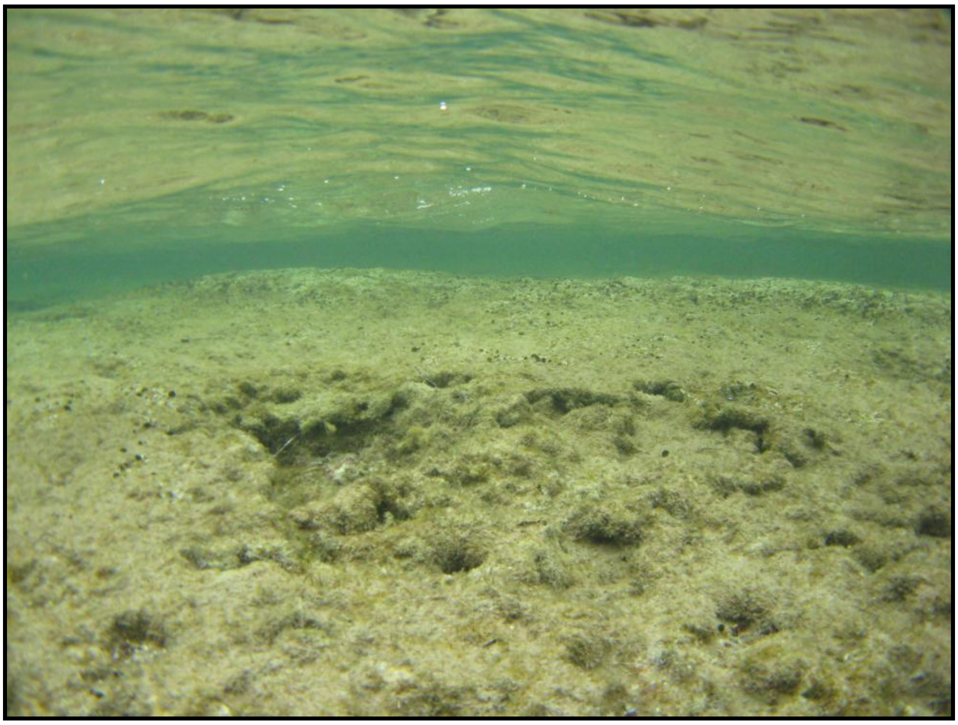
Declining Water Quality as a Driver of Changes to Subtidal Communities



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DEDICATION

I dedicate this thesis to my late father, Phillip Roy Gorman. The help and encouragement Dad gave me throughout undergraduate years and at the onset of my PhD were key influences that drove me to the finishing line. Not only did he push me to reach my goals, but he was also the first to celebrate success. Phillip died on the 19th October 2004, aged 53 years. You will be missed by all who knew you, and remembered as the "king of your castle". As part of this dedication I include the following lyric – from a favourite poet of Dad's and one that I read at his funeral.

A Lyric

If space and time, as sages say,
Are things that cannot be,
The fly that lives a single day
Has lived as long as we.
But let us live while yet we may,
While love and life are free
For time is time, and runs away,
Though sages disagree.
The flowers I sent thee when the dew
Was trembling on the vine,
Were withered ere the wild bee flew
To suck the eglantine.
But let us haste to pluck anew
Nor mourn to see them pine,
And though the flowers of life be few
Yet let them be divine.

T.S. ELIOT

Declaration of Authorship

This work contains no material which has been accepted for the award of any other degree or diploma in any university or tertiary institution to Daniel Gorman and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Cover image: Regime-shifted landscape? An example of structurally simple turfed habitat, common along southern Australia‟s urbanised coastlines. Photograph taken along the Adelaide metropolitan coast in 2008 by the author.

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“Man has only recently come to realise the finite limitations of the coast as a place to live, work and play and as a source of valuable resources. This realisation has come along with overcrowding, overdevelopment in some areas, and destruction of valuable resources by his misuse of this unique environment”. Ketchum 1972

Abstract

This body of work examines the influence of land use on nearshore water quality, and how this can drive changes to algal and invertebrate communities along Australia"s southern coastline. The overall aim of the thesis was to investigate links between increasing coastal water-column nitrogen concentrations (derived from terrestrial inputs) and the expansion of turf-forming habitats that can alter the structure and function of subtidal ecosystems.

I initially tested whether human activities in coastal catchments can increase subsidies of nitrogen to open rocky coasts. I identified landscape-scale variation in the supply of Dissolved Inorganic Nitrogen (DIN) to coastal waters adjacent to natural, agricultural and urban catchments. Compared to natural catchments, subsidies of DIN were 8 - 407 times greater in urban catchments, and 1 - 63 times greater in agricultural catchments. Subsidies of nitrogen from urban catchments were attributed to the release of sewage effluent, as delineated by $\delta^{15}N$ isotopic values of transplanted algae.

