re-examining travel distances by active transportation. *Canadian Journal of Urban Research: Canadian Planning and Policy (supplement),* 19(1)**,** pp.70-88.

Laurin, I. 1998. *Facteurs de risque de la condition de sans domicile fixe. Comparaison d'une cohorte de nouveau sans domicile fixe et d'une cohorte de domiciliés pauvres.* Thèse de Docotrat, Université de Montréal.

Lazarus, R. S. & Folkman, S. 1984. *Stress, appraisal, and coping,* New York, NY, Springer Publishing Company.

Lazzari, A., de Waure, C. & Azzopardi-Muscat, N. 2015. Health in All Policies. *A Systematic Review of Key Issues in Public Health.* Switzerland: Springer International Publishing.

Lebel, A., Pampalon, R. & Villeneuve, P. Y. 2007. A multi-perspective approach for defining neighbourhood units in the context of a study on health inequalities in the Quebec City region. *International Journal of Health Geographics,* 6(1)**,** pp.27-41.

Lederbogen, F., Kirsch, P., Haddad, L., Streit, F., Tost, H., Schuch, P., Wüst, S., Pruessner, J. C., Rietschel, M. & Deuschle, M. 2011. City living and urban upbringing affect neural social stress processing in humans. *Nature,* 474(7352)**,** pp.498-501.

Lee, A. & Maheswaran, R. 2011. The health benefits of urban green spaces: a review of the evidence. *Journal of Public Health,* 33(2)**,** pp.212-222.

Lee, C. & Moudon, A. V. 2006. The 3Ds+ R: Quantifying land use and urban form correlates of walking. *Transportation Research Part D: Transport and Environment,* 11(3)**,** pp.204-215.

Lee, K. J. & Carlin, J. B. 2010. Multiple imputation for missing data: fully conditional specification versus multivariate normal imputation. *American Journal of Epidemiology,* 171(5)**,** pp.624-632.

Leslie, E., Sugiyama, T., Ierodiaconou, D. & Kremer, P. 2010. Perceived and objectively measured greenness of neighbourhoods: Are they measuring the same thing? *Landscape and Urban Planning,* 95(1-2)**,** pp.28-33.

Lewicka, M. 2005. Ways to make people active: The role of place attachment, cultural capital, and neighborhood ties. *Journal of Environmental Psychology,* 25(4)**,** pp.381-395.

Li, M., Harring, J. R. & Macready, G. B. 2014. Investigating the Feasibility of Using Mplus in the Estimation of Growth Mixture Models. *Journal of Modern Applied Statistical Methods,* 13(1)**,** pp.484-513.

Liefländer, A. K., Fröhlich, G., Bogner, F. X. & Schultz, P. W. 2013. Promoting connectedness with nature through environmental education. *Environmental Education Research,* 19(3)**,** pp.370-384.

Lin, T.-P., Tsai, K.-T., Liao, C.-C. & Huang, Y.-C. 2013. Effects of thermal comfort and adaptation on park attendance regarding different shading levels and activity types. *Building and Environment,* 59**,** pp.599-611.

Little, R. J. 1988. A test of missing completely at random for multivariate data with missing values. *Journal of the American Statistical Association,* 83(404)**,** pp.1198-1202.

Little, T. D. 2009. *Longitudinal structural equation modeling*, Guilford Press.

Little, T. D., Bovaird, J. A. & Card, N. A. 2007. *Modeling contextual effects in longitudinal studies,* Mahwah, NJ, Lawrence Erlbaum Associates.

Little, T. D., Jorgensen, T. D., Lang, K. M. & Moore, E. W. G. 2014. On the joys of missing data. *Journal of Pediatric Psychology,* 39(2)**,** pp.151-162.

Liu, M. & Hancock, G. R. 2014. Unrestricted mixture models for class identification in growth mixture modeling. *Educational and Psychological Measurement,* 74(4)**,** pp.557-584.

Lohr, V. I. & Pearson-Mims, C. H. 2006. Responses to scenes with spreading, rounded, and conical tree forms. *Environment and Behavior,* 38(5)**,** pp.667-688.

Long, D. A. & Perkins, D. D. 2003. Confirmatory factor analysis of the sense of community index and development of a brief SCI. *Journal of Community Psychology,* 31(3)**,** pp.279-296.

Long, D. A. & Perkins, D. D. 2007. Community social and place predictors of sense of community: A multilevel and longitudinal analysis. *Journal of Community Psychology,* 35(5)**,** pp.563-581.

Loughran, T. & Nagin, D. S. 2006. Finite sample effects in group-based trajectory models. *Sociological Methods & Research,* 35(2)**,** pp.250-278.

Lubke, G. & Muthén, B. O. 2007. Performance of factor mixture models as a function of model size, covariate effects, and class-specific parameters. *Structural Equation Modeling,* 14(1)**,** pp.26-47.

Lupton, R. 2003. Neighbourhood effects: can we measure them and does it matter? CASEpaper 73. London: Centre for Analysis of Social Exclusion, London School of Economics.

Maas, J., Spreeuwenberg, P., Van Winsum-Westra, M., Verheij, R. A., de Vries, S. & Groenewegen, P. P. 2009a. Is green space in the living environment associated with people's feelings of social safety? *Environment and Planning A,* 41(7)**,** pp.1763-1777.

Maas, J., Van Dillen, S. M. E., Verheij, R. A. & Groenewegen, P. P. 2009b. Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place,* 15(2)**,** pp.586-595.

Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Schellevis, F. G. & Groenewegen, P. P. 2009c. Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health,* 63(12)**,** pp.967-973.

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S. & Spreeuwenberg, P. 2006. Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology and Community Health,* 60(7)**,** pp.587-592.

Macintyre, S. & Ellaway, A. 2003. Neighborhoods and health: an overview. *In:* Kawachi, I. & Berkman, L. F. (eds.) *Neighborhoods and health.* New York: Oxford University Press.

Macintyre, S., Ellaway, A. & Cummins, S. 2002. Place effects on health: how can we conceptualise, operationalise and measure them? *Social Science & Medicine,* 55(1)**,** pp.125-139.

Macintyre, S., Macdonald, L. & Ellaway, A. 2008. Lack of agreement between measured and self-reported distance from public green parks in Glasgow, Scotland. *International Journal of Behavioral Nutrition and Physical Activity,* 5(1)**,** pp.26-33.

MacKinnon, D. P., Fairchild, A. J. & Fritz, M. S. 2007. Mediation analysis. *Annual Review of Psychology,* 58**,** pp.593-614.

MacKinnon, D. P., Krull, J. L. & Lockwood, C. M. 2000. Equivalence of the mediation, confounding and suppression effect. *Prevention Science,* 1(4)**,** pp.173-181.

Mair, C., Roux, A. V. D. & Galea, S. 2008. Are neighbourhood characteristics associated with depressive symptoms? A review of evidence. *Journal of Epidemiology and Community Health,* 62(11)**,** pp.940-946.

Manzo, L. C. & Perkins, D. D. 2006. Finding common ground: The importance of place attachment to community participation and planning. *Journal of Planning Literature,* 20(4)**,** pp.335-350.

Marcus, C. C. & Barnes, M. 1999. *Healing gardens: Therapeutic benefits and design recommendations*, John Wiley & Sons.

Marin, M.-F., Lord, C., Andrews, J., Juster, R.-P., Sindi, S., Arsenault-Lapierre, G., Fiocco, A. J. & Lupien, S. J. 2011. Chronic stress, cognitive functioning and mental health. *Neurobiology of Learning and Memory,* 96(4)**,** pp.583-595.

Marsh, H. W., Lüdtke, O. & Trautwein, U. M., Alexandre J. S. 2009. Classical latent profile analysis of academic self-concept dimensions: synergy of person- and variable-centered approaches to theoretical nodels of self-concept. *Structural Equation Modeling,* 16(2)**,** pp.191-225.

Martin, C. A., Warren, P. S. & Kinzig, A. P. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landscape and Urban Planning,* 69(4)**,** pp.355-368.

Martin, L. Implementation and outcomes of a park prescription program in Washington, DC. 141st APHA Annual Meeting, 2013 Boston, Massachussetts. APHA.

Massey, D. S. 1998. Back to the future: The rediscovery of neighborhood context. *Contemporary Sociology,* 27(6)**,** pp.570-572.

Masyn, K. E. 2013. Latent class analysis and finite mixture modeling. *In:* Little, T. D. (ed.) *The Oxford Handbook of Quantitative Methods in Psychology.* New York, NY: Oxford University Press.

Maughan, B. 2005. Developmental trajectory modeling: A view from developmental psychopathology. *The Annals of the American Academy of Political and Social Science,* 602(1)**,** pp.118-130.

Maxmen, A. 2016. Stress: The privilege of health. *Nature,* 531(7594)**,** pp.S58-S59.

Maxwell, S. E. & Cole, D. A. 2007. Bias in cross-sectional analyses of longitudinal mediation. *Psychological Methods,* 12(1)**,** pp.23.

Maxwell, S. E., Cole, D. A. & Mitchell, M. A. 2011. Bias in cross-sectional analyses of longitudinal mediation: Partial and complete mediation under an autoregressive model. *Multivariate Behavioral Research,* 46(5)**,** pp.816-841.

Mayer, F. S., Frantz, C. M., Bruehlman-Senecal, E. & Dolliver, K. 2009. Why is nature beneficial? The role of connectedness to nature. *Environment and Behavior,* 41(5)**,** pp.607-643.

McAllister, D. M. 1976. Equity and efficiency in public facility location. *Geographical Analysis,* 8(1)**,** pp.47-63.

McCormack, G. R., Rock, M., Toohey, A. M. & Hignell, D. 2010. Characteristics of urban parks associated with park use and physical activity: a review of qualitative research. *Health & Place,* 16(4)**,** pp.712-726.

McDonald, R. P. & Ho, M.-H. R. 2002. Principles and practice in reporting structural equation analyses. *Psychological Methods,* 7(1)**,** pp.64.

McEwen, B. S. 1998a. Protective and damaging effects of stress mediators. *New England Journal of Medicine,* 338(3)**,** pp.171-179.

McEwen, B. S. 1998b. Stress, adaptation, and disease: allostasis and allostatic load. *Annals of the New York Academy of Sciences,* 840(1)**,** pp.33-44.

McLachlan, G. & Peel, D. 2000. *Finite mixture models,* Hoboken, NJ, John Wiley & Sons.

McPherson, E. G., Maco, S. E., Simpson, J. R., Peper, P. J., Xiao, Q., VanDerZanden, A. & Bell, N. 2002. Western Washington and Oregon community tree guide: benefits, costs and strategic planting. Washinton, D.C.: Center for Urban Forest Research, USDA Forest Service.

Melamed, S., Ugarten, U., Shirom, A., Kahana, L., Lerman, Y. & Froom, P. 1999. Chronic burnout, somatic arousal and elevated salivary cortisol levels. *Journal of Psychosomatic Research,* 46(6)**,** pp.591-598.

Mendoza, J. L. 1993. Fisher transformations for correlations corrected for selection and missing data. *Psychometrika,* 58(4)**,** pp.601-615.

Mersch, P. P. A., Middendorp, H. M., Bouhuys, A. L., Beersma, D. G. & van den Hoofdakker, R. H. 1999. Seasonal affective disorder and latitude: a review of the literature. *Journal of Affective Disorders,* 53(1)**,** pp.35-48.

Michels, K. B. & Rosner, B. A. 1996. Data trawling: to fish or not to fish. *The Lancet,* 348(9035)**,** pp.1152-1153.

Mikulincer, M. 1994. *Human learned helplessness: A coping perspective,* New York, Springer Science & Business Media.

Miller, R. B. & Hollist, C. S. 2007. Attrition bias. *In:* Salkind, N. J. (ed.) *Encyclopedia of measurement and statistics.* Sage Publications.

Milligan, C. & Bingley, A. 2007. Restorative places or scary spaces? The impact of woodland on the mental well-being of young adults. *Health & Place,* 13(4)**,** pp.799-811.

Mirowsky, J. & Ross, C. E. 1995. Sex differences in distress: Real or artifact? *American Sociological Review,* 60(3)**,** pp.449-468.

Mirowsky, J. & Ross, C. E. 2003. *Social causes of psychological distress,* Hawthorne, NY, Aldine de Gruyter.

Mirowsky, J. & Ross, C. E. 2010. Well-being across the life course. *In:* Scheid, T. L. B., Tony N. (ed.) *A Handbook for the Study of Mental Health.* 2nd ed. New York: Cambridge University Press.

Mitchell, R., Astell-Burt, T. & Richardson, E. A. 2011. A comparison of green space indicators for epidemiological research. *Journal of Epidemiology and Community Health,* 65(10)**,** pp.853-858.

Mitchell, R. & Popham, F. 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *The Lancet,* 372(9650)**,** pp.1655-1660.

Mitchell, R. J., Richardson, E. A., Shortt, N. K. & Pearce, J. R. 2015. Neighborhood Environments and Socioeconomic Inequalities in Mental Well-Being. *American Journal of Preventive Medicine,* 49(1)**,** pp.80-84.

Molenberghs, G., Fitzmaurice, G. M., Kenward, M. G., Tsiatis, A. & Verbeke, G. 2015. *Handbook of Missing Data Methodology,* Boca Raton, FL, CRC Press.

Moons, K. G. M., Donders, R. A. R. T., Stijnen, T. & Harrell Jr, F. E. 2006. Using the outcome for imputation of missing predictor values was preferred. *Journal of Clinical Epidemiology,* 59(10)**,** pp.1092-1101.

Moore, S., Bockenholt, U., Daniel, M., Frohlich, K., Kestens, Y. & Richard, L. 2011. Social capital and core network ties: a validation study of individual-level social capital measures and their association with extra-and intra-neighborhood ties, and self-rated health. *Health & Place,* 17(2)**,** pp.536-544.

Moore, S., Gauvin, L., Daniel, M., Kestens, Y., Bockenholt, U., Dubé, L. & Richard, L. 2010. Associations among park use, age, social participation, and neighborhood age composition in Montreal. *Leisure Sciences,* 32(4)**,** pp.318-336.

Moore, S. & Kestens, Y. 2011. Neighbourhood environmental correlates of perceived park proximity in Montreal. *Canadian Journal of Public Health/Revue Canadienne de Santé Publique,* 102(3)**,** pp.176-179.

Morin, A. J., Maïano, C., Nagengast, B., Marsh, H. W., Morizot, J. & Janosz, M. 2011. General growth mixture analysis of adolescents' developmental trajectories of anxiety: the impact of untested invariance assumptions on substantive interpretations. *Structural Equation Modeling,* 18(4)**,** pp.613-648.

Morse, G. e. a. 1985. *Homeless people in St. Louis: a mental health program evaluation, field study, and followup investigation*, Department of Mental Health, State of Missouri.

Morton, L. M., Cahill, J. & Hartge, P. 2006. Reporting participation in epidemiologic studies: a survey of practice. *American Journal of Epidemiology,* 163(3)**,** pp.197-203.

Mujahid, M. S., Diez Roux, A. V., Morenoff, J. D. & Raghunathan, T. 2007. Assessing the measurement properties of neighborhood scales: from psychometrics to ecometrics. *American Journal of Epidemiology,* 165(8)**,** pp.858-867.

Mumford, E. A., Liu, W., Hair, E. C. & Yu, T.-C. 2013. Concurrent trajectories of BMI and mental health patterns in emerging adulthood. *Social Science & Medicine,* 98**,** pp.1-7.

Murray, A. L. 1967. Frederick Law Olmsted and the Design of Mount Royal Park, Montreal. *The Journal of the Society of Architectural Historians***,** pp.163-171.

Muthén, B. 2001. Second-generation structural equation modeling with a combination of categorical and continuous latent variables: New opportunities for latent class–latent growth modeling.

Muthén, B. 2003. Statistical and substantive checking in growth mixture modeling: comment on Bauer and Curran (2003).

Muthén, B. 2006. The potential of growth mixture modelling. *Infant and Child Development,* 15(6)**,** pp.623-625.

Muthén, B. & Brown, H. C. 2009. Estimating drug effects in the presence of placebo response: causal inference using growth mixture modeling. *Statistics in Medicine,* 28(27)**,** pp.3363-3385.

Muthén, B. & Muthén, L. K. 2000. Integrating person-centered and variable-centered analyses: Growth mixture modeling with latent trajectory classes. *Alcoholism: Clinical and Experimental Research,* 24(6)**,** pp.882-891.

Muthén, B. & Shedden, K. 1999. Finite mixture modeling with mixture outcomes using the EM algorithm. *Biometrics,* 55(2)**,** pp.463-469.

Muthén, B. O. 2004. Latent variable analysis: Growth mixture modeling and related techniques for longitudinal data. *In:* Kaplan, D. (ed.) *Handbook of quantitative methodology for the social sciences.* Newbury Park, CA: Sage Publications.

Muthén, B. O. & Muthén, L. K. 2004. Mplus technical appendices. *Los Angeles, CA: Muthén & Muthén,* 2004.

Muthén, L. K. & Muthén, B. O. 2012. *Mplus User's Guide. Seventh Edition.,* Los Angeles, Muthén & Muthén.

Nagin, D. 2009. *Group-based modeling of development*, Harvard University Press.

Nagin, D. S. 1999. Analyzing developmental trajectories: a semi-parametric, group-based approach. *Psychological Methods,* 4**,** pp.139-177.

Nagin, D. S. & Odgers, C. L. 2010. Group-based trajectory modeling in clinical research. *Annual Review of Clinical Psychology,* 6**,** pp.109-138.

Nagin, D. S. & Tremblay, R. E. 2001. Analyzing developmental trajectories of distinct but related behaviors: a group-based method. *Psychological Methods,* 6(1)**,** pp.18.

Nagin, D. S. & Tremblay, R. E. 2005. Developmental trajectory groups: fact or a useful statistical fiction? *Criminology,* 43(4)**,** pp.873-904.

Nario-Redmond, M., Coulton, C. & Milligan, S. 2000. Measuring resident perceptions of neighborhood conditions: Survey methodology. Cleveland, OH: Center on Urban Poverty and Social Change, Case Western Reserve University

National Recreation and Park Association 1983. Recreation, park and open space standards and guidelines. *In:* Lancaster, R. A. (ed.) *Recreation, park and open space standards and guidelines.* Ashburn, Virginia: National Recreation and Park Association.

New South Wales Government 2015. Metropolitan Greenspace Program Guidelines 2015. Sydney, NSW: Department of Planning and Environment.

Newman, D. A. 2003. Longitudinal modeling with randomly and systematically missing data: A simulation of ad hoc, maximum likelihood, and multiple imputation techniques. *Organizational Research Methods,* 6(3)**,** pp.328-362.

Nicholls, S. 2001. Measuring the accessibility and equity of public parks: a case study using GIS. *Managing Leisure,* 6(4)**,** pp.201-219.

Nielsen, T. S. & Hansen, K. B. 2007. Do green areas affect health? Results from a Danish survey on the use of green areas and health indicators. *Health & Place,* 13(4)**,** pp.839-850.

Nikolopoulou, M., Baker, N. & Steemers, K. 2001. Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy,* 70(3)**,** pp.227-235.

Nikolopoulou, M. & Steemers, K. 2003. Thermal comfort and psychological adaptation as a guide for designing urban spaces. *Energy and Buildings,* 35(1)**,** pp.95-101.

Nisbet, E. K. & Zelenski, J. M. 2011. Underestimating nearby nature: affective forecasting errors obscure the happy path to sustainability. *Psychological Science,* 22(9)**,** pp.1101-1106.

Nohr, E. A., Frydenberg, M., Henriksen, T. B. & Olsen, J. 2006. Does low participation in cohort studies induce bias? *Epidemiology,* 17(4)**,** pp.413-418.

Nohr, E. A. & Olsen, J. 2013. Commentary: Epidemiologists have debated representativeness for more than 40 years—has the time come to move on? *International Journal of Epidemiology,* 42(4)**,** pp.1016-1017.

Nordh, H., Alalouch, C. & Hartig, T. 2011. Assessing restorative components of small urban parks using conjoint methodology. *Urban Forestry & Urban Greening,* 10(2)**,** pp.95-103.

Nordh, H., Hartig, T., Hagerhall, C. & Fry, G. 2009. Components of small urban parks that predict the possibility for restoration. *Urban Forestry & Urban Greening,* 8(4)**,** pp.225-235.

Nordh, H. & Østby, K. 2013. Pocket parks for people–A study of park design and use. *Urban Forestry & Urban Greening,* 12(1)**,** pp.12-17.

Norman, P., Boyle, P. & Rees, P. 2005. Selective migration, health and deprivation: a longitudinal analysis. *Social Science & Medicine,* 60(12)**,** pp.2755-2771.

Nutsford, D., Pearson, A. & Kingham, S. 2013. An ecological study investigating the association between access to urban green space and mental health. *Public Health,* 127(11)**,** pp.1005-1011.

Nylund-Gibson, K., Grimm, R., Quirk, M. & Furlong, M. 2014. A Latent Transition Mixture Model Using the Three-Step Specification. *Structural Equation Modeling,* 21(3)**,** pp.439-454.

Nylund, K. L., Asparouhov, T. & Muthén, B. O. 2007. Deciding on the number of classes in latent class analysis and growth mixture modeling: A Monte Carlo simulation study. *Structural Equation Modeling,* 14(4)**,** pp.535-569.

O'Dea, K. & Daniel, M. 2001. How social factors affect health: neuroendocrine interactions. *In:* Eckersley, R., Dixon, J. & Douglas, B. (eds.) *The social origins of health and wellbeing.* Cambridge, UK: Cambridge University Press.

O'Campo, P., Salmon, C. & Burke, J. 2009. Neighbourhoods and mental well-being: what are the pathways? *Health & Place,* 15(1)**,** pp.56-68.

Oakes, J. M. 2004. The (mis)estimation of neighborhood effects: causal inference for a practicable social epidemiology. *Social Science & Medicine,* 58(10)**,** pp.1929-1952.

Oakes, J. M. 2006. Commentary: advancing neighbourhood-effects research - selection, inferential support, and structural confounding. *International Journal of Epidemiology,* 35(3)**,** pp.643-647.

Oh, K. & Jeong, S. 2007. Assessing the spatial distribution of urban parks using GIS. *Landscape and Urban Planning,* 82(1)**,** pp.25-32.

Oliver, L. N., Schuurman, N. & Hall, A. W. 2007. Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International Journal of Health Geographics,* 6(1)**,** pp.41-51.

Openshaw, S. 1996. Developing GIS-relevant zone-based spatial analysis methods. *In:* Longley, P. A. & Batty, M. (eds.) *Spatial analysis: modelling in a GIS environment.* New York, NY: John Wiley & Sons, Inc.

Orians, G. H. & Heerwagen, J. H. 1992. Evolved responses to landscapes. *In:* Barkow, J. H., Cosmides, L. & Tooby, J. (eds.) *The adapted mind: evolutionary psychology and the generation of culture.* New York: Oxford University Press.

Ottenbreit, N. D. & Dobson, K. S. 2004. Avoidance and depression: the construction of the Cognitive–Behavioral Avoidance Scale. *Behaviour Research and Therapy,* 42(3)**,** pp.293-313.

Palka, E. 1999. Accessible wilderness as a therapeutic landscape: Experiencing the nature of Denali National Park, Alaska. *In:* Williams, A. (ed.) *Therapeutic Landscapes: The Dynamic Between Place and Wellness.* Lanham, MD: University Press of America.

Paquet, C., Orschulok, T. P., Coffee, N. T., Howard, N. J., Hugo, G., Taylor, A. W., Adams, R. J. & Daniel, M. 2013. Are accessibility and characteristics of public open spaces associated with a better cardiometabolic health? *Landscape and Urban Planning,* 118**,** pp.70-78.

Park, J. J., O'Brien, L., Roe, J., Ward Thompson, C. & Mitchell, R. 2011. The natural outdoors and health: assessing the value and potential contribution of secondary public data sets in the UK to current and future knowledge. *Health & Place,* 17(1)**,** pp.269-279.

Partonen, T. & Lönnqvist, J. 1998. Seasonal affective disorder. *The Lancet,* 352(9137)**,** pp.1369-1374.

