SUSTAINING THE WESTERN MYALL WOODLANDS: ECOLOGY AND MANAGEMENT

by

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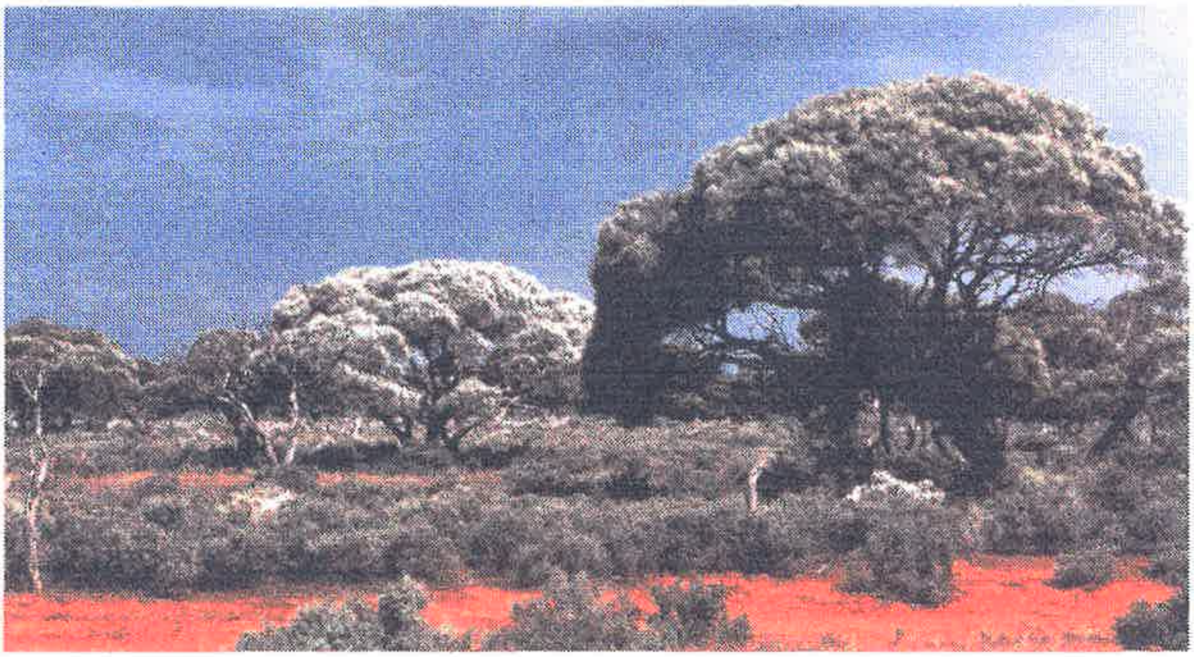

"Myall is the most attractive tree found in the arid country of South Australia...its branches and foliage sweep to the ground and the new foliage...has a silvery grey colour."

R.W. Jessup (1951)
Soil Conservation Officer, Department of Agriculture, South Australia
The Soils, Geology and Vegetation of North-Western South Australia.
Transactions of the Royal Society of South Australia 74

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ABSTRACT

When this study began, the western myall (*Acacia papyrocarpa* Benth.) was widely perceived to be under threat. There were concerns about the future sustainability of the species. In the Whyalla area in South Australia where the species has been well studied, evidence suggested that the population was aging with recruitment being suppressed, apparently by herbivores. Compared to the pre-settlement era, the western myall woodlands are now subjected to sheep grazing, rabbit infestation and much larger kangaroo populations. The aim of this project was to assess the sustainability of western myall under current land usage across the major part of its range in South Australia and thus provide a basis for land management strategies to ensure its survival.

Key features of the population dynamics of western myall were not known. For example, it was regarded as a long-lived species but its true life span had not been established. Prior to this study, a minimum life span of at least two hundred and fifty years had been inferred from a short (10 year) growth study. Recruitment is infrequent, possible only a few events every century, in keeping with the unpredictable, arid environment in which it grows. A review of the existing knowledge about western myall indicated the following key issues as the most relevant to my broad objective:

- confusion about its geographic range,
- the impact today of the introduction of vertebrate herbivores about a century ago,
- uncertainty about its population dynamics,
- the lifespan of the species, and
- variations in population structure across its range: are the Whyalla populations typical?

I determined the likely limits to the geographic range of western myall in South Australia by a review of the literature and from Herbarium and other records of the South Australian Department of Environment and Natural Resources and then investigated its geographic boundary by field surveys..

I used the knowledge that western myall recruits infrequently, information about the grazing behaviour of sheep, rabbits and kangaroos, and century-old maps of paddock subdivision and watering point location to investigate the historical impact of the introduction of vertebrate herbivores on the landscape. In the process I developed the new concept of "fossil paddocks" (FP). An FP is an old paddock that has had a new pattern of smaller paddocks and new watering points progressively imposed upon it. Evidence from this study suggests that many cohorts of western myall that emerged this century are essentially missing even in the absence of sheep grazing. The study also indicated that recruitment has occurred in the presence of sheep. There is no evidence that kangaroos suppressed the cohorts however rabbits are certainly implicated; my study shows that recruitment occurred most abundantly in areas where there are no modern rabbit populations, and was almost completely absent where rabbit populations flourish.

The population dynamics of the species were studied to assess the adequacy of seedling recruitment. The focus of that study was on the various factors that eliminate seedlings, because seedling emergence is driven by episodic events and is unlikely to be under the direct influence of pastoral managers. My study revealed that recruitment is much more common across the woodlands as a whole than had previously been assumed from the Whyalla research. Furthermore recruitment was associated with the absence of rabbits, and was apparently independent of the presence or absence of sheep and kangaroos. This is an important finding.

My studies show that rabbits appear to be more of a threat to western myall seedlings than sheep. The seedlings and adult foliage of western myall are palatable to both rabbits and sheep, however sheep show a clear preference for adult foliage over seedlings and reject both (particularly seedlings) if other forage species are available. Rabbits appear not to discriminate between adult foliage and seedlings.

I undertook three studies to gain an understanding of the life span of mature individuals (dendrochronology, mortality from aerial photographs and radiocarbon dating) as a prerequisite to estimating the rate of recruitment needed to maintain the populations and thus allow management strategies to be formulated. Mature and aged western myall trees posses a very striking habit; with age their branches sweep to the ground with the increasing weight of foliage - eventually they becoming procumbent. By repeatedly propping on the ground and growing upright again (up to six times) the gnarled branches of some of the oldest specimens become polyprocumbent. The dendrochronology study yielded credible age ranges for all but the oldest life stages of western myall. The greatest age I obtained using dendrochronology was 350 years for a middle aged specimen with one event of procumbency. There are trees which are clearly very much more aged than this; unfortunately these generally have rotten heartwood and are thus not good candidates for dendrochronology. However, I speculate that these oldest trees must be at least 500 years and likely very much older.

Results of my mortality study also indicate that the life span of the oldest trees in the populations may be much more than 500 years. Other findings from the mortality study are that rates of mortality vary across the woodlands in South Australia and are higher in the south than in the north. I was able to calculate the numbers of recruits needed at each recruitment event in order to maintain the populations; in the south at least 11 recruits are needed per 100 trees at each event whereas in the north the number required is only six. While these levels of recruitment are observed in some areas of the woodlands, particularly in the north, clearly in many areas the required rate of recruitment is not being sustained.

I examined the population structure of western myall across the woodlands in the study area. My studies show an aging population in the south with a younger, more vigorous, population to the north. Given the fluctuating climate of the late Pleistocene and Holocene Periods the woodlands we see today can only have been in existence for a maximum of 10,000 years, and given that trees are long-lived, I propose that the western myall may still be expanding its range northwards from prehistoric refugia located further south.

In aggregate, the results of these investigations cast doubt on the conventional view that the continued viability of the western myall woodlands is unsustainable in the current pastoral sheep-grazing regime. The occurrence of episodic events obviously plays a major role in recruitment. Rabbits, when present, remain a threat to both seedlings and juveniles; sheep on the other hand, whilst consuming both in small quantities, appear to have less of an impact on seedlings. Furthermore the recruitment patterns vary significantly in different parts of the species' range possibly due to long-term biogeographic trends. Currently in the north mortality is lower, trees are generally younger and rates of recruitment are higher than in the south.

From my study a picture begins to emerge of a species that is recruiting in the arid zone in spite of pressure from some vertebrate herbivores. This is however an oversimplification. Whilst it is recruiting well in some areas, mortality and life span studies show that in many areas not nearly enough recruits survive at each event in order to maintain the populations. In spite of this, it is apparent that some western myall recruitment can occur under the current sheep stocking rates in the absence of rabbits. Whether rates of recruitment would be higher in the absence of sheep is not known; the precautionary principle should thus prevail and no attempt should be made to raise the current conservative stocking levels.

If the western myall woodlands are to be preserved, the fundamental management aim must be to maintain the populations by enabling the recruitment of enough individuals and by maximising the survival of adults. The removal of pastoralism at its current rates of stocking and the spelling of paddocks after recruitment occurs would not obviously improve the situation for western myall in South Australia. Proposed strategies for the management of the western myall woodlands include the control of rabbits (the recent release of calicivirus into the area coupled with follow-up warren ripping is an obvious strategy) and the protection of juveniles with rabbit-proof tree guards. These measures however, are extremely time consuming and costly.

The real threat to western myall is at the contracting edge of its range (the south) and active management may be needed to ensure the maintenance of populations here. The precise technology to do this is not clear but this thesis provides insights for future research to this end.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution 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.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopy.

Carolyn Ireland

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Finally, I dedicate this thesis to my mother, Peggy, who unfortunately and very tragically died before I could finish. How she would have loved to share this moment with me!

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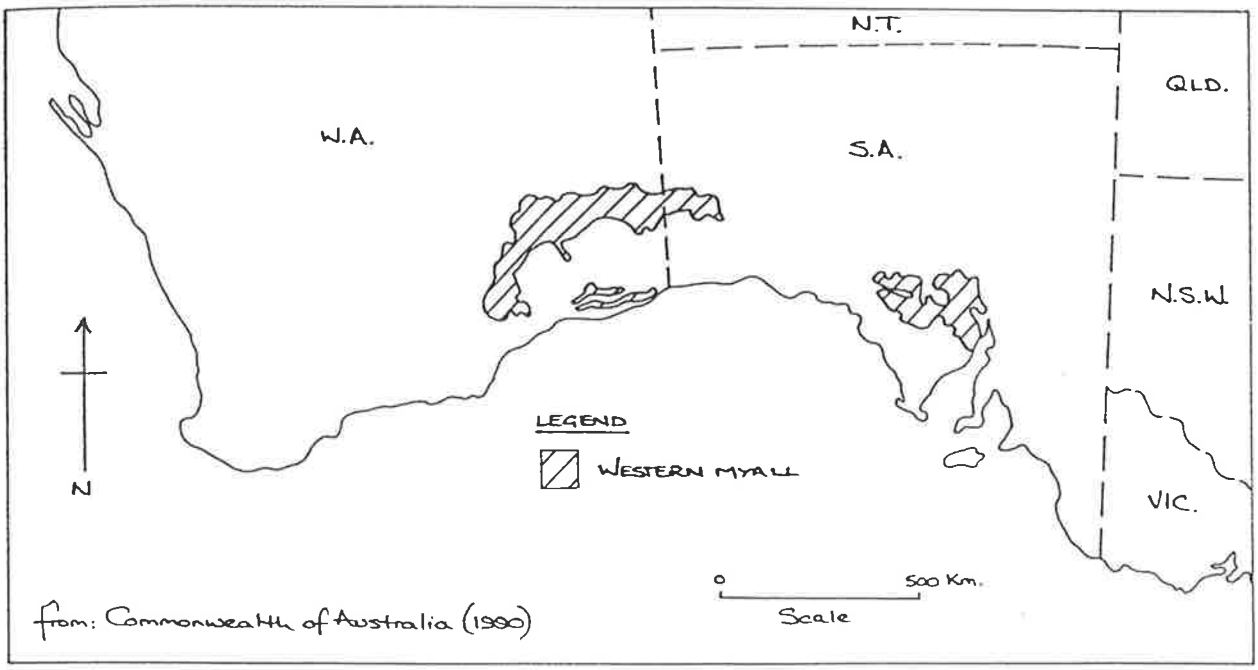
CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Acacia papyrocarpa Benth.[1] (western myall) is a characteristic and important overstorey species of a portion of the chenopod shrubland in South and Western Australia. A major occurrence of these woodlands is found on calcareous soils in the 150-300 mm annual rainfall zone to the north-west of Spencer Gulf and it is also prominent along the margins of the Nullarbor Plain in Western Australia. The areas of Australia where western myall is the dominant tree species in the landscape (Commonwealth of Australia, 1990) are shown in **Figure 1.1**.



from: Commonwealth of Australia (1990)

Figure 1.1: The areas of Australia where western myall is the dominant tree species

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[1] For simplicity, *Acacia papyrocarpa* Benth. is referred to as the western myall throughout this thesis

Western myall is described by Whibley and Symon (1992) as:

> *"Tall shrubs or small trees 3-7 m high, normally multi-stemmed and forming neat rounded, spreading, umbrageous canopies which often appear silvery-green with new growth".*

The species grows either as an individual (**Plate 1**) or in groves of several trees (**Plate 2**) (Lange and Purdie, 1976). **Plate 3** shows a tree that is typical of the oldest found in the western myall woodlands. It was estimated by Correll and Lange (1966) to be at least 250 years old and probably much more. The older members of the population have branches that become procumbent with age, a distinctive and most attractive characteristic of the species.

Plate 1: *Acacia papyrocarpa* Benth. - The western myall

Plate 2: A grove of western myall

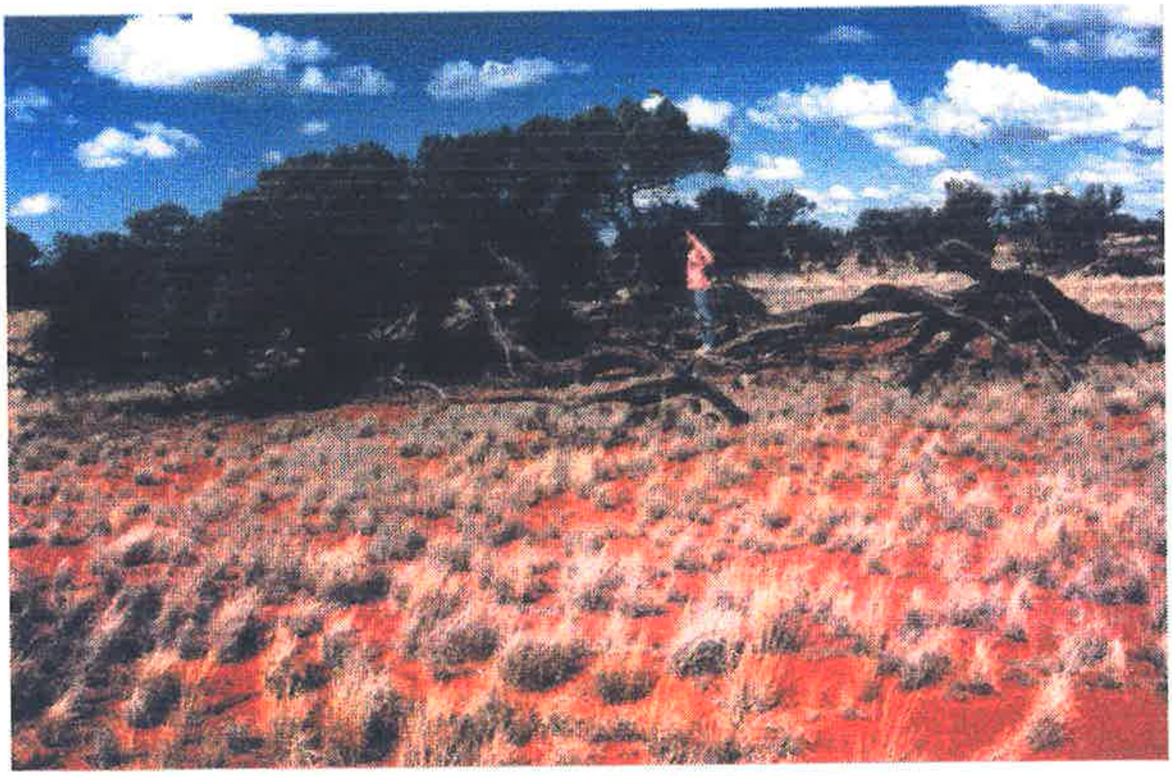

Plate 3: A very old specimen of western myall

The western myall is a valuable tree, not only in terms of pastoral use and functioning of the ecosystem, but also for its aesthetic appeal. Economically the species has value as browse, as shade for stock and as a source of fence timber (Lange and Purdie, 1976). Ecologically it is a very important leguminous tree, the habitat of a unique community of plants and animals (insects, birds, lizards, bats, spiders, centipedes, arthropods, annelids and reptiles) that do not occur out in the open (Murray 1931; Reid, 1984; Tester *et al.*, 1987; Read, 1987), and it is a likely key hydrological factor in the landscape. It also provides an important environmental focus; each tree is an ecological microcosm surrounded by a "halo" of open ground virtually bare of ephemeral species (Brock, 1993; M.H. Andrew *pers. comm.*). These haloes occupy approximately 15-20% of the land surface in the western myall woodlands (M.H. Andrew, *pers. comm.*). Aesthetically the species adds beauty to the landscape with economic benefits for eco-tourism and recreation. Jessup (1951) describes western myall as:

> *"...the most attractive tree found in the arid country of South Australia".*

When this study began, the western myall was perceived to be under threat. Evidence from the Whyalla area in South Australia where the species has been well studied (Correll and Lange, 1966; Lange and Purdie, 1976; Lange and Graham, 1983; Ireland 1992), indicates that the populations appear to be aging and not being replaced. In the past, domestic and feral herbivores have been implicated in the suppression of recruitment. Certainly in the region where it is best known, it is of concern to pastoralists, government agencies and the general public alike that recruitment of the western myall is seldom seen.