Having made this link, I then assessed whether catchment-scale variation in nitrogen subsidies may predict patterns of subtidal habitat structure, particularly as related to theories of regime shifts from forested landscapes to structurally depauperate turf-forming habitats. I validated this hypothesis, demonstrating that both relative covers and patch-sizes of turfed habitat were greater where the ratio of terrestrial nitrogen inputs to ambient coastal resources was large. An important realisation was that loss of forests may be more strongly related to the size of subsidy (i.e. the relative increases in water column nitrogen concentrations along urban coasts) rather than the size of coastal populations. Together, these data link coastal development with modified land-to-sea subsidies, and indirectly support the model that ecological effects may be proportional to the disparity between donor and recipient resources.

Having demonstrated a link between nitrogen subsidies and subtidal habitat change, I then investigated factors likely to initiate and maintain such shifts. My results demonstrate that nutrient elevation can alter the natural phenology of turfs, sustaining dense covers throughout periods of natural senescence (winter). Perennial turf covers are able to accumulate large volumes of sediment; a synergy can impede the winter recruitment of canopy-forming species (kelps and fucoid algae). My observations of reduced forest recovery along urban coasts serve to highlight the complex interaction between elevated nutrients, persistent turf covers and increased sediment accumulation, which can reduce the resilience of coastal ecosystems to disturbance.

In recognition that regime shifts are likely to have consequences for higher trophic levels, I compared the diet of invertebrate herbivores from healthy and degraded coastlines using stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$). Dietary modelling showed that turfs contributed more to the diet of consumers along degraded coastlines where turfed landscapes have replaced extensive covers of macroalgal forest. Additionally, there were strong correlations between covers of turfed habitat, herbivore diet and relative densities. Changes to ambient food quality associated with regime shift may be an important aspect of nutrient-driven change along human-dominated coastlines.

The final component of my thesis redressed some of the uncertainty about restoration initiatives for urban coasts by demonstrating that regime shifts are not necessarily permanent. I showed that turf removal can facilitate the recovery of degraded forests. Future restoration, therefore, is a possible outcome of polices that aim to decouple the link between nutrient inputs and recalcitrant turfed habitats that prevent forest recovery. Initiatives that reduce nutrient discharge to coastal waters (e.g., wastewater recycling) are likely to restore the resilience of nearshore marine ecosystems and promote their rehabilitation.

Acknowledgements

I am indebted to my supervisors Sean Connell and Bronwyn Gillanders, whose energy and enthusiasm for subtidal and estuarine ecology is truly inspiring. To colleagues and members of the Southern Seas Ecology Laboratories (past and present) who helped with fieldwork, labwork, and to make time spent in the office both stimulating as well as entertaining. Special thanks, in addition to photo credits (below) to, The Livore family, A. Irving, T. Saunders, S. Hart, B. Roberts, C. Izzo and J. Brooks. Thanks also, to the many who offered passionate discussions about science held on the green couch or in various Rundle Street hotels. I am also thankful for the love and support of my family and friends, especially Mum and Rainer; Amy Vomiero, Delphine Fleury, Claire Doughty and the group-of-8 brotherhood (while not exactly beneficial to a life of study, were always there when needed).

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Chapter Acknowledgements

(As per individual manuscripts)

Chapter two

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Chapter three

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Chapter four

This research was driven by the need to understand the affects and the potential for reversing subtidal regime shifts along the southern coastline of Australia. We are thankful for the helpful comments of Bronwyn M. Gillanders and Bayden D. Russell. Financial support was provided through an Australian Research Council Grant to Sean Connell and a Lirabenda Endowment Fund Research Grant to Daniel Gorman. We thank R. Diocares for mass spectrometry, I.J. Carlson for assistance with nutrient analysis, T. Saunders and A.F. Dobrovolskis for field assistance. The experiments performed in this study comply with the current laws of Australia.

Chapter five

We thank the farsighted recognition of P. von Baumgarten (Principle Marine Policy Adviser) and her department (The Department of Environment and Heritage) for commissioning this research to guide development of new policy on coastal management. The Australian Research Council (ARC Linkage) provided leverage funds to assist DEH achieve our work in an applied context. These research outcomes have been used by the South Australian Department of Premier and Cabinet as part of its coastal planning and water recycling initiatives. Helpful comments were provided by T. Wernberg. Field assistance was provided by J. Brooks, J.P. Livore and J.R. Naumann. Daniel Gorman was supported by a Wildlife Conservation Foundation Research Grant (0254), and Sean Connell by a QEII Fellowship.

Conducting broad-scale subtidal research along Australia‟s southern coastline requires a great deal of logistical planning, and a „big‟ boat. Research vessel „Odax‟ in front of Australia‟s parliament house. Photograph taken by the author during the Southern Ocean trip 2005.