Pearce, J., Shortt, N., Rind, E. & Mitchell, R. 2016. Life course, green space and health: incorporating place into life course epidemiology. *International Journal of Environmental Research and Public Health,* 13(3)**,** pp.331.

Pearl, J. 2009. *Causality,* New York, NY, Cambridge University Press.

Pearlin, L. I. 1989. The sociological study of stress. *Journal of Health and Social Behavior,* 30(3)**,** pp.241-256.

Pearlin, L. I. 1999. The stress process revisited: reflections on concepts and their interrelationships. *In:* Aneshensel, C. S. & Phelan, J. C. (eds.) *Handbook of the sociology of mental health.* 1st ed. New York: Springer.

Pearlin, L. I., Menaghan, E. G., Lieberman, M. A. & Mullan, J. T. 1981. The stress process. *Journal of Health and Social Behavior,* 22(4)**,** pp.337-356.

Pearlin, L. I. & Schooler, C. 1978. The structure of coping. *Journal of Health and Social Behavior,* 19(1)**,** pp.2-21.

Peen, J., Schoevers, R., Beekman, A. & Dekker, J. 2010. The current status of urban–rural differences in psychiatric disorders. *Acta Psychiatrica Scandinavica,* 121(2)**,** pp.84-93.

Perkins, D. D., Florin, P., Rich, R. C., Wandersman, A. & Chavis, D. M. 1990. Participation and the social and physical environment of residential blocks: Crime and community context. *American Journal of Community Psychology,* 18(1)**,** pp.83-115.

Perkins, D. D. & Long, D. A. 2002. Neighborhood sense of community and social capital. *In:* Fisher, A. T., Sonn, C. C. & Bishop, B. J. (eds.) *Psychological Sense of Community.* New York, NY: Springer.

Perkins, S., Searight, H. R. & Ratwik, S. 2011. Walking in a natural winter setting to relieve attention fatigue: a pilot study. *Psychology,* 2(8)**,** pp.777-780.

Peters, K., Elands, B. & Buijs, A. 2010. Social interactions in urban parks: Stimulating social cohesion? *Urban Forestry & Urban Greening,* 9(2)**,** pp.93-100.

Petras, H. & Masyn, K. 2010. General growth mixture analysis with antecedents and consequences of change. *In:* Piquero, A. R. & Weisburd, D. (eds.) *Handbook of quantitative criminology.* New York: Springer.

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J.-M., Tucker, C. J. & Stenseth, N. C. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution,* 20(9)**,** pp.503-510.

Poortinga, W. 2006. Social capital: an individual or collective resource for health? *Social Science & Medicine,* 62(2)**,** pp.292-302.

Powell, L. M., Slater, S. & Chaloupka, F. J. 2004. The relationship between community physical activity settings and race, ethnicity and socioeconomic status. *Evidence-Based Preventive Medicine,* 1(2)**,** pp.135-144.

Preacher, K. J. & Hayes, A. F. 2004. SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers,* 36(4)**,** pp.717-731.

Preacher, K. J. & Hayes, A. F. 2008. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods,* 40(3)**,** pp.879-891.

Preacher, K. J. & Selig, J. P. 2012. Advantages of Monte Carlo confidence intervals for indirect effects. *Communication Methods and Measures,* 6(2)**,** pp.77-98.

Pretty, G. M. H., Andrewes, L. & Collett, C. 1994. Exploring adolescents' sense of community and its relationship to loneliness. *Journal of Community Psychology,* 22(4)**,** pp.346-358.

Prezza, M., Amici, M., Roberti, T. & Tedeschi, G. 2001. Sense of community referred to the whole town: Its relations with neighboring, loneliness, life satisfaction, and area of residence. *Journal of Community Psychology,* 29(1)**,** pp.29-52.

Price, K., Gill, T., Winefield, H., Chittleborough, C., Taylor, A. 2008. Determinants of psychological distress: a literature review. *The assessment of the determinants and epidemiology of psychological distress (ADEPD) study.* Adelaide.

Priebe, S., Burns, T. & Craig, T. K. J. 2013. The future of academic psychiatry may be social. *The British Journal of Psychiatry,* 202(5)**,** pp.319-320.

Pruitt, S. L., Jeffe, D. B., Yan, Y. & Schootman, M. 2012. Reliability of perceived neighbourhood conditions and the effects of measurement error on self-rated health across urban and rural neighbourhoods. *Journal of Epidemiology and Community Health,* 66(4)**,** pp.342-351.

Puska, P. 2007. Health in all policies. *The European Journal of Public Health,* 17(4)**,** pp.328-328.

Ram, N. & Grimm, K. J. 2009. Growth mixture modeling: a method for identifying differences in longitudinal change among unobserved groups. *International Journal of Behavioral Development,* 33(6)**,** pp.565-576.

Rehkopf, D. H., Glymour, M. M. & Osypuk, T. L. 2016. The consistency assumption for causal inference in social epidemiology: when a rose is not a rose. *Current Epidemiology Reports,* 3(1)**,** pp.63-71.

Reiss, D. & Price, R. H. 1996. National research agenda for prevention research: the National Institute of Mental Health report. *American Psychologist,* 51(11)**,** pp.1109-1115.

Renshaw, T. L. & Cohen, A. S. 2014. Life satisfaction as a distinguishing indicator of college student functioning: further validation of the two-continua model of mental health. *Social Indicators Research,* 117(1)**,** pp.319-334.

Rhew, I. C., Vander Stoep, A., Kearney, A., Smith, N. L. & Dunbar, M. D. 2011. Validation of the normalized difference vegetation index as a measure of neighborhood greenness. *Annals of Epidemiology,* 21(12)**,** pp.946-952.

Richardson, E. A., Mitchell, R., Hartig, T., de Vries, S., Astell-Burt, T. & Frumkin, H. 2012. Green cities and health: a question of scale? *Journal of Epidemiology and Community Health,* 66(2)**,** pp.160-165.

Richardson, E. A., Pearce, J., Mitchell, R. & Kingham, S. 2013. Role of physical activity in the relationship between urban green space and health. *Public Health,* 127(4)**,** pp.318-324.

Richiardi, L., Pizzi, C. & Pearce, N. 2013. Commentary: representativeness is usually not necessary and often should be avoided. *International Journal of Epidemiology,* 42(4)**,** pp.1018-1022.

Rindskopf, D. 2003. Mixture or homogeneous? Comment on Bauer and Curran (2003). *Psychological Methods,* 8(3)**,** pp.364-368.

Ringel, N. B. & Finkelstein, J. C. 1991. Differentiating neighborhood satisfaction and neighborhood attachment among urban residents. *Basic and Applied Social Psychology,* 12(2)**,** pp.177-193.

Ro, E. & Clark, L. A. 2009. Psychosocial functioning in the context of diagnosis: assessment and theoretical issues. *Psychological Assessment,* 21(3)**,** pp.313-324.

Roe, J. & Aspinall, P. 2011. The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health & Place,* 17(1)**,** pp.103-113.

Roe, J. J., Thompson, C. W., Aspinall, P. A., Brewer, M. J., Duff, E. I., Miller, D., Mitchell, R. & Clow, A. 2013. Green space and stress: evidence from cortisol measures in deprived urban communities. *International Journal of Environmental Research and Public Health,* 10(9)**,** pp.4086-4103.

Rogers, E. M. 2002. Diffusion of preventive innovations. *Addictive Behaviors,* 27(6)**,** pp.989-993.

Rogerson, M., Brown, D. K., Sandercock, G., Wooller, J.-J. & Barton, J. 2016. A comparison of four typical green exercise environments and prediction of psychological health outcomes. *Perspectives in Public Health,* 136(3)**,** pp.171-180.

Rogosa, D. 1995. Myths and methods: "myths about longitudinal research" plus supplemental questions. *In:* Gottman, J. M. (ed.) *The Analysis of Change.* Mahwah, NJ: Lawrence Erlbaum Associates.

Rollero, C. & De Piccoli, N. 2010. Does place attachment affect social well-being? *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology,* 60(4)**,** pp.233-238.

Rosner, B. 2006. *Fundamentals of biostatistics,* Belmont, CA, Thomson Higher Education.

Ross, C. E. & Mirowsky, J. 2001. Neighborhood disadvantage, disorder, and health. *Journal of Health and Social Behavior,* 42(3)**,** pp.258-276.

Ross, C. E. & Mirowsky, J. 2013. The sense of personal control: social structural causes and emotional consequences. *In:* Aneshensel, C. S. & Phelan, J. C. (eds.) *Handbook of the Sociology of Mental Health.* New York, NY: Springer.

Roth, P. L., Switzer, F. S. & Switzer, D. M. 1999. Missing data in multiple item scales: A Monte Carlo analysis of missing data techniques. *Organizational Research Methods,* 2(3)**,** pp.211-232.

Rothman, K. J. 1990. No adjustments are needed for multiple comparisons. *Epidemiology,* 1(1)**,** pp.43-46.

Rothman, K. J., Gallacher, J. E. & Hatch, E. E. 2013. Why representativeness should be avoided. *International Journal of Epidemiology,* 42(4)**,** pp.1012-1014.

Rothman, K. J., Greenland, S. & Lash, T. L. 2008. *Modern epidemiology,* Philadelphia, PA, Lippincott Williams & Wilkins.

Rubin, D. B. 1987. *Multiple imputation for nonresponse in surveys,* New York, NY, John Wiley & Sons.

Rucker, D. D., Preacher, K. J., Tormala, Z. L. & Petty, R. E. 2011. Mediation analysis in social psychology: current practices and new recommendations. *Social and Personality Psychology Compass,* 5(6)**,** pp.359-371.

Sackett, P. R. & Yang, H. 2000. Correction for range restriction: an expanded typology. *Journal of Applied Psychology,* 85(1)**,** pp.112-118.

Sampson, R. J. 1988. Local friendship ties and community attachment in mass society: A multilevel systemic model. *American Sociological Review,* 53(5)**,** pp.766-779.

Sampson, R. J. & Laub, J. H. 2005. Seductions of method: rejoinder to Nagin and Tremblay's developmental trajectory groups: fact or fiction. *Criminology,* 43**,** pp.905-913.

Sampson, R. J., Raudenbush, S. W. & Earls, F. 1997. Neighborhoods and violent crime: a multilevel study of collective efficacy. *Science,* 277(5328)**,** pp.918-924.

Santé Québec 1988. *Et la santé, ça va? Rapport de l'enquête Santé Québec 1987,* Montréal, Québec, Ministère de la Santé et des Services sociaux, Gouvernement du Québec.

Santin-Janin, H., Garel, M., Chapuis, J.-L. & Pontier, D. 2009. Assessing the performance of NDVI as a proxy for plant biomass using non-linear models: a case study on the Kerguelen archipelago. *Polar Biology,* 32(6)**,** pp.861-871.

Sarmiento, O. L., Schmid, T. L., Parra, D. C., Díaz-del-Castillo, A., Fernando Gómez, L., Pratt, M., Jacoby, E., Pinzón, J. D. & Duperly, J. 2010. Quality of life, physical activity,

and built environment characteristics among colombian adults. *Journal of Physical Activity & Health,* 7(2)**,** pp.S181-S195.

Satorra, A. & Bentler, P. M. 2001. A scaled difference chi-square test statistic for moment structure analysis. *Psychometrika,* 66(4)**,** pp.507-514.

Schaeffer, N. C. & Presser, S. 2003. The science of asking questions. *Annual Review of Sociology,* 29**,** pp.65-88.

Schafer, J. L. 1997. *Analysis of incomplete multivariate data,* London, Chapman & Hall.

Schafer, J. L. 1999. Multiple imputation: a primer. *Statistical Methods in Medical Research,* 8(1)**,** pp.3-15.

Schafer, J. L. & Graham, J. W. 2002. Missing data: our view of the state of the art. *Psychological Methods,* 7(2)**,** pp.147.

Schafer, J. L. & Olsen, M. K. 1998. Multiple imputation for multivariate missing-data problems: a data analyst's perspective. *Multivariate Behavioral Research,* 33**,** pp.545-571.

Schimmack, U. & Oishi, S. 2005. The influence of chronically and temporarily accessible information on life satisfaction judgments. *Journal of Personality and Social Psychology,* 89(3)**,** pp.395-406.

Schisterman, E. F., Cole, S. R. & Platt, R. W. 2009. Overadjustment bias and unnecessary adjustment in epidemiologic studies. *Epidemiology,* 20(4)**,** pp.488-495.

Schwarz, G. 1978. Estimating the dimension of a model. *The Annals of Statistics,* 6(2)**,** pp.461-464.

Schwarz, N. & Clore, G. L. 1983. Mood, misattribution, and judgments of well-being: informative and directive functions of affective states. *Journal of Personality and Social Psychology,* 45(3)**,** pp.513-523.

Sclove, S. L. 1987. Application of model-selection criteria to some problems in multivariate analysis. *Psychometrika,* 52(3)**,** pp.333-343.

Seaman, P. J., Jones, R. & Ellaway, A. 2010. It's not just about the park, it's about integration too: why people choose to use or not use urban greenspaces. *International Journal of Behavioral Nutrition and Physical Activity,* 7**,** pp.78-86.

Seeman, T. E., Singer, B. H., Rowe, J. W., Horwitz, R. I. & McEwen, B. S. 1997. Price of adaptation—allostatic load and its health consequences: MacArthur studies of successful aging. *Archives of Internal Medicine,* 157(19)**,** pp.2259-2268.

Selig, J. P. & Little, T. D. 2012. Autoregressive and cross-lagged panel analysis for longitudinal data. *In:* Laursen, B., Little, T. D. & Card, N. A. (eds.) *Handbook of developmental research methods.* New York, NY: The Guilford Press.

Selig, J. P. & Preacher, K. J. 2008. Monte Carlo method for assessing mediation: An interactive tool for creating confidence intervals for indirect effects [Computer software].

Selig, J. P. & Preacher, K. J. 2009. Mediation models for longitudinal data in developmental research. *Research in Human Development,* 6(2-3)**,** pp.144-164.

Seltenrich, N. 2015. Just what the doctor ordered: using parks to improve children's health. *Environmental Health Perspectives,* 123(10)**,** pp.A254-A259.

Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barber, E. & Fuller, R. A. 2016. Health Benefits from Nature Experiences Depend on Dose. *Scientific Reports,* 6**,** pp.e28551.

Shanahan, D. F., Lin, B. B., Bush, R., Gaston, K. J., Dean, J. H., Barber, E. & Fuller, R. A. 2015. Toward improved public health outcomes from urban nature. *American Journal of Public Health,* 105(3)**,** pp.470-477.

Sher, K. J., Jackson, K. M. & Steinley, D. 2011. Alcohol use trajectories and the ubiquitous cat's cradle: cause for concern? *Journal of Abnormal Psychology,* 120(2)**,** pp.322-335.

Shumaker, S. A. & Brownell, A. 1984. Toward a theory of social support: closing conceptual gaps. *Journal of Social Issues,* 40(4)**,** pp.11-36.

Sijtsma, K. & Van der Ark, L. A. 2003. Investigation and treatment of missing item scores in test and questionnaire data. *Multivariate Behavioral Research,* 38(4)**,** pp.505-528.

Sindall, K., Sturgis, P., Steele, F., Leckie, G. & French, R. 2015. A reassessment of socio-economic gradients in child cognitive development using Growth Mixture Models (Working paper). *Working Papers.* Southampton, UK: National Center for Research Methods.

Skinner, J. H., Teresi, J. A., Holmes, D., Stahl, S. M. & Stewart, A. L. 2002. *Multicultural measurement in older populations,* New York, NY, Springer Publishing Company.

Smith, T. W. 2009. A revised review of methods to estimate the status of cases with unknown eligibility. *National Opinion Research Center, University of Chicago.* Chicago, IL.

Smyth, N., Siriwardhana, C., Hotopf, M. & Hatch, S. L. 2015. Social networks, social support and psychiatric symptoms: social determinants and associations within a multicultural community population. *Social Psychiatry and Psychiatric Epidemiology,* 50(7)**,** pp.1111-1120.

Sonne-Holm, S., Sørensen, T. I., Jensen, G. & Schnohr, P. 1989. Influence of fatness, intelligence, education and sociodemographic factors on response rate in a health survey. *Journal of Epidemiology and Community Health,* 43(4)**,** pp.369-374.

South Australian Department of Health 2010. The state of public and environmental health report for South Australia 2009-10. Adelaide, SA: SA Health.

SPSS Inc. 2010. IBM SPSS Statistics for Windows. 19.0 ed. Armonk, NY: IBM Corp.

Staats, H. & Hartig, T. 2004. Alone or with a friend: A social context for psychological restoration and environmental preferences. *Journal of Environmental Psychology,* 24(2)**,** pp.199-211.

Staats, H., Jahncke, H., Herzog, T. R. & Hartig, T. 2016. Urban Options for Psychological Restoration: Common Strategies in Everyday Situations. *PloS one,* 11(1)**,** pp.e0146213.

Staats, H., Kieviet, A. & Hartig, T. 2003. Where to recover from attentional fatigue: An expectancy-value analysis of environmental preference. *Journal of Environmental Psychology,* 23(2)**,** pp.147-157.

Staats, H., Van Gemerden, E. & Hartig, T. 2010. Preference for restorative situations: Interactive effects of attentional state, activity-in-environment, and social context. *Leisure Sciences,* 32(5)**,** pp.401-417.

Ståhl, T., Wismar, M., Ollila, E., Lahtinen, E. & Leppo, K. 2006. Health in all policies: prospects and potentials. Helinki: Finnish Ministry of Social Affairs and Health.

State Government of Victoria 2013. Creating liveable open space: case studies. Melbourne, VIC: Department of Transport, Planning and Local Infrastructure.

Statistics Canada 2002. Canadian Community Health Survey (CCHS) Cycle 1.2 Mental Health and Well-being: Public Use Microdata File Documentation. Ontario, Canada: Statistics Canada.

Statistics Canada 2006. Canada Census. Ontario, Canada: Statistics Canada.

Statistics Canada. 2007. *2006 Community Profiles. 2006 Census. Statistics Canada Catalogue no. 92-591-XWE* [Online]. Ottawa, Ontario: Statistics Canada. Available: http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E [Accessed 25 February 2014].

Statistics Canada 2010. Low Income Lines, 2008-2009. *In:* Division, I. S. (ed.) *Income Research Paper Series.* Ottawa, Ontario: Statistics Canada,.

Statistics Canada. 2012a. *Census Profile: Montreal Census Metropolitan Area* [Online]. Ottawa, Ontario: Statistics Canada. Last updated February 8, 2012. Available: http://www12.statcan.ca/census-recensement/2011/dp-pd/prof/details/page.cfm?Lang=E&Geo1=CMA&Code1=462&Geo2=PR&Code2=24&Data=Count&SearchText=montreal&SearchType=Begins&SearchPR=01&B1=All&Custom=&TABID=1 [Accessed 26 February 2014].

Statistics Canada. 2012b. *Focus on Geography Series, 2011 Census: Census metropolitan area of Montréal, Quebec* [Online]. Ottawa, Ontario: Statistics Canada. :Last updated October 24, 2012. Available: http://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-cma-eng.cfm?LANG=Eng&GC=462 [Accessed 26 February 2014].

Statistics Canada. 2013. *Median total income, by family type, by census metropolitan area (table)* [Online]. Ottawa, Ontario: Statistics Canada. Last updated February 10, 2013. Available: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil107a-eng.htm [Accessed 26 February 2014].

Stedman, R. C. 2003. Is it really just a social construction?: The contribution of the physical environment to sense of place. *Society &Natural Resources,* 16(8)**,** pp.671-685.

Stigsdotter, U. A. & Grahn, P. A garden at your doorstep may reduce stress–Private gardens as restorative environments in the city. Open Space - People Space: an international conference on inclusive environments., 2004 Edinburgh, UK.

Stigsdotter, U. K., Ekholm, O., Schipperijn, J., Toftager, M., Kamper-Jørgensen, F. & Randrup, T. B. 2010. Health promoting outdoor environments-Associations between green space, and health, health-related quality of life and stress based on a Danish national representative survey. *Scandinavian Journal of Public Health,* 38(4)**,** pp.411-417.

Stokols, D. 1996. Translating social ecological theory into guidelines for community health promotion. *American Journal of Health Promotion,* 10(4)**,** pp.282-298.

Stokols, D., Allen, J. & Bellingham, R. L. 1996. The social ecology of health promotion: implications for research and practice. *American Journal of Health Promotion,* 10(4)**,** pp.247-251.

Streiner, D. L. 2003. Starting at the beginning: an introduction to coefficient alpha and internal consistency. *Journal of Personality Assessment,* 80(1)**,** pp.99-103.

Sturm, R. & Cohen, D. 2014. Proximity to urban parks and mental health. *The Journal of Mental Health Policy and Economics,* 17(1)**,** pp.19-24.

Sugiyama, T., Francis, J., Middleton, N. J. & Neville, O. 2010. Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces. *American Journal of Public Health,* 100(9)**,** pp.1752-1758.

Sugiyama, T., Leslie, E., Giles-Corti, B. & Owen, N. 2008. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of Epidemiology and Community Health,* 62(5)**,** pp.e9-e15.

Sugiyama, T., Paquet, C., Howard, N. J., Coffee, N. T., Taylor, A. W., Adams, R. J. & Daniel, M. 2014. Public open spaces and walking for recreation: Moderation by attributes of pedestrian environments. *Preventive Medicine,* 62**,** pp.25-29.

Sugiyama, T., Thompson, C. W. & Alves, S. 2009. Associations between neighborhood open space attributes and quality of life for older people in Britain. *Environment and Behavior,* 41(1)**,** pp.3-21.

Suh, E., Diener, E., Oishi, S. & Triandis, H. C. 1998. The shifting basis of life satisfaction judgments across cultures: emotions versus norms. *Journal of Personality and Social Psychology,* 74(2)**,** pp.482-493.

Suldo, S. M. & Shaffer, E. J. 2008. Looking beyond psychopathology: the dual-factor model of mental health in youth. *School Psychology Review,* 37(1)**,** pp.52.

Sullivan, W. C., Kuo, F. E. & Depooter, S. F. 2004. The fruit of urban nature vital neighborhood spaces. *Environment and Behavior,* 36(5)**,** pp.678-700.

Swanwick, C., Dunnett, N. & Woolley, H. 2003. Nature, role and value of green space in towns and cities: An overview. *Built Environment,* 29(2)**,** pp.94-106.

Swaroop, S. & Morenoff, J. D. 2006. Building community: The neighborhood context of social organization. *Social Forces,* 84(3)**,** pp.1665-1695.

Szklo, M. 1998. Population-based cohort studies. *Epidemiologic Reviews,* 20(1)**,** pp.81-90.

Tabachnick, B. G. & Fidell, L. S. 2001. *Using multivariate statistics*, Pearson.

Tan, X., Dierker, L., Rose, J., Li, R. & Network, T. E. R. 2011. How spacing of data collection may impact estimates of substance use trajectories. *Substance Use & Misuse,* 46(6)**,** pp.758-768.

Tang, I.-C., Sullivan, W. C. & Chang, C.-Y. 2015. Perceptual evaluation of natural landscapes: the role of the individual connection to nature. *Environment and Behavior,* 47(6)**,** pp.595-617.

Tavano Blessi, G., Grossi, E., Pieretti, G., Ferilli, G. & Landi, A. 2015. Cities, the urban green environment, and individual subjective well-being: the case of Milan, Italy. *Urban Studies Research,* 2015(e1-e13).

Taylor, A. F., Wiley, A., Kuo, F. E. & Sullivan, W. C. 1998. Growing up in the inner city: green spaces as places to grow. *Environment and Behavior,* 30(1)**,** pp.3-27.

Taylor, B. T., Fernando, P., Bauman, A. E., Williamson, A., Craig, J. C. & Redman, S. 2011. Measuring the quality of public open space using Google Earth. *American Journal of Preventive Medicine,* 40(2)**,** pp.105-112.

Taylor, S. E. & Stanton, A. L. 2007. Coping resources, coping processes, and mental health. *Annual Review of Clinical Psychology,* 3**,** pp.377-401.

Tennessen, C. M. & Cimprich, B. 1995. Views to nature: effects on attention. *Journal of Environmental Psychology,* 15(1)**,** pp.77-85.