One of the fundamental aspects of this work was to try to ascertain a life span for the species. The western myall is thought to be long-lived - at least 250 years (Correll and Lange, 1966; Lange and Sparrow, 1992) and possibly much longer. In the arid and unpredictable environment in which it grows, recruitment events are infrequent, possible only a few every century (Lange, 1971c). We need to study the population dynamics of the species to assess the adequacy of this recruitment and the seriousness of recruitment suppression. It is clear that unless we know what the lifespan of the species is, we cannot predict how many new recruits are needed to maintain the populations or make sensible suggestions for their management.

There are 729 described species of *Acacia* in Australia and an estimated 150 undescribed taxa (Maslin and Pedley, 1982); as such, it is the largest genus of higher plants on the continent. Little is known about the dynamics of many *Acacia* species in the Australian arid zone, however, there have been some specific studies. Preece (1971) studied the climatic requirements for regeneration of *Acacia aneura*; Brown (1985) using the same species, looked at the growth and survival of young populations under different levels of sheep grazing. Friedel (1985) examined the possible influences of range condition, rabbit abundance, soil erosion and soil characteristics on the trees and shrubs (including *A. aneura, A. estrophiolata, A. murrayana* and *A. tetragonophylla*) of four central Australian pasture types. At Middleback Station in South Australia both Purdie (1969) and Dickson (1983) studied the population structure of *A. papyrocarpa*, whilst Lange and Graham (1978) conducted experiments to test the effect of rabbit grazing on recruitment of seedling populations of *A. papyrocarpa, A. kempeana, A. oswaldii* and *A. burkittii.* The age structure, distribution and survival under grazing of *A. burkittii* was determined by Crisp and Lange (1976) at the T.G.B. Osborn Vegetation Reserve on Koonamore Station in South Australia. Grice *et al.* (1994) looked at the dynamics and population structure of *A. victoriae*. The conservation status, regeneration and impacts of grazing on populations of *A. carnei* and *A. oswaldii* (Auld, 1990 and 1993) were examined at Kinchega Conservation Park in western New South Wales as were the population dynamics of *A. ligulata* and *A. loderi* (Auld, 1995).

Researchers in other parts of the world, particularly in Africa, have studied aspects of the biology of *Acacia*. In Kenya *A. nilotica* flowers during the rainy season (Tybirk, 1989). Giraffe in Kruger National Park, South Africa were implicated by Du Toit (1990) in the pollination of *A. nigrescens*. In the Mana Pools National Park in Zimbabwe, Dunham (1991) studied the phenology of *A. albida* over a period of eight years. Ernst *et al.* (1989) examined the predation of *A. tortilis* seeds by insects in Botswana finding that bruchid beetles were the major predators. Lamprey et al. (1974) found the same relationship in the Serengeti National Park in Tanzania. However, Miller (1994) found that infestation of seeds by Bruchid beetles did not effect germination rates in *A. tortilis, A nilotica* and *A. hebeclada*; Mucunguzi (1995) found the same relationship for *A. sieberiana* but not for *A. gerrardii* in Queen Elizabeth National Park, Uganda. Conversely, Sabiiti and Wein (1987) found that germination was significantly reduced in *A. sieberiana* at the same location, they also found that fire tended to kill the infestations of Bruchid beetles and that seedlings were commonly found growing from elephant dung. In South Africa Holmes (1990) found that ants were the major dispersers and rodents the major predators of *A. cyclops* and *A. saligna* seeds.

Ecosystems in Australia are very different from those elsewhere. Rainfall is highly unpredictable and the rainfall events that are likely to have beneficial effects on ecosystems are infrequent and heavy. In the North-West Pastoral District of South Australia widespread rainfall events, referred to as flood years, have happened this century in 1921, 1946, 1973 and 1974. Scattered but very heavy falls occurred over some parts of the District in 1938, 1968 and 1989[2]. The landscape of much of arid Australia is mature and fairly flat and soils are relatively infertile. Heavy rains that recharge water tables also cause extensive surface flows and create flows in subsurface systems moving water and nutrients to and through the vegetation (Stafford Smith and Morton, 1990). Overland flow of water results in patterns of fertile patches in run-on areas that are more productive than those in adjacent run-off areas. The same infertile soils and arid, unpredictable climate have influenced plants and animals to develop distinct life strategies unique to each part of the landscape. Fire also plays a major role as a driving force in many parts of the arid zone; nutrients are recycled and adult plants removed thus maintaining species diversity (Stafford Smith and Morton, 1990). Stafford Smith and Morton (1990) conclude that forces shaping the vegetation and animal communities in arid Australia are different from those elsewhere in the world because no other arid ecosystem experiences unpredictability to the same extent.

The western myall is a species well adapted to those characteristics of the Australian arid environment. It exists in a variable climate and consequently generates erratic recruitment which is perceived to be under threat from introduced and native herbivores. Moreover, our knowledge about the lifespan of the species and its population dynamics is imperfect. Just how best to manage the woodlands wisely in order to sustain the populations of the western myall is problematic. This thesis will attempt to address some of these aspects of western myall ecology in which greater understanding is most likely to lead to better management of the extensive ecosystems which they dominate.

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[2] Climate data from the Bureau of Meteorology, 25 College Road, Kent Town South Australia

1.2 LITERATURE REVIEW OF WESTERN MYALL AND RELATIONSHIPS TO THESIS STRUCTURE

Studies of individual perennial plant species in the arid zone are useful tools for our understanding of ecological processes. Some examples in the Australian arid zone include mulga (*Acacia aneura*) by Preece (1971) and Nix and Austin (1973), and pearl bluebush (*Maireana sedifolia*) by Wotton (1993). Elsewhere in the world studies of creosote bush (*Larrea divericata*) ecology were undertaken by Barbour (1969) and Mabry *et al.* (1977).

Studies through time of perennial plants in the arid zone can provide insights into their life histories that would not otherwise be available. One of the more famous of these is Hastings and Turner's (1965) *"The Changing Mile"* in which a study of vegetation change over time was undertaken using photographs taken between 70 and 80 years apart. White (1985) describes a long-term study of the saguaro cactus (*Carnegiea gigantea*) at the Desert Botanical Laboratory near Tucson, Arizona; the species was mapped plant by plant over about 700 ha. (Spalding, 1909) and parts of the area were re-mapped in 1964 and 1970 by J.R. Hastings and R.M. Turner. In Australia a long-term census of vegetation began in 1925 at the T.G.B Osborn Vegetation Reserve at Koonamore in South Australia (Wood, 1936; Hall *et al.*, 1964) and continues to this day (Russell Sinclair *pers. comm.*).

Tree-rings may also be used to age long lived tree species. Two examples are the bristlecone pines (*Pinus aristata*) of the White Mountains of California (Ferguson, 1969) which have a tree-ring chronology reaching back more than 7000 years; more recently in Tasmania, Australia, Cook *et al.* (1991) studied a 1089 year tree-ring chronology of the Huon pine (*Lagarostrobus franklinii*).

1.2.1 AUTECOLOGY AND PHENOLOGY

The western myall is restricted to arid and semi-arid saltbush and bluebush pastoral lands of South and Western Australia where it enhances much of the landscape (its distribution is investigated more extensively in CHAPTER 2). Continuous pastoralism in these areas for over 100 years has shown that the western myall woodlands enable productive pastoralism (Lange and Purdie, 1976; Mitchell *et al.* 1988).

In 1991-92 I undertook an autecological and recruitment study of the western myall at Middleback Station in South Australia during one seasonal cycle of the species (Ireland, 1992) and this work provides the basis for the following account. Studies of phenology begun in 1991 have shown a regular seasonal cycle of flowering and seed set. Generally they display their yellow blooms between August and September and set large, shiny brown seeds in papery pods between October and December. Vegetative growth occurs every year between November and February - these new phyllodes shimmer brilliantly silver in the wind. (This verifies the work of Maconochie and Lange (1970) at Yudnapinna Station in South Australia who found that, irrespective of rainfall, foliation and defoliation of western myall was cyclic on a seasonal basis. Foliation rates increased rapidly between spring and midsummer, declining slowly towards mid-winter).

The cycle differs in detail from tree to tree and in abundance from year to year: flowering, fruiting and growth of new phyllodes begins at slightly different times in different trees; the length of time any individual spends in flower, carrying seed pods or growing new phyllodes also varies widely; 1990-91 was a mast year but in 1991-92 flowering and fruit production was sparse and further curtailed by high pre-dispersal losses.

Flowering was significantly greater in all parts of the trees in 1991 compared to 1992. In both years more flowers were located on the lower canopy than on any other part of the tree. If a tree flowered or was barren in one of eight segments in 1991, there was a high probability that it would flower or remain barren in that same segment in 1992. Flowering and fruiting was not randomly distributed on trees in 1991, but preferentially located on the more northerly segments of the trees. Conversely, the distribution of flowers and pods in 1992 was random. However, in 1992 there was less flowering and therefore less sensitivity for the test. It appeared that a relative abundance or paucity of total flowers on individual trees in 1991 was not repeated in 1992. An abundance or lack of flowers and fruit on any individual in 1992 was not, as might have been expected, directly related to that of the previous year. That a tree should preferentially partition its flowering resources into the same segments two years in a row, particularly when the first of those years produced such an abundant crop, is also difficult to understand. The hypothesis concerning the random or non-random distribution of fruits on trees showed that the process was not random in the mast year but was effectively so in the following year. It appears from the above results that the trees may favour the north or sunnier side of the tree on which to concentrate their reproductive effort. This study will continue for 10 years from 1991 and results will be published at that time.

By the end of January seeds fall and most are quickly removed and probably destroyed by harvester ants. Ants, rather than vertebrates, are the major removers of western myall seeds. These ants are destructive seed predators rather than benign seed dispersers and even though they do show a significant preference for seeds with arils (Ireland and Andrew, 1995a), effectively all seeds are removed and destroyed. It is not known whether a changing regime of disturbance since the beginning of pastoralism may have altered the composition of the ant fauna from one dominated by seed dispersers to one dominated by seed harvesters (Andersen, 1990). At Middleback, an undergraduate project (McAlister, 1995) compared the composition of ant faunas in heavily grazed and ungrazed areas (a cross-fence comparison). Although on a very small scale and not very well replicated because of time constraints, results have indicated that there may be a trend in the differences between the ant faunas in these two land types.

1.2.2 RECRUITMENT

The causes of recruitment suppression have resisted attempts at understanding. There appears to be little evidence that points exclusively to either rabbits or sheep (Lange and Purdie 1976; Lange and Graham 1983). During the past few years it has become more apparent that many factors can inhibit recruitment of western myall (and also many other arid zone perennials):

- Undoubtedly, recruitment in the western myall itself has been moderately to severely suppressed since the introduction of exotic herbivores - rabbits and sheep (Lange and Purdie, 1976; Lange and Graham, 1983). However there are no earlier records against which to compare pre-settlement rates of recruitment.

- Kangaroos are also present in the rangelands in much larger numbers than in the pre-pastoral era (Sturt, 1849; Wilson *et al.*, 1984; Robertson *et al.*, 1987; D.A. Nicolson, *pers. comm.*) and their impact on western myall has not been studied.
- Small herbivorous marsupials (<3 kg.) which are now either extinct or much less common because they have been displaced by introduced species (particularly the European rabbit - *Oryctolagus cuniculus*) may have had a role to play in the suppression of recruitment (Caughley, Short and Wellard, 1987). Morton (1985), however, considers that these mammals are often insignificant consumers in the Australian arid zone; he further proposes a conceptual model (Morton, 1990) of small mammals restricted to *"scattered pockets of suitable habitat"* because most of the land was originally difficult for them to colonise. Noble (1996) hypothesises that a factor in the past regulation of shrub densities in the Australian rangelands may have been a combination of periodic wildfires and browsing by the burrowing bettong (*Bettongia lesueur*) and brush-tailed bettong (*B. penicillata*); both species now have drastically reduced ranges in Australia. He cites Archer (1993) who suggested that seedling establishment of mesquite (*Prosopis glandulosa*) prior to pastoral settlement may have been controlled by the fossorial black-tailed prairie dog (*Cynomus ludovicianus*) in Texas. In the Serengeti National Park, Tanzania, the small browsers, Thomson's gazelle (*Gazella thomsoni*), Grant's gazelle (*G. granti*), dik-dik (*Madoqua kirki*) and impala (*Aepyceros melampus*) are thought to be responsible for the slow regeneration of *A. senegal-A. hockii* woodlands (Belsky, 1984).
- I have found that species of *Pheidole* ants are the most abundant seed removers at Middleback. No evidence was found that the ant faunas there assist in the process of recruitment; most western myall seeds are taken too far underground for recruitment to occur. However, because western myall is a long-lived species and recruitment appears to occur abundantly but in rare circumstances, this routine but near-complete seed predation may not affect the overall rates of recruitment in the long term (Ireland and Andrew, 1995). Although natural shallow burial of seeds is rare, a high percentage of experimentally buried seeds exhibited innate dormancy and the capacity to remain viable in the soil for at least eight months during 1991-92 (Ireland, 1992).
- Aridity may play a role in failure of recruitment of the western myall. Read (1995) found that all his monitored *Callitris glaucophylla* seedlings at Roxby Downs in South Australia died from desiccation within 18 months of germination despite above average rainfall.

Acacia seedlings may often die in similar circumstances after germination events (although information is lacking).

In most years there is no recruitment to western myall populations (Lange and Purdie, 1976). I have hypothesised (Ireland, 1992; Ireland and Andrew, 1992) that the years that are important for recruitment are those in which a substantial rainfall event occurs at seed fall. The species generally does not produce adventitious regrowth and thus relies on seed alone for regeneration (Lange and Purdie, 1976). My hypothesis is that it is the rare co-occurrence of inundation; scarification and shallow burial of seed by the resulting action of sheet water flow; and the consequential protection from seed harvester ants (Ireland and Andrew, 1992) together with a favourable micro-environment for germination and establishment which is crucial for large emergence events in the western myall. Lay (1972) also observed that a factor common to many occurrences of western myall regeneration is soil disturbance. This hypothesis is expanded in CHAPTER 3.

A characteristic of the Australian arid zone is the episodic nature of recruitment events (Noble, 1986). Years of exceptional rainfall (i.e. years in which a monthly rainfall total exceeded 100 mm) are estimated to occur approximately five times per century in the Whyalla area (Lange, 1971c). During the past 100 years, such events have occurred in 1893, 1921, 1946 and 1973-74, the last three within living memory (Lange, 1971c). Each resulted in a major emergence of western myall seedlings in the Middleback area. In the intervening years, little if any recruitment occurred in the open paddocks (Lange and Purdie, 1976; R.T. Lange. D.A. Nicolson and A.D. Nicolson *pers. comm.).* Recruitment has occurred in the intervening years at sites with favourable water regimes and high levels of disturbance (e.g. on roadside verges); because of edge effects these can hardly be considered representative of normal populations. Widespread recruitment is thus likely to occur only four to five times a century, following rare rainfall events. Because western myall trees are so long lived - at least 250 years (Correll and Lange 1966; Lange and Sparrow, 1992) and most likely a lot older (see CHAPTER 5) - this of itself should not affect overall population survival (Ireland, 1992).

However, the onward growth of many of the seedlings that have successfully established appears to have been suppressed for much of the twentieth century, as evidenced by the lack of young trees in many situations. It is interesting that seedlings have also been suppressed in areas that have never been grazed by sheep (Ireland and Andrew, 1994 and 1996; CHAPTER 7). Recruitment does occur, but appears to be restricted to localised patches scattered throughout the western myall woodlands; it is more common in the northern parts of the species' range (see CHAPTER 3). This patchiness is not altogether surprising given the erratic nature of the circumstances under which recruitment seems to occur. Previous research on other species has shown that whether seedlings successfully establish is strongly dependent upon the activities of feral and domestic herbivores introduced since European settlement (Graetz, 1978; Lange and Graham, 1978; Cooke, 1987; Leigh *et al.*, 1989; Johnston, 1991; Henzell, 1991; Lange *et al.*, 1992; Read, 1995; Auld, 1993 and 1995a). However, I have observed that western myall does show some ability to endure grazing; the resulting individuals are small and stunted but surviving (see **Plate 8** in CHAPTER 4).

1.2.3 LIFE STAGE STRUCTURES

Although dendrochronology works well in clearly seasonal climates, it is rarely possible to age long-lived plants accurately in very erratic climates (Crisp, 1978; Silander, 1983). However, the validity of western myall dendrochronology is demonstrated, and it has been used in this study to determine age ranges various life stages and a life span for western myall. The results are presented in CHAPTER 5.

True age structures of a population are often not available; even using dendrochronology they would be time consuming and expensive to collect. An alternative, the "life stage" approach, for large scale studies of population dynamics has been used here. Estimates can be made by applying a detailed census to a strictly defined life stage class based on the idea that size or some other attribute of each class **may** reflect age (Harper, 1977; Silvertown and Lovett Doust, 1993). These are life stages; they relate loosely to age since trees must grow sequentially through successive stages, and they can be applied to a population as an approximate substitute for true age structures. These can then be illustrated with a frequency histogram.

Lange and Purdie (1976) proposed six life stages for the western myall at Middleback Station **(Figure 2.5)** which included three juvenile, two mature and one senescent stage. Lange and Purdie's (1976) scheme of six life stages has been expanded to nine (**Figure 2.6**): two juvenile, six mature and one senescent (Ireland, 1992). A more detailed description of life stages and their use as a fundamental tool for research is given in CHAPTER 2.

Lange and Graham (1976) stated that western myall populations at Middleback exhibit conspicuous and almost ubiquitous gaps in the life stage histograms which correspond with most of the younger life stages; these are also found in other arid zone perennial species such as *Acacia burkittii* at the T.G.B. Osborn Vegetation Reserve at Koonamore Station, South Australia (Crisp and Lange, 1976). Lange and Graham (1976) point out that the life stage of the youngest adults present in Middleback populations of western myall correspond with recruitment at the beginning of pastoralism. Their statement is not disputed. However, limited subsequent recruitment **is** apparent on detailed inspection, and is much more abundant elsewhere in the species' range.

This study proposes that the actual situation in the paddocks may be much more subtle given that grazing at Middleback, and throughout the western myall woodlands, developed progressively across the landscape over a long period of time. Previously inaccessible areas have become increasingly more accessible to sheep grazing. Lange, Nicolson and Nicolson (1984), describe the progressive subdivision of paddocks and water-point proliferation over a period of almost 70 years at Middleback; a process which continues today. The implications of this are explored in CHAPTER 7.

1.2.4 TAXONOMY

Acacia papyrocarpa Benth. (Bentham, 1863-1878) is a member of the subfamily Mimosoideae of the family Leguminosae (Jessop and Toelken, 1986) and has been previously referred to as *Acacia sowdenii* Maiden (Maiden, 1920).

Robert Brown, the *"doyen of British botanists"* (Jessop and Toelken, 1986), accompanied Matthew Flinders on his visit to South Australia between January and April, 1802. Brown collected the type specimen of *A. papyrocarpa* Benth. from Inlet XII in the vicinity of Mt. Brown near the head of Spencer Gulf. The type specimen for *A. sowdenii* Maiden was collected by J.H. Maiden in 1920 from an area close to Port Augusta. It appears that Maiden (1920) may have mistakenly described this specimen as *A. sowdenii* Maiden; Whibley (1980) and Maslin (1980) therefore changed the name back to *A. papyrocarpa* Benth.

Maslin (1980), in considering the two taxa as conspecific, noted that they share the following significant characteristics:

> *".......phyllodes flat, finely longitudinally multistriate, silvery appressed puberulous (at least when young), apices attenuate and delicately curved; legumes chartaceous, flat, c. 1 cm wide, reticulate; seeds compressed. The collections exhibit slight differences...but these are not considered significant."*

A specimen collected by Max Koch from Mount Lyndhurst Station in South Australia and attributed by him to *A. papyrocarpa* is described by Jessop and Toelken (1986) as *Acacia* sp. aff. *papyrocarpa* Benth. Jessop and Toelken (1986) consider that this is probably the specimen described as *A. papyrocarpa* by J. Black (1948). Maslin (1980) refers to this specimen as *A.* sp. aff. *papyrocarpa* Benth. however Whibley and Symon (1992) consider that it is probably an *Acacia* sp. nov.

There are at least three different forms of western myall , the true western myall, the water myall and the Lake Torrens myall. These forms and their distribution are discussed in more detail in CHAPTER 6.

A. papyrocarpa Benth. is related to *Acacia loderi* Maiden ("nealie"). The two species are, however, thought to be geographically isolated from one another although there is conjecture regarding intermediate forms (Crocker and Wood, 1947; Whibley and Simon, 1992). Crocker and Wood (1947) have suggested that they are evolved from the same parent species. The distribution of the different forms of *A. papyrocarpa* Benth. and its related species, *A. loderi* Maiden are discussed in detail in CHAPTER 2[3].

1.3 KEY QUESTIONS, ISSUES AND OBJECTIVES

There have been major concerns about the future sustainability of the species. The project was conceived to assess the sustainability of western myall in a grazing regime and to suggest possible mechanisms to ensure its long-term survival.

The preceding sections of this chapter, particularly the reviews of the existing literature, summarise the aspects of the natural history of the species that were reasonably well understood at the beginning of this study. However, there remained many areas that were only partially understood and also areas for which there was no knowledge (**Table 1.1**).

It can be seen from **Table 1.1** that there are aspects of the ecology of western myall that were not addressed in this thesis; many of these are already reasonably well understood. It was also felt that the following topics were beyond the scope of this thesis: pre-dispersal predation, ecophysiology, pollination ecology and genetics. Flowering and seed set - a ten year study begun as part of my Honours thesis (Ireland, 1992) spanning the time period 1991 to 2001 - will be reported on separately. An investigation of the palatability of western myall seedlings and adult trees to kangaroos was not attempted because of logistic and monetary restraints.

This thesis tackles the following fundamental questions:

- How long do western myall trees live? It is clear that unless a life span for the species is known, predictions can not be made about how many new recruits are needed to maintain the populations. Furthermore, without this knowledge, sensible suggestions for management can not be made.

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[3] The two, less common, forms will be referred to as water myall and Lake Torrens myall. *A. loderi* Maiden will be referred to as nealie.

- **Table 1.1:** A summary of the status of knowledge relating to the ecology and management of western myall

ASPECTS THAT WERE REASONABLY WELL UNDERSTOOD

- Phenology (Maconochie and Lange, 1970; Ireland, 1992)
- Seed dispersal and predation (Ireland and Andrew, 1995a)
- Dormancy and germination (Ireland 1992)
- Life stage structures (Lange and Purdie 1976; Ireland, 1992)
- Use to pastoralism (Murray, 1931; Lange and Purdie 1976; Ireland, 1992)
- Aesthetic appeal in the landscape (Jessup, 1951; Lange and Purdie 1976; Ireland, 1992)
- Taxonomy (Various authors - see SECTION 1.2.4 of this thesis)

ASPECTS THAT WERE PARTIALLY UNDERSTOOD

- ▨ The regeneration niche (Grubb, 1977, Ireland, 1992)
- ▨ Recruitment of individuals to the population (Lange and Purdie 1976; Ireland and Andrew, 1992)
- ▨ Palatability of seedlings and adult trees to rabbits (Lange and Graham, 1983)
- ▨ Population structures (Ireland 1992)
- ▨ Distribution (Various authors - See SECTION 2.3.1. of this thesis)
- ▨ Life span (Lange and Sparrow, 1992)
- Flowering and seed set (Ireland, 1992)
- Pre-dispersal predation (R.T. Lange *pers. comm.*)

ASPECTS FOR WHICH THERE WAS NO PUBLISHED KNOWLEDGE

- ▨ Definitive distribution
- ▨ Recruitment and mortality rates and the environmental variables that may control recruitment
- ▨ Biogeography, the effects of historic climate change on the range of the species and ecotypic variation
- ▨ Palatability of seedlings and adult trees to sheep and rabbits
- ▨ Historical ecology
- ▨ Sustainable management of the species
- Palatability of seedlings and adult trees to kangaroos
- Ecopsysiology
- Pollination ecology
- Genetics

LEGEND	▨	Topics addressed in this thesis
		Topics not addressed

- What is the true distribution of the species? There are significant conflicts between various authors' attempts to map the distribution of western myall. It was decided that a definitive distribution map of the species was required.

- Do population structures change across this range? Information about recruitment and mortality rates is fundamental to the species' survival; knowledge was needed not only about where the species grows and whether population structures differ over the species' range but also what variables may be controlling the patchy recruitment process.

- What is the biogeography of the species (i.e. why are individuals distributed the way they are and have they always occupied the same space)? This had never been examined. In order to explain features observed, an investigation of the possible impacts of historic climate change on the range of the species was required.

- Are seedlings palatable to exotic herbivores? A study had already been carried out to investigate the palatability of seedlings and adult trees to rabbits (Lange and Graham, 1983). However, the palatability of these to sheep had not been investigated, nor had a comparison ever been made between the two exotic animal species or whether ecotypic variation (which affects shoot appearance) influences their palatability to herbivores.

- What are the historical effects of exotic herbivores on the landscape? An investigation of this type on the western myall woodlands had never been attempted. Studies were conducted using a new concept of fossil paddocks (Ireland and Andrew, 1996).

What are the implications of all of this to the ecology and management of the woodlands?

1.4 OUTLINE OF THE THESIS

Between 1993 and 1996 various studies and experiments were conducted in order to achieve the objectives of the project. This thesis addresses those studies; a flow diagram (**Figure 1.2**) shows the position of each study within the logic of the thesis and the various relationship between those studies. The thesis also builds on work undertaken during an Honours year in 1991-92 (Ireland, 1992).

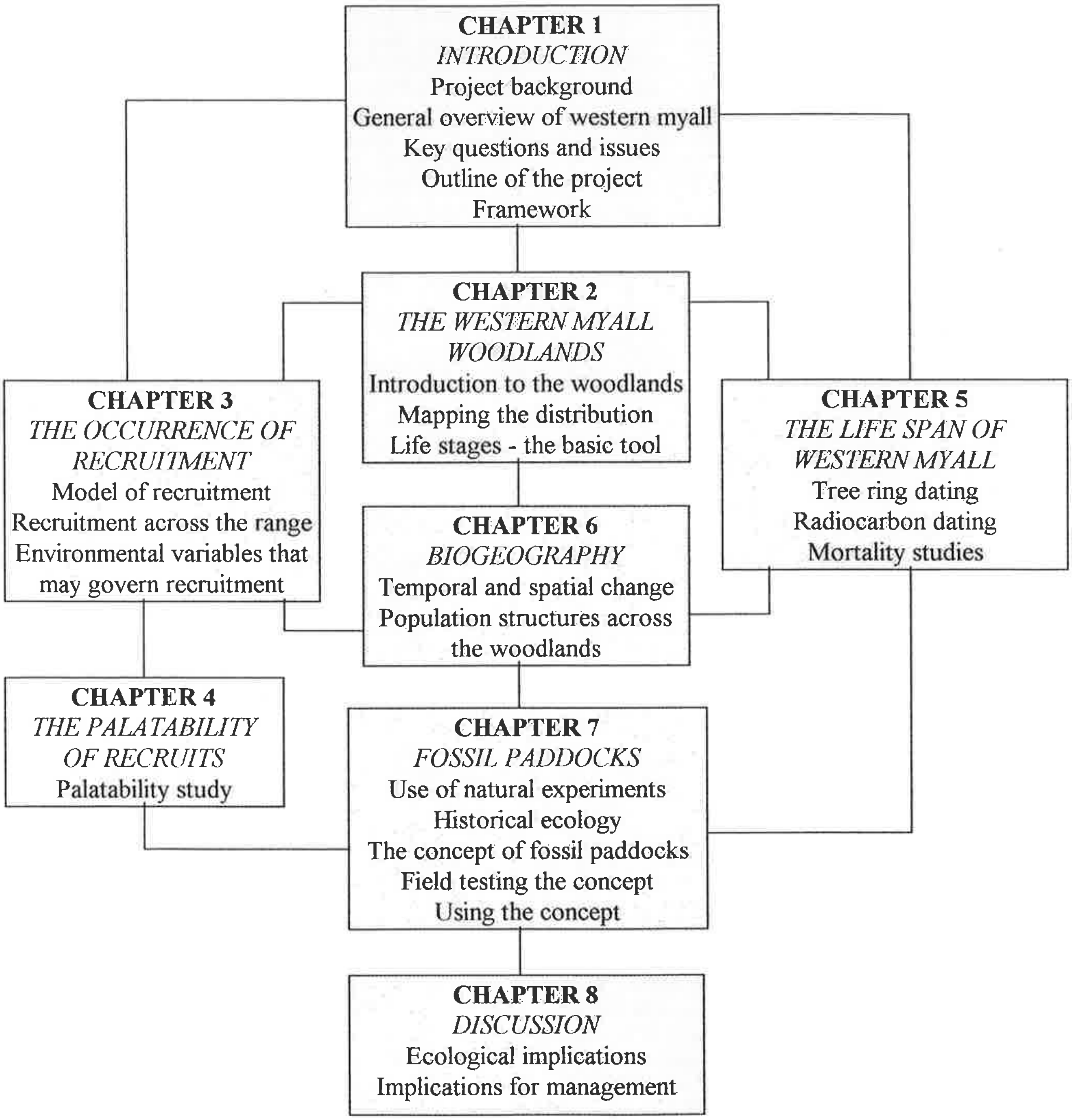

Figure 1.2: Outline and structure of the thesis

In this introductory chapter (CHAPTER 1), the basic knowledge about the western myall has been outlined, key questions and issues concerning its ecology and management have been identified and the objectives and scope of the study defined.

Broad scale distribution of the woodlands and the use of life stages in the study of population structures are addressed in CHAPTER 2.

As recruitment is so fundamental to the survival of western myall this issue has been looked at from two perspectives. CHAPTER 3 examines an updated model of recruitment originally proposed by Ireland (1992); it also evaluates possible variables that may be influencing the patchy recruitment that occurs across the woodlands. CHAPTER 4 takes another approach by examining the palatability of western myall seedlings and adult plants to both sheep and rabbits.