Terhaar, T. L. 2009. Evolutionary advantages of intense spiritual experience in nature. *Journal for the Study of Religion, Nature and Culture,* 3(3)**,** pp.303-339.

Tester, J. & Baker, R. 2009. Making the playfields even: evaluating the impact of an environmental intervention on park use and physical activity. *Preventive Medicine,* 48(4)**,** pp.316-320.

Theodori, G. L. 2001. Examining the effects of community satisfaction and attachment on individual wellbeing. *Rural Sociology,* 66(4)**,** pp.618-628.

Thoits, P. A. 1995. Stress, coping, and social support processes: Where are we? What next? *Journal of Health and Social Behavior,* 35(Extra Issue: Forty Years of Medical Sociology: The State of the Art and Directions for the Future)**,** pp.53-79.

Thoits, P. A. 2006. Personal agency in the stress process. *Journal of Health and Social Behavior,* 47(4)**,** pp.309-323.

Thoits, P. A. 2010. Stress and health. *Journal of Health and Social Behavior,* 51**,** pp.S41-S53.

Thomas, F. 2015. The role of natural environments within women's everyday health and wellbeing in Copenhagen, Denmark. *Health & Place,* 35**,** pp.187-195.

Thomson, S., Osborn, R., Squires, D. & Jun, M. 2013. International Profiles of Health Care Systems, 2013. New York: The Commonwealth Fund.

Tofighi, D. & Enders, C. K. 2008. Identifying the correct number of classes in growth mixture models. *In:* Hancock, G. R. & Samuelson, K. M. (eds.) *Advances in Latent Variable Mixture Models.* Charlotte, NC: Information Age Publishing.

Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., Basagaña, X., Gražulevičienė, R. & Nieuwenhuijsen, M. J. 2015. Natural outdoor environments and mental and physical health: relationships and mechanisms. *Environment International,* 77**,** pp.35-41.

Truong, K. D. & Ma, S. 2006. A systematic review of relations between neighborhoods and mental health. *The Journal of Mental Health Policy and Economics,* 9(3)**,** pp.137.

Tu, Y. K. & Law, G. R. 2010. Reexamining the associations between family backgrounds and children's cognitive developments in early ages. *Early Child Development and Care,* 180(9)**,** pp.1243-1252.

Turner, R. J. 2010. Understanding health disparities: The promise of the stress process model. *Advances in the conceptualization of the stress process.* New York, NY: Springer.

Turner, R. J. & Marino, F. 1994. Social support and social structure: A descriptive epidemiology. *Journal of Health and Social Behavior,* 35(3)**,** pp.193-212.

Turner, R. J., Wheaton, B. & Lloyd, D. A. 1995. The epidemiology of social stress. *American Sociological Review,* 60(1)**,** pp.104-125.

Twigge-Molecey, A. 2009. Is gentrification taking place in the neighbourhoods surrounding the MUHC? A census-based analysis of relevant indicators. Montréal, QC: Institut national de la recherche scientifique (INRS), Urbanisation Culture Société.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J. & James, P. 2007. Promoting ecosystem and human health in urban areas using green infrastructure: a literature review. *Landscape and Urban Planning,* 81(3)**,** pp.167-178.

Ulrich, R. S. 1983. Aesthetic and affective response to natural environment. *Behavior and the natural environment.* Springer.

Ulrich, R. S. 1993. Biophilia, biophobia, and natural landscapes. *In:* Kellert, S. R. & Wilson, E. O. (eds.) *The biophilia hypothesis.* Washington, D.C.: Island Press.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A. & Zelson, M. 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology,* 11(3)**,** pp.201-230.

United Nations 2014. World urbanisation prospects: the 2014 revision, highlights. New York: United Nations.

Vallée, J., Le Roux, G., Chaix, B., Kestens, Y. & Chauvin, P. 2015. The 'constant size neighbourhood trap'in accessibility and health studies. *Urban Studies,* 52(2)**,** pp.338-357.

van den Berg, A. E., Jorgensen, A. & Wilson, E. R. 2014. Evaluating restoration in urban green spaces: Does setting type make a difference? *Landscape and Urban Planning,* 127**,** pp.173-181.

van Den Berg, A. E., Maas, J., Verheij, R. A. & Groenewegen, P. P. 2010. Green space as a buffer between stressful life events and health. *Social Science & Medicine,* 70(8)**,** pp.1203-1210.

van Dillen, S. M. E., De Vries, S., Groenewegen, P. P. & Spreeuwenberg, P. 2012. Greenspace in urban neighbourhoods and residents' health: adding quality to quantity. *Journal of Epidemiology and Community Health,* 66(6)**,** pp.e8-e12.

van Eck, M., Berkhof, H., Nicolson, N. & Sulon, J. 1996. The effects of perceived stress, traits, mood states, and stressful daily events on salivary cortisol. *Psychosomatic Medicine,* 58(5)**,** pp.447-458.

van Heeswijck, T., Paquet, C., Kestens, Y., Thierry, B., Morency, C. & Daniel, M. 2015. Differences in associations between active transportation and built environmental exposures when expressed using different components of individual activity spaces. *Health & Place,* 33**,** pp.195-202.

van Herzele, A. & de Vries, S. 2012. Linking green space to health: a comparative study of two urban neighbourhoods in Ghent, Belgium. *Population and Environment,* 34(2)**,** pp.171-193.

van Herzele, A. & Wiedemann, T. 2003. A monitoring tool for the provision of accessible and attractive urban green spaces. *Landscape and Urban Planning,* 63(2)**,** pp.109-126.

Veal, A. 2013. Open space planning standards in Australia: in search of origins. *Australian Planner,* 50(3)**,** pp.224-232.

Veal, T. 2001. Using Sydney's parks. *Australian Parks and Leisure,* 4(3)**,** pp.21-23.

Veitch, J., Ball, K., Crawford, D., Abbott, G. R. & Salmon, J. 2012. Park improvements and park activity: a natural experiment. *American Journal of Preventive Medicine,* 42(6)**,** pp.616-619.

Velarde, M. D., Fry, G. & Tveit, M. 2007. Health effects of viewing landscapes– Landscape types in environmental psychology. *Urban Forestry & Urban Greening,* 6(4)**,** pp.199-212.

Verheij, R. A. 1996. Explaining urban-rural variations in health: a review of interactions between individual and environment. *Social Science & Medicine,* 42(6)**,** pp.923-935.

Vermunt, J. K. 2010. Latent class modeling with covariates: two improved three-step approaches. *Political Analysis,* 18(4)**,** pp.450-469.

Victorian Government Department of Health 2010. Using policy to promote mental health and wellbeing: an introduction for policy makers. Melbourne, VIC: Prevention and Population Health Branch, Victorian Government.

Villanueva, K., Badland, H., Hooper, P., Koohsari, M. J., Mavoa, S., Davern, M., Roberts, R., Goldfeld, S. & Giles-Corti, B. 2015. Developing indicators of public open space to promote health and wellbeing in communities. *Applied Geography,* 57**,** pp.112-119.

Ville de Montréal. 2013. *Hyperliens et liste - Jardins communautaires* [Online]. Montréal, Canada: Ville de Montréal. Available: http://www1.ville.montreal.qc.ca/banque311/node/108 [Accessed 15 January 2013].

Völker, B., Flap, H. & Lindenberg, S. 2007. When are neighbourhoods communities? Community in Dutch neighbourhoods. *European Sociological Review,* 23(1)**,** pp.99-114.

von Hippel, W. & Gonsalkorale, K. 2005. "That is bloody revolting!" Inhibitory control of thoughts better left unsaid. *Psychological Science,* 16(7)**,** pp.497-500.

Wahowiack, L. 2016. Park prescription: recipy for healthy success. *The Nation's Health*, p.20.

Walks, R. A. & Maaranen, R. 2008. Gentrification, social mix, and social polarization: Testing the linkages in large Canadian cities. *Urban Geography,* 29(4)**,** pp.293-326.

Ward, P., McKenzie, T. L., Cohen, D., Evenson, K. R., Golinelli, D., Hillier, A., Lapham, S. C. & Williamson, S. 2014. Physical activity surveillance in parks using direct observation. *Preventing Chronic Disease,* 11**,** pp.e130147.

Ward Thompson, C. 2007. Playful nature. *In:* Travlou, P. & Ward Thompson, C. (eds.) *Open Space: People Space.* Abingdon, UK: Taylor & Francis.

Ward Thompson, C., Aspinall, P. & Montarzino, A. 2008. The childhood factor: Adult visits to green places and the significance of childhood experience. *Environment and Behavior,* 40(1)**,** pp.111-143.

Ward Thompson, C., Roe, J., Aspinall, P., Mitchell, R., Clow, A. & Miller, D. 2012. More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning,* 105**,** pp.221-229.

Wasserman, L. 2000. Bayesian model selection and model averaging. *Journal of Mathematical Psychology,* 44(1)**,** pp.92-107.

Wears, R. L. 2002. Advanced statistics: Statistical methods for analyzing cluster and cluster‐randomized data. *Academic emergency medicine,* 9(4)**,** pp.330-341.

Weich, S., Brugha, T., King, M., McManus, S., Bebbington, P., Jenkins, R., Cooper, C., McBride, O. & Stewart-Brown, S. 2011. Mental well-being and mental illness: findings from the Adult Psychiatric Morbidity Survey for England 2007. *The British Journal of Psychiatry,* 199(1)**,** pp.23-28.

Weimann, H., Rylander, L., Albin, M., Skärbäck, E., Grahn, P., Östergren, P.-O. & Björk, J. 2015. Effects of changing exposure to neighbourhood greenness on general and mental health: A longitudinal study. *Health & Place,* 33**,** pp.48-56.

Weiss, R. 1974. The provisions of social relationships. *In:* Rubin, Z. (ed.) *Doing unto others.* Englewood Cliffs, NJ: Prentice-Hall.

Wells, N. M. 2000. At home with nature effects of "greenness" on children's cognitive functioning. *Environment and Behavior,* 32(6)**,** pp.775-795.

Wells, N. M. & Evans, G. W. 2003. Nearby nature: a buffer of life stress among rural children. *Environment and Behavior,* 35(3)**,** pp.311-330.

Westerhof, G. J. & Keyes, C. L. 2010. Mental illness and mental health: the two continua model across the lifespan. *Journal of Adult Development,* 17(2)**,** pp.110-119.

Wheaton, B. 1985. Models for the stress-buffering functions of coping resources. *Journal of Health and Social Behavior***,** pp.352-364.

Wheaton, B. 1994. Sampling the stress universe. *In:* Avison, W. R. & Gotlib, I. H. (eds.) *Stress and mental health: contemporary issues and prospects for the future.* New York: Springer.

Wheaton, B. & Clarke, P. 2003. Space meets time: integrating temporal and contextual influences on mental health in early adulthood. *American Sociological Review,* 68(5)**,** pp.680-706.

White, I. R., Royston, P. & Wood, A. M. 2011. Multiple imputation using chained equations: issues and guidance for practice. *Statistics in Medicine,* 30(4)**,** pp.377-399.

White, M. P., Alcock, I., Wheeler, B. W. & Depledge, M. H. 2013. Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. *Psychological Science,* 24(6)**,** pp.920-928.

Whiteford, H. A., Degenhardt, L., Rehm, J., Baxter, A. J., Ferrari, A. J., Erskine, H. E., Charlson, F. J., Norman, R. E., Flaxman, A. D. & Johns, N. 2013. Global burden of disease attributable to mental and substance use disorders: findings from the Global Burden of Disease Study 2010. *The Lancet,* 382(9904)**,** pp.1575-1586.

Williams, A. 1998. Therapeutic landscapes in holistic medicine. *Social Science & Medicine,* 46(9)**,** pp.1193-1203.

Williams, A. 1999. Introduction. *In:* Williams, A. (ed.) *Therapeutic Landscapes: The Dynamic Between Place and Wellness.* Lanham, MD: University Press of America.

Williams, G. H. 2003. The determinants of health: structure, context and agency. *Sociology of Health & Illness,* 25(3)**,** pp.131-154.

Wilson, E. O. 1984. *Biophilia,* Cambridge, MA, Harvard University Press.

Wilson, E. O. 1993. Biophilia and the conservation ethic. *In:* Kellert, S. R. & Wilson, E. O. (eds.) *The biophilia hypothesis.* Washington, D.C.: Island Press.

Wilson, J. S. & Kelly, C. M. 2011. Measuring the quality of public open space using Google Earth: a commentary. *American Journal of Preventive Medicine,* 40(2)**,** pp.276-277.

Windhorst, E. & Williams, A. 2015. "It's like a different world": Natural places, post-secondary students, and mental health. *Health & Place,* 34**,** pp.241-250.

Wolch, J., Wilson, J. P. & Fehrenbach, J. 2005. Parks and park funding in Los Angeles: an equity-mapping analysis. *Urban Geography,* 26(1)**,** pp.4-35.

Wolf, K. L. Public value of nature: Economics of urban trees, parks and open space. *In:* Miller, D. & Wise, J. A., eds. 35th Annual Conference of the Environmental Design Research Association, 2004 Albuquerbue, NM. 88-92.

World Health Organisation 2001. The World Health Report 2001. Mental health: new understanding, new hope. Geneva: WHO.

World Health Organisation 2010. Mental health: strengthening our response. *WHO fact sheets.*

Wu, J. & Plantinga, A. J. 2003. The influence of public open space on urban spatial structure. *Journal of Environmental Economics and Management,* 46(2)**,** pp.288-309.

Xiao, Q. & McPherson, E. G. 2002. Rainfall interception by Santa Monica's municipal urban forest. *Urban Ecosystems,* 6(4)**,** pp.291-302.

Yaroslavsky, I., Pettit, J. W., Lewinsohn, P. M., Seeley, J. R. & Roberts, R. E. 2013. Heterogeneous trajectories of depressive symptoms: Adolescent predictors and adult outcomes. *Journal of Affective Disorders,* 148(2)**,** pp.391-399.

Yin, Z. & Williams, T. L. 1997. Obtaining spatial and temporal vegetation data from Landsat MSS and AVHRR/NOAA satellite images for a hydrologic model. *Photogrammetric Engineering and Remote Sensing,* 63(1)**,** pp.69-77.

Young, A. 1980. The discourse on stress and the reproduction of conventional knowledge. *Social Science & Medicine,* 14B(3)**,** pp.133-146.

Zapf, D., Dormann, C. & Frese, M. 1996. Longitudinal studies in organizational stress research: a review of the literature with reference to methodological issues. *Journal of Occupational Health Psychology,* 1(2)**,** pp.145-169.

Zhang, Y., van Dijk, T., Tang, J. & Berg, A. E. 2015. Green space attachment and health: a comparative study in two urban neighborhoods. *International Journal of Environmental Research and Public Health,* 12(11)**,** pp.14342-14363.

Zhao, X., Lynch, J. G. & Chen, Q. 2010. Reconsidering Baron and Kenny: myths and truths about mediation analysis. *Journal of consumer research,* 37(2)**,** pp.197-206.

Ziersch, A. M., Baum, F. E., MacDougall, C. & Putland, C. 2005. Neighbourhood life and social capital: the implications for health. *Social Science and Medicine,* 60(1)**,** pp.71-86.

Appendix 3.1
Ethical approval

This appendix presents documentation of ethical approval for the ZEPSOM epidemiological catchment area study by the Research Ethics Committee of the Douglas Mental Health University Institute, in accordance with the Canadian Tri-Council Guidelines.

Ouverts d'esprit. Depuis 125 ans
Caring with Open Minds. For 125 Years
Hôpital Douglas Hospital

Comité d'éthique de la recherche

Lors d'une réunion du Comité d'éthique de la recherche de l'Hôpital Douglas, tenue le *12 septembre, 2006*

Le comité compose de:

GAUTHIER, Serge, M.D., Président et Éthicien	Neurologue
BRUCE, Kenneth, Ph.D.	Psychologue
BRUNET, Alain, Ph.D.	Psychologue
DEBRUILLE, Jacques-Bruno, M.D.	Psychiatre
DE CHAZAL, Denis	Représentant de la communauté
EDWARDS, Moira	Représentant de la communauté
MALINSKI, Cecilia, BSc.N.	Infirmière bachelière
THOMAS, Françoise	Représentant de la communauté
TREMBLAY, Jacques, M.D.	Omnipraticien

A confirmé l'approbation du protocole intitulé:

Le développement d'une zone circonscrite d'études épidémiologiques en psychiatrie dans le sud-ouest de Montréal – Phase 1: Étude épidémiologique longitudinale. Équipe des Instituts de recherche en santé du Canada (IRSC) en épidémiologie sociale et psychiatrique

Tel que propose par: Dr Jean Caron

Ce protocole est approuvé pour une période d'une année

Serge Gauthier, M.D., F.R.C.P(c), Président
Comité d'éthique de la recherche de l'Hôpital Douglas
/lb

Date: 12/09/06
REB #: 06/33

SOIGNER.
DÉCOUVRIR.
ENSEIGNER.

Douglas
INSTITUT UNIVERSITAIRE EN SANTÉ MENTALE
MENTAL HEALTH UNIVERSITY INSTITUTE

CARING.
DISCOVERING.
TEACHING.

Comité d'éthique de la recherche

Lors de la réunion du Comité d'éthique de la recherche de l'Hôpital Douglas tenue *le 12 janvier 2010*

Le comité composé de:

DEBRUILLE, J. Bruno, M.D., Ph.D., Président	Psychiatre
BRUCE, Kenneth Ph.D	Psychologue
DE CHAMPLAIN, Johanne, B.A., B.C.L.	Avocate
JAITOVICH GROISMAN, Iris, Ph.D. Éthicienne inter,	Chercheuse
HOFFMAN, Rachel	Représentant la Communauté
LÉVEILLÉ, Éliane	Archiviste médicale
MALINSKI, Cécilia, BSc.N.	Infirmière bachelière
RAJAH, Natasha	Chercheuse
SCHMITZ, Norbert, Ph.D	Chercheur
THOMAS, Françoise	Représentant la communauté

A confirmé le renouvellement annuel du protocole de recherche intitulé:

Le développement d'une zone circonscrite d'études épidémiologiques en psychiatrie dans le sud-ouest de Montréal

Tel que proposé par: Dr Jean Caron

Ce protocole est approuvé pour une période d'une année

J. Bruno Debruille, M.D., Ph.D., Président
Comité d'éthique de la recherche de l'Hôpital Douglas
/mg

12/01/2010
REB #: 06/33

18 octobre 2011

Dr Jean Caron
Centre de recherche de l'Institut Douglas
Pavillon Perry, Bureau E-3112

Sujet: **Protocole 06/33** *Le développement d'une zone circonscrite d'études épidémiologiques en psychiatrie dans le sud-ouest de Montréal*
Amendement – Réponse aux questions du CÉR

Cher Dr Caron,

Nous accusons réception de votre réponse aux questions qui avaient été soulevées par le CÉR concernant la demande d'amendement du protocole cité en titre. Les examinateurs assignés et moi-même avons étudiés votre réponse et l'avons jugée satisfaisante.

À titre de Vice-président, j'accorde donc une approbation accélérée à ce protocole car votre réponse aux questions soulevées ainsi que les documents révisés sont satisfaisants et rencontrent les exigences du CÉR.

Merci de votre collaboration.

Émilie Campeau

pour :
Kenneth R. Bruce, Ph.D.
Vice-président
Comité d'éthique de la recherche
de l'Institut Douglas
/éc

C.c. Marthe Pelletier (copie électronique)

Appendix 3.2
Validation of public open space data sources

1 Preface

This appendix describes the procedure for validation of the public open space (POS) data sources used in this thesis. The POS polygon map layer was validated between December 2012 and April 2013 using ArcMap 10 (ESRI, Redlands, California) with reference to geographically matched cadastre and road network information from 2004, high-resolution background satellite imagery from 2007, and Google Maps (2013) Street View imagery available online at the time of validation. Remote validation methods using these tools are a valid, reliable and efficient alternative to direct (on-the-ground) observation of POS and other features of neighbourhood environments (Taylor et al., 2011, Edwards et al., 2013, Kelly et al., 2013).

Satellite imagery provides an aerial view of the spaces and their surrounds, while Google Street View provides omnidirectional street-level imagery from roads adjacent to the spaces. This allows virtual navigation of POS perimeters from a pedestrian viewpoint, providing an alternative perspective to assist in the identification of features such as buildings, fence lines, or 'corridor' entranceways linking POS to streets from which they are otherwise detached (Wilson and Kelly, 2011). Turning attention to one neighbourhood at a time, all POS polygons in the City of Montréal-DMTI Spatial layer were validated to ensure that they satisfied the definition of POS in this study and that their boundaries were accurately recorded, in accordance with the guidelines detailed below. During this process, the satellite imagery and Google Maps were visually scanned for spaces that could possibly fit the criteria of POS, but were not yet included in map layer. These spaces were then subjected to the same validation procedure. After validation, there were 252 POS identified in the ZEPSOM region (plus 1km).

2 Definition of public open space

For the purposes of this thesis, POS includes 'spaces within the urban environment that are readily and freely accessible to the wider community, regardless of size, design or physical features and are intended primarily for amenity or recreation purposes – whether active or passive' (adapted from Kellett, 2009). This definition includes, for example, parks, sports fields, playgrounds, public squares, and community gardens. It excludes divided road median strips, sidewalk nature strips and street greenery, cemeteries, vacant

house blocks, and islands in the St Lawrence River that are inaccessible by land-based vehicle or foot. In addition, semi-private open space, such as that in the vicinity of apartment buildings provided for the use of residents, was not classified as POS. These spaces are generally surrounded by residential buildings, or are fenced, and may therefore be inaccessible to the general public (non-residents). Similarly, school ovals and grounds were not classified as POS, because they often constitute private property that is inaccessible to the general public. Private and semi-private golf courses were not coded as POS due to the nature of their membership-based operation and potentially prohibitive costs (and restricted availability) for use by the general public. On the other hand, outdoor public swimming pools that lie within a parcel of POS were included in the POS polygon on the basis that entry costs are modest, and the availability of these facilities is not restricted based on membership or non-membership. Outdoor winter sporting facilities, such as skating rinks, were not specifically considered within the validation. This was due to a focus of the research on POS greenness, as well as the fact that many of these facilities are temporary installations that would typically be located in spaces already counted in the POS map layer (i.e. outdoor parks).

Making reference to the 2004 land cadastre, spaces defined as POS were required to have a land use code of either ‘vacant land’ (6B) or ‘built up land not subject to government subsidies’ (1B). The former was one of several ‘vacant land’ codes that appeared to be reserved solely for the classification of POS, while the latter can arise when some built transformation had been made to the land, such as conversion to a sporting field, the installation of a playground, or conversion to a public square as opposed to natural POS. Open spaces that carried land use codes such as railways (5A), plants or factories (5B), commercial (4B), or undeveloped land occupied for commercial purposes (4K), as well as those carrying any residential code, were not coded as POS.

3 POS boundaries

Boundaries of POS polygons were drawn to fit the perimeters of the spaces, within fence lines and excluding adjacent footpaths. While footpaths separating POS from the road were excluded from the polygon, footpaths and bike paths that were encompassed within a POS (e.g. that traversed the POS, or were further separated from the road by grass and/or trees) were included in the polygon. In addition, pedestrian ‘corridors’ that linked POS to surrounding streets from which they would otherwise be detached (e.g. a tree-lined

path running from the street, between two house blocks, to the POS) were included in the polygon.

All parcels of POS that exist on opposite sides of a road that is part of the city street network were split apart along the road and considered to be separate entities. This was not the case for access roads that traverse or exist within POS, which were considered to be a part of the POS. However, where the distance between two separate parcels of POS was 25 metres or less, the POS polygons were merged to create one large POS rather than two smaller POS. While road casements were still excluded from merged parks, after merging they were represented by one divided polygon rather than two (or more) distinct polygons.

A distance of 25 metres or less was selected as the merge criterion because it was considered to be close enough that residents would likely consider the parcels to be one POS, rather than two smaller POS; it allows for the separation of POS parcels by smaller roads that can be easily traversed in order to continue into the next parcel of POS. This approach to the treatment of POS parcels separated by roads has implications for measures of the number and size of POS within the neighbourhood, favouring larger sizes over greater numbers. This approach should not only represent more realistically the perceptions of POS by residents, but is also useful for urban planning purposes, as it reflects the apportionment of large areas of land in one location (even though, out of necessity due to street networks, these areas must be divided by roads) in contrast with the apportionment of smaller areas of land across various locations. In addition, it more accurately represents the accessibility of the furthest parcel of POS to the resident by travelling through POS; that is, despite the fact that the two parcels are divided by a road, the resident can easily reach the second parcel of POS by travelling through POS once they have entered the first parcel. To separate the two parcels may inaccurately convey that the furthest parcel is not part of POS that is easily accessible to the resident.

A linear POS that follows the St Lawrence River, the Lachine Canal, or the Canal de l'Aqueduc, on one side of the body of water and heading in one direction, was considered to be a single, long POS. This is despite the existence of small interruptions to the spaces, generally by roads and, on occasion, houses and other built structures. These interrupting elements, which in all cases represented a break in the POS of no more than 30 meters, were excluded from the POS such that the linear POS was represented by one divided polygon rather than several autonomous polygons. Although these interrupting elements do split apart the linear POS, bike and footpaths continue between the different parcels of linear POS, providing continuity between them. These linear parks provide many

kilometres of landscaped walking and bicycling trails and are an important recreational resource for the people of Montréal; as such, we sought to preserve the continuous nature of these parks rather than conceptualise them as a series of separate POS.

When it came to computing a summary of POS size for individual participants, the linear parks were dissected where they thinned to a width of less than 25 meters. Typically, this reflects a portion of the linear POS that would be considered to have little recreational value besides linking other portions of the trail. This approach was employed so that a linear park (which could approach to 100 hectares when left as a single area) did not unduly inflate POS size summary statistics for individuals with only one or two parks accessible within the LRA. Because these linear POS cut through most of the study region, intersection with LRA buffers was very common and reduced the discriminatory power in resulting size measures. For instance, there was concern that this would result in exposure misclassification where individuals were categorised as having access to very large POS even though this might comprise a number of smaller POS linked by a pathway along the canal.

Built features that would not reasonably be presumed to be used for the outdoor recreational purposes of the general public – such as car parks, indoor community centres and sporting complexes, and libraries – were excluded from POS polygons even where they were attached to or encompassed within POS. Where such a feature was adjacent to the POS, it was excluded entirely from the POS polygon boundary. Where the feature was encompassed by the POS, it was cut out of the area of the POS polygon.

Appendix 3.3
Approaches to defining the ‘residential area’

1 Preface

This appendix presents background information pertaining to the choice of egocentric road network buffers as a means of defining the local residential area (LRA) from which measures of POS are extracted and attributed to individuals in this thesis.

2 Predefined spatial units

One method of defining the LRA in order to measure residential exposures is to use pre-defined spatial units, such as statistical local areas, census tracts, or planning neighbourhoods (Oliver et al., 2007). Predefined area units are popular because they can provide quick access to existing information, often precluding the need for further data collection, and a simple means of linking numerous datasets from different sources to the same geographical frame (Diez Roux, 2001, Lebel et al., 2007, Green, 2012). These units are also advantageous for the development of urban planning policy, because they facilitate comparison of the distribution of POS within and between cities and the establishment of spatially quantifiable and measurable guidelines for entities that are meaningful to the delivery of services (Villanueva et al., 2015, Green, 2012). However, while these area units are useful at the macro level, there are several reasons why they may be unsuitable for investigating relationships between POS and health at the individual level. Of primary concern is the fact that these areas are often delineated more or less arbitrarily, lacking any conceptual underpinning or intrinsic meaning (Openshaw, 1996, Macintyre et al., 2002, Lupton, 2003), yet act as artificial 'containers' for the residents, resources and opportunities within them (Nicholls, 2001). This method ignores the true spatial distribution of resources and makes a generic assumption that what exists within a predefined area is equally – and exclusively – accessible to its residents. This assumption is particularly untenable for people living near the area limits, who are considered to have perfect access to resources at the opposite end of the zone but derive no spatial externalities from neighbouring zones. Measures of residential exposures may therefore suffer from differential levels of error depending on the specific location of individuals within the area unit, potentially introducing bias into the analysis (Oliver et al., 2007).

3 Egocentric buffers

Given shortcomings with the use of predefined area units, it has become increasingly common for researchers to use geocoded locational information (e.g. home address) to purposefully define a unique residential area for each individual. A continuous 'buffer' is established at a given distance (*D*) around each geocoded location and environmental exposures are measured for the area that falls within that buffer. Because this area is centred at the participant's specific residential location, it successfully captures those resources and opportunities that are proximal to the home, irrespective of their division across administrative boundaries. A buffer of size *D* is typically created using either a straight line or the road network to traverse this distance. To create a straight line (also known as Euclidian, circular, or radial) buffer, one simply extends a straight line from the geocoded location to establish a circular area of radius *D*. Although unique in their geographic location, circular buffers will be the same size for all participants. To create a road network buffer, on the other hand, one follows the road network in all possible directions from the geocoded location until *D* has been travelled. The end points of these paths are then connected to create the buffer.

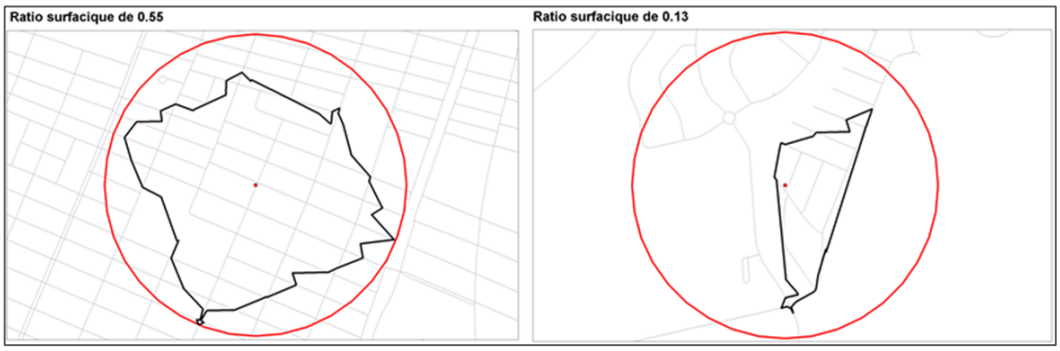


Figure 32: Circular (red) and road network (black) buffers within high and low density road networks

Road network buffers more accurately represent the accessibility of resources than do circular buffers, because the resident cannot travel 'as the crow flies' but must follow existing roadways and avoid barriers to travel (Nicholls, 2001, Oh and Jeong, 2007, Oliver et al., 2007). This is particularly pertinent where landmarks such as highways, railroads, rivers, industrial estates, or even cul-de-sacs, seriously impede access to resources that are otherwise 'nearby' (van Herzele and Wiedemann, 2003, Zhang et al., 2015) and may act as boundaries to the 'neighbourhood' as perceived by residents (Jenks and Dempsey, 2007).

As a result, road network buffers are generally smaller and more irregular in shape than circular buffers, with this effect intensified in areas with low levels of street connectivity (Nicholls, 2001, Frank et al., 2005). To illustrate, Figure 32 compares a circular buffer to a road network buffer of the same size, within high- and low-density road networks. Circular buffers have been shown to substantially overestimate the accessibility of POS when compared with road network buffers applied to the same data, and use of the latter has been recommended where possible (Nicholls, 2001, La Rosa, 2014, Oh and Jeong, 2007).

Appendix 3.4
Missing data and imputation strategy

1 Preface

This appendix presents a comprehensive discussion of the problem of missing data in epidemiological research, highlighting the need to explicitly investigate and account for missing data using principled methods. It describes the three basic processes that drive the occurrence of missing data, in order to guide the diagnosis and treatment of the missing data mechanism in this research. A missing data imputation strategy is then developed through the exploration of observed rates and correlates of (1) missing responses to items within multiple-item scales and (2) missing data on covariates and scale totals. These sources of missing data are treated separately using a two-stage imputation procedure. First, data missing from items within a multiple-item scale were substituted using person-mean imputation. Provided the participant had valid responses to at least 50% of the items on the scale, any missing responses were replaced with the participant's score across the other (complete) items. Any remaining missing data, i.e. missing data on covariates and on scale totals for which the participant did not respond to enough items to perform person-mean imputation, were handled using multiple imputation with 50 imputed datasets.

These strategies were only applied to data missing due to non-response at the item level (incomplete information collected from a participant within an occasion of measurement) and not due to attrition at the unit level (no information collected from a participant at one or more occasions of measurement). As outlined in Chapter 3 (Section 3.4), any participant who did not complete all three waves of ZEPSOM data collection was excluded from the participant pool.

2 The problem of missing data

Missing data are a ubiquitous problem in the health and social sciences. Lost information due to missing observations can lead to a loss of precision and statistical power and, more seriously, introduce bias in parameter estimation if not treated in a suitable manner (Dong and Peng, 2013, Molenberghs et al., 2015). The amount of missing data has a direct impact on precision, power and the quality of statistical inferences. Yet, generally speaking, it is the pattern of missing data that is most crucial, because this has the potential to induce bias and affect the generalisability of results (Tabachnick and Fidell, 2001). The properties of statistical methods may be strongly influenced by assumptions about the mechanism that led to missing values: some explanations for missing data will satisfy restrictive assumptions and have relatively benign implications for analysis, while

others are more complex and can potentially introduce bias into the estimation of statistical parameters (Fitzmaurice et al., 2012). It is therefore important to carefully investigate the sources or reasons for missingness in a given sample, in an attempt to diagnose the missing data mechanism.

2.1 Missing data mechanisms

The missing data mechanism can be thought of as a probability model for the distribution of missing responses, describing rates and patterns of missingness as well as any associations between missingness and the values of other variables. Typically, a hierarchy of three missing data mechanisms is defined with respect to the nature of the relationship between missingness and the values of variables that are observed, or would have been observed were the data not missing:

- Data missing completely at random (MCAR)
- Data missing at random (MAR)
- Data missing not at random (MNAR), i.e. non-ignorable non-response

The mechanisms reflect, respectively: a truly random process; a measured or predictable process; and an unmeasured or unpredictable process (Little, 2009). Accordingly, this classification is hierarchical in terms of both the stringency of assumptions about what drives missing data and the potential for those missing data to bias research findings. The following section briefly outlines criteria for diagnosing the missing data mechanism in a longitudinal context with respect to the probability of participant *i* missing a response at time *t* (R_{it}=1 if Y_{it} is missing or R_{it}=0 if Y_{it} is observed); the values of the variable with missingness that were observed for participant *i* at other time points ($Y_{i(t\neq t)}^{O}$); the value of the missing variable that would have been observed at time *t* if it had been collected ($Y_{i(t\neq t)}^{M}$); and the values of other observed covariates X_i in the dataset (note that the values $Y_{i(t\neq t)}^{O}$ and $Y_{i(t\neq t)}^{M}$ are henceforth referred to in shorthand as Y_i^{O} and Y_i^{M}). In reality, all three mechanisms may be operating at the same time in a given dataset, and the missing data mechanism can never be determined definitively without knowing the true values of the missing data ($Y_{i(t\neq t)}^{M}$) (Graham, 2009, Little, 2009). However, a thorough diagnostic investigation may assist the researcher to make a reasonable assumption about the missing data mechanism in order to minimise the impact of missing values on the generalisability of results.

2.1.1 Missing completely at random

Longitudinal data are missing completely at random (MCAR) when the probability of a missing response is unrelated to values in either the missing or observed components of responses to that variable or other variables (Fitzmaurice et al., 2012). In other words, missingness arises purely by chance and does not depend on the value of the variable recorded at other time points, or the value that would have been recorded if the data were not missing, nor is it dependent on observed covariates:

$$Pr(R_i|Y_iO, Y_iM, X_i) = Pr(R_i)$$

Under these conditions, the observed data may be regarded as a random sample of the complete data that would have been obtained if no values were missing. The marginal distribution of the outcome variable in the observed data (Y^O) does not differ from that of the missing data (Y^M). Moreover, for each subpopulation with a distinct missing data pattern, the distribution of the outcome variable coincides with that of the target population (provided the original sample was adequately representative) (Fitzmaurice et al., 2012). Classical missing data techniques such as listwise deletion (also known as complete-case analysis) assume that data are MCAR and can be used in this situation without any detriment to the validity of statistical inferences, besides a loss of power due to the reduced sample size.

2.1.2 Missing at random

When data are missing at random (MAR), the pattern of missing data is predictable from the observed values of other variables but is conditionally unrelated to the specific missing values that should have been obtained. In other words, given the data that was observed, missingness is independent of the unobserved value of the missing response. In a longitudinal research setting, MAR may occur if missingness on an outcome variable at T2 occurs stochastically within groups of participants with similar observed values of the variable at T1 (Y_i^O). Missingness may be also be dependent on other measured variables, such as covariates (X_i), such that an MAR mechanism is appropriate provided those covariates are included in the analysis:

$$Pr(R_i|Y_i^O, Y_i^M, X_i) = Pr(R_i|Y_i^O, X_i) .$$

In short, although missingness is not a truly random process under the MAR condition, accounting for known and measured influences on missingness renders the missing data functionally random (Little, 2009). The conditional nature of this random process means that, unlike under MCAR, the marginal distribution of the outcome differs between

participants with missing (Y^M) versus observed data (Y^O), and the observed distribution of the outcome (Y^O) no longer accords with the distribution in the target population (Y) (Fitzmaurice et al., 2012). The observed data cannot be considered a random subset of the complete data and will generate biased estimates of marginal population means, variances and covariances. However, the *conditional* distributions of the outcome variable *given* any measured influences on missingness do coincide between the observed data (Y^O), the missing data (Y^M), and the target population (Y). The missing data mechanism is therefore 'recoverable' in the sense that estimates from the observed data may be corrected for any systematic impact of lost information by accounting for the variables associated with missingness. Common principled missing data methods such as multiple imputation (MI) and full information maximum likelihood (FIML) assume that data are MAR and will produce valid statistical inferences as long as those variables are accounted for during the procedure (Little, 2009).

2.1.3 Missing not at random

Unlike the MAR mechanism, in which missingness is predictable from the values of other observed variables, MNAR reflects a systematic but *unmeasured* influence on the pattern of missing data (Little, 2009). These data points are missing for an unknown reason, which may be related to the unobserved value of the missing variable itself (Y_i^M) or some other unmeasured variable. MNAR is often referred to as 'non-ignorable' missingness because there is no information in the dataset that allows complete recovery of the missing data mechanism. However, proxies or correlates of the unknown reason for missingness might be available to aid in the recovery of some lost information. Even if the missing data mechanism is only partly recoverable, principled missing data methods that assume MAR (such as MI and FIML) will generate less biased results than classical approaches such as listwise deletion (which assumes MCAR) because, by conditioning at least to some extent on correlates of missingness, the imputed data will resemble the population more than unimputed data (Little, 2009). In many instances, these MAR approaches might be preferable to pursuing highly complex and sensitive methods of modelling MNAR missingness (Schafer and Olsen, 1998, Enders, 2010, Allison, 2009).

2.1.4 Diagnosing the missing data mechanism

Generally speaking, the missing data mechanism might be diagnosed as follows. First, Little's (1988) MCAR test may be performed to formally and simultaneously test the equality of the distribution of observed responses across distinct patterns of missingness for *p* variables. If the null hypothesis is rejected, this indicates that the overall pattern of

missing data is not consistent with a purely random missing data mechanism (not MCAR). In this instance, dichotomous indicators of missingness (0=observed, 1=missing) on each of the *p* variables may be constructed and tested individually using a series of t-tests or chi-square tests in order to determine whether the propensity for that variable to be missing is related to other observed variables in the dataset (Tabachnick and Fidell, 2001). If missingness is predictable based on the values of those other variables (Y_i^O or X_i), then MAR may be inferred (Tabachnick and Fidell, 2001). On the other hand, MNAR would be inferred if missingness was driven by unmeasured variables, such as the (unobserved) magnitude of the missing value (Y_i^M).

In reality, all three mechanisms may be operating at the same time within a given dataset, and the missing data mechanism can never be determined definitively without knowing the unobserved values of the missing data (Schafer and Olsen, 1998, Little, 2009, Allison, 2009). It is certainly not possible to test whether the data are MAR or MNAR; the best we can do is to test whether the data are 'observed at random' using the method described above (Newman, 2003). When missingness is unplanned, it is likely that there will be some departure from MAR (Schafer, 1999). In fact, Graham (2009, p.567) argues that:

> The best way to think of all missing data is as a continuum between MAR and MNAR. Because all missingness is MNAR (i.e., not purely MAR), then whether it is MNAR or not should never be the issue. Rather than focusing on whether the ML assumptions are violated, we should answer the question of whether the violation is big enough to matter to any practical extent.

3 Missing responses to items within multiple-item scales

This section describes the rate of missing responses to items within multiple-item scales, and the person-mean imputation strategy used to substitute plausible values for these missing data. Refusals to answer an item and "don't know" responses were both treated as missing responses with an unobserved value that did not necessarily reflect a lack of opinion, but might be driven at least partly by momentary task difficulty or satisficing (Krosnick et al., 2002). Evidence suggests that "don't know" responses may obscure valid and reliable opinions that would be offered with further encouragement (Gilljam and Granberg, 1993, Krosnick et al., 2002, Schaeffer and Presser, 2003).

Therefore, treating these responses as neutral opinions (rather than imputing based on the direction of opinion reported in neighbouring items) would risk attenuating the measurement of latent attitudes among participants who do hold a non-neutral attitude but experience difficulty or reluctance in expressing it initially. “Non-applicable” responses, which occurred in a limited number of instances of planned missingness, are discussed separately at the end of this section.

3.1 Prevalence of item missingness within scales

Table 45 (p.396) presents the prevalence of item missingness within scales used in this thesis. At any wave of data collection, the proportion of participants missing some item responses within a given scale ranged from approximately 1% (psychological distress; neighbouring behaviour; community participation) to 25% (life satisfaction). Most commonly, those participants were only missing one item within the scale. The proportion of participants missing two or more items exceeded 2% only once, for the social support scale (3.6%).

Elevated missingness on the life satisfaction scale was largely attributable to data missing on Item 7, which referred to satisfaction with “the people you live with” and was not administered to participants living alone. Discounting those responses, only 3-5% of participants were missing data on any life satisfaction item at T1-T3. Unlike missingness on other items, Item 7 data are missing systematically by design (MAR) whereby persons missing data are known a priori to differ from those with complete data. Special mention is therefore made to the treatment of missing data on this item in (Section 3.2.1).

Excluding this artefact of questionnaire design, missing data were generally evenly spread across the items within each scale, indicating an absence of particularly ‘problematic’ items that were driving non-response. One exception was the final item in the social cohesion scale, which exhibited significantly elevated rates of missingness compared with the remaining four items. Item five (“People in this neighbourhood do not share the same values”) accounted for 61% of missing responses within the scale. The scale as a whole requires participants to reflect on other-focused constructs, such as whether people in the neighbourhood get along with one another or can be trusted, and unsurprisingly suffered from a higher rate of missingness than scales of a similar length focusing on purely personal experiences or activities. The fifth item was particularly abstract in nature, and some participants clearly had difficulty articulating a response to this question.

Table 45: Proportion of scale items missing per participant at each time point (final sample, n=929)

Scale	Proportion of scale items missing	T1		T2		T3	
		n	(%)	n	(%)	n	(%)
Life satisfaction (17 items)	None	698	(75.1)	693	(74.6)	686	(73.8)
	1 item	212	(22.8)	228	(24.5)	235	(25.3)
	2 items	15	(1.6)	8	(0.9)	6	(0.6)
	≥3 items	4	(0.4)	0	(0.0)	2	(0.2)
Psychological distress (10 items)	None	917	(98.7)	919	(98.9)	924	(99.5)
	1 item	5	(0.5)	9	(1.0)	3	(0.3)
	2 items	2	(0.2)	1	(0.1)	0	(0.0)
	3 items	0	(0.0)	0	(0.0)	0	(0.0)
	4 items	0	(0.0)	0	(0.0)	1	(0.1)
	5 items	0	(0.0)	0	(0.0)	0	(0.0)
	≥6 items	5	(0.5)	0	(0.0)	1	(0.1)
Social cohesion (5 items)	None	877	(94.4)	-	-	-	-
	1 item	37	(4.0)	-	-	-	-
	2 items	10	(1.1)	-	-	-	-
	≥3 items	5	(0.5)	-	-	-	-
Neighbouring behaviour (5 items)	None	917	(98.7)	-	-	-	-
	1 item	10	(1.1)	-	-	-	-
	2 items	1	(0.1)	-	-	-	-
	≥3 items	1	(0.1)	-	-	-	-
Community participation (5 items)	None	925	(99.6)	-	-	-	-
	1 item	4	(0.4)	-	-	-	-
	≥ 2 items	0	(0.0)	-	-	-	-
Social support (24 items)	None	844	(90.9)	-	-	-	-
	1 item	52	(5.6)	-	-	-	-
	2 items	14	(1.5)	-	-	-	-
	3 items	12	(1.3)	-	-	-	-
	4 items	1	(0.1)	-	-	-	-
	5 items	2	(0.2)	-	-	-	-
	≥6 items	4	(0.4)	-	-	-	-
Stressful life events (22 items)	None	888	(95.6)	895	(96.3)	912	(98.2)
	1 item	34	(3.7)	24	(2.6)	15	(1.6)
	2 items	2	(0.2)	10	(1.1)	0	(0.0)
	≥3 items	5	(0.5)	0	(0.0)	2	(0.2)

a. *This scale was not administered to participants if, in the preceding question, they failed to nominate the greatest source of stress in their daily life (e.g. stated 'nothing' or 'don't know'). This was responsible for >99% of missing responses.*

3.2 Person-mean imputation of missing item responses

This section outlines the treatment of missing item responses in this study. The approach detailed below was selected with consideration to the low rates of missingness observed across all scales, both in terms of the number of participants missing some item(s) and the low numbers of items missing per participant, and the generally even spread of missingness across items within each scale. This combination of factors means that missing item responses are likely to have a relatively benign impact on statistical inference if treated in a reasonably principled manner (Tabachnick and Fidell, 2001, Schafer and Graham, 2002).

In order to preserve sample size and statistical power, missing responses to survey items within a multiple-item scale were imputed cross-sectionally using information from the participant's non-missing item responses. Specifically, on the condition that a participant had provided valid responses to at least 50% of the items in a scale, a person-mean imputation technique was implemented to substitute missing item values on the basis of the participant's mean score across other items in the scale (the 'person mean') (Hawthorne and Elliott, 2005). If the participant responded to fewer than 50% of the items in a scale, no imputation was made, and their total score was coded as missing. For scales comprising ordinal response variables – including life satisfaction, psychological distress, social cohesion, neighbouring behaviour, social support, and coping – this imputation technique simply substitutes missing values with the participant's mean score across items with valid responses. In the case of scales comprising dichotomous response variables – i.e. community participation – the participant's mean score across non-missing items is adopted as the probability parameter of the Bernoulli distribution, from which random draws are taken to replace missing values (Sijtsma and Van der Ark, 2003). In either case, total scores are calculated by summing across original (non-missing) item responses and imputed values (substitutes for missing responses).

Person-mean imputation assumes a close correlation between a participant's score on any given item in the scale, and their scores on the remaining items. Accordingly, this technique is a reasonable choice for imputing items within scales that capture a single, well-defined domain and exhibit high levels of internal consistency (say, $\alpha > 0.70$) (Roth et al., 1999, Schafer and Graham, 2002, Fox‐Wasylyshyn and El‐Masri, 2005, Graham, 2009). In addition, it is desirable that a high proportion of items within the scale are available (not missing) to form the imputed scale total, and never fewer than half the variables (Graham, 2009). Although two of the scales in this research were

multidimensional in nature (life satisfaction and social support), adequate consistency with a single domain sampling model was supported by the similarity of item-total correlations for the variables within each scale (Graham, 2009) and the prior identification of second order factors representing 'global life satisfaction' and 'global social support' (Cutrona and Russell, 1987, Caron, 1996, Caron et al., 1997). Given the acceptable levels of internal consistency observed for all scales used in this research, and the low rates of item missingness, a person-mean approach to imputing missing data within scales was justified.