As stated before, the estimation of a life span for the species is critical to an understanding of population dynamics and trends over time. The three complementary methods used to assess the age of the oldest individuals - mortality studies, dendrochronology and radiocarbon dating - are examined in CHAPTER 5.

Drawing on all of the aspects of western myall distribution addressed in previous chapters, CHAPTER 6 takes up the theme of the biogeography of the species by examining temporal and spatial change and population structures across the woodlands.

In CHAPTER 7, the idea the idea of the Fossil Paddock is presented - a new concept for discerning the effects of domestic stock on the landscape, which addresses the historical ecology of sheep grazing in the western myall woodlands. The concept is explained and the results of field testing are presented.

Finally, CHAPTER 8 examines the ecological implications of the findings and discusses management options for the western myall woodlands.

CHAPTER 2

THE WESTERN MYALL WOODLANDS

2.1 INTRODUCTION

As introduced in CHAPTER 1, western myall is the dominant tree species across a broad area of the arid and semi-arid sheep pastoral lands of South and Western Australia (Commonwealth of Australia, 1990; Maslin and Hopper, 1982) (**Figure 1.1**). It forms a low open woodland mostly associated with chenopod shrublands (Lange and Purdie, 1976; Ireland, 1992); these woodlands occupy about one per cent of the land surface of continental Australia. Although the distribution of the species has been described, mapped in part and interpreted by a number of researchers there are significant inconsistencies between their reports of the limits of its range.

An introduction to life stages was given in CHAPTER 1. Life stages provide an efficient method of rapidly classifying large numbers of trees and are used extensively in this thesis to describe populations of western myall.

In this chapter investigations of the qualitative aspects of the biogeography of the species are reported including:

- A description of the study area. This includes information on climate, geology, soils and vegetation associations.

- A new distribution map of the species. Information was gathered from the literature; gaps or inconsistencies were resolved by information drawn from field surveys and other authors.

- A development of the idea of life stages, which provides a basis for the investigation of the demography of western myall populations.

2.2 THE STUDY AREA

This study of the western myall has been confined mainly to the woodlands in South Australia within the Gawler Ranges and Kingoonya Soil Conservation Districts of South Australia - the main study area (**Figure 2.1**). However, field surveys were also carried out in the far west and far north of South Australia in order to ascertain the boundary of the species' range within the State.

The Gawler Ranges Soil Conservation District (GRSCD) is located to the north of the Eyre Peninsula within latitudes 31° 30'S and 33° 30'S and longitudes 134° 30'E and 138° 00'S (Gawler Ranges Soil Conservation Board, 1996). It covers an area of approximately 51,000 square kilometres and comprises 53 pastoral leases (**Appendix 1**). Lying within latitudes 29° 30'S and 31° 30'S and longitudes 133° 00'E and 136° 30'E, the Kingoonya Soil Conservation District (KSCD) is located directly north of the GRSCD. It has 22 pastoral leases covering an area of approximately 66,000 square kilometres (**Appendix 1**). The main study area covered most of the GRSCD and the southern half of the KSCD, approximately 84,000 square kilometres in total - an area roughly the size of Austria, albeit much flatter!

The species occupies a similar spatial area of Western Australia (**Figure 1.1**), however constraints of time and funding have not enabled this study to include those areas. A review of the species' distribution in Western Australia according to the existing literature is however, included as part of this chapter.

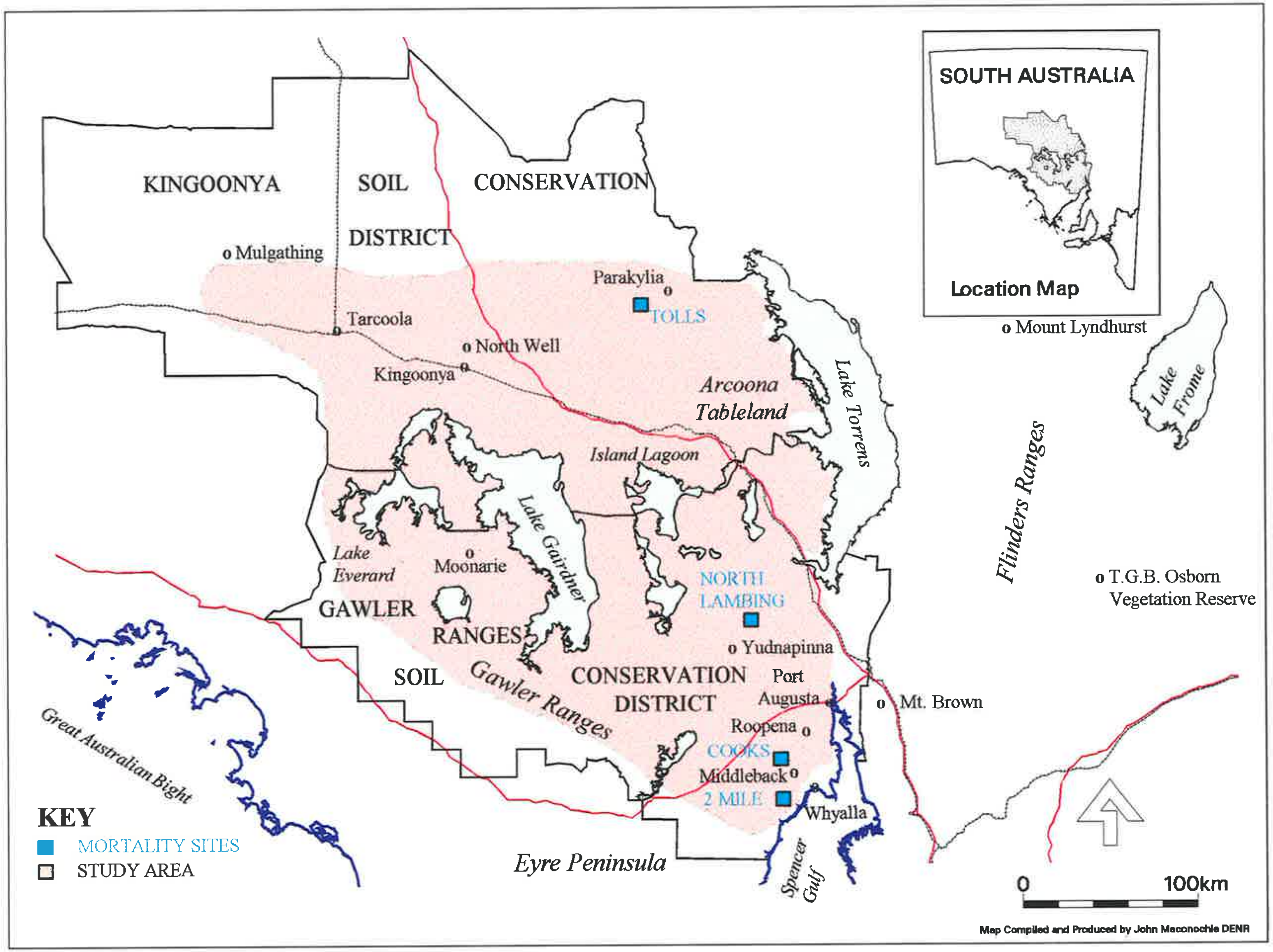

Figure 2.1 The main study area

2.2.1 CLIMATE[1]

The study area lies on and above the southern boundary of the arid zone and has hot, dry summers, cool to mild short winters and low annual rainfall (Kingoonya Soil Conservation Board, 1996; Gawler Ranges Soil Conservation Board, 1996).

2.2.1.1 Rainfall

Over the entire area year to year rainfall variability is very high. Mean annual totals vary from about 150 mm in the north east to 300 mm in the south west. However, in the study area (as in most of the arid and semi-arid areas of Australia) mean annual rainfall can give a misleading impression of the rainfall regime because historically there are many years of low rainfall interspersed with a few years of very high rainfall (**Table 2.1; Figures 2.2 and 2.3**). About one year in twenty tropical cyclones move sufficiently far south during mid to late summer to bring 80-150 mm of rain in a few days (Lange, 1971c); these events occur more often in the northern part of the study area. Little seasonality in the rainfall is apparent; in the south a weak winter rainfall maximum is evident but this is absent in the north of the study area; there rare but intense summer thunderstorms usually produce most of the annual rainfall.

Table 2.1: Years of very high rainfall (so-called flood years) and years of acute water shortage ("droughts") which have affected the whole of the study area since 1893.

	Years of very high rainfall	**Years of acute water shortage**
Kingoonya Soil Conservation District	1921, 1946, 1968, 1973, 1974 and 1989 (High rainfall occurred in localised areas in 1938, 1981 and 1992)	1888, 1902, 1905, 1928, 1929, 1940, 1943, 1944, 1961, 1967 and 1972
Gawler Ranges Soil Conservation District	1921, 1946, 1973 and 1974 (High rainfall occurred in localised areas in 1938, 1968 and 1992)	1897, 1902, 1914, 1927, 1928, 1929, 1940, 1943, 1948, 1957, 1967 and 1982

Note: Acute water shortages often extended for two or more years on either side of the year shown.

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[1] Climate data from the Bureau of Meteorology, 25 College Road, Kent Town, South Australia

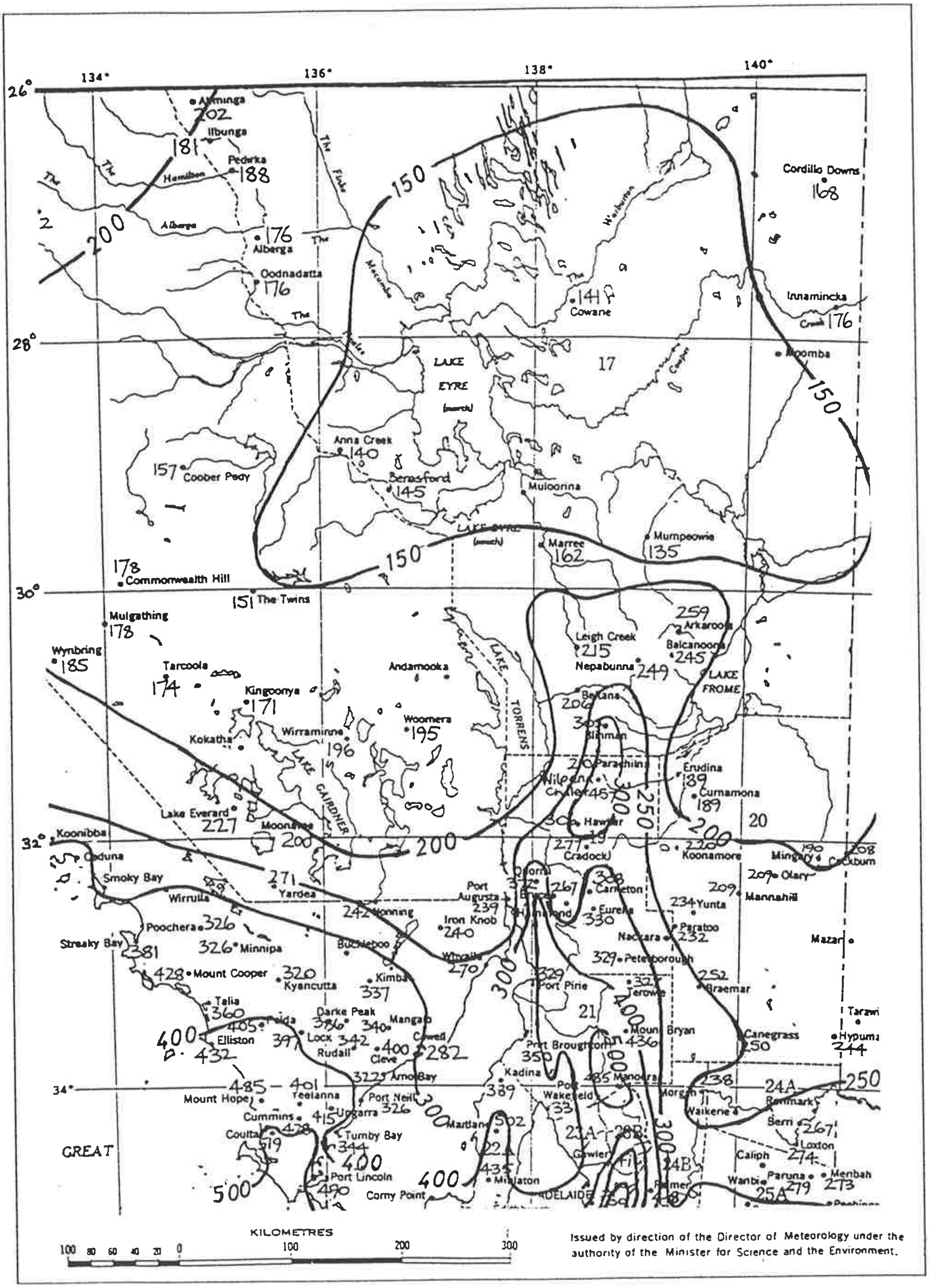
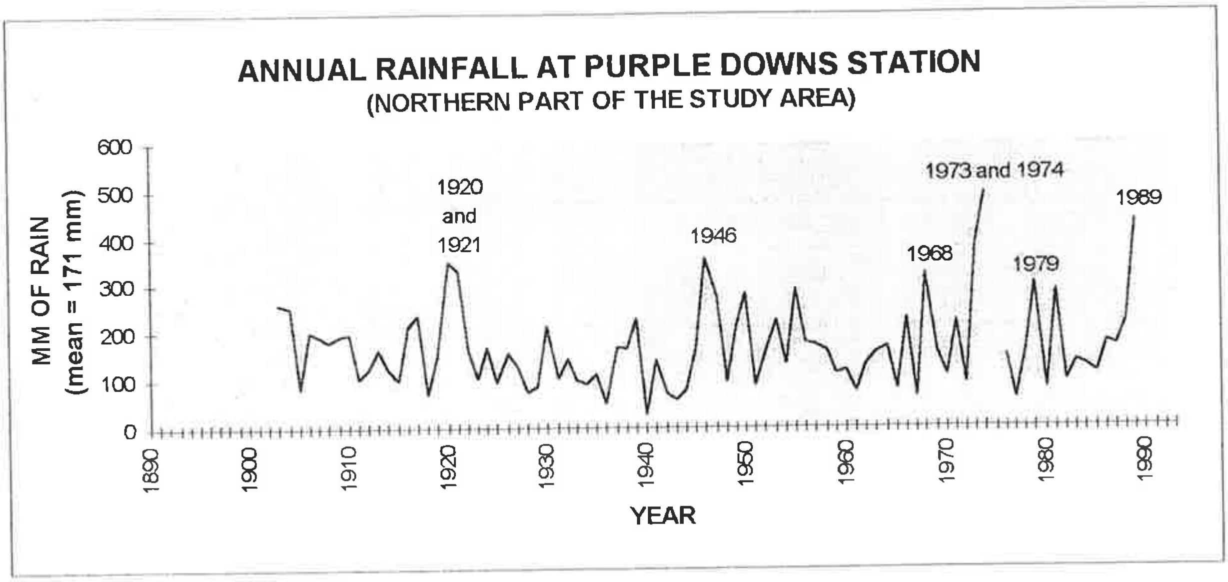


Figure 2.2: Mean annual rainfall for the study area


ANNUAL RAINFALL AT PURPLE DOWNS STATION
(NORTHERN PART OF THE STUDY AREA)

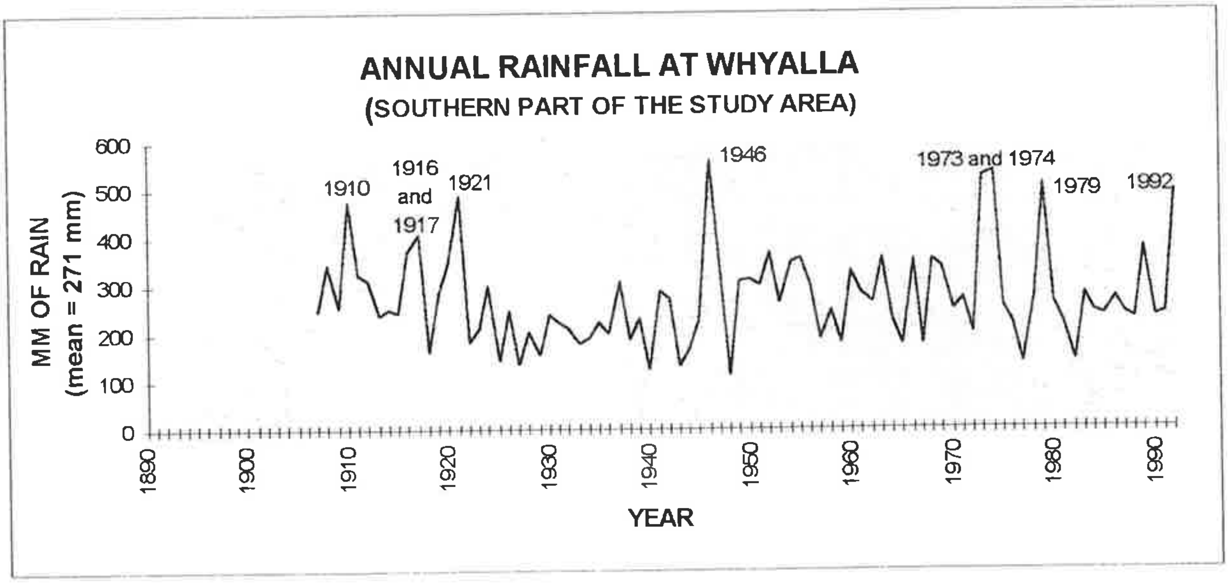

ANNUAL RAINFALL AT WHYALLA
(SOUTHERN PART OF THE STUDY AREA)

Figure 2.3: Annual rainfall on Stations in the north and south of the study area

Arid rangeland vegetation is dominated by the fortuitous co-occurrence of episodic events (Noble, 1986) such as rainfall. Evidence of sheet flow caused by these heavy rains is shown in **Plate 4**. Episodic rainfall events, occurring as late summer thunderstorms, cause extensive sheet flow of water across the land surface and are extremely important in the growth and life histories of many of the perennial plant species (Noble, 1986).