Under these conditions, retaining and using information contained within participants' responses to non-missing items allows the informed estimation of missing values and saves a great deal of data that would be discarded under listwise deletion (Roth et al., 1999). Additionally, unlike an item-mean imputation approach in which missing item values are replaced with the sample mean, the person-mean technique acknowledges differences between participants and is less liable to artificially deflate the measure's variability or attenuate its covariance with other variables (Downey and King, 1998, Fox‐Wasylyshyn and El‐Masri, 2005, Bono et al., 2007). Previous studies have shown that person-mean imputation can adequately replicate true scale means, standard deviations, and coefficient alphas (Downey and King, 1998); t-scores for the comparison of a pertinent variable between groups differing according to some other behaviour (Hawthorne and Elliott, 2005); and cross-sectional correlation and regression coefficients (Roth et al., 1999). These studies suggest that the technique is very robust if 20% of respondents are missing less than 20% of the items within a scale (Downey and King, 1998) but could still perform well when within-scale item missingness reaches 30-50% (Roth et al., 1999, Hawthorne and Elliott, 2005). Roth et al.'s (1999) findings also held across scales of varying length and with varying degrees of inter-item correlations. The authors found that the technique mostly underestimated correlations between the independent and dependent variables, but the level of bias was minute for correlation coefficients and nearly imperceptible for regression coefficients. Finally, equivalent results were obtained for both random (MCAR) and systematic (MAR) patterns of missing data (Roth et al., 1999).

One drawback of single imputation techniques such as the person-mean imputation is that they do not adequately account for the uncertainty inherent in the estimation of replacement values for missing data (Schafer and Graham, 2002) and so standard errors may be too small (Sijtsma and Van der Ark, 2003, Little et al., 2014). However, person-mean imputation has been advocated for its computational simplicity (Hawthorne and Elliott, 2005) and is a reasonable approach to take here given the limited incidence of item

missingness and the fairly even spread of missing values across items (Schafer and Graham, 2002).

3.2.1 Person-mean imputation of items missing by design

As mentioned in Section 3.1 of this appendix, item 7 of the life satisfaction scale (referring to satisfaction with 'the people you live with') was not administered to participants living alone and accounted for 74-85% of missing data on the scale at T1-T3. These data are missing systematically by design (MAR), whereby participants with missing data are known to differ from those with complete data. Essentially, this item was not applicable to some participants and it made no sense to ask them this question. Implementing person-mean imputation in this instance is akin to calibrating the length of the scale for participants who live alone (16 items) to match that for participants who do not (17 items). As mentioned previously, person-mean imputation is fairly robust to patterns of MAR missingness (Roth et al., 1999, Fox‐Wasylyshyn and El‐Masri, 2005). By using the participant's other item scores to generate an imputed value, it implicitly conditions upon the cause of missingness and will reproduce systematic differences in life satisfaction that might exist between people who do or do not live with others. The approach outlined above is therefore considered suitable for handling missing data on this item and was not amended for the life satisfaction scale.

4 Missing scale totals and covariates

This section describes the rate of missing data on scale totals and covariates following the imputation of missing item responses described in Section 3. It then investigates whether missingness on scale totals and covariates (with more than 1% missing data) is related to other observed variables in the dataset, in an attempt to diagnose the missing data mechanism and guide the selection of an appropriate method of treating these missing data in later analyses. Based on evidence that the data are not MCAR, and that missingness is at least partially predictable from other variables in the analysis, multiple imputation was chosen as a defensible method for handling these missing values. This section ends with a description of the multiple imputation procedure implemented in this thesis, incorporating discussion of its underlying assumptions and relevant considerations in the choice of the imputation model and the number of imputed datasets.

4.1 Prevalence of missingness on scale totals and covariates

Table 46 presents rates of missingness on scale totals and covariates following person-mean imputation of missing scale items described in Section 3.2. Variables are classified as time-invariant covariates, time-varying covariates, or scale totals, and ordered under these headings by the proportion of participants missing data at any wave of data collection. Only two variables were missing greater than 1% of responses at any wave of data collection (indicated in bold). These were household income (7.4-12.8 % missing at T1-T3) and coping (12.7% missing at T1). Overall, one-fifth of participants failed to report their household income at one or more waves of the study (19.8%). However, the vast majority responded to this question at least once (98.2%) and many did so twice (92.9%) meaning that the coverage of income estimates across the life of the study was reasonable despite conspicuous levels of missingness within the distinct waves of data collection.

Table 46: Proportion of participants missing data on scale totals and covariates at each time point following person-mean imputation of missing item responses (final sample, n=929)

	Scale / Covariate	T1		T2		T3		Any wave	
		n	(%)	n	(%)	n	(%)	n	(%)
Time invariant covariates	Duration of residence (at T1)	0	(0.0)	-	-	-	-	0	(0.0)
	Sex	0	(0.0)	-	-	-	-	0	(0.0)
	Age	0	(0.0)	-	-	-	-	0	(0.0)
	Highest level of education	0	(0.0)	-	-	-	-	0	(0.0)
	Area SES	0	(0.0)	-	-	-	-	0	(0.0)
Time varying covariates	Household income	**79**	**(8.5)**	**119**	**(12.8)**	**69**	**(7.4)**	**184**	**(19.8)**
	Worked in past 12 months	5	(0.5)	1	(0.1)	1	(0.1)	7	(0.8)
	Marital status	1	(0.1)	2	(0.2)	0	(0.0)	3	(0.3)
	Physical health	0	(0.0)	3	(0.3)	0	(0.0)	3	(0.3)
Scale totals[a]	Coping	**118**	**(12.7)**	**-**	**-**	**-**	**-**	**118**	**(12.7)**
	Stressful Life Events	5	(0.5)	0	(0.0)	2	(0.2)	7	(0.8)
	Psychological	5	(0.5)	0	(0.0)	1	(0.1)	6	(0.6)
	Social Cohesion	5	(0.5)	-	-	-	-	5	(0.5)
	Neighbouring Behaviour	1	(0.1)	-	-	-	-	1	(0.1)
	Life Satisfaction	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
	Community Participation	0	(0.0)	-	-	-	-	0	(0.0)
	Social Support	0	(0.0)	-	-	-	-	0	(0.0)

a. *Reflects the number of participants still missing a scale total following person-mean imputation of missing items; i.e. those who were missing >50% of the items within the scale.*

4.2 Missing data mechanisms: scale totals and covariates

Little's (1988) MCAR test was performed on all scale totals and covariates listed in Table 46 to test the null hypothesis that the data were missing completely at random. The null hypothesis was rejected (chi square=1001.53, DF=600, sig=0.000) indicating that a MCAR mechanism is unlikely to apply. This is a common occurrence in empirical research with unplanned missingness (Allison, 2009). The following sections assess the plausibility of a MAR mechanism for all variables with >1% missingness at any of wave of data collection (coping and household income).

4.2.1 Missing data mechanism: coping

As described in Chapter 3 (Section 6.4.2) the vast majority (93%) of missingness on the coping scale was the direct result of a questionnaire screener that excluded participants from responding to the item if they had previously selected "nothing" as the biggest contributor to feelings of stress in their everyday life (or "did not know"). This selection design is a classic example of planned MAR missingness, since the probability of response to the coping scale does not differ within levels of response to the selection variable (0=no source of stress, 1=some source of stress) (Enders, 2010). Essentially, the selection mechanism is the missing data mechanism such that the cause of missing data is known and observed. By definition, data missing as a result of this skip pattern are MAR so long as an indicator of the participant's response to the screening variable is included the model.

4.2.2 Missing data mechanism: household income

In relation to household income, the cause of missingness is unknown and an automatic assumption that the data are MAR is not justified. In fact, one cannot even empirically test the validity of a MAR mechanism (against the alternative of MNAR) without knowing the values of the unobserved data. However, relationships between missingness and other observed variables may be examined in an attempt to discern the extent to which the missing data mechanism is potentially recoverable and therefore ignorable (Little, 2009).

To test whether missingness on household income could be predicted by other variables in the analysis, binary indicators were created to identify whether income was observed or missing for each participant at a given time point. Generalised estimating equation (GEE) models adjusted for the clustering of individuals (n=929) within census tracts (n=74) were then performed to determine whether individuals with missing versus complete income data at each timepoint differed in relation to a range of sociodemographic variables. Age was tested using linear models, binary outcomes with logistic models, and duration of

residence and household income were tested using poisson models. Full details pertaining to the measures of these variables was presented in Chapter 3 (Section 6.6).

Results are presented in Table 47 (p.403). Given the large sample size (n=929), mean values for binary (yes/no) predictors are interpreted as the proportion of participants that met the relevant criterion (Rosner, 2006). Bolded cells indicate statistically significant differences between participants with missing and complete data (alpha=0.05), while cells shaded in grey indicate that the test was not applicable (e.g. because the predictor is time-invariant). Generally speaking, participants missing data on measures of household income tended to be younger, female, less educated and less likely to be employed. These associations were broadly consistent at all time points, although they did vary in magnitude and statistical significance. Commensurate with these findings, there was also some evidence that participants missing a value for household income at one time point would report lower incomes than those with complete data at other waves of the study. For the sake of brevity, I do not venture into a discussion of specific details pertaining to associations with income missingness at each time point.

4.2.2.1 Plausibility of an MAR missing data mechanism

The relationships presented in Table 47 are broadly consistent with the notion that lower income participants were less likely to report their income. Participants missing data tended to be younger, less educated, and less likely to have worked in the past twelve months. There was also indicative evidence that the incomes reported by these participants at other time points were lower than those of participants with complete data.

These findings give reason to believe that the data may be MNAR to some extent. In reality, all unplanned missingness is likely to fall on a continuum between these assumptions. Our concern should therefore be how serious the potential is for a violation of MAR to influence statistical inferences from this study (Schafer and Graham, 2002, Graham, 2009). The analyses presented in Table 47 indicate that missingness on household income is associated with a reasonable number of variables contained within the dataset, both at concurrent and adjacent time periods. These variables provide information about the reasons data are missing, as well as some indication of their likely 'true' values. This lends confidence to our ability to approximate the missing data mechanism reasonably well, reducing the residual dependence of missingness on values of the missing variable itself. This, in turn, increases the relative plausibility of an MAR assumption and will help to correct some of the bias introduced by nonresponse (Allison, 2009, Little et al., 2014).

Table 47: Results of Generalised Estimating Equation (GEE) models (adjusted for the clustering of individuals within census tracts) for testing associations between household income missingness and sociodemographic factors. Final sample (n=929)

	Test variable (# binary)	Income missing?	T1 mean	p-val	T2 mean	p-val	T3 mean	p-val
T1 Household Income (Missing n=79)	**Age (years at T1)**	**Observed**	**46.3**	**.003**				
		Missing	**39.6**					
	Male gender#	Observed	38%	.105				
		Missing	27%					
	College diploma (DCS) or higher education#	**Observed**	**59%**	**.040**				
		Missing	**48%**					
	Duration of residence (years, at T1)	Observed	9.9	.537				
		Missing	10.8					
	Household income (Canadian dollars)	**Observed**			55,494	.092	**59,994**	**.005**
		Missing			50,011		**44,981**	
	Worked in past 12 months#	**Observed**	**77%**	**.014**	73%	.078	73%	.608
		Missing	**64%**		66%		71%	
	Married or in common law relationship#	Observed	52%	.280	52%	.200	51%	.408
		Missing	39%		40%		38%	
T2 Household Income (Missing n=119)	**Age (years at T1)**	**Observed**	**46.4**	**.040**				
		Missing	**41.7**					
	Male gender#	Observed	38%	.138				
		Missing	32%					
	College diploma (DCS) or higher education#	Observed	59%	.267				
		Missing	50%					
	Duration of residence (years, at T1)	**Observed**	**9.8**	**.014**				
		Missing	**11.5**					
	Household income (Canadian dollars)	Observed	54,995	.896			59,994	.675
		Missing	50,011				50.011	
	Worked in past 12 months#	Observed	77%	.180	73%	.194	73%	.615
		Missing	69%		67%		73%	
	Married or in common law relationship#	Observed	52%	.277	52%	.085	52%	.378
		Missing	41%		39%		40%	
T3 Household Income (Missing n=69)	Age (years at T1)	Observed	45.9	.719				
		Missing	44.3					
	Male gender[B]	Observed	37%	.912				
		Missing	39%					
	College diploma (DCS) or higher education#	Observed	59%	.218				
		Missing	45%					
	Duration of residence (years at T1)	**Observed**	**9.8**	**.006**				
		Missing	**12.6**					
	Household income (Canadian dollars)	**Observed**	**54,995**	**.003**	**54,995**	**.041**		
		Missing	**48,491**		**59,994**			
	Worked in past 12 months#	**Observed**	**77%**	**.019**	73%	.054	**74%**	**.002**
		Missing	**65%**		62%		**62%**	
	Married or in common law relationship#	Observed	51%	.226	52%	.195	51%	.938
		Missing	39%		39%		43%	

These findings give reason to believe that the data may be MNAR to some extent. As mentioned previously, there is no way to empirically distinguish between MAR and MNAR mechanisms without knowing the values of the missing data and, in reality, all unplanned missing data is likely to fall on a continuum between these assumptions. Our concern should therefore be how serious the potential is for a violation of MAR to influence statistical inferences from this study (Schafer and Graham, 2002, Graham, 2009). Preceding sections have illustrated how missingness on household income was associated with a considerable number of variables contained within the dataset, both at concurrent and adjacent time periods (Table 47). These variables provide information about the reasons why data are missing, as well as some indication of the likely values of the missing data. This lends confidence to our ability to approximate the missing data mechanism reasonably well and thereby reduce the residual dependence of missingness on values of the missing variable itself. This, in turn, increases the relative plausibility of an MAR assumption and will help to correct some of the bias introduced by nonresponse (Allison, 2009, Little et al., 2014).

4.3 Multiple imputation of scale totals and covariates

Missing scale totals (those that were not imputed using person-mean substitution because fewer than 50% of the items were answered) and missing values on covariates were treated using Multiple Imputation (MI). MI is a three-step technique in which (1) *m* complete datasets are simulated by replacing each missing value with *m* plausible versions, (2) the analysis model is fit separately to each of the *m* imputed datasets, and (3) model estimates are amalgamated by averaging across the *m* imputed datasets, with an adjustment to standard errors to account for additional variability introduced by the random imputations (Molenberghs et al., 2015). Plausible values for missing data are predicted based on the participant's own observed responses to other variables, with added random variability to reflect uncertainty inherent in both (a) the estimation of a plausible value from a given conditional distribution, and (b) uncertainty about the true parameters of that data generating distribution (Schafer and Graham, 2002, Asparouhov and Muthén, 2010c). Strict assumptions of MCAR missingness required by classical missing data methods are relaxed to provide valid statistical inference under the MAR condition (Molenberghs et al., 2015). In fact, provided that correlates of MAR missingness are included in the imputation model, MI yields unbiased estimates of both parameters and their standard errors (Little et al., 2014). This is a state of the art method of handling missing data that is highly recommended by research methodologists (Schafer and Graham, 2002, Little et al., 2014).

4.3.1.1 Multiple imputation procedure

50 imputed datasets (m=50) were created using parametric Markov Chain Monte Carlo (MCMC) techniques in M*plus* 7.2 (Muthén and Muthén, 2012) under a saturated variance-covariance model (Asparouhov and Muthén, 2010c). In this model, all variables are treated as dependent variables and an attempt is made to estimate a covariance matrix and mean vector that resemble the population from which the original sample was drawn (Little, 2009). Plausible values are thus substituted for missing data in a manner that complies with the relationships identified among the observed data and supports the estimation of these arrays. Parameter estimates and standard errors from the 50 imputed datasets were combined using Rubin's (1987) rules. Overall parameter estimates were computed as the average of the parameter estimates obtained from the 50 sets of analyses. Standard errors were computed as the square root of a modified sum of the average within-imputation variance in parameter estimates (sampling variability) and the between-imputation variance in parameter estimates (variability due to the stochastic nature of the imputed missing values) over the 50 sets of analyses. The following sections briefly address the statistical assumptions of this method and describe more fully the imputation model used to generate imputed values.

4.3.2 Addressing the key assumptions of multiple imputation

The MI procedure implemented in this thesis makes two key assumptions pertaining to the mechanism that led to missing data and the shape of the joint distribution of the data being analysed. First, as already mentioned, it assumes that data are MAR (Schafer and Olsen, 1998, Little, 2009). Second, it assumes that all of the variables in the imputation model follow a joint multivariate normal distribution (Schafer and Olsen, 1998). The first of these assumptions was addressed in Section 4.2.2 of this appendix, which concluded that it is reasonable to assume that a sizeable amount of the missing data mechanism is recoverable and the MAR assumption is approximated reasonably well. In any case, to forgo the assumption of MAR missingness only introduces the need for a different set of assumptions (the researcher must propose a formal probability model for missingness) that are equally unverifiable and potentially far more tenuous (Schafer and Olsen, 1998, Enders, 2010). MNAR methods are not advocated in the absence of significant expertise in the area, particularly as results can be highly sensitive to the choice of the missing data model (Allison, 2009). In fact, some authors argue that a well-executed MAR analysis (e.g. MI with a rich imputation model containing many correlates of missingness) may be

preferable to MNAR analysis even when the MAR assumption seems unrealistic (Schafer and Olsen, 1998, Enders, 2010).

The second assumption of MI, which is "patently wrong for almost all real applications" (Molenberghs et al., 2015, p.256) is that all of the variables in the imputation model follow a joint multivariate normal distribution. In theory, this assumption could be problematic in analyses with categorical or highly skewed variables and may motivate procedural solutions to minimise its effect on end results. For instance, it is well known that if the sample size is moderately large, and the probability of an event is not too extreme (neither near 0 or 1), the binomial distribution tends to be symmetric and well approximated by a normal distribution (Rosner, 2006). Under these conditions, binary variables may be used directly in normal-model MI, while categorical variables with *p* levels need simply be converted into a series of *p-1* binary variables (Graham, 2009). Right-skewed variables, on the other hand, may be normalised for the purposes of imputation by transforming them to a logarithmic scale, then back transformed for the analysis if desired (Schafer and Graham, 2002, Lee and Carlin, 2010).

In practice, multivariate normality is rarely realistic and yet the MI algorithm may be fairly robust to departures from this assumption if the amount of missing information is not large (Schafer, 1997, Graham and Schafer, 1999). Lee and Carlin (2010) noted that estimation of regression parameters using MI was not sensitive to the presence of binary and ordinal variables. They did caution, however, against ignoring skewness in continuous covariates; doing so resulted in considerable bias and poor coverage for the corresponding regression parameter, while normalising the variable dramatically improved the accuracy of estimation.

4.3.3 The imputation model

The aim of the multiple imputation model is to produce *m* imputed datasets that contain realistic predictions (on average) for missing values and introduce a reasonable amount of between-imputation variability to reflect the uncertainty inherent in making those predictions (Schafer, 1999). The extent to which the model achieves this may depend on the variables included, their relationship with the missing data mechanism or the missing values themselves, the number of imputed datasets, and the consistency between the imputation model and the substantive analytic model for which imputed data are used (Schafer and Graham, 2002).

At the very least, all variables in the analysis model – both dependent and independent – must be included in the imputation model (Graham, 2009). Omitting a variable effectively assumes that this variable is uncorrelated with all others contained in the imputation model. Imputed values and, in turn, estimates from the analysis model will reproduce this assumption by suppressing correlations between the omitted and imputed variables towards zero (Schafer, 1999, Moons et al., 2006). In practice, it is often beneficial to specify an imputation model that is even more general than the substantive analysis model (Schafer 1999). The imputation model need not be parsimonious, since its sole purpose is to preserve the joint distribution of variables in the face of missing data (Schafer and Graham, 2002). The degree to which MI is able to recover parameter estimates that would have been obtained with complete data depends on the strength of associations between the missing data mechanism and variables included in the imputation model (Little, 2009). Incorporating into the imputation model any variables that predict missingness or are correlated with the variables missing data will improve the prediction of missing values, and therefore generalisations from the study, regardless of whether those variables are included in the analysis model (Graham, 2009). Importantly, there appears to be no downside to accidentally including covariates that are unrelated to missingness in the hope of better satisfying the MAR assumption (Collins et al., 2001).

For these reasons, the imputation model in this research incorporated a wide range of variables that were: related to missingness on scale totals and covariates (as described in Section 4.2); correlated with values of the variables missing data; or intended for use in any of the substantive analytic models in this thesis. These variables are listed in Table 48 (p.408). Most were also employed in the analytic models for this research and are therefore described within Chapter 3 (Section 6). One exception was the selection variable used to exclude participants from responding to the coping scale (described in Section 6.4.2), which was not used in any analyses but was included in the imputation model to satisfy the MAR assumption for missing coping data (see Section 4.2.1). In addition, two further auxiliary variables were added to the imputation model because they displayed moderate correlations with values of household income. These were self-reported time-varying measures of perceived neighbourhood social disorder[109] (correlations ranging -0.22 to -0.24 from T1 to T3) and whether the participant had access to a vehicle at the time of the interview (yes or no, correlations ranging 0.43 to 0.50 from T1 to T3).

[109] Neighborhood Disorder Scale {Nario-Redmond, 2000 #95) includes nine items collecting self-reports of neighbourhood problems such as garbage on the sidewalks, abandoned vehicles, graffiti, and drug dealers.

As mentioned in Chapter 3 (Section 6.6.1) household income variables were transformed to the natural logarithm of their original values in order to better satisfy the multivariate normality assumption (Lee and Carlin, 2010). Categorical variables with *p* levels were entered as a series of *p-1* binary variables (Graham, 2009). All variables were entered into the imputation model at their time-varying values (T1to T3) with the exception of the objectively derived area level measures (Area SES and population density) which were measured at T1 only. A large number of imputations (*m*=50) was performed in order to minimise the impact of added between-imputation variability on statistical power (Graham et al., 2007, Bodner, 2008).

Table 48: Variables included in the multiple imputation model

Variable	Continuous or categorical	Variable	Continuous or categorical
Life Satisfaction	*Continuous* Scale total	Natural logarithm of household income	*Continuous* Log ($CAD)
Psychological distress	*Continuous* Scale total	Age	*Categorical* 15 to 35 36 to 50 (ref) 51 and over
Social cohesion	*Continuous* Scale total	Sex	*Categorical* Male Female (ref)
Neighbouring behaviour	*Continuous* Scale total	Highest level of education	*Categorical* Diploma of college studies (DCS) or higher[a]
Community participation	*Continuous* Scale total	Marital status	*Categorical* Married, common law Divorced, separated, widowed Single (ref)
Social support	*Continuous* Scale total	Population density	*Continuous*
Coping	*Continuous* Scale total	Area Socioeconomic Deprivation	*Continuous*
Stressful life events	*Continuous* (weighted scale total)	Duration of residence at baseline	*Categorical* 1 to 5 years 6 to 15 years (ref) Greater than 15 years
Perceived neighbourhood disorder	*Continuous* Scale total	Worked in past 12 months	*Categorical* Yes No (ref)
Coping screener (main source of stress not cited)	*Categorical* Screened out Not screened out (ref)	Access to a vehicle	*Categorical* Yes No (ref)
		Self-rated physical health	*Continuous*

Appendix 4.1
GMM and LGCM with individually-varying versus fixed time scores

1 Preface

This appendix compares the optimal unconditional growth mixture models (GMM) and latent growth curve models (LGCM) estimated using individually-varying times of observation (as reported in the body of the paper) to those estimated using fixed (discrete) timing scores. Individually-varying timing scores were entered for each participant as the number of years since participant *i* first interviewed. Thus, T1 interviews were coded as t=0 for all participants, while T2 and T3 interviews were assigned individually-varying timing scores corresponding to the amount of time that had elapsed since participant *i* completed the T1 interview. By contrast, fixed timing scores were specified universally at the sample average number of years between interviews, i.e. t=0 for the T1 interview, t=1.79 for the T2 interview, and t=4.18 for the T3 interview. In both instances, growth function intercepts reflect mental health status at the first measurement occasion and slopes reflect the average change in the outcome per year. This appendix evaluates whether the unconditional models estimated using individually-varying time scores are adequately replicated using fixed timing scores.

2 Psychological distress

Table 49 presents parameter estimates from the final unconditional K10 GMM and the K10 LGCM with individually-varying (top panel) versus fixed (bottom panel) timing scores. There was essentially no difference in parameter estimates between these models, with one minor exception. In the K10 GMM with individually-varying timing scores, the mean slope in the low-stable class was significantly different from zero, but very small in magnitude ($\alpha_{\eta 1}$=-0.01, p<0.01). In the model with fixed timing scores, the mean slope for this class was the same magnitude but no longer statistically significant due to a somewhat enlarged standard error around the estimate ($\alpha_{\eta 1}$=-0.01, p=0.92). This inconsistency is not greatly concerning considering that the slope estimate in both cases is so close to zero that, substantively, it would be interpreted as a pattern of no change despite its statistical significance in the initial model. Besides this discrepancy, the estimates of class sizes, class-specific growth trajectory means and variances, and residual outcome variances were essentially unchanged after fixing the timing scores. In the GMM, entropy remained stable (varying *t*=0.55; fixed *t*=0.54) and BIC actually improved (varying *t*=16271; fixed *t*=16262) after fixing the timing scores.

Table 49: Parameter estimates from final unconditional GMM and LGCM of psychological distress with fixed versus individually-varying timing scores

VARYING TIMING SCORES	GMM			LGCM
Parameter	Low-stable (LS, 46%) Est. (SE)	Low-ascending (LA, 27%) Est. (SE)	High-declining (HD, 27%) Est. (SE)	Est. (SE)
Intercept mean ($\alpha_{\eta 0}$)	3.92 (0.23)**	5.87 (0.44)**	14.7 (0.60)**	7.32 (0.23)**
Slope mean ($\alpha_{\eta 1}$)	-0.01 (0.01)**	1.00 (0.21)**	-0.88 (0.13)**	0.02 (0.06)
Intercept variance ($\Psi_{\eta 0, \eta 0}$)	3.72 (0.62)**	3.72 (0.62)**	23.3 (4.24)**	25.0 (2.43)**
Slope variance ($\Psi_{\eta 1, \eta 1}$)	0.00 (NA)	1.58 (0.16)**	1.58 (0.16)**	0.52 (0.26)*
Growth factor covariance ($\Psi_{\eta 0, \eta 1}$)	0.00 (NA)	–	–	-0.68 (0.51)
T1 error variance ($\Theta_{1,1}$)	6.44 (0.88)**	–	–	14.4 (2.13)**
T2 error variance ($\Theta_{2,2}$)	18.8 (1.50)**	–	–	15.1 (1.52)**
T3 error variance ($\Theta_{3,3}$)	3.04 (0.91)**	–	–	10.8 (3.16)**
BIC = 16271, entropy = 0.55				
FIXED TIMING SCORES	GMM			LGCM
Parameter	Low-stable (LS, 45%) Est. (SE)	Low-ascending (LA, 27%) Est. (SE)	High-declining (HD, 27%) Est. (SE)	Est. (SE)
Intercept mean ($\alpha_{\eta 0}$)	3.92 (0.23)**	5.81 (0.45)**	14.6 (0.62)**	7.31 (0.23)**
Slope mean ($\alpha_{\eta 1}$)	-0.01 (0.05)	0.97 (0.26)**	-0.89 (0.13)**	0.03 (0.06)
Intercept variance ($\Psi_{\eta 0, \eta 0}$)	3.90 (0.65)**	3.90 (0.65)**	23.8 (4.59)**	25.1 (2.64)**
Slope variance ($\Psi_{\eta 1, \eta 1}$)	0.00 (NA)	1.65 (0.18)**	1.65 (0.18)**	0.61 (0.29)*
Growth factor covariance ($\Psi_{\eta 0, \eta 1}$)	0.00 (NA)	–	–	-0.78 (0.58)
T1 error variance ($\Theta_{1,1}$)	6.25 (0.92)**	–	–	13.9 (2.38)**
T2 error variance ($\Theta_{2,2}$)	18.7 (1.50)**	–	–	15.2 (1.57)**
T3 error variance ($\Theta_{3,3}$)	2.76 (1.10)**	–	–	9.93 (3.30)**
BIC = 16262, entropy = 0.54				

*Note. GMM = growth mixture model. LGCM = latent growth curve model. BIC = Bayesian information criterion. Trajectory classes are named according to mean intercept and slope characteristics: LS=low-stable; LA=low-ascending; HD=high-declining. Intercepts reflect K10 score at first interview; slopes reflect average change in K10 scores per year. Class proportions (%) based on estimated posterior probabilities. (NA) identifies a fixed parameter, '–' identifies a fully class-invariant parameter. ^p≤0.10 *p≤0.05 **p≤0.01.*

In addition to the equivalence of parameter estimates between K10 models with fixed versus individually-varying timing scores, there was also almost total agreement in individual classifications based on the assignment to the class with the highest posterior probability (the 'most likely' class). In total, 98.3% of participants (n=913) were assigned to the same class under both models (Table 51).

Table 50: Correspondence in modal class assignments between final unconditional psychological distress GMM with fixed versus individually-varying timing scores

	Fixed timing scores							
	Low-stable		Low-ascending		High-declining		Total	
Individually-varying timing scores	n	%	n	%	n	%	n	%
Low-stable	**496**	**97.6**	7	1.4	5	1.0	508	100
Low-ascending	1	0.6	**179**	**98.9**	1	0.6	181	100
High-declining	0	0.0	2	0.8	**238**	**99.2**	240	100

Overall rate of agreement = 98.3%. χ^2=1750.4, df=4, p<0.0001.

The 16 participants whose 'most likely' class changed were typically borderline cases in the model with individually-varying timing scores, for whom the difference in posterior probabilities of membership between the first and second most likely classes differed by less than 0.10 (and more than half the time, by less than 0.03). Thus, only a minor reshuffling of posterior probabilities was required to see a change in most likely class after fixing the timing scores. Among participants whose most likely class did not change, only 3.8% (n=35) were affected by ≥0.05 absolute change in posterior probability of membership in any given class. The maximum change in posterior probability for any individual in any class was 0.11.

3 Life satisfaction

The same analyses just described were repeated for the life satisfaction GMM, and results are presented on the following page. Table 51 presents parameter estimates from the final unconditional SLDS GMM and the SLDS LGCM with individually-varying (top panel) versus fixed (bottom panel) timing scores. Once again, the estimates of class sizes, class-specific growth trajectory means and variances, and residual outcome variances remained essentially unchanged after fixing the timing scores. In the GMM specifically, entropy remained stable (varying t =0.72; fixed t =0.72) and BIC improved (varying t =20761; fixed t =20757) after fixing the timing scores.

In addition, Table 52 illustrates almost total agreement in individual classifications based on the assignment to the class with the highest posterior probability (the 'most likely' class). In total, 99.6% of participants (n=925) were assigned to the same class under both models (Table 52). The four participants whose 'most likely' class changed were borderline cases in the model with individually-varying timing scores, for whom the difference in posterior probabilities of membership between the first and second most likely classes differed by less than 0.10. Thus, it took only a minor reshuffling of these posterior probabilities to see a change in most likely class after fixing the timing scores.

Among participants whose most likely class did not change, only 1.3% (n=12) were affected by ≥0.05 absolute change in posterior probability of membership in a given class. The maximum change in posterior probability for any individual in any class was 0.30. This particular individual had the longest lag between T1 and T2 interviews (3.26 years) of any participant in the study, so it is intuitive that the largest effect of fixing the timing scores should manifest here. This deviation did not correspond with a change in 'most

likely' class membership, but merely served to strengthen the estimated probability that this participant belonged in the high-declining class. The next highest change in posterior probability for any individual in any class was substantially lower at 0.13.

Table 51: Parameter estimates from the final unconditional three-class GMM and single-population LGCM of life satisfaction (SLDS) with fixed versus individually-varying timing scores

VARYING TIMING SCORES	GMM			LGCM
Parameter	High-stable (HS, 79%) Est. (SE)	High-declining (HD, 8.0%) Est. (SE)	Low-ascending (LA, 13%) Est. (SE)	Est. (SE)
Intercept mean ($\alpha_{\eta 0}$)	98.5 (0.82)**	93.8 (2.36)**	71.6 (2.90)**	94.7 (0.47)**
Slope mean ($\alpha_{\eta 1}$)	-0.08 (0.08)	-3.41 (1.28)**	2.31 (0.56)**	-0.03 (0.09)
Intercept variance ($\Psi_{\eta 0, \eta 0}$)	57.8 (9.01)**	57.8 (9.01)**	111 (24.5)**	129 (9.65)**
Slope variance ($\Psi_{\eta 1, \eta 1}$)	0.00 (NA)	8.04 (2.13)**	8.04 (2.13)**	1.15 (0.86)
Growth factor covariance ($\Psi_{\eta 0, \eta 1}$)	0.00 (NA)	–	–	-2.75 (1.83)
T1 error variance ($\Theta_{1,1}$)	41.0 (5.15)**	–	–	65.0 (11.6)**
T2 error variance ($\Theta_{2,2}$)	50.3 (6.58)**	–	–	41.0 (6.15)**
T3 error variance ($\Theta_{3,3}$)	28.6 (3.31)**	–	–	44.6 (8.57)**
BIC = 20761, entropy = 0.72				
FIXED TIMING SCORES	GMM			LGCM
Parameter	High-stable (HS, 79%) Est. (SE)	High-declining (HD, 8.3%) Est. (SE)	Low-ascending (LA, 13%) Est. (SE)	Est. (SE)
Intercept mean ($\alpha_{\eta 0}$)	98.6 (0.83)**	93.7 (2.34)**	71.6 (2.90)**	94.7 (0.47)**
Slope mean ($\alpha_{\eta 1}$)	-0.09 (0.08)	-3.34 (1.28)**	2.35 (0.56)**	-0.04 (0.09)
Intercept variance ($\Psi_{\eta 0, \eta 0}$)	57.4 (9.15)**	57.4 (9.15)**	109 (24.8)**	128 (10.0)**
Slope variance ($\Psi_{\eta 1, \eta 1}$)	0.00 (NA)	7.97 (2.05)**	7.97 (2.05)**	1.24 (1.00)
Growth factor covariance ($\Psi_{\eta 0, \eta 1}$)	0.00 (NA)	–	–	-2.71 (2.09)
T1 error variance ($\Theta_{1,1}$)	41.1 (5.18)**	–	–	64.9 (11.6)**
T2 error variance ($\Theta_{2,2}$)	50.3 (6.51)**	–	–	41.2 (6.55)**
T3 error variance ($\Theta_{3,3}$)	28.1 (3.33)**	–	–	43.7 (10.1)**
BIC = 20757, entropy = 0.72				

*Note. SLDS = Reduced (17-item) Satisfaction with Life Domains Scale (total score). GMM = growth mixture model. LGCM = latent growth curve model. BIC = Bayesian information criterion. Trajectory classes are named according to mean intercept and slope characteristics: LS=low-stable; HD=high-declining; LA=low-ascending,. Intercepts reflect SLDS score at commencement of study; slopes reflect average change in SLDS scores per year. Class proportions (%) based on estimated posterior probabilities. (NA) identifies a fixed parameter, '–' identifies a fully class-invariant parameter. ^p≤0.10 *p≤0.05 **p≤0.01.*

Table 52: Correspondence in modal (most likely) class assignments between final unconditional life satisfaction (SLDS) growth mixture model estimated with fixed versus individually-varying timing scores

	Fixed timing scores							
	High-stable		High-declining		Low-ascending		Total	
Individually-varying timing scores	n	%	n	%	n	%	n	%
High-stable	785	99.5	1	0.1	3	0.4	789	100
High-declining	0	0.0	39	100	0	0.0	39	100
Low-ascending	0	0.0	0	0.0	101	100	101	100

Overall rate of agreement = 99.5%. χ^2=1803.4, df=4, p<0.0001.

4 Summary

In summary, both the GMM and LGCM models estimated using fixed timing scores closely reproduced the models with individually-varying time scores in terms of the estimated class proportions, class-specific growth trajectory means and variances, and assignment of individual participants to the various classes. This applied for both 'hard' (assignment to the class with the highest posterior probability) and 'soft' classifications (changes to posterior probabilities across classes). In fact, the models with fixed timing scores were supported by more favourable scores on various information criteria (e.g. AIC, BIC, SSABIC). Given the substantial practical advantages to the discrete timing structure, all conditional GMMs were subsequently estimated using these fixed time scores. Interpretation of the latent growth parameters remains unchanged; growth function intercepts reflect mental health status at the first measurement occasion and slopes reflect the average change in the outcome per year.

Appendix 4.2
Criteria for assessing the quality of growth mixture solutions

1 Preface

This appendix details the criteria used to determine the optimal growth mixture model (GMM) solutions for describing and explaining inter-individual variability in trajectories of psychological distress and life satisfaction. Section 2 describes measures and tests of model fit including BIC, SSABIC and approximate Bayes factors (Section 2.1), the scaled likelihood ratio test (Section 2.2), and the Wald test (Section 2.3). Section 3 describes measures of classification quality, including Entropy (Section 3.1), Average Posterior Probability, and Odds of Correct Classification (Section 3.2). The appendix concludes with a brief comment on the importance of considering the substantive utility of the GMM solution (Section 4).

In determining the optimal unconditional GMM, the aim is not to identify the "true" or "correct" number of classes, but rather to ascertain the number of classes that is statistically and substantively adequate to describe heterogeneity within the population with respect to growth trajectories on the outcome of interest (Nagin and Odgers, 2010, Masyn, 2013). Much like adding additional predictors in a regression equation, adding an extra class to a GMM will always improve model fit in terms of the absolute likelihood of the data; however, this does not mean that the model is not over parameterised. The optimal class solution should achieve a suitable balance between model fit, parsimony, and the substantive utility of the solution with reference to classification quality and the meaning of extracted classes (Ram and Grimm, 2009).

2 Model fit and parsimony

Presently, there is no measure of overall goodness-of-fit that can be implemented directly in statistical packages commonly used for GMM analysis (Petras and Masyn, 2010). Conventional chi-square based fit indices usually used in SEM analyses (e.g., CFI, GFI, RMSEA) are unavailable in mixture modelling because means and covariances are not sufficient statistics for model estimation and there is no unrestricted model against which to compare the target model (McLachlan and Peel, 2000, Ram and Grimm, 2009). However, there are numerous statistical indicators of relative model fit that are available to assist in determining the optimal number of classes with which to define a GMM. These are primarily based on log-likelihood values and are broadly categorised into information-based indices (including the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and sample-size adjusted BIC (SSABIC)) and likelihood-ratio tests

(including the Lo–Mendell–Rubin test (LMRT) and Bootstrap Likelihood Ratio Test (BLRT)) (Nylund et al., 2007). Information criteria weigh model fit against model complexity, in recognition that the addition of new parameters will always improve model fit but at a cost to model parsimony (Masyn, 2013). Their values may be compared across two or more models simultaneously, thereby providing a useful indication of the diminishing returns of adding each consecutive class to a mixture model (Petras and Masyn, 2010). Moreover, they may be used to compare between both nested and non-nested models (Nagin and Tremblay, 2001).

On the other hand, likelihood ratio tests are employed specifically to contrast two neighbouring class models. Note that the standard likelihood ratio chi-square (LRCS) difference test is inappropriate for comparing between mixture models with differing numbers of classes, as a k-class mixture model is not a nested linear subspace of a k + 1 class model (Nagin and Tremblay, 2001). 'Nesting' these models requires that class probabilities for the *k + 1th* class are set to zero, forcing them to the boundary of the admissible parameter space (0 to 1) and violating the regularity conditions required for the test statistic to follow a chi-square distribution (Muthén and Muthén, 2004, Nylund et al., 2007, McLachlan and Peel, 2000). The LRCS has accordingly been documented to perform poorly in the context of class enumeration, and alternative procedures (e.g. the Lo-Mendell-Rubin Test [LMRT] or Bootstrap Likelihood Ratio Test [BLRT]) that approximate the distribution of the log-likelihood difference between models (rather than assuming a chi-square distribution) are recommended (Nylund et al., 2007). The LRCS is, however, perfectly acceptable for the comparison of nested mixture models that differ in their parameterisation of within-class variance-covariance structures, but not in the number of classes (Petras and Masyn, 2010, Morin et al., 2011).

Limited evidence exists regarding the relative performance of the various likelihood-based indicators in correctly identifying the number of classes in a GMM, and a 'universal standard' remains to be determined (Liu and Hancock, 2014). For the interested reader, the simulation studies of Nylund et al. (2007) and Tofighi and Enders (2008) provide good insight into the relative merits of available approaches across varied conditions of model complexity and sample size. In relation to this thesis, the choice of indicators was limited by a desire to enumerate latent classes under a model that employed individually-varying timing scores. Under these conditions, *Mplus* 7.2 does not perform BLRT or LMR likelihood-ratio tests suitable for class enumeration (Muthén and Muthén, 2012). By contrast, the AIC, BIC, and SSABIC information criteria were all available for use.

Although there is no clear consensus as to which information-based index is ideal in the GMM context, BIC and SSABIC have each been shown to perform well under different conditions.

Evidence from Nylund et al. (2007) and Tofighi and Enders (2008) indicates that BIC tends to favour the under extraction of latent classes and performs better in simpler models under population conditions conducive to the extraction of latent classes (i.e. high class separation with no very small classes). On the other hand, SSABIC tends to favour the over extraction of latent classes but performs better in more complex models under less ideal conditions (i.e. low class separation with a very small class). In fact, these indices frequently performed as well as, if not better, than the LMR and BLRT tests (Nylund et al., 2007, Tofighi and Enders, 2008, Liu and Hancock, 2014). When the true population model is simple, both indices were shown to perform extremely well in samples as small as n=500 (Nylund et al., 2007). Under more complex conditions, BIC performed poorly in sample sizes of 1000 or less, displaying a strong tendency to extract too few classes (Tofighi and Enders, 2008). Thus, taking into consideration the sample size in the present research (n=929), there is a possibility that sole reliance on BIC (a standard approach in applied GMM research) could result in the under extraction of latent classes if, for example, more than two classes 'truly exist' in the population, these classes are poorly separated, or one of the classes is quite small.

Of course, the observational nature of the research means that the complexity of the 'true' population model is unknown. Under these conditions, making reference to both BIC and SSABIC, with additional reference to substantive utility and classification quality in reaching a final decision about the number of classes, seems a reasonable compromise between their competing strengths and weaknesses across different conditions. By contrast, AIC has been shown to perform poorly in the context of class enumeration, due to its tendency to overfit models, and is not considered in this thesis (Celeux and Soromenho, 1996, McLachlan and Peel, 2000, Dziak et al., 2012). The following section briefly describes the BIC and SSABIC, as well as the conversion of BIC scores into approximate Bayes factors that permit a meaningful quantification of relative fit across models.

2.1 BIC, SSABIC and approximate Bayes factors

Schwarz's (1978) BIC balances model fit and parsimony by weighting the log likelihood with a penalty for model complexity, as follows:

$$BIC = -2L + p \ln n$$

Where L is the log likelihood of the specified model, p is the number of model parameters, and n is the sample size. The sample size adjusted BIC (SSABIC), defined by Sclove (1987), reduces the size of the penalty term by replacing the sample size n in the above equation with n*:

$$\mathrm{n}^{*} = (\mathrm{n} + 2)/24$$

Both the BIC and SSABIC are used to compare plausible models, with the lowest value of each criterion indicative of a better fitting (and/or more parsimonious) model. To quantify the extent to which one model may be preferable to another, the difference in BIC values between two competing models can be converted into an approximate Bayes factor reflecting the relative odds of each model being the 'correct' model. The Bayes factor (B_{ij}) represents the ratio of the probability of *i* being the correct model to the probability of *j* being the correct model. Thus, a Bayes factor of 1 implies that the two models are equally likely, whereas a Bayes factor of 10 implies that model *i* is 10 times more likely than model *j* (Nagin, 1999). While computation of Bayes factors is complex, an approximation in which equal weight is placed on the prior probabilities of models *i* and *j* can be obtained using the following formula, adapted from Nagin (1999) for use with the Schwarz BIC:

$$B_{ij} \approx e^{\frac{BIC_i - BIC_j}{-2}}$$

Accordingly, the difference between two Schwarz BIC values is approximately equal to twice the natural logarithm of the Bayes factor (with an ignorable negative sign) (Wasserman, 2000):

$$\mathrm{BIC_i} - \mathrm{BIC_j} \approx -2 \ln\left(\mathrm{B_{ij}}\right)$$

Kass and Raftery provide rules of evidence for Bayes factors in the -2*log scale (i.e. approximate BIC differences) alongside untransformed Bayes factor values (Table 53, p.420). The authors declare that a difference between two Schwarz BIC values of greater than 10 provides very strong evidence for the model with the lower BIC, equivalent to a minimum Bayes factor of 150. That is, where the difference in BIC values exceeds 10, the model with the lower BIC is deemed to be at least 150 times more likely to be the correct model than that with the higher BIC.

Table 53: Interpretation of the magnitude of Bayes factors in both the original and -2*log scales

$-2*\ln(B_{ij})$	B_{ij}	Evidence against model *j*
0 to 2	1 to 3	Not worth more than a bare mention
2 to 6	3 to 20	Positive
6 to 10	20 to 150	Strong
>10	>150	Very strong

Reproduced from Kass and Raftery (1995).

As well as considering absolute differences in BIC and SSABIC, it is instructive to consider relative changes in these values with an increasing number of classes. This may assist in cases where the information criterion never arrives at a minimum value for any *k*-class model, or where pronounced differences in IC values do not exist between several models under consideration. Elbow plots of BIC and SSABIC values are constructed to allow the graphical inspection of marginal gains in model fit with the extraction of each additional class. While lower BIC and SSABIC values are indicative of better model fit overall, attenuation in the decline of these values reflects diminishing returns from estimating additional classes. A pronounced angle ('elbow') in the plot may then indicate the point at which adding further classes to the model is not justified by the additional information they provide (Petras and Masyn, 2010, Masyn, 2013).

2.2 Scaled likelihood ratio test

Scaled likelihood ratio tests are employed in this thesis to compare the fit of nested *k*-class models that differ in their specification of within-class covariance structures but not in the number of classes (Satorra and Bentler, 2001, Bauer and Curran, 2004, Petras and Masyn, 2010). These tests allowed us to determine whether placing restrictions on certain parameters – such as fixing the within-class covariance among growth factors to zero, or specifying equality in growth factor variances for a subset of classes – significantly deteriorated model fit. The LRCS test statistic is specified on the following page.

The LRCS test statistic was computed as minus two times the difference in the log likelihoods of the nested models, and scaled for use with the MLR estimator by the scaling correction composite *cd* (Satorra and Bentler, 2001, Asparouhov and Muthén, 2010b):

$$LRCS = \frac{-2(L_0 - L_1)}{cd}$$

where

$$cd = \frac{(p_0 * c_0) - (p_1 * c_1)}{p_0 - p_1}$$

and L_0 and L_1 are the log likelihoods of the nested and comparison models; p_0 and p_1 are the number of free parameters in the nested and comparison models; and c_0 and c_1 are the MLR scaling correction factors for the nested and comparison models. LRCS is interpreted as a chi-square distributed statistic with degrees of freedom equal to the difference in the number of free parameters between models ($p_1 - p_0$). An alpha level of 0.05 was used as the decision rule for whether to retain the nested model in preference to the comparison model.

2.3 Wald test

Wald tests are employed in this thesis to test the joint significance of multiple parameters, typically in relation to the null hypothesis that the effects of a set of covariates on trajectory class membership or within-class variation in trajectory intercepts and/or slopes are simultaneously equal to zero. Whereas classic likelihood ratio tests cannot be implemented with multiple imputation because the proper value of the likelihood derived from *m* models is unclear, the Wald test uses the joint distribution of parameter estimates and may be applied by averaging across the *m* estimates of parameters and their asymptotic distribution (Asparouhov and Muthén, 2010a).