Plate 4: Litter trains left by sheet flow of water during heavy rains

2.2.1.2 *Temperature and Sunshine Hours*

During summer, mean daily temperature maxima exceed 30°C over most of the study area and extreme temperatures of over 40°C have been recorded in all months between October and March. Monthly average minima usually vary between 14°C and 20°C through the summer months. In winter mean daily maxima vary between 18°C and 27°C. Monthly average minima vary between 15°C and 5°C with below zero temperatures recorded in all winter months.

Across the study area, there is an average of 11 hours of bright sunshine every day in summer and 7 hours in winter.

2.2.1.3 Wind

Across the study area during the summer months winds are predominantly from the south to south east during the morning typically shifting south west during the day with speeds of 10-30 km/hr. In autumn and early winter the winds are generally light with little net directional trend. By mid to late winter the wind is mostly from a westerly direction at speeds less than 20 km/hr. In spring the prevailing winds become easterly in the north with little directional preference in the south at speeds of up to 30 km/hr. Average wind speed is generally strongest in spring.

2.2.1.4 Potential Evaporation

Average annual pan evaporation varies from 2300 mm in the south of the study area to 3200 in the north. Mean monthly evaporation estimates are shown in **Table 2.2**.

Table 2.2: Mean monthly evaporation estimates for the study area (from: Kingoonya Soil Conservation Board, 1996; Gawler Ranges Soil Conservation Board, 1996).

	January	**April**	**July**	**October**
North	450	225	125	300
South	360	170	80	210

2.2.2 GEOLOGY, SOILS AND LAND SYSTEMS

Weathering and erosion over the millennia have matured the landscape. Relief is subdued. Rock types are predominantly quartz-rich, and have produced generally siliceous, nutrient-poor soils, in part supplemented by or covered by wind-blown quartz sand. Conditions of fluctuating aridity and water table during the last few millennia have caused the precipitation of carbonate substrates (“calcretes”) within these soil horizons (Jessup and Wright, 1971). These themselves have weathered to produce calcareous, alkaline subsoils throughout almost all of the western myall's range. It is to these relatively inhospitable soil assemblages that the western myall is preferentially adapted. (See **Appendix 2** for an overview of the geology of the study area and CHAPTER 6 and **Appendix 6** for a more detailed description of landform development over the Quaternary period).

Land systems, i.e. areas of land that reflect recurring patterns of topography, soils and vegetation, have been mapped and described by The Pastoral Management Branch (PMB) of the South Australian Department of Environment and Natural Resources (DENR). DENR has mapped land systems for both the KSCD and for the GRSCD as part of its assessment process. Land systems that contain western myall are listed in **Table 2.3**; dominant overstorey and understorey plant species and soil types which typify each of these land systems are listed in **Appendix 2**.

Table 2.3: Land systems in each Soil Conservation District that contain western myall (see **Appendix 2** for details).

GAWLER RANGES SOIL CONSERVATION DISTRICT	**KINGOONYA SOIL CONSERVATION DISTRICT**
• **Ac** - Acraman	• **Wa** - Waulalumbo
• **Ro** - Roxby	• **Ro** - Roxby
• **Wa** - Waulalumbo	• **Gl** - Glendambo
• **Eb** - Ebunbannie	• **Ya** - Yarna
• **Gl** - Glendambo	• **Eb** - Ebunbannie
• **Ya** - Yarna	• **Lo** - Lookout
• **Ho** - Horseshoe	
• **Pp** - Peter Pan	
• **Pt** - Peterlumbo	
• **Rp** - Roopena	
• **Be** - Beacon	
• **Jd** - Jungle Dam	
• **He** - Hesso	
• **Yk** - Yorkey	
• **Bo** - Bowen	

2.3 DISTRIBUTION OF WESTERN MYALL

The distribution of western myall has been mapped by various authors (**Table 2.4** and **Appendix 3**) - many of whom do not agree on a definitive boundary. A literature review follows. A broad scale distribution survey of the western myall woodlands in the study area was undertaken as part of this thesis and a new distribution map (**Figure 2.4**) is presented. It incorporates this survey, elements of surveys done by previous authors and the location of specimens held in the South Australia State Herbarium. The discovery and taxonomy of the species has already been described in Section 1.2.4.

2.3.1 LITERATURE REVIEW

In 1931 Jean Murray mapped the vegetation of the Lake Torrens Plateau. She described western myall as the dominant or character tree throughout the "myall association on the loam flats". Wood (1937) mapped a similar boundary for what he described as the "*Acacia sowdenii - Myoporum platycarpum* co-climax association" which occurred on the loamy flats between the sandhills. At the old Mortlock Research Station on Yudnapinna Station, Crocker and Skewes (1941) conducted a detailed soil and ecological survey of 25 square miles of North and South Lambing Paddocks describing the "*Acacia sowdenii - Myoporum platycarpum* association" as the most extensive in the area extending northwards to the Arcoona Tableland and South to the Gawler Ranges. Further south, Crocker (1946) mapped the "*Acacia sowdenii - Casuarina lepidophloia* edaphic complex" on the northern edge of the Eyre Peninsula referring to it as the most important vegetation association in the Whyalla region. In 1947, Crocker and Wood mapped the discontinuity of the two species *Acacia sowdenii* and *Acacia loderi* referring to their relationship as "an example of biotype isolation of a more widespread parent species or population".

It was not until Jessup (1951) carried out his soil and vegetation surveys of the southern part of the North West Pastoral that western myall was mapped further north than the Arcoona Tableland. Jessup's "*Acacia sowdenii - Kochia* (now *Maireana*) *sedifolia* association" appears well to the north and north-west of this area even as far west as Mulgathing Station.

Table 2.4: Distribution surveys of western myall (The key distribution maps are reproduced in **Appendix 3**)

Author	**Year**	**Method**	**Area**
Murray	1931	Field surveys	Lake Torrens Plateau
Wood	1937	Field surveys	South Australia
Crocker and Skewes	1941	Aerial surveys	Yudnapinna Station
Crocker	1946	Field differentiation of major communities combined with survey diagrams	Northern Eyre Peninsula
Crocker and Wood	1947	Not known	North West Pastoral
Jessup**	1951	Field surveys along tracks	Kingoonya Soil Conservation District
Lay**	1972	Field surveys along tracks	Kingoonya Soil Conservation District
Specht	1972	Literature survey and other existing information and	South Australia
Nature Conservation Society of South Australia	1972	Field Survey	Gawler Ranges
Beard	1975	Air photos and field surveys	Nullarbor Mapsheet, Western Australia
Laut *et al.*	1977a	LANDSAT imagery	Eyre Peninsula
Laut *et al.***	1977b	LANDSAT imagery	Western Pastoral
Laut *et al.***	1977c	LANDSAT imagery	Northern Arid
Hnatiuk and Maslin	1980	Herbarium specimens	Western Australia
Boomsma and Lewis	1980	Not known	South Australia
Boomsma	1981	Not known	South Australia
Maslin and Hopper	1982	Herbarium specimens	Australia
Maslin and Pedley	1982	Herbarium specimens	Western Australia
McKenzie and Robinson**	1987	Field surveys	Nullarbor Region
Mitchell. McCarthy and Hacker	1988	Air photos and field surveys	Part of Nullarbor region in Western Australia
Robinson *et al.***	1988	Field surveys and herbarium specimens	Gawler Ranges
Simmons	1988	From existing information	Australia
Young**	1988	From existing information	Far west coast
Beard	1990	Field survey and aerial photography	Western Australia
Commonwealth of Australia	1990	Landsat imagery and existing information	Australia
Whibley and Simon**	1992	Herbarium specimens	South Australia
Copley and Kemper**	1993	Field surveys	Yellabinna Region
Mitchell and Wilcox	1994	From existing information	Western Australia
Biological Survey and Research, DENR**	1996	From existing information	South Australia
Maconochie and Lay**	1996	Field surveys along tracks	Kingoonya Soil Conservation District

Note: All studies in South Australia unless otherwise stated.
**Surveys incorporated in Figure 2.4

During the broad scale distribution survey undertaken for this thesis, Jessup's map proved to be most reliable. Follow-up surveys of Jessup's work were undertaken by Brendon Lay (Lay, 1972) and John Maconochie (Maconochie and Lay, 1996); the three surveys together comprise a unique long-term study of bush density changes over 46 years. Lay also mapped the distribution of 41 woody plant species (one of which was western myall). Maconochie re-surveyed the distribution of the species; both he and Lay also recorded regeneration.

Specht (1972) mapped the vegetation of South Australia and included *Acacia sowdenii* in his "Low open-woodland formation". He produced three maps showing the distribution of the species based primarily on the work of other authors previously described in this section. His maps, however, also show large areas of western myall low open-woodland extending into the area beyond Mulgathing Station as far west as the Western Australian border fringing the Nullarbor Plain. The broad scale vegetation surveys undertaken for this thesis, Greenslade *et al.* (1986) in their vegetation survey of the Great Victoria Desert and Brendon Lay (*pers. comm.*) all indicate that the species is not present in much of this area, although it has been observed in occasional small patches west of Mulgathing Station away from roads (Brendon Lay *pers. comm*). It does, however, fringe the northern edge of the Nullarbor in Western Australia (Beard, 1975 and 1990). Beard (1975) mapped the vegetation of the Nullarbor area describing the western myall woodlands as "lightly-wooded succulent steppe". This vegetation type is found on the Nyanga Plain which forms a broad band on the northern edge of the Nullarbor and the narrower Roe Plain on the southern fringe. In 1990 Beard produced a map of the western myall woodland in Western Australia using the same boundaries.

Using LANDSAT imagery, Laut *et al.* (1977a, 1977b and 1977c) mapped "environmental regions, associations and units" across the three "Provinces" which contain western myall woodlands - the Eyre Peninsula, the Western Pastoral and the Northern Arid. The boundaries of their "environmental associations" accord well with some other surveys and with the broad scale vegetation survey in many areas, however, particularly in the far west of the State they bear little relationship to the vegetation found on the ground. Another map compiled from satellite imagery was produced by the Commonwealth of Australia (1990). The Atlas of Australian Vegetation used 1:1 million scale imagery combined with existing vegetation and soil maps. The maps are not intended as species distribution maps and the *Acacia* species named are those identified as dominant in each map unit (**Figure 1.1**). The boundary shown for western myall is thus not very reliable.

In 1972 the Nature Conservation Society of South Australia conducted a field survey of part of the Gawler Ranges. Vegetation assemblages were mapped on air photo mosaics at a scale of 1:63,360; these were checked on the ground. The map corresponds well with the broad scale distribution survey undertaken for this thesis. Other biological surveys conducted in South Australia by various State Government agencies mapped the extent of western myall woodlands in a variety of regions. These are the Western Australia Nullarbor Region by Mitchell *et al.* (1988), the whole Nullarbor Region by McKenzie and Robinson (1987), the Gawler Ranges by Robinson *et al.* (1988), the Far West Coast by Young (1988) and the Yellabinna Region by Copley and Kemper (1993). Many of the maps accompanying these reports agree reasonably well with the broad scale vegetation survey although in most cases they are based on widely separated survey sites. The Biological Survey and Research Group of DENR (1996) have produced a large data base of South Australian plant species (VIRIDANS); a map of western myall distribution from this data base is included.

Some published distribution maps are based on locations for herbarium specimens lodged at the major Australian herbaria. These include Western Australia by Hnatiuk and Maslin (1980), Australia by Maslin and Pedley (1982) and South Australia by Whibley and Symon (1992). Maslin and Hopper (1982) mapped the distribution of western myall and its species-group (consisting of *Acacia papyrocarpa, A.* aff. *papyrocarpa*, and *A. loderi*) using herbarium data. They considered members of the species group to be allopatric.

Several plant identification manuals include maps of western myall distribution. These maps are small and give very generalised boundaries which are often only indicative of where the species may be found. These include Boomsma and Lewis (1980), Boomsma (1980), Simmons (1988) and Mitchell and Wilcox (1994).

Most of these maps are reproduced in **Appendix 3**.

2.3.2 THE BROAD SCALE DISTRIBUTION SURVEY

A new distribution map for western myall is presented at **Figure 2.4**.

Presentation of species distribution and range information is always problematic (Pielou, 1991). There are basically three different ways in which the range of a species can be illustrated, none of which is ideal. The first has hollow and solid dots delineating the extent of the survey; the solid dots indicate where the species was found, the hollow dots where it was not found. The second places a dot on the map to show every point on the ground at which the species was collected. The third has an outline enclosing an area showing what is believed to be the limit of the species' range. Both of the dot methods make no assumptions and are therefore accurate, but only reflect the extent and density of the survey. Gaps between the dots do not indicate whether the species exists there or not, because the locality has not been visited. The enclosed area method of drawing range maps has obvious drawbacks. The meaning of the enclosed area is unclear as the species will not be ubiquitous and the area outlined depends entirely on the judgement of the person drawing the map.

The western myall distribution map produced as **Figure 2.4** is a combination of the second and third methods. The solid dots are taken from South Australian State Herbarium records[2] and also incorporate reliable observations from various sources marked with ** on **Table 2.4**; the grey dots are records held by the South Australian Department of Environment and Natural Resources (more particularly these are the assessment sites set up by the Pastoral Management Program); the enclosed areas indicate the most likely extent of the range that could be ascertained from the broad scale distribution survey carried out as part of this study, from the literature survey, from personal communications with Brendon Lay and John Maconochie and from a postal survey which was responded to by 94% of the landholders in the study area.

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[2] The South Australian State Herbarium and the Department of the Environment and Natural Resources have given their permission to use their records for western myall as a basis for the map shown at **Figure 2.4**.

Figure 2.4: The distribution of western myall in South Australia

2.4 USING LIFE STAGES IN THE STUDY OF POPULATION STRUCTURE

It is often not possible to age long-lived plants accurately(Crisp, 1978; Silander, 1983) and thus true age structures of a population are usually not available. Estimates can be made by applying a detailed census to a strictly defined age class, from the fact that size or some other attribute may reflect age, or by counting tree growth rings (Harper, 1977). These are life stages; they relate loosely to age since trees must grow through successive stages one at a time and they can applied to a population as an approximate substitute for true age structures. The resulting life stages can be illustrated with a frequency histogram.