3 Classification quality

GMM classification quality is assessed with reference to each individual's probability of membership in each class (posterior probabilities). If the classes estimated by the model are distinct and well defined, then each person will have only a single large posterior probability reflecting a high degree of confidence that the individual has been classified into their 'true' class (Henson et al., 2007). Conversely, if the posterior probabilities for an individual are spread evenly across multiple classes, with moderate non-zero probabilities of belonging to each class, this indicates an ambiguous and potentially meaningless

classification scheme. Therefore, while evaluation of classification quality has little to do with the fit of a model to data, it does reflect the usefulness of a GMM in identifying homogenous groupings of individuals with fundamentally distinct growth trajectories (Feldman et al., 2009, Petras and Masyn, 2010). This has important implications for direct applications of GMM, such as predicting class membership or predicting distal outcomes of class membership, which require the classes to have some degree of separation and substantive utility. However, this requirement is not necessarily satisfied through model selection driven by likelihood-based statistics that may lead to the selection of parsimonious models with poorly distinguished classes (Celeux and Soromenho, 1996).

3.1 Entropy

A summary of GMM classification quality is given by the entropy measure (Muthén and Muthén, 2004), which is calculated for the whole model as a function of each individual's posterior probability of membership in each class (Muthén and Muthén, 2004):

$$E_K = 1 - \frac{\sum_i \sum_k (-\hat{p}_{ik}\, ln\hat{p}_{ik})}{n\, lnK}$$

where $\hat{p}_{ik}$ denotes the estimated conditional probability of membership in class *k* for individual *i.* Entropy ranges from 0 to 1, with higher scores indicating that the GMM separates participants into classes with greater precision. Its value will be positively affected by the extent of class separation (between-class variation) in the population and negatively affected by the degree of within-class variation (Celeux and Soromenho, 1996, Muthén, 2004). Entropy will also be improved by incorporating covariates into the model that discriminates well between the classes (Lubke and Muthén, 2007). I reiterate that entropy is not a measure of model fit and is not intended for model selection; it simply describes the classification of participants assuming that the model is correctly specified (Nylund-Gibson et al., 2014). However, if comparing among models with similar relative fit indices (e.g. BIC) one would generally favour models with higher entropy (Ram and Grimm, 2009). Although there is no accepted cut-off criterion, Clark & Muthén (2009) suggest values of 0.8, 0.6 and 0.4 as corresponding to high, medium and low levels of entropy. These values generally vary with the rate of correct class assignment, with indications that entropy values below 0.6 relate to misclassification rates of 20% or more, and values above 0.8 relate to misclassification rates of 10% or less (Lubke and Muthén, 2007).

3.2 Average Posterior Probability and Odds of Correct Classification

As well as evaluating the overall classification precision of the model as a whole (entropy), it is also useful to inspect the classification quality for each class individually in order to determine whether membership in any given class is predicted particularly poorly (Jung and Wickrama, 2008, Berlin et al., 2013b). This might highlight a situation in which some classes are easily differentiated but others are not. For instance, a model may achieve a poor level of entropy overall but still contain some classes that are clearly distinguishable and substantively useful. Alternatively, the extraction of additional well-defined classes may result in a marked improvement to entropy, masking the fact that certain existing classes remain poorly differentiated. Class-specific assignment accuracy is generally determined based on the average posterior probabilities (APP) of membership in each class. A classification table is constructed in which individuals are assigned to their most likely class (rows) and the average conditional probabilities of membership in each of the *k* classes (columns) are computed for the individuals in each row (Muthén and Muthén, 2004). APPs for each class are found on the diagonal of this table, indicating the average probability that an individual assigned to class *k* (based on his or her maximum posterior probability) is actually a member of class *k*. Nagin (2009) suggests, as a rule of thumb, that APPs should be at least 0.7 for each trajectory class. In addition, he outlines a diagnostic statistic that measures the odds of correct classification for the *k*th group (OCC_k):

$$OCC_k = \frac{APP_k/(1 - APP_k)}{\hat{\pi}_k/(1 - \hat{\pi}_k)}$$

where $\hat{\pi}_k$ is the estimated base probability of membership in group k. This statistic compares the odds of correct classification into group *k* based on assignment to the class with the highest individual posterior probability (the most likely class) against the odds of correct classification based on random assignment according to the estimated base rate of membership in group *k*. Higher values of OCC_k indicate greater predictive power of the most likely class assignment compared to random chance, and therefore better classification quality. Nagin (2009) identifies OCC_k values that are consistently greater than 5 as indicative of high assignment accuracy. Finally, the extent of correspondence between model-estimated base probabilities of membership in each class, and the proportion of individuals assigned to each class based on posterior probabilities, may be assessed (Nagin, 2009).

4 Substantive utility: class size and interpretability

Finally, the class-specific mean growth trajectories and class proportions implied by different GMMs are examined in order to evaluate the utility and face validity of the extracted classes. Essentially, one wishes to determine whether the classes are substantively distinct and meaningful. This process may highlight situations in which the extraction of a k+1th class, while improving model fit over the k-class model, does not improve the utility of the model because this class does not convey much new information. For instance, an additional class may serve merely to split an existing class into two parallel trajectories; although fitting the observed data well, this model may not prove useful for direct applications (such as predicting class membership) because limited separation between the classes renders their distinction meaningless. This is especially liable to occur when within-class variances in the growth factors are constrained to equality (Nagin and Tremblay, 2001, Morin et al., 2011). Alternatively, an additional class may contain an inconsequential number of participants (proportionally or numerically), limiting its utility in both a statistical (low power and precision relative to the larger classes) and practical sense (limited scope for translation at a population or policy-level). Ideally, for these reasons, classes should not comprise less than 1% of the total sample, or 25 participants in total (Jung and Wickrama, 2008, Berlin et al., 2013b).

Appendix 4.3

Single-step versus three-step approaches to latent class regression

1 Preface

In general, two approaches to latent class regression are available to analysts wishing to investigate the relationship between a covariate and the probability of latent class membership. These approaches, referred to as single-step and three-step methods, are largely differentiated by whether the latent trajectory groups identified in the unconditional GMM are 'fixed' prior to the addition of covariates.

2 Single-step approach

In a single-step GMM analysis, the latent class measurement model and the latent class regression model are combined and estimated simultaneously (Bolck et al., 2004, Vermunt, 2010, Asparouhov and Muthén, 2014, Bakk et al., 2013). This means that the influence of the covariates on trajectory class membership is estimated at the same time as the parameters that define the trajectory classes themselves. Rather than treating covariates as predictors in a post-hoc analysis of the latent classes formed under an unconditional model, this approach allows them to influence the pattern of clustering into latent classes while also potentially explaining differences in growth trajectories within those classes. This approach generates asymptotically unbiased, efficient, and consistent estimates of relationships between covariates and the latent class variable (Bolck et al., 2004). The addition of covariates to the latent class model therefore has the potential to substantially reduce classification errors by increasing the multivariate separation between classes (Lubke and Muthén, 2007). But, by the same token, this approach is liable to alter the meaning of the latent class variable because individuals are no longer partitioned solely according to values of the outcome (Clark and Muthén, 2009). This is not always desirable, and may be especially problematic when the revised latent class variable does not coincide with the theorised organization of the constructs being studied. For instance, one may wish to use a covariate to predict, validate or explain – but not partially define – latent trajectory profiles on an outcome process that is viewed as distinct (Clark and Muthén, 2009, Petras and Masyn, 2010, Bakk et al., 2013).

3 Three-step approach

In a three-step analysis, sometimes termed a 'classify-analyse' approach, the formation of the latent classes is performed independently to the estimation of relationships between the covariate and the latent class variable. The structural model is treated as auxiliary to the measurement model so that it does not influence the determination of class membership nor, in turn, the substantive interpretation of the latent classes (Clark and Muthén, 2009, Berlin et al., 2013b). This is often a primary motivation for using a three-step technique and is particularly pertinent when prediction of distal outcome (which is specified in an identical manner as the indicators for the latent class variable) or estimation of a complex secondary model (e.g. containing a second latent class variable) pose a threat to the construct validity of the latent class variable (Bakk et al., 2013, Nylund-Gibson et al., 2014, Asparouhov and Muthén, 2014). A number of three-step methods are available, each sharing the same basic procedure: (1) establish the unconditional growth mixture model, (2) use this unconditional GMM to predict class membership for each individual in the sample, and (3) export and use these class assignments to estimate the structural relationships between class membership and other variables (Clark and Muthén, 2009, Vermunt, 2010). Traditionally, it is the second step that differs between methods and, potentially, accommodates uncertainty in the classification of participants. For instance, one may perform a 'hard' classification by assigning participants to the class with the highest posterior probability (the modal or most likely class); a 'soft' classification by assigning the participant proportionally across classes in line with his or her posterior probabilities of membership; or perform multiple 'hard' classifications using *M* random 'pseudo class' draws from the posterior probability distribution, in a manner similar to multiple imputation (Bolck et al., 2004, Vermunt, 2010, Asparouhov and Muthén, 2010c, 2014). Evidence continues to accumulate about the relative performance of these techniques and, concurrently, their popular usage evolves with the integration of new approaches into software packages such as M*plus* (e.g. Clark and Muthén, 2009, Bakk et al., 2013, Berlin et al., 2013b, Asparouhov and Muthén, 2014).

4 Choice of single-step over three-step approach

Although computationally far more intensive, a one-step approach remains the standard way to perform latent class regression analysis and is adopted in this thesis primarily because it yields less biased and more precise estimates of covariate effects, and more accurate classifications, than the three-step approaches (Bolck et al., 2004, Lubke and Muthén, 2007, Clark and Muthén, 2009, Huang et al., 2010, Vermunt, 2010, Asparouhov and Muthén, 2014). The one-step method employs conditional probabilities of class membership (given covariates; P(C=k|X)) directly in the estimation of structural relationships, generating asymptotically unbiased, efficient, and consistent estimates of the relationships between covariates and the latent class variable (Bolck et al., 2004). On the other hand, three-step methods suffer due to the fact that these conditional probabilities are only employed indirectly in order to predict latent class membership, which is then treated as an 'observed' variable in further analyses. Unless the misclassification rate is zero, the true latent class assignment for an individual cannot be identified mathematically even if all pertinent population parameters are known. As a result, predicted individual class assignments (C*) and their conditional probabilities (P(C*=k|X)) will never exactly reproduce the "true" individual class assignments (C) and conditional probabilities (P(C=k|X)) (Bolck et al., 2004). Traditional three-step methods fail to adequately take into account the error in these predictions, and therefore yield estimates for the relationships among the latent variables and observed predictors (or their standard errors) that are biased towards zero regardless of the classification method used in the second step (Bolck et al., 2004, Clark and Muthén, 2009, Vermunt, 2010).

A recent addition to the M*plus* software corrects for these biases in the third step by treating predicted (modal) class membership as a response variable with known measurement error probabilities, reflecting the probability of membership in the predicted class given true class membership (P(C*=k | C=k)) (Bolck et al., 2004, Vermunt, 2010, Asparouhov and Muthén, 2014). This 'new three-step' method is able to yield estimates that are approximately as unbiased and efficient as those from a one-step analysis, provided there is adequate separation between the classes (e.g. entropy ≥ 0.6) (Vermunt, 2010, Asparouhov and Muthén, 2014). However, it assumes that covariates in the structural model do not exert direct effects on the latent class indicators after controlling for class membership and may perform poorly if this condition is violated (Bolck et al.,

2004, Vermunt, 2010, Asparouhov and Muthén, 2014). The standard unconditional measurement model used in the first step embodies this assumption, effectively fixing all direct effects to zero while assigning participants to the various classes. The observed outcomes and estimated growth trajectories for individual participants are then discarded, making it impossible to investigate direct effects when covariate effects are estimated in the third step. Asparouhov and Muthén (2014) noted that the 'new three-step' generates biased estimates of indirect effects (C on X) when direct effects (Intercept, Slope on X) are omitted from the latent class measurement model in the first step, even if the classes are very well separated (e.g. entropy = 0.85). This is unsurprising, given the previously noted potential for omitted direct effects to distort the relationships between a latent class variable, its indicators, and covariates (Muthén, 2004). Including the direct effects in the first-step measurement model greatly improved the estimation, but the level of bias was still unacceptable in conditions of moderate class separation (entropy = 0.6) (Asparouhov and Muthén, 2014).

The nature of the latent class regression models in this thesis – which did not incorporate distal outcomes or relationships between multiple latent class variables – did not pose a notable a priori threat to the construct validity of the latent class variable. I was therefore not motivated to use a three-step method by any particular concern about changes to the classification scheme with the inclusion of covariates (although I did monitor the extent to which such changes occurred, as described in Chapter 4, Section 2.2). There was concern, however, about the potential for the omission of direct effects from predictors to the latent growth factors to bias the estimation of indirect relationships between those predictors and latent class membership (Muthén, 2004). As demonstrated through the single-step analyses, there was evidence of significant direct effects between certain sociodemographic and psychosocial variables and within-class mental health trajectories after accounting for the influence of these variables on class membership. Moreover, the level of class separation in the optimal unconditional GMM for psychological distress was relatively low (entropy = 0.53). Together, these factors raised concern about the ability of even the 'new three-step' method to yield unbiased estimates of covariate effects on latent class membership. A one-step method, on the other hand, allowed us to explore the presence of direct effects and correctly specify of a model including these direct effects where necessary.

Appendix 4.4

Assessing the influence of regression to the mean on latent class trajectories

1 Preface

This appendix evaluates, graphically and statistically, the expected influence of regression to the mean (RTM) on observed changes in psychological distress and life satisfaction among members of the non-healthful ('worsening' and 'improving') classes identified in each model. Its primary aim is to determine the extent to which the mean trajectory slopes used to describe these classes reflect true change over time, or are merely statistical artefacts of the manner in which participants are partitioned across the spectrum of baseline mental health scores. It concludes that RTM is likely to account fully for the mean decline in psychological distress among the 'improving' K10 class, and partially for the mean increase in life satisfaction among the 'improving' SLDS class. Conversely, RTM is unlikely to account for a significant portion of the change in these outcomes among the 'worsening' K10 or 'worsening' SLDS classes.

In light of this analysis, the 'high-declining' distress class is renamed the *chronic high-distress* class, and the 'low-ascending' life satisfaction is renamed the *chronic low-satisfaction* class to better reflect the extent to which initial scores define these trajectories and result in apparent improvements over time due to regression to the mean.

2 Regression to the mean

Regression to the mean (RTM) is a statistical phenomenon in repeated measures data, in which relatively extreme (high or low) observations collected from a subject at one point in time are likely to be followed by less extreme observations (closer to the subject's true mean) at a later point in time. These stochastic fluctuations reflect natural within-person variation about the mean level of some construct, but masquerade as 'real' or consequential change in that construct over time. This phenomenon is particularly problematic when participants with initially extreme values are isolated into subsamples according to some baseline cut-point, where erroneous classifications due to initial random error may result in spurious group-mean differences upon follow-up (Barnett et al., 2005). The greater the distance between the group- and population-means initially, the further the group is likely to regress.

This is particularly pertinent to the 'improving' classes identified in the psychological distress (K10) and life satisfaction (SLDS) growth mixture models. As detailed in Chapter

4, these classes each feature a mean trajectory of initially poor but apparently improving mental health. Groupings in a GMM are, by definition, determined according to the pattern of observations across all time points, and not by initial observations alone. Yet, while the 'improving' classes do exhibit discriminatory power with regard to trajectory slopes, assignment to these classes is overwhelmingly influenced by baseline scores; specifically, whether an individual reports an unusually high K10 score or unusually low SLDS score[110]. Given the extremity of these initial observations in relation to the population distribution of each measure (Table 54), it is plausible that some of the 'improvement' in scores observed for these participants may be a statistical artefact of random error in the initial observations[111].

Random error might arise due to momentary affective states at the point of measurement (Schwarz and Clore, 1983) but also as short-term fluctuations due to situational factors or life events. For instance, many individuals experience transitory elevation of psychological distress symptoms in response to stressful stimuli, but most will return to a normal state relatively quickly without succumbing to clinically significant mental disorder[112]. Psychological distress is an expectable and culturally sanctioned response that fluctuates in relation to external circumstances, generally persisting only so long as those circumstances endure, or until people adapt to them (Horwitz, 2007). In this sense, I reiterate the distinction raised in Chapter 2 between immediate psychological stress reactions and longer-term psychopathological consequences (Elliott and Eisdorfer, 1982), where the former are ordinary adaptive responses whose translation into abnormal and enduring states of mental disorder depends on a complex interaction of individual, contextual and procedural factors. From this perspective, short-term fluctuations in the level of distress are anticipated at the individual level, with recovery to some 'true' mental health status facilitated by typical coping processes and the abatement of precipitating stressors. Happiness and life satisfaction may be subject to similar homeostatic processes, where individuals exposed to changing circumstances frequently return to a 'soft set point' of wellbeing that is determined to a significant extent by personality and other heritable

[110] This point is illustrated graphically in Figure 33 (page 438) and discussed further in the following sections.

[111] In fact, in their analysis of 17 annual measures of life satisfaction, Fujita and Diener (2005) illustrate that year-to-year variability in life satisfaction scores is greater among individuals with a lower 'baseline' set-point, perhaps because these individuals are more reactive to external events.

[112] In the ZEPSOM catchment area, this distinction is evidenced at the population level by a far greater prevalence of high psychological distress (capturing anxiety and depressive symptoms during the past month) compared with diagnoses of mood and anxiety disorders (reflecting symptoms lasting a minimum of three months) (Caron et al., 2012).

traits (Diener and Lucas, 1999, Kahneman, 1999, Fujita and Diener, 2005). Coupled with the essentially random nature of measurement timing, these processes might induce a general trend of 'improvement' upon follow-up (as a statistical artefact) among participants partitioned into a class on the basis of particularly poor mental health scores at baseline[113].

Regression to the mean is less concerning in the 'worsening' classes, within which the expected values of initial scores align quite closely to the sample mean[114] (Table 54). Importantly, baseline scores in the 'worsening' classes tended to be slightly less extreme (i.e. closer to the sample mean) than those in the 'healthful' classes, and deviated from 'healthful' class scores in the direction opposite to that expected to precipitate RTM effects. That is, baseline K10 scores tended to be higher in the low-ascending class (versus the low-stable class) and baseline SLDS scores tended to be lower in the high-declining class (versus the high-stable class). Together, these findings indicate limited scope for RTM to explain the general deterioration of mental health (rise in psychological distress or decline in life satisfaction) observed among participants in the 'worsening' classes.

Table 54: Distribution of outcome scores at T1; baseline cut-points used to approximate class membership; and observed correlations between paired observations of outcomes at T1 and T3

	DISTRIBUTION OF OBSERVED SCORES AT T1	Raw data			Log-transformed^	
		Median	Mean	SD	Mean	SD
K10	Whole sample	6.0	7.48	6.01	2.19	0.56
	High-declining* *('improving')*	15.0	15.8	4.69	2.90	0.24
	Low-ascending* *('worsening')*	6.0	5.73	2.75	2.11	0.36
	Low-stable* *('healthful')*	4.0	4.05	2.62	1.88	0.39
SLDS	Whole sample	97.0	94.7	13.9	4.69	0.14
	Low-ascending* *('improving')*	69.1	66.8	11.5	4.39	0.16
	High-declining* *('worsening')*	92.4	92.4	7.68	4.67	0.07
	High-stable* *('healthful')*	99.0	98.5	9.51	4.73	0.09

** Categories reflect modal (most likely) class membership determined by maximum individual posterior probability. ^ Data are transformed to approximate normality using the procedures previously outlined in Chapter 4. K10 data transformation = ln(K10 + 3). SLDS data transformation = ln(SLDS + 15).*

[113] The use of only three measurement occasions could leave the present research particularly vulnerable to the influence of abnormal initial observations.

[114] Means of log-transformed baseline means among participants modally assigned to the low-ascending (K10) or high-declining (SLDS) classes were roughly equivalent to the overall mean scores. Thus, similar numbers of individuals reported better/worse than expected baseline mental health.

The remainder of this appendix evaluates, graphically and statistically, the expected influence of RTM on observed changes in psychological distress and life satisfaction among members of the non-stable ('worsening' and 'improving') classes identified in each model. Our primary aim is to determine the extent to which the mean trajectory slopes used to describe these classes reflect true change over time, or are merely statistical artefacts of the manner in which participants are partitioned across the spectrum of baseline mental health scores. For this reason, I am less concerned by regression to the mean within classes, and most interested in the possibility that class membership itself embodies or engenders regression to the mean; in other words, is the between-class variation captured by class membership simply a reflection of RTM?

3 Graphical assessment of RTM

This section assesses the potential for regression to the mean with a graphical inspection of the observed individual difference in each outcome between the first and last measurement occasions (T3 minus T1) against observed individual scores at baseline (T1) (Figure 33, p.436). Panels *a* and *b* present this relationship for the sample as a whole, while Panels *c* and *d* partition participants according to their modal (most likely) class membership under each model. Prior to computing and plotting these values, the data were log-transformed to approximate normality using procedures first described in Chapter 4[115].

In each plot, the horizontal line at zero represents the expected relationship between baseline values and difference scores in the absence of RTM (and any general intervention or treatment effect) (Barnett et al., 2005). Here, expected change in the outcome is unaffected by the subject's initial position in the baseline sample. Conversely, in the presence of RTM, an inverse association between baseline scores and difference scores is anticipated (Rogosa, 1995). This reflects a general expectation for initially extreme values to 'regress' towards the norm, where the absolute magnitude of change correlates positively with the level of extremity in initial values (Krause, 2009). These scenarios are evaluated, below, using linear trend lines to summarise the observed relationship between baseline values and difference scores for each outcome. In this respect, it is important to note the distinct interpretation of trend lines in the whole-sample (panels *a*, *b*) versus class-partitioned figures (panels *c*, *d*). Whereas the former assess the general, sample-wide

[115] K10 data transformation = ln(K10 + 3). SLDS data transformation = ln(SLDS + 15). Data were transformed prior to computing difference scores.

tendency for regression to the mean (across the full range of baseline values), the latter reflect only the *within-class tendency* for RTM. That is, stratifying by class membership partitions out any RTM effects that may be captured by the distinct 'defining' growth trajectories of each class.

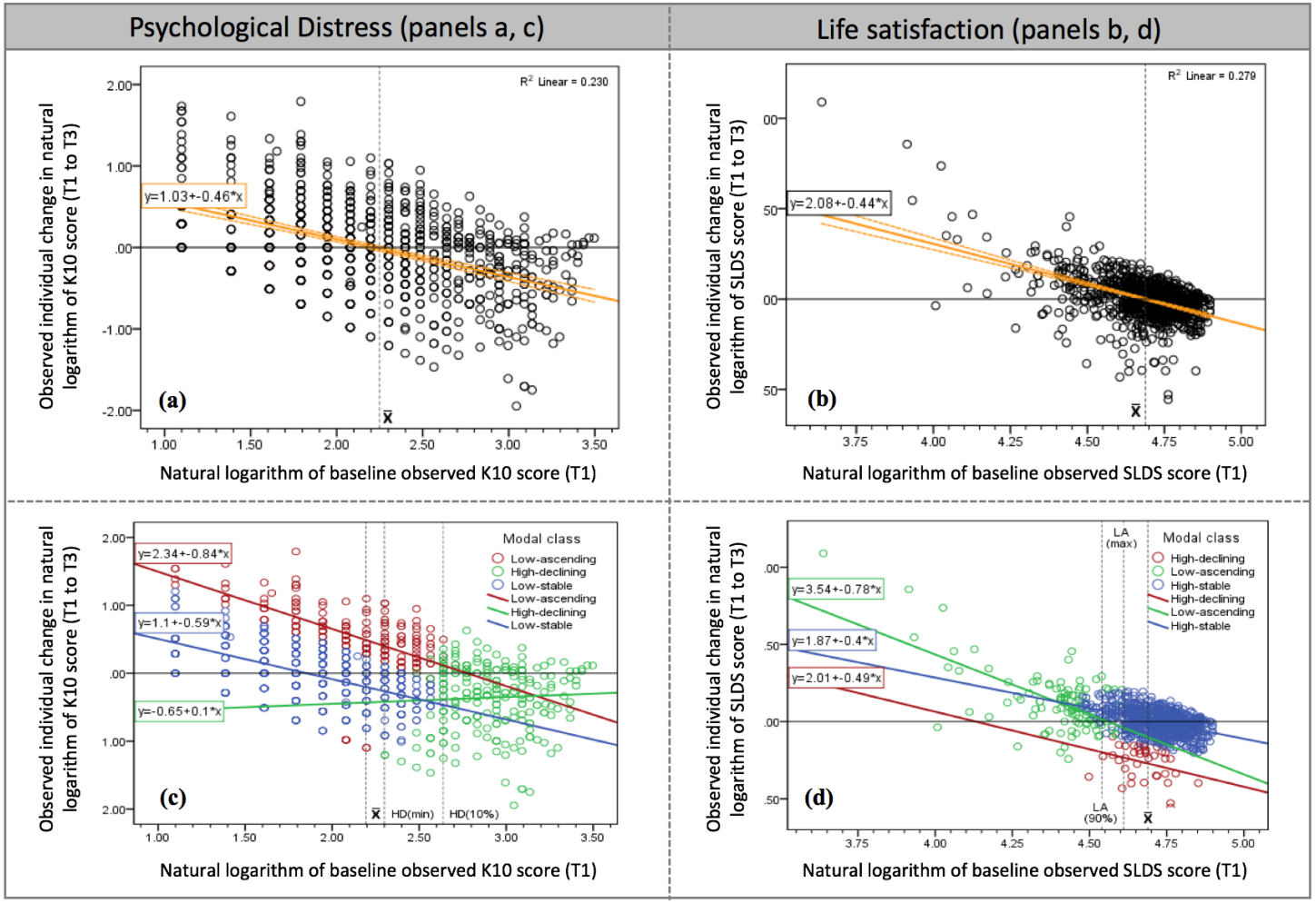
An inverse association between baseline scores and observed individual differences is immediately apparent (Figure 33, panels *a* and *b*). For both psychological distress and life satisfaction, baseline values account for roughly a quarter of the variation in difference scores. Consistent with an RTM hypothesis, the further an individual's score deviates from the mean initially, the greater the absolute magnitude of change expected between the first and last measurement occasions[116]. These findings indicate a general tendency for unusually high or low mental health scores, recorded at baseline, to attenuate towards the sample mean across subsequent waves of data collection.