This approach has been widely used and examples include the following. Using phenological condition classes, Mueller-Dombois and Ellenberg (1974) divided plants into 11 classes by their stage in the life cycle. Gatsuk *et al.* (1980) designed a 10 class system to describe life stages for over 100 species in Russia. In Australia, life stages have been used by several researchers: Lange and Purdie (1976) in their studies of *Acacia papyrocarpa*; Chesterfield and Parsons (1985) for *Casuarina cristata, Heterodendrum oleifolium* and *Myoporum platycarpum*; Wisniewski and Parsons (1986) for *H. oleifolium*; Auld (1990) for *Acacia oswaldii* and *Acacia carnei*; Grice *et al.* (1994) for *Acacia victoriae*. In a different approach Crisp and Lange (1976) working with *Acacia burkittii* used a size-age relationship to examine populations

2.4.1 LIFE STAGES OF THE WESTERN MYALL

Lange and Purdie (1976) proposed six life stages for the western myall at Middleback Station which included three juvenile, two mature and one senescent stage (**Figure 2.5**). Whilst they found it was possible to categorise western myall into these successive growth stages in any one place, they found it was not always easy to generalise from one place to another. They also reported evidence that it took approximately 30-50 years for a tree in the open paddock to reach stage III and 75 years to reach stage IV. Dickson (1983) defined the six stages

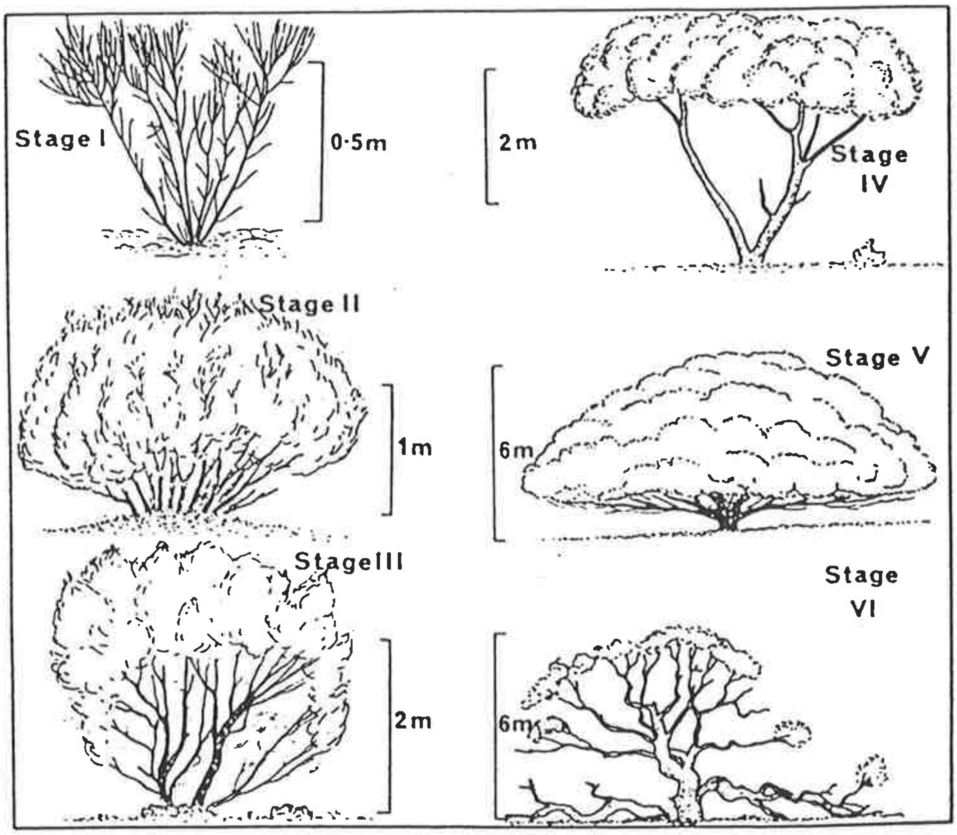

Figure 2.5: The six Life Stage system used by Lange and Purdie (1976)

quantitatively, using discriminant analysis. She found that only four of the 16 variables she initially chose were suitable for classifying the six stages in the field. These were:

- branch angle difference (the angle between the base of the tree and the branch at the last 10% of the canopy radius),
- whether the branches touched the ground,
- height of canopy above the ground and
- an index she devised and referred to as shape number.

Three of these reflect the most prominent developmental processes of the tree:

- the lifting of the canopy,
- the change in shape of the canopy AND
- the gradual procumbence of the branches.

Ireland (1992) expanded Lange and Purdie's (1976) scheme of six life stages to nine. Mature and senescent trees can be categorised from the point of view of Dickson's (1983) variables. The changes in branch angle, canopy shape and lifting of the canopy are relatively easy to identify; with practice it becomes apparent that by using this purely empirical technique, mature and senescent trees can be assigned with reasonable confidence to one of the six mature and senescent stages within the nine stage scheme, particularly within a site. The nine life stage scheme is thus a more useful tool for analysing population structure, particularly with mature and senescent trees. Illustrated in **Figure 2.6**, the nine life stages are:

- a very young juvenile stage (Life Stage I),
- a juvenile stage (Life Stages II),
- a young mature stage (Life Stage III),
- four mature stages (Life Stages IV, V, VI and VII) and
- two senescent stages (Life Stages VIII and IX).

This nine stage system of life stages has been used extensively in this study as the means of quantifying population structures at sites across the study area. At each site a random bearing was traversed until at least 100 trees had been scored within 25 metres of the traverse line - a modified version of Kent and Coker's (1992) random walks procedure. Particular care was taken to search for all seedlings and juvenile plants.

Lange and Graham (1983) state that western myall populations exhibit conspicuous and almost universal gaps in the younger life stages. They point out that the life stage of the youngest adults present in these populations corresponds with the beginning of pastoralism. There is however, much anecdotal evidence about the existence of the western myall cohorts of 1921, 1946 and 1973/74 at various sites in the Gawler Ranges. Examples of this are the 1973/74 seedlings fenced off in Two Mile Paddock, Middleback Station (R.T. Lange *pers. comm.*), 1946 individuals in Gatum Gatum Paddock, Middleback Station (A.D. Nicolson *pers. comm.*) and 1921 individuals that have recruited on a large fire scar on Yudnapinna Station (Crocker and Skewes, 1941; Jackson, 1958; A.D. Nicolson *pers. comm.*). With practice, these younger cohorts can now be recognised in the open paddocks and they are able to be assigned to Life Stages I, II and III respectively (**Figure 2.6**). Further north in the KSCD these younger cohorts are much more prevalent.

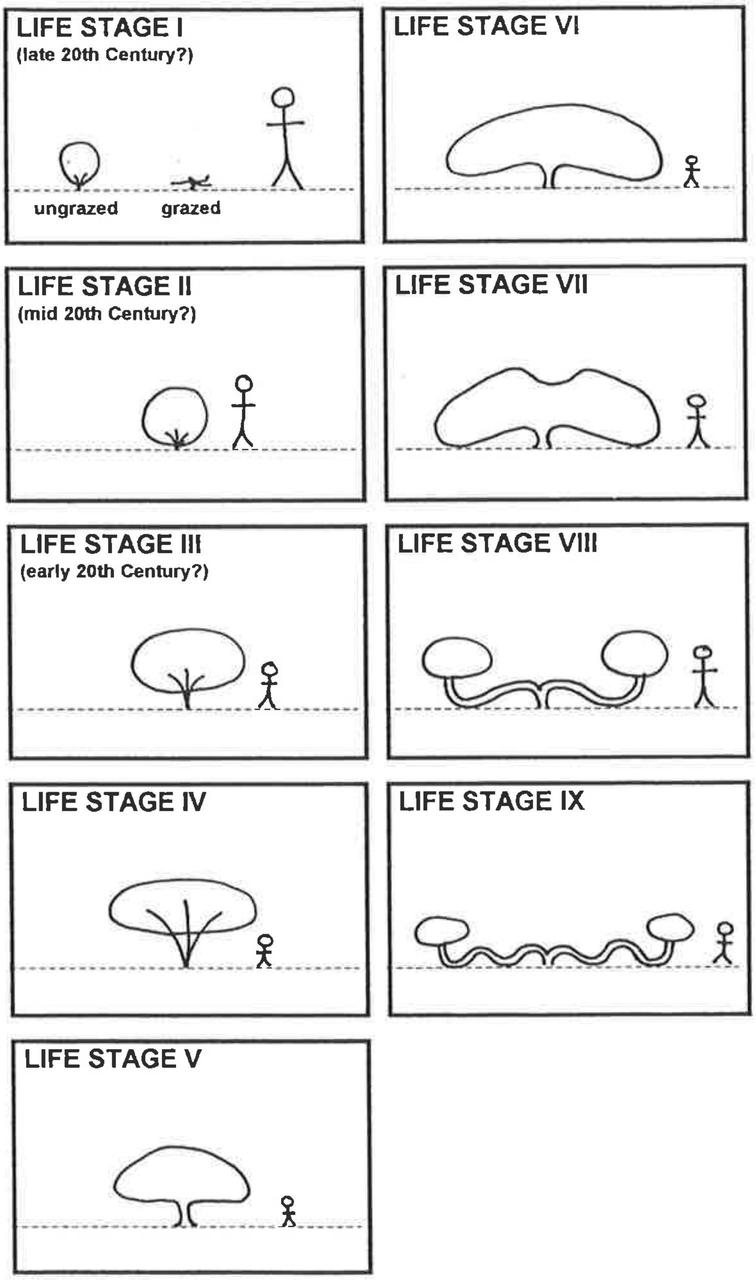

Figure 2.6: The nine Life Stage system used by Ireland (1992)

The life stage approach has some very real and practical advantages: it is inexpensive and large numbers of trees can be scored with relative speed and ease; it is also reasonably easy to teach. In the interests of consistency however, I collected all the data for this study. More than 200 sites were scored across the study area; most of these were part of the Fossil Paddock study which is described in detail in CHAPTER 7. This method of describing population structures for the species was also used for several other purposes in this thesis.

CHAPTER 3

THE OCCURRENCE OF RECRUITMENT

3.1 INTRODUCTION

In 1977 Grubb discussed the importance of the regeneration niche and defined it as follows:

> *"The regeneration niche is an expression of the requirements for a high chance of success in the replacement of one mature individual of a species by a new mature individual of the next generation."* (Grubb, 1977)

He identified the processes which define the regeneration niche. These included production of viable seed (flowering, pollination and the seed setting), dispersal of seed (through space and time), germination, establishment and onward growth. Recruitment, encompassing dispersal, germination, establishment and onward growth, is a vital part of this concept.

It has been suggested that the combined influence of grazing by introduced and native herbivores (sheep, rabbits and kangaroos) usually precludes the recruitment of western myall in all but exceptional circumstances (Lange and Graham, 1983; Lange and Purdie, 1976). However, recruitment of the species, although very patchy, is occurring in most parts of its range; it has been observed particularly in highly disturbed areas within 100-1500 metres from watering points and in the northern part of the species range. Thus there is an inconsistency. It appears that the populations may be aging in the southern part of its range, particularly at the place (Middleback Station) where it has been most studied in the past. In many other parts of its range, particularly in the north and north west, populations appear younger and more flourishing. There is a need to put these extremes in context.

Western myall was one of the species included in the South Australian Department of Environment and Natural Resources Pastoral Management Branch (PMB) pastoral assessment database. Records are available within this database for sites in every paddock in the 75 pastoral leases of the Gawler Ranges and Kingoonya Soil Conservation Districts (a total of approximately 2,000 sites). At each site the presence or absence of both adult western myall and recruits was recorded with information about other species and some environmental variables. This large data base has been accessed with the permission of the PMB.

An analysis of the historical ecology of the species forms part of this thesis (CHAPTER 7). A variety of data was collected for this study at about 200 sites across the species' range within the study area; this included recruitment data.

This chapter reports the occurrence in space and time of western myall recruitment by:

- Examining a model of western myall recruitment.

- Investigating recruitment across the study area by analysing the data collected for the study described in CHAPTER 7 coupled with information from the PMB data base.

3.2 THE REGENERATION NICHE

Grubb's (1977) regeneration niche provided a particularly useful framework within which to study the autecology of the western myall. Ireland (1992) examined aspects of the life history of the western myall, particularly its reproductive strategies, seed bank characteristics, recruitment and regeneration. A study of these, during one seasonal cycle of flowering, pollination, seed set and seed dispersal/predation provided many insights into the ecology of the species and some suggestions for conservation and management were proposed.

The stages in the life cycle of a plant species provide useful intervals for analysing the changes that take place in its populations over time (Silvertown, 1987). The stages are the seed bank, germination and initial establishment, the seedling and the various juvenile stages leading up to reproductive maturity (Harper 1977). New plants may be recruited to a population from seeds, i.e sexually, or asexually from vegetative offshoots that have the potential to lead an independent existence (Silvertown, 1987). As with most other *Acacia* species (New, 1984), the western myall produces seeds and has rarely been observed to reproduce vegetatively (R.T. Lange and A.D. Nicolson *pers. comm.*). Compared to the majority of vegetative propagules, seeds are numerous, independent and tolerant of stress (Grime, 1979). These three characteristics confer the potential for rapid multiplication, dispersal and dormancy.

3.3 A MODEL OF RECRUITMENT

Western myall seeds retain a high viability in the seed bank for at least six years (Ireland, 1992). The combined effects of grazing by introduced and native herbivores have been seen to suppress the growth of seedlings (Lange and Graham, 1983; Lange and Purdie, 1976). New seedlings appear only rarely, about once in 25 years. What are the conditions necessary for seedling establishment? During the period September 1991 to April 1992 a number of experiments and observations were conducted to examine seed dispersal and predation, and dormancy and germination characteristics of the species (Ireland, 1992).

Western myall trees have a regular seasonal cycle of flowering and seed set which differs in detail from tree to tree and in abundance from year to year. Seed fall occurs every year in late summer. This is also the most likely time for the thunderstorms that bring the episodic major rainfall events which occur about every 25 years (**Figure 2.3**). In the summer of 1992 only three seeds survived to maturity for every 100 inflorescences on a tree. At least 50% of this loss was caused by pre-dispersal predation of the fruit. Bruchid beetles have been implicated (R.T. Lange *pers. comm.*) as one of the major pre-dispersal predators of western myall seeds. Beetles of this group are known to be predators of *Acacia* species in other parts of the world, for example, Mucunguzi (1995) reported that bruchid beetles in Uganda significantly reduced the germination of *Acacia gerrardii* whilst *Acacia sieberriana* appeared to have adapted itself to survive bruchid beetle infestation.

Ants are the major removers of western myall seeds. Nearly all seeds (99%) in removal experiments were lost to ants (or ant-like organisms), rather than to vertebrates. *Pheidole* species ants remove most western myall seeds within a few hours and are destructive seed predators, not benign seed dispersers; most seed is taken too far underground for recruitment to occur (Ireland and Andrew, 1995); near Sydney in New South Wales a high proportion of *Acacia suaveolens* seeds are also buried too deeply for successful establishment (Auld, 1986). Only one western myall seed was found in an extensive seed bank investigation undertaken in the woodlands at Middleback Station during 1993 (Zita Stokes *pers. comm.*). Because western myall is a long-lived species and recruitment appears to occur in rare circumstances, this routine but near-complete seed predation may not impact on overall recruitment (Ireland and Andrew, 1995). A high percentage (70%) of artificially buried seeds exhibited innate dormancy, remaining viable for at least eight months. No western myall seedlings recruited during the year from these buried seeds despite above average rainfall (Ireland, 1992).

It follows then, that the chance that a viable seed will eventually develop into an established seedling, let alone a new mature individual, is very small.

The foregoing has been integrated into a model of western myall recruitment (Ireland and Andrew, 1992). This model has two conditions. In normal or most years (such as the year of the study) there is no recruitment to western myall populations because of sparse production of fruit, actions of pre-dispersal predators, almost total destruction of the seed by harvester ants and less than ideal climatic conditions. Given the long-term population dynamics of the western myall, this does not matter. In abnormal years (where various episodic events coincide to produce substantial recruitment of the species) widespread and intense rainfall events occur as late summer thunderstorms. The successful establishment of western myall requires these rains to stimulate germination; sufficient follow-up rains to promote onward growth; and low herbivore (especially rabbit) density (Noble, 1986). Ireland and Andrew (1992) refined Noble's model by adding the following features:

- late summer thunderstorms which coincide with seed fall,
- overland sheet flow of water caused by the rainfall, which scarifies the seeds, tumbling them along with gravel and debris, and buries them in safe sites (litter trains, illustrated in **Plate 4**, which contain enough moisture and nutrients for germination and establishment, and provide protection by burial from seed harvester ants),
- moisture levels maintained by milder than usual temperatures and/or follow-up rain, and growth of ephemeral species which protects seedlings from herbivores.

The scarification of seeds in this model is important, as many of the seeds would remain dormant without it. While disturbance or fire may also scarify the seeds it is the co-occurrence of scarification, inundation and shallow burial which is crucial for a large recruitment event in western myall. I surmise that shallow burial after seed fall protects seeds from predatory ants as this is what happens in other circumstances. For example, the shallow burial of *Eucalyptus incrassata* seeds under sand (Wellington and Noble, 1985) and of *Sorghum intrans* seeds via the action of the awn and the callus (Andrew, 1986), protects these seeds from predation. In mulga woodlands Tongway (1994) and Tongway and Ludwig (1994) introduce the idea of *"fertile patches"* which have high values of fertility because they are *"top-dressed"* with litter, topsoil and water from time to time brought about by rainfall runoff or wind deposition. Seeds also accumulate in these fertile patches (John Ludwig and David Tongway, *pers. comm.*).

An understanding of the timing and probability of rain, the timing of seed fall and the behaviour of harvester ants, is vital. The effects of harvester ants may be more exaggerated because of changes to the grazing regime since European settlement. Increased numbers of harvester ants in the arid zone since European settlement (Andersen, 1990) may have a major effect on reducing the successful recruitment in the western myall, and possibly other perennials.

Thus, Ireland and Andrew (1992) hypothesised that it is the inundation, scarification and shallow burial of seeds by the action of sheet water flow which, given the long-term population dynamics of the western myall, are the keys to successful regeneration. It appears that in most years there is no recruitment to western myall populations but this does not matter. The occasional years that are important for recruitment are those in which there is a co-occurrence of rare episodic events, as described in the model. Nevertheless, under the present grazing regime (rabbits and sheep) the onward growth of many seedlings is suppressed. Managing these hazards remains a challenge.

3.3.1 TESTING PART OF THE HYPOTHESIS

Two hypotheses that arose out of the recruitment model proposed by Ireland and Andrew (1992) were tested during this PhD study. These were:

1. That shallow but complete burial under litter or soil protects *Acacia* seeds from harvester ants.

2. That increasing depth of burial under litter or soil will increasingly protect *Acacia* seeds from predation by harvester ants.

During the summer of 1994, western myall seeds were buried under various depths of soil or litter (shallow and deep soil or litter); a control of unburied seed was incorporated into the design. An analysis of variance (**Table 3.1**) was carried out on a number of variables (REPLICATE BLOCKS, TREATMENTS, DAYS and the interaction between TREATMENTS and DAYS). A pairwise comparisons was made using T-tests (**Table 3.2**).

Table 3.1: The analysis of variance

SOURCE	**DF**	**F VALUE**	**Pr > F**
BLOCKS	10	16.44	0.0001
TREATMENT	4	18.77	0.0001
DAY	4	7.42	0.0001
TREATMENT*DAY	16	1.35	0.1706

Note: TREATMENT*DAY not significant

REPLICATE BLOCKS were found to be a significant variable (i.e. results obtained in different experimental locations differed significantly from each other); we propose that the varying proximities of the 11 replicates to ant nests may account for this. I also found that DAY was a significant variable; weather conditions were different on each of the five days and this may have affected the amount of seeds removed by the ants. TREATMENT was also significant; this means that the presence or absence of certain coverings affected the number of seeds removed. The variable DAY*TREATMENT was not significant; this means that even if the weather was warmer on a particular day, thus increasing the activity of the ants, they took proportionally more seeds from **all** treatments. This allowed me to disregard day when considering the effects of each treatment.

Table 3.2: The pairwise comparisons between treatments

TREATMENT	N	MEAN	T GROUPING
CONTROL	55	0.5001	A
SHALLOW LITTER	55	0.4888	A
DEEP LITTER	55	0.3503	B
SHALLOW SOIL	55	0.3376	B
DEEP SOIL	55	0.0898	C

Note: Means with the same letter are not significantly different

Results of the pairwise comparisons between treatments showed that unburied seeds (the control) and those buried under a very shallow layer of litter were removed most often, those buried under a shallow layer of soil or deep layer of litter were removed at a lesser rate and fewest seeds were removed if they were sufficiently buried under enough soil to conceal their shape.

I concluded that seeds may achieve the shallow burial necessary for protection from predation under debris (e.g. soil and litter) that accumulates (**Plate 4**) during the sheet flow of water caused by heavy rainfall. The null hypotheses were accepted and confidence in the recruitment model was increased.

3.4 THE OCCURRENCE OF RECRUITMENT

Since the arrival of people in Australia some tens of thousands of years ago the vegetation has changed dramatically. For much of this time Aborigines altered the vegetation patterns through the use of fire and possibly by the indirect effect of exterminating the megafauna. The advent of European settlement over the past two hundred years has, however, fundamentally and permanently changed the land cover again (Commonwealth of Australia, 1990; Adamson and Fox, 1982). About two-thirds of Australia is grazed by domestic stock and introduced feral animals. Much of this is in the arid zone. Pastoralism, coupled with the introduction of the rabbit (*Oryctolagus cuniculus*), has generated intense pressures on natural vegetation in the arid zone. In particular, the rabbit has been implicated in the decline of numerous shrubland types and in the lack of regeneration of various native species (Commonwealth of Australia, 1990).

As the western myall is a very long-lived species, many of the present trees established before European settlement and are today (at least in the Whyalla - Iron Knob area that has been studied in most detail) showing senescence as the crowns gradually break down and the trees become procumbent or even polyprocumbent with extreme old age (**Plate 3**). Many researchers agreed that the western myall woodlands in the Whyalla - Iron Knob area were declining for similar reasons, although whether this was a recurring pattern across the woodlands was not known. The potential loss of these woodlands, however, was seen to be of some significance (Adamson and Fox, 1982).

Western myall has commonly been assumed not to be recruiting in grazed paddock situations (Lange and Purdie, 1976). During a brief survey in 1991 I found that exceptions to this do occur; small, isolated groups (future groves?) of juveniles that are commonly thought to have resulted from the 1973 inundation exist on Middleback, Roopena and Katunga Stations. The Nicolson family have periodically noticed them whilst mustering (A.D. Nicolson and D.A. Nicolson, *pers. comm.*) and during 1991-1992 I also discovered some of these seedlings. An example is an area of juvenile western myalls discovered on Katunga Station (Site SS13). Located within a paddock that has been continuously grazed for many years (A.D. Nicolson *pers. comm.*), many of the plants appeared to have escaped the predations of herbivores. Other sites on Yudnapinna and Siam Stations (CY1, CLN7, CLN8, CLS1, and CLS12) some 100 km to the north of Middleback Station, are located in a large area affected by wildfire in 1922; an early century cohort of western myalls resulted from this fire. In the north, northwest and far west areas of the study area there are many other examples.

To Lange and Purdie (1976), who actually witnessed the 1973 inundation and subsequent germination of western myall, recruitment appeared at first to be very dramatic, however, only about 1 grove of trees in 50 showed any associated seedlings. From this they assumed that the 1973 inundation, like those in 1921 and 1946 would not yield significant inputs into the groves under prevailing conditions. A search of paddocks at Middleback in 1992 confirmed this view

- very much less than 1 in 50 groves supported any survivors of the 1973/74 cohort described by Lange and Purdie (1976).

In order to maintain a stable population in any plant population some recruitment is essential to replace those individuals that die; relative rates of recruitment and mortality may determine whether the population is increasing its range or is in decline (Harper, 1977). Examinations of life stage structures of widely distributed populations in the western myall woodlands have identified areas where recruitment has been poor or nonexistent since European settlement of the area.

The early periods of life for a woody perennial are devoted to gaining height; reproduction is delayed until maturity (Harper, 1977) and both the rate of colonisation by trees and their rate of recovery from disaster tends to be slow. The tree has not only to be successful in a variety of life stages but also meet the hazards of each vegetation layer that it penetrates (Harper, 1977).

3.4.1 EPISODIC EVENTS IN THE ARID ZONE

Historically, rainfall inundations (described in Section 2.2.1.1) that may have been suitable for recruitment of western myall have occurred only 4-6 times in the last century in the woodlands **(Figure 2.3)**. The recruitment of new individuals to the population is clearly limited by the infrequency of these events.

Many Australian *Acacia* spp. are highly adapted to fire, and their germination is facilitated by it. In the case of western myall, fire may facilitate germination by cracking the seed coat, but it may also kill many mature trees. Several authors have commented on an increase in mean germination rates in fire-treated seeds of *A. pulcella* and *A. aneura* in Australia and *A. sieberiana* in Uganda (Portlock *et al.*, 1990; Hodgkinson and Oxley, 1990; Sabiiti and Wein, 1987). Conversely, fire also kills adult individuals of many species which cannot regenerate by root or stem suckers (Lay, 1976; New, 1984); western myall is of this type. Most western myalls are associated with an understorey of chenopod shrubs which will only carry a fire in exceptional circumstances and are not considered to be adapted to it (Graetz and Wilson, 1984). Beard (1975) states that the occurrence of old trees of a fire-tender species such as western myall on the Nullarbor Plain in Western Australia indicates freedom from fire. Jessup (1951) has suggested, however, that before European settlement the Aborigines had frequently burnt the shrublands and had thus contributed to a greater regeneration of the western myall. He said that there was ample evidence throughout the woodlands that prior to settlement much of the country had been burned probably by small fires possibly without sufficient intensity to destroy mature trees. The "halo" of open ground, virtually bare of ephemeral species, which surrounds each tree may act as a natural fire- break (Martin Andrew, *pers. comm.*).

3.4.1.1 The Yudnapinna western myall populations

In the summer of 1922 an extensive wildfire started in dense ephemeral vegetation that had grown after heavy rains in 1921, destroying much of the mulga and western myall scrub on Oakden Hills, Yudnapinna and Carriewerloo Stations in the Gawler Ranges Soil Conservation District. In 1930, Murray (1931) stated that the country was still fairly barren with little regrowth. Stock were not reintroduced to the area until the late 1920's (Jackson, 1958). By 1941, Crocker and Skewes (1941) recognised that western myall regeneration had been stimulated by the fire; it was regenerating readily in the burnt areas. They assumed that the young myalls would grow to maturity and the association would resume its old appearance. Jessup (1951) visited the are in the late 1940s and found *"a very dense growth of "young" myalls, so much so that the trees are frequently touching, and yet no deaths have occurred and, in fact all the trees appear very vigorous"*. He commented that in stands of mature myalls, on the other hand, the individual trees are quite scattered. By 1954 (32 years after the fire), Jackson (1958) reported that the new trees were between five and eight feet tall (1.5-2.5 m).

I have visited the same populations on Yudnapinna frequently since 1991; the woodlands consist of vigorous Stage III western myall trees interspersed with very rare live older members of what I assume to be survivors of the population present before the 1922 fire. The population still has much the same appearance as that described by Jessup (1951) only the *"young"* myalls are, of course, 45 years older and an unknown number of deaths have occurred through the natural process of thinning through competition. The *"young"* myalls grow in dense single aged groves many of which surround the carcass of an old burnt out "parent" tree. These groves at Yudnapinna are difficult to photograph adequately so I have provided an illustration (**Plate 5**) of a typical grove from a younger population on North Well Station. It is probable that the Yudnapinna groves would have looked like those in Plate 5 some 50 years ago. At a site in Koolgarra Paddock I recorded information from an area containing about 150 burnt out "parents" and groves of the 1922 cohort of western myall trees. **Table 3.3** displays the results of those investigations.

Plate 5: A grove of western myall (10-20 years old) surrounding a burnt-out parent tree.

Table 3.3: Demography of the Koolgarra Paddock populations on Yudnapinna Station

SITUATION	%
Groves of *"young"* western myall with burnt out "parent"	86
Groves of *"young"* western myall with no "parent"	14
Burnt out "parents" with no grove of *"young"* western myall	10
Burnt out "parents" located within a grove of *"young"* western myall	90

The severe effect of fire on another western myall population on Wirraminna Station was investigated by Lay (1976). Following widespread bush fires in 1974/75 after the inundation of 1973, more than 70% of the western myalls were killed by complete destruction of the trunk even when the fire was of a low intensity (Lay, 1976; A.D. Nicolson, *pers. comm.*).

3.4.2 RECRUITMENT IN THE STUDY AREA THIS CENTURY

A total of 226 separate populations of western myall and the associated evidence of major vertebrate herbivores were examined across the woodlands of South Australia for other studies described elsewhere in this thesis. Locations were targeted for the purposes of those studies, but in detail, were selected by a process of randomisation (discussed elsewhere) within the target areas. The sample sites were located in the areas designated Δ in **Figure 7.4**. Here I have used the data set to investigate the recruitment that is occurring across the study area.

3.4.2.1 Methods

At each of the 226 locations the life stage array of a minimum 100 trees was scored (in all, approximately 23,000 trees). A Maturity Index (proportion of the population which were adults) was calculated on all populations. Juveniles comprised Life Stages I-III (i.e. recruited post-settlement) and adults comprised Life Stages IV-IX. If there are all juveniles at a site then that site will have an index of zero; if there are all adults at a site then it will have an index of one. If a site has an index of 0.71 then 71% of the trees are adults and 29% are juveniles.

3.4.2.2 Results and discussion

A trend is evident in the Maturity Index across the range of western myall. This is illustrated by plotting the Maturity Index at each site against the latitude of the site (recorded by a global positioning system). The lack of populations between the central and northern populations is not an artefact; this belt contains Lake Gairdner, Lake Everard and Island Lagoon and the virtually treeless Arcoona Tableland (**Figure 2.1**) - there are few western myall woodlands.