Panels *c* and *d* of Figure 33 illustrate how the subsumption of sample-wide RTM effects into the definition of latent subpopulations risks legitimising a spurious change process, by virtue of its representation as a 'quintessential characteristic' of class membership. In a growth modelling context, latent class variables are designed to account for substantively meaningful covariance between initial values and subsequent change, in order to succinctly summarise the typical change process for a group of individuals. Ostensibly, this classification approach should alleviate RTM effects on the basis that group membership is determined by trajectory patterns across all observations, rather than a somewhat arbitrary baseline cut-off (Tu and Law, 2010, Sindall et al., 2015)[117]. However, I contend that GMM is no 'silver bullet' for RTM, and that the implications of RTM should be carefully assessed before interpreting the trajectory shapes that are identified. In future, this problem might be attenuated by collecting two baseline measures (and e.g. taking the mean of these assessments as the initial value) in order to minimise the influence of random situational factors and imperfect test-retest reliability on observed trajectories of change.

---

[116] For both outcomes, the correlation between extremity in initial values (as absolute deviations from the mean log-transformed value of K10 at T1) and absolute change in log-transformed values (from T1 to T3) was positive and statistically significant. K10: Pearson's r=0.126, p<0.0001; SLDS: Pearson's r=0.472, p<0.0001)

[117] In addition, the probabilistic nature of both trajectory class membership and the post hoc assessment of its relation to auxiliary variables might prevent the reification of random fluctuations as 'true change'; an interpretational threat exacerbated when individuals are deterministically pre-assigned to groups along the lines of baseline scores and standing on the auxiliary variable of interest. Jerrim and Vignoles (2013) describe a classic example of the latter situation, where the baseline stratification of individuals by initial measures of academic achievement and socioeconomic status generates spurious 'crossover effects' indicating differential longitudinal patterns of mobility in academic achievement between children from high versus low SES homes.



Panels a & b: orange trend lines depict the global expected relationship between initial scores and observed change at follow-up (with dashed 95% CI).
Panels c & d: Individuals are partitioned according to modal (most likely) class membership. Class-specific trend lines indicate the expected relationship *within* classes.

Figure 33: Paired, log-transformed measurements of psychological distress (panels a, c) and life satisfaction (panels b, d) illustrating the relationship between baseline scores (x axis) and observed change from baseline to final follow-up (y axis)

In the present study, although membership in the 'improving' classes is notionally determined according to both initial status and the rate of change, it remains very strongly influenced by baseline scores. Panels *c* and *d* of Figure 33 reveal a distinct clustering of these classes around the 'worst' scores of either outcome at T1 that differentiates them more clearly from the other classes than do observed changes in these scores. To investigate this further, I cut the distribution of baseline scores for each outcome at the percentile corresponding to the size of the 'improving' class – i.e. the top 27.5% of K10 scores (K10≥10) and the bottom 12.8% of SLDS scores (SLDS≤79) – and estimated the average posterior probabilities for membership in the 'improving' class among these participants. I then repeated this procedure using the same percentiles within the distribution of change in log-transformed values from T1 to T3 (i.e. the bottom 27.5% of change in K10 scores and the top 12.8% of change in SLDS scores). Average posterior probabilities for membership in the 'improving' classes were at least 1.5 times higher among participants with extreme initial scores (0.82 for K10; 0.75 for SLDS) than with extreme change scores (0.47 for K10; 0.49 for SLDS). Evidently, simply scoring 'poorly' on a given outcome at T1 is a strong predictor of membership in the 'improving' classes, while relatively strong improvement in the measure is less influential. One might argue that these classes achieve little more than imposing an arbitrary cut-off toward the extremities of baseline scores, and that the tendency towards 'improvement' among class members merely reflects the intersection of RTM and class membership. This assertion is consistent with our a priori concerns, and is explored statistically in the following section.

We previously stated, based on the class-specific distributions of initial scores, that RTM presents little threat to the interpretation of average change in the 'worsening' classes. This contention is supported in Figure 33 (panels *c* and *d*), where there is little to distinguish the 'worsening' from the 'healthful' classes except for observed changes in the outcome. Despite the fact that RTM clearly influences the magnitude of change within the regions of baseline scores encompassed by these classes, it appears to operate in a similar fashion across classes. That is, RTM effects do not appear to be subsumed into the 'worsening' class by virtue of a distinct set of baseline scores.

4 Statistical assessment of RTM

The influence of RTM on the average rate of change in the 'improving' trajectory classes was assessed using module D5 ('Assessment of regression to the mean') of the PairsEtc program in WinPepi Version 11.56 (Abramson, 2011). This module estimates the expected change in scores attributable to RTM[118] among a subsample of participants, given characteristics of the whole-sample distribution (mean and variability) of the outcome at baseline; the cut-off criterion used to distinguish between groups of individuals within this distribution; and the sample correlations between repeated measures of the outcome over time (Barnett et al., 2005)[119]. WinPepi will not estimate an RTM effect if the chosen cut-off straddles the mean of the distribution, hence it was not feasible to assess RTM for the worsening classes. However, as I have already discussed, RTM is unlikely to account for a significant portion of change in these classes given the reasonably representative nature of initial values among their members.

The approach taken here is to treat the 'improving' classes as though their members were partitioned into a group based on a cut-off score applied at T1. Thus, membership in the high-declining psychological distress class, for example, is treated as though these individuals were identified solely according to their baseline K10 score. RTM theory dictates that we should expect scores for these individuals to decline over time, because the relatively extreme level of distress they reported at the first interview is likely to be partially attributable to chance timing or other random effects. On this basis, WinPepi considers the full distribution of the outcome and, depending on (a) how far into the extremes of the distribution a cut-point is placed and (b) the between-wave correlation in the outcome, calculates the expected RTM effect in terms of the unit change one would anticipate to observe at the next observation point *in the absence of any true change*. In this section, I estimate approximate baseline cut-point within the distributions of each mental health outcome (to reflect membership in the improving class) and use this to estimate the expected change attributable to RTM. Then, I compare this

---

[118]

[119] Thus, the RTM estimation assumes that the 'improving' classes were defined concretely at the first observation according to a certain threshold score. This is not entirely correct; the groups were, in fact, derived probabilistically as a function of *both* initial status *and* the rate of change over time. However, as I will illustrate, the extremity of initial values among participants in the 'improving' classes tends to supersede the influence of change over time in determining class membership, and baseline cut-offs approximated modal class membership reasonably well.

estimate with the average rate of change estimated within the corresponding GMM. Pertinent values used in the present analysis are summarised in Table 54 (whole-sample score distributions) and Table 55 (class-specific baseline cut-points and between-wave correlations).

To determine approximate baseline cut-points for membership in the 'improving' classes, each participant was assigned to his or her most likely class (based on maximum posterior probability in the unconditional GMM) and computed the minimum (or maximum) observed value of the outcome at T1 among members of the high-intercept (or low-intercept) class. To account for uncertainty in these classifications, the analysis was repeated with a more stringent cut-off, taken as the 10th (or 90th) percentile of the outcome at T1 among members of the 'improving' class[120]. This cut-off is consistent with the estimated rates of classification error in each model (see Chapter 4) and tends to discard borderline cases that contribute least to the estimation of mean trajectories[121]. These cut-points are illustrated graphically in panels *c* and *d* of Figure 33 (p.436), and both sets of estimates are reported as the approximate lower and upper bounds, respectively, of probable RTM effects[122].

A log-normal distribution was assumed for each outcome[123] and the RTM effect was computed as the expected ratio of the class-mean score at T3 against the class-mean score at T1. This ratio was multiplied by the class-specific intercept from the unconditional GMM to determine the expected difference in scores attributable to RTM between T1 and T3, then divided by 4.18 years to reflect the annual rate of change attributable to RTM. This allowed direct comparison of the estimated RTM effect to the class-specific slope estimate from the unconditional GMM, as an indication of the extent to which RTM explains observed changes

---

[120] Note also the close alignment between these cut-off values and the cut-off values determined using the percentiles of baseline scores that correspond to the size of the 'improving' class in each model, as described in the previous section.

[121] Average posterior probabilities for membership in the 'improving' class (among those for whom this was the most likely class) were substantially lower for those individuals falling between the two cut-offs (0.55 for K10, 0.64 for SLDS) than those satisfying the more stringent cut-off (0.89 for K10, 0.86 for SLDS).

[122] For each outcome, both the estimated class size and the class-specific mean intercept (i.e. average baseline score) from the unconditional GMM fell between the estimates of these values achieved when using the lenient (minimum/maximum) vs. more stringent (10th/90th percentile) cut-offs. Specifically, the lenient (minimum/maximum) cut-off tended to isolate far too many participants, with an average baseline score that was somewhat less extreme than the GMM intercept. Conversely, the more stringent (10th/90th percentile) cut-off tended to isolate a suitable number of participants (although slightly lower than the GMM solution), but these participants returned an average baseline score that was somewhat more extreme than the GMM intercept. Thus, it is beneficial to report results for both sets of criteria.

[123] Data were transformed to approximate normality using the procedures previously outlined in Chapter 4. K10 data transformation = ln(K10 + 3). SLDS data transformation = ln(SLDS + 15).

in the outcome over time. Wald tests were performed within the unconditional GMM (in Mplus 7.2) to test the statistical equivalence of these estimates, under the null hypothesis that the mean slope parameter in the 'improving' class was equal to the annual RTM effect estimated using WinPepi.[124]

Table 55: Baseline cut-points used to approximate class membership and observed correlations between paired observations of outcomes at T1 and T3

	CLASS CUT-OFF VALUES (AT T1) AND RTM ESTIMATES	Approximate cut-off value (at T1) defining class membership		Log transformed^	
		Min/Max score	$10^{th}/90^{th}$ percentile	Min/Max score	$10^{th}/90^{th}$ percentile
K10	High-declining* *('improving')*	7.0 (n=421)	11.0 (n=227)	2.30	2.64
SLDS	Low-ascending* *('improving')*	85.0 (n=183)	78.6 (n=112)	4.61	4.54
	CORRELATION BETWEEN T1, T3 OBSERVATIONS	K10 = 0.54		SLDS = 0.64	

** Categories reflect modal (most likely) class membership determined by maximum individual posterior probability. ^ Data are transformed to approximate normality using the procedures previously outlined in Chapter 4. K10 data transformation = ln(K10 + 3). SLDS data transformation = ln(SLDS + 15).*

For the outcome of psychological distress, the estimated mean decline in K10 scores attributable to RTM among members of the 'improving' class ranged between -0.73 (minimum cut-off) and -1.02 (10^{th} percentile cut-off) per year. Thus, RTM appeared to account fully for the mean decline in scores estimated within the unconditional GMM (-0.89 points per year). This assertion was supported by a Wald test of equivalence between the unconditional mean slope in the 'improving' class and the RTM effect estimated under the most lenient (minimum) baseline cut-off score (Wald statistic = 1.413, df=1, p=0.235).

For life satisfaction, the estimated mean growth in SLDS scores attributable to RTM among members of the 'improving' class ranged between 1.03 (maximum cut-off) and 1.39 (90^{th} percentile cut-off) per year. In this instance, RTM did not appear to account fully for the mean improvement in scores among members of this class (+2.35 points per year). Wald tests rejected the null hypothesis of equivalence between the mean slope parameter and the RTM effect under the most lenient (maximum) cut-off (Wald statistic = 5.38, df=1, p=0.020) but

[124] These tests accommodate error in the estimates of slope parameters, but treat the RTM effect as a constant value entered as the WinPepi estimate.

retained the null hypothesis of equivalence with the RTM effect under the more stringent (90^{th} percentile) cut-off (Wald statistic = 2.92, df=1, p=0.088). Thus, RTM appears to account for a substantial portion, but not all, of the rise in life satisfaction within this class (roughly 44-66% depending on the cut-off applied). The clinical significance of the unexplained portion of the slope, which reflects an expected change of 0.96 to 1.32 points (on a 102-point scale) every two years, is debatable. This might reflect the restriction of our sample to participants whose residential location remained unchanged, potentially offering a greater sense of predictability, security and control over time, and temporal processes such as aging, educational attainment, and gradual adjustment to stressful circumstances over time (Blanchflower and Oswald, 2008, Horwitz, 2007).

In light of these findings, I feel it is statistically and substantively appropriate to rename the 'improving' classes for each outcome to more adequately reflect the significant role that initial scores play in determining membership in these classes, but also in explaining a substantial proportion of the observed 'improvement' as a statistical artefact of regression to the mean. Thus, I renamed the 'high-declining' distress class to the *'chronic high-distress'* class, and renamed the 'low-ascending' life satisfaction class to the *'chronic low-satisfaction'* class.

Appendix 6.1
Sensitivity analysis: POS 'greenness' and psychosocial resources

1 Preface

This appendix presents the results of sensitivity analyses undertaken to determine whether null associations between POS 'greenness' and coping, social support, neighbouring behaviour, and community participation (reported in Chapter 6, Section 3.1) were attributable to the manner in which the variables had been scaled. Descriptions of the measures, including details of their operationalisation in the original analyses, were presented in Chapter 3 (Section 6.3 and 6.4).

To briefly recap, the four variables were scaled as follows in the analyses presented in Chapter 6:

- Coping was dichotomised to distinguish individuals with 'poor', 'fair' or 'good' perceived coping ability (reference group) from those with 'very good' or 'excellent' coping ability.
- Social support was modelled as a continuous variable (total score) using a censored normal distribution to account for possible ceiling effects.
- Neighbouring behaviour was modelled as a continuous variable (total score) using a censored normal distribution to account for possible floor effects.
- Community participation was dichotomised to distinguish individuals reporting none of four community-focused behaviours (reference group) from those reporting one or more.

A set of sensitivity analyses was subsequently performed to allow for the possibility that effects of POS 'greenness' could be sensitive to the region of the outcome being considered. For example, POS resources could be most beneficial to individuals with an otherwise poor stockpile of psychosocial resources, such that a focus on the full distribution of an outcome obscures the conditions under which POS is most potent. Additionally, in relation to the coping measure specifically, sensitivity to distinctions in the items measured between French and English questionnaires was also assessed. Specific manipulations to the manner in which psychosocial resource variables were operationalised are described on the next page.

2 Manipulations to the outcome variables

Nine sets of sensitivity analyses were performed across the two spatial scales (500m and 1000m) within which POS greenness was measured. The following manipulations were made to the scaling of the psychosocial resource variables:

- ***Coping*** was reanalysed **(i)** using an alternative binary cut point (distinguishing 'poor' and 'fair' coping from 'good', 'very good' and 'excellent' coping) to assess effects in the lower region of coping abilities and **(ii)** as an ordered categorical variable to capture the full range of variability in the outcome.
- ***Coping*** was also reanalysed using **(iii)** the original binary cut point, but with the addition of a dummy covariate for language of interview to account for the distinction in questions posed to French versus English-speaking participants (i.e. coping with 'day to day demands' versus 'unexpected and difficult events'). French-speaking participants were the reference group. A final analysis **(iv)** expanded this model again to include a language*greenness interaction term, which allows for the fact that effects of greenness could differ according to the type of coping being reported.
- ***Social Support*** was reanalysed as a binary variable, employing **(v)** the first, i.e. lowest and **(vi)** the third, i.e. highest tertiles of scores as the cut point. In both cases, the largest group was the reference group. These analyses were intended to explore effects within distinct regions of the outcome.
- ***Neighbouring behaviour*** was also reanalysed as a binary variable using **(vii)** the first and **(viii)** the third tertiles as cut points, for the same reasons as stated above.
- Finally, ***community participation*** was **(ix)** reanalysed as a count (Poisson-distributed) variable to capture the full range of variability in the outcome.

As in Chapter 6, all of the analyses were adjusted for age, sex, physical health, education, income, marital status, employment status and length of residence, as well as socioeconomic deprivation and population density at the level of census tracts. Results are presented in Table 56 and Table 57. No statistically significant effects of POS greenness were identified at either spatial scale. However, two important conclusions were reached from the sensitivity analysis. Firstly, point estimates for all variables were directionally consistent with the point estimates in Chapter 6; for example, POS greenness was associated with lower odds of being in the

lowest tertiles of social support and neighbouring behaviour, and higher odds of being in the highest tertiles of those variables. Thus, the findings seem to be robust to different means of operationalising the psychosocial resource variables. Secondly, associations between POS greenness and coping did not change after accounting for interview language (i.e. the coping item asked) nor was there any evidence for effect moderation by interview language. Thus, although this error in the data collection is likely to have reduced the precision of the coping measure, the majority of evidence presented in this thesis (see also Chapter 3, Section) is consistent with the notion that the items tap into the same underlying construct.

Results of the sensitivity analyses are presented below without further comment. For the sake of parsimony, most covariate effects are not reported in the tables.

Table 56: Sensitivity analyses pertaining to cross-sectional associations between POS greenness within 1000m of the home and coping, social support, neighbouring behaviour, and community participation

	Coping (i) Cut point at 'fair'			Coping (ii) Ordinal variable			Coping (iii) Cut point at 'good'			Coping (iv) Cut point at 'good'		
1000m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	1.29	[0.72	2.30]	1.02	[0.78	1.35]	1.02	[0.76	1.37]	1.02	[0.68	1.53]
POS Availability	1.00	[0.95	1.05]	0.99	[0.96	1.02]	0.99	[0.96	1.02]	0.99	[0.95	1.02]
POS Size >9.31ha#	0.92	[0.57	1.48]	0.87	[0.63	1.19]	0.83	[0.59	1.16]	0.83	[0.60	1.16]
English language	---	---		---	---		1.16	[0.85	1.56]	1.16	[0.85	1.56]
English*Greenness	---	---		---	---		---	---		1.01	[0.57	1.77]
	Social support (v) Cut point 1st tertile			Social support (vi) Cut point 3rd tertile			Neighbouring (vii) Cut point 1st tertile			Neighbouring (viii) Cut point 3rd tertile		
1000m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	0.99	[0.93	1.06]	1.03	[0.97	1.10]	0.97	[0.88	1.07]	1.07^	[0.99	1.14]
POS Availability	1.00	[0.99	1.00]	1.00	[1.00	1.01]	1.00	[0.99	1.01]	1.00	[0.99	1.01]
POS Size >9.31ha#	0.99	[0.92	1.08]	0.95	[0.89	1.01]	1.09^	[1.00	1.19]	0.93^	[0.87	1.00]
	C'ty participation (ix) Count variable											
1000m buffer	IRR	[95% CI]										
POS Greenness	0.87	[0.67	1.13]									
POS Availability	1.02	[0.99	1.04]									
POS Size >9.31ha#	0.94	[0.70	1.26]									

*OR = odds ratio for binary outcomes; IRR = incidence rate ratio for count outcomes. Reference groups reflect the lowest levels of coping in models **(i)** to **(iv);** highest levels of social support or neighbouring in models **(v)** and **(vii)**; and lowest levels of social support or neighbouring in models **(vi)** and **(viii). English** questionnaire asked about coping with 'unexpected or difficult events'; **French** questionnaire asked about coping with the 'demands of daily life'. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median. [95% CI] = 95% confidence interval around odds ratio/estimate. Models adjust for age, sex, self-rated physical health, education, household income, marital status, employment status, length of residence at the current address, area socioeconomic deprivation and population density. ^p≤0.10 *p≤0.05 **p≤0.01.*

Table 57: Sensitivity analyses pertaining to cross-sectional associations between POS greenness within 500m of the home and coping, social support, neighbouring behaviour, and community participation

	Coping (i) Cut point at 'fair'			Coping (ii) Ordinal variable			Coping (iii) Cut point at 'good'			Coping (iv) Cut point at 'good'		
500m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	0.71	[0.40	1.26]	1.06	[0.76	1.47]	1.01	[0.74	1.38]	1.02	[0.70	1.48]
POS Availability	1.00	[0.96	1.04]	1.00	[0.97	1.02]	0.99	[0.96	1.02]	0.99	[0.96	1.02]
POS Size >12.4ha[#]	1.13	[0.59	2.16]	0.91	[0.61	1.35]	0.90	[0.59	1.38]	0.90	[0.59	1.39]
English language	---	---		---	---		1.15	[0.85	1.55]	1.15	[0.85	1.55]
English*Greenness	---	---		---	---		---	---		0.98	[0.56	1.71]
	Social support (v) Cut point 1st tertile			Social support (vi) Cut point 3rd tertile			Neighbouring (vii) Cut point 1st tertile			Neighbouring (viii) Cut point 3rd tertile		
500m buffer	OR	[95% CI]		OR	[95% CI]		OR	[95% CI]		OR	[95% CI]	
POS Greenness	0.97	[0.91	1.04]	1.03	[0.98	1.09]	1.01	[0.94	1.08]	1.01	[0.96	1.07]
POS Availability	1.00	[0.99	1.00]	1.00	[1.00	1.01]	1.00	[0.99	1.00]	1.00	[0.99	1.01]
POS Size >12.4ha[#]	1.03	[0.95	1.11]	0.95	[0.88	1.02]	1.03	[0.94	1.12]	0.96	[0.89	1.03]
	C'ty participation (ix) Count variable											
500m buffer	IRR	[95% CI]										
POS Greenness	0.88	[0.69	1.12]									
POS Availability	1.02	[0.99	1.04]									
POS Size >12.4ha[#]	0.90	[0.67	1.22]									

*OR = odds ratio for binary outcomes; IRR = incidence rate ratio for count outcomes. Reference groups reflect the lowest levels of coping in models **(i)** to **(iv);** highest levels of social support or neighbouring in models **(v)** and **(vii)**; and lowest levels of social support or neighbouring in models **(vi)** and **(viii). English** questionnaire asked about coping with 'unexpected or difficult events'; **French** questionnaire asked about coping with the 'demands of daily life'. POS greenness = average NDVI of POS intersected by buffer; POS Availability = total proportion of buffer comprising POS; POS Size = Median size of POS intersected by buffer, modelled as a binary variable split at the sample median. [95% CI] = 95% confidence interval around odds ratio/estimate. Models adjust for age, sex, self-rated physical health, education, household income, marital status, employment status, length of residence at the current address, area socioeconomic deprivation and population density. ^p≤0.10 *p≤0.05 **p≤0.01.*