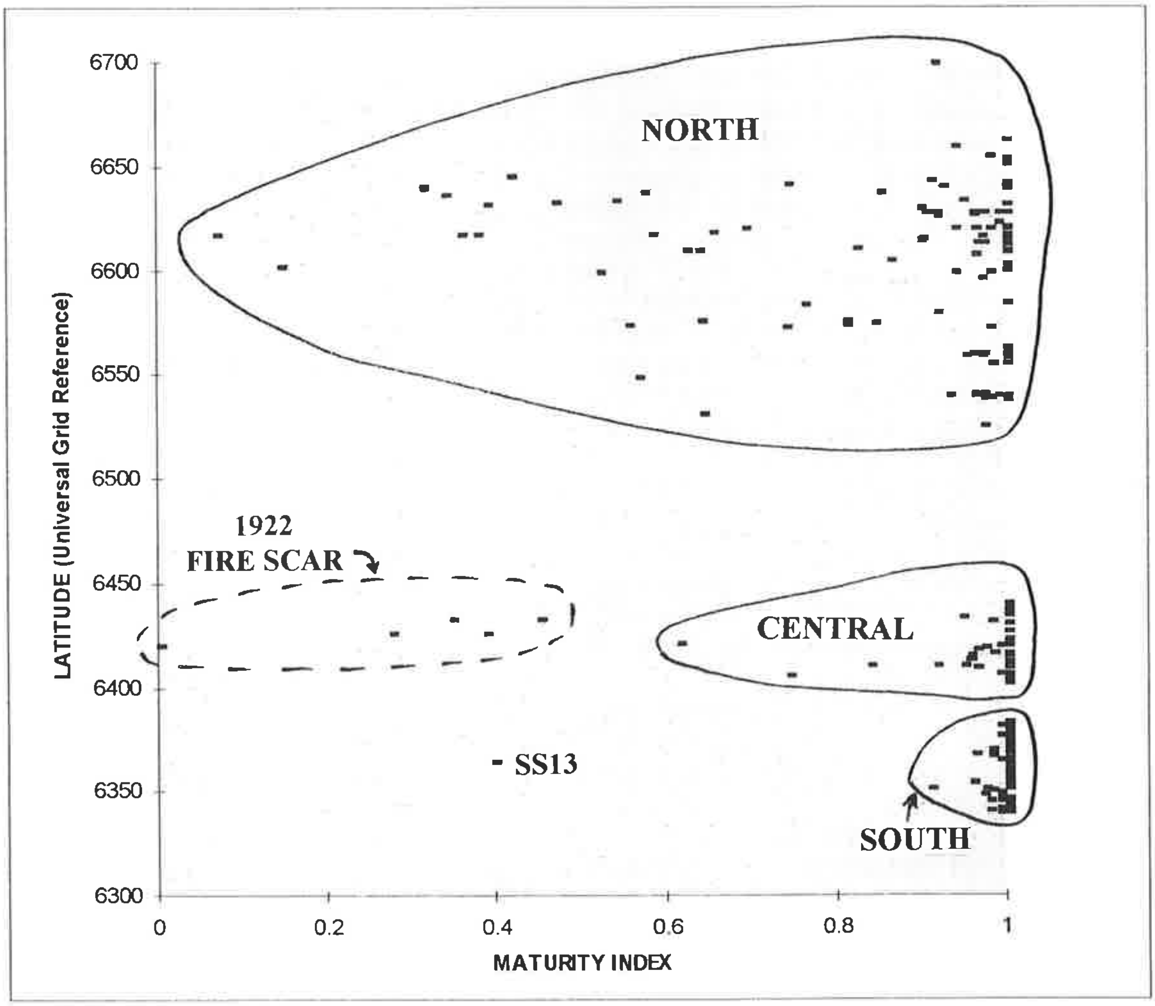

Figure 3.1: Occurrence of recruits from south to north over the study area

The distribution of the Maturity Index (ignoring the fire scar) is broadly triangular (**Figure 3.1**) showing that there are many more juvenile populations in the northern part of the species' range declining to very few in the south. The only exceptions are at site SS13 and sites within the 1922 fire scar, both discussed in Section 3.4. I believe that this is a real trend because of the thoroughness of the survey; the exceptions are indeed exceptions (i.e. the fire scar on Yudnapinna Station).

From **Figures 3.1** and **3.2** it can be seen that the populations appear to fall naturally into three maturity categories on the basis of range - north, central and south.

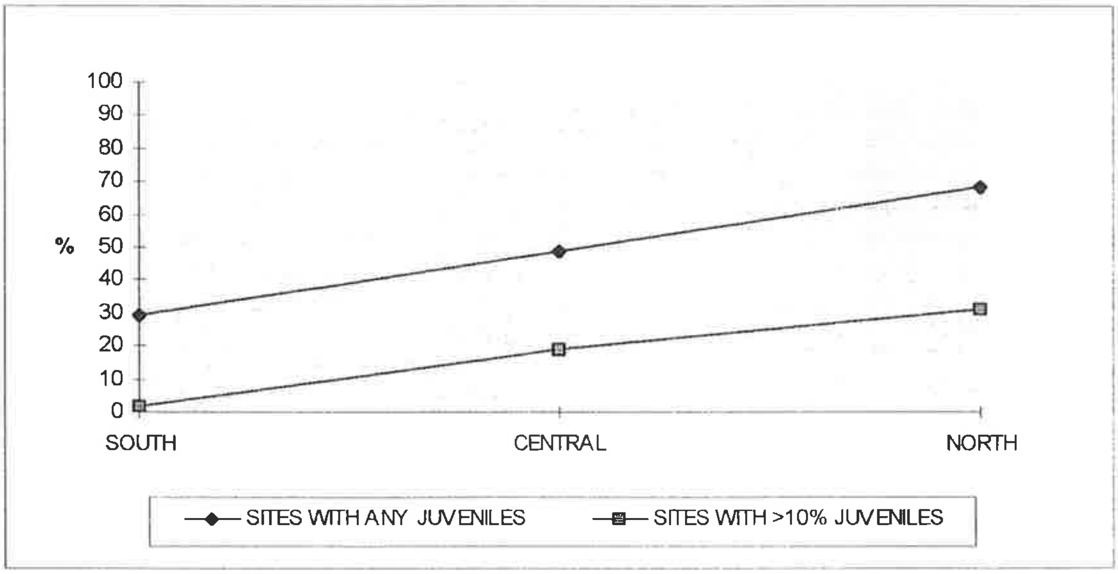

Figure 3.2: Percentage of populations containing juveniles

The populations are:

1. SOUTH (66 Populations)
   A group of populations located at or near the southern limit of the woodlands; they include 20 on Tregalana Station, 16 on Roopena Station, 14 on Katunga Station, six on Corunna Station and ten on Nonowie Station.

2. CENTRAL (43 Populations)
   These populations are located in the Gawler Ranges south of Lake Gairdner and include 22 on Siam Station, 10 on Wartaka Station, 10 on Cariewerloo Station and one on Yudnapinna Station.

3. NORTH (116 Populations)
   Located at or near the northern limit of the woodlands these populations include 31 on Parakylia Station, ten on Mount Vivian Station, two on Roxby Downs Station, one on Andamooka Station, two on Mount Eba Station and two on Billa Kalina Station. The north western boundary of the western myall woodlands occurs on North Well Station; 47 of the populations are located here. Nine others are located on Mulgathing Station, one on Commonwealth Hill Station and the remaining six on Wilgena Station. In the far west but still in the northern area two populations were examined in the Nullarbor Regional Reserve, one in the Yellabinna Regional Reserve and two on the Yalata Aboriginal Land.

Overall a very high percentage of populations in all regions (south - 29%, central - 49% and north - 68%) contained some individuals of the three youngest life stages (I, II and III) although less were recorded with more than 10% young trees. This was particularly apparent in the south where only 2% of populations were seen to contain more than 10% young trees. This low percentage was in sharp contrast to the much more active recruitment apparent in the central (19%) and northern (31%) areas. The differences between the three regions are apparent in both **Figures 3.1** and **3.2** with the high levels of recruitment that occur in the north declining markedly towards the southern parts of the study area.

Another intriguing finding of my study is that no rabbit dung, or new or old warrens were observed at any of the populations where more than 10% recruitment had occurred. This may indicate that the local environment in these locations was unfavourable for occupation by rabbit populations and therefore rabbits were possibly <u>not</u> present during recruitment. Conversely, either none or very few recruits were ever found where rabbit signs were present. Moreover, recruitment was not demonstrably suppressed at those sites located within 3 km of watering points where the presence of sheep could be inferred from the proximity to water and the presence of dung and tracks. <u>This work is described in detail in Section 7.3</u>.

3.5 DISCUSSION

The results show conclusively that recruitment of western myall does occur throughout the woodlands but that the amount of recruitment varies across the region. This finding alone is very significant.

Evidence from the Whyalla area (Correll and Lange, 1966; Lange and Purdie, 1976; Lange and Graham, 1983; Ireland 1992) has always pointed to aging populations that were not being replaced. My results for the south region (which includes the Whyalla area) support this interpretation. Although 29% of populations studied have a few juveniles, only 2% of populations show recruitment of more than 10% total juvenile Life Stages (**Figure 3.2**). It is therefore not surprising that all researchers who have reported results for the Whyalla area have reached the conclusion that the western myall is under threat.

The Pastoral Management Branch (PMB) of the South Australian Department of Natural Resources (DENR) is charged with undertaking the assessment of land condition across the pastoral leasehold lands in South Australia. As a part of this process photopoint monitoring sites are set up in every paddock of every Station within approximately 1.5 km. from water. At each site (among other standard recordings) a plant species list is assembled which contains simple presence/absence data on recruitment; western myall was one of the plant species thus recorded. Assessment has already been undertaken across the whole of my study area; and some 2000 photopoint monitoring sites have been set up and data recorded[1].

I did a simple analysis of the number of sites that contain western myall and the number of those sites that have recruitment (**Table 3.4**) using the same north, central and south regions (recruitment here means Life Stages I, II and III).

Table 3.4: Western myall data recorded by the Pastoral Management Branch

	SOUTH	**CENTRAL**	**NORTH**	**TOTAL STUDY AREA**
SITES WITH WESTERN MYALL	132	288	191	611
NUMBER OF SITES WITH RECRUITMENT	16	61	48	125
% OF SITES WITH RECRUITMENT	12%	21%	25%	20%

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[1] Permission to use this data was given by the Pastoral Management Branch of the Department of Environment and Natural Resources, 248 Portrush Road, KENSINGTON, SA, 5068.

The results show a similar (though less pronounced) pattern to my own of more recruits in the north declining towards the south. Results do however confirm a much more widespread pattern of recruitment across the woodlands than has previously been assumed.

Work conducted by Lay (1972) and Maconochie and Lay (1996) also corroborates my findings in at least the northern region where they worked (**Table 3.5**). Both researchers systematically sampled and recorded the occurrence of western myall and also the recruitment of the species at 3 km intervals along many of the station tracks in the area; both were looking for the younger recruits (Brendon Lay and John Maconochie *pers. comm.*). In 1971 Brendon Lay recorded recruitment at 2.7% of all sites visited; in 1994 John Maconochie recorded recruitment at 14% of the same sites. It should be remembered that the recruitment event of 1973/74 occurred just after Lay's survey conducted in 1971; Maconochie would have been recording recruits from that event and Lay would have been observing recruits from the 1946 event that happened some 25 years previously (in 1971 these would have had a similar appearance to the Life Stage I recruits from 1973/74 found today). Both researchers were recording from a moving vehicle and would possibly have only been able to see conspicuous recruitment; their figures may be conservative. It is for this reason that the figures for my own work in **Table 3.5** only include sites where >10% recruitment of a particular young Life Stage occurred.

Table 3.5: A comparison of the findings of Ireland, Lay and Maconochie in the north west

Life Stage I (the 1973/74 cohort)		**Life Stage II (the 1946 cohort)**	
IRELAND 1995	MACONOCHIE 1994	IRELAND 1995	LAY 1971(then Life Stage I)
19% of sites with western myall that have >10% Life Stage I	14% of sites with conspicuous recruitment	0 sites that had >10% Life Stage II	2.7% of sites with conspicuous recruitment

In my data, the association of western myall recruits with the absence of rabbits and the apparent lack of association with the presence or absence of sheep is an important finding and will be discussed in more detail in CHAPTER 7. Indeed, another clue is the incidence of myxomatosis in the early 1950s (Fenner and Ratcliffe, 1969; Rolls, 1969; Myers, 1971, Stodart and Parer, 1988). If the presence of rabbits suppresses recruitment in the western myall then the Life Stage II and III cohorts would tend towards extinction because they came into existence in the early and middle parts of the 20th Century well before the introduction of the myxoma virus which had such a devastating effect on the rabbit infestation. Jessup (1951) reported that in 1948 when one of the rabbit plagues was at its worst, rabbits could be seen climbing shrubs throughout the North West Pastoral District in South Australia. Many young plants including those of western myall, were destroyed and others lost much of their bark. Jessup (1951) predicted that unless the survivors matured by the next rabbit plague (an unlikely event in such a slow growing species) then they would probably be ringbarked; rabbits would eventually eliminate the western myall. The Life Stage I cohort recruited in the early 1970's some 20 years afterwards and the populations that survive may have done so because of drastically reduced numbers (or absence) of rabbits. Indeed, Wilson (1990) points to a reduction in rabbit populations and more controlled livestock grazing as a possible explanation for the slowing of the decrease in perennial herbs and complementary increase in annual herbaceous, inedible woody plants and soil erosion across southern Australia in recent times.

CHAPTER 4

THE PALATABILITY OF RECRUITS

4.1 INTRODUCTION

Although seasonal climatic fluctuations appear to be one of the major influences on the germination of seed and survival of seedlings in most plant communities (Section 3.4.1) there are other extrinsic factors that can affect recruitment. The presence or absence of one or a few species of large vertebrate herbivore can have major impacts on the vegetation (Edwards and Gillman, 1987), furthermore, the process of herbivory influences the organisation of every plant community (Crawley, 1983). Together, kangaroos which represent a significant grazing impact in arid and semi-arid areas where numbers have increased since European settlement (Robertson *et al.*, 1987), domestic livestock and rabbits are the major herbivores that affect the survival of vegetation communities in the Australian rangelands.

The relationships between vegetation available to the principal vertebrate herbivores in the rangelands and their diet is crucial (Dawson and Ellis, 1994). The comparative impacts on the vegetation of the original native herbivores and the domestic stock that replaced them obviously varies greatly with the amount of time that this impact has occurred. On a world-wide scale rangelands such as those in the Middle East have been utilised for grazing in much the same way for thousands of years whilst those in the new World have only a relatively short history of between 100-150 years (Walker, 1993). The implication of the ecological effects of the domestication of plants and animals on human culture and the environment was discussed at length by Flannery (1969).

For at least 5,000 years most of the Middle East has been grazed by livestock (Noy-Meir and Seligman, 1979); the intensity of grazing has fluctuated between historical periods. Noy-Meir (1990) suggests that this long history of grazing has undoubtedly had an effect on the vegetation and that furthermore there is little evidence to suggest how this vegetation would have differed in the past (presumably under grazing by native herbivores). However, Noy-Meir and Seligman (1979) state that sheep (*Ovies aries*) and goats (*Capra hircus*) were the dominant livestock species; *"they were probably domesticated in adjacent areas and are biologically adapted to the semi-arid winter rainfall environment"*.

In contrast with the Middle East livestock production has only been carried out for the past 150 years in many rangelands of the USA (Young, 1994). Grazing by large native herbivores has been part of the evolutionary and developmental environment of the Great Plains for 10,000 years (Lauenroth *et al*., 1994). The change from wild ungulates to properly managed domestic stock in this area has not given conclusive evidence of detrimental ecological effects even though European settlement has had major impacts (Lauenroth *et al*., 1994); large herds of bison that grazed the Great Plains provided selection pressure for animals and plants resulting in an ecosystem that appears similarly sustainable under grazing by domestic livestock. In a comparative study on the same range Schwartz and Ellis (1981) found that dietary overlap was greatest between pronghorn deer and sheep, was intermediate with cattle and least with bison. Grant *et al.* (1980) found no relationship between pocket gopher density and decreasing grazing intensity. Cattle were found by Hansen and Gold (1977) to be heavy grazers on prairie-dog-towns but diet overlap was considered moderate. Coppock (1983) found that bison selectively grazed prairie-dog-towns in South Dakota. In contrast, plant composition has changed at an unprecedented rate over the last 120 years in the Intermountain Sagebrush Region of the USA (Miller *et al*., 1994) although it was also in flux over the past 10,000 years under shifts in climate and fire regimes. Miller *et al.* (1994) proposed that heavy livestock grazing had accelerated succession towards a less desirable steady state but that moderate to light grazing could be compatible with the sagebrush ecosystem. Pieper (1994) concluded that livestock had a larger impact on the Intermountain Region, the Great Basin and the South West of the USA than on the Great Plains where domestic livestock replaced bison as the dominant herbivore.

A twelve year study at Fowler's Gap in NSW has provided a comparison of the diet of the sheep, rabbit and kangaroo that has never before been available for a single habitat over a long period of time. Dawson and Ellis (1994) concluded that their data pointed to marked competition between all three herbivores. When conditions deteriorated, sheep impacted more on kangaroo grazing and rabbits overlapped with both of the other species. It was in times of severe drought that the long-term impact of rabbits became apparent; their dependence on bark, twigs and roots killed many shrubs and small trees, thus removing these as a source of drought reserve for the other two species. In the mulga-box country of south-west Queensland, Griffiths *et al.* (1974) found that kangaroos consumed mostly grasses whilst sheep ate mostly forbs and browse. At Lake Mere Station in New South Wales, Wilson (1991) found that kangaroos caused a significant reduction in the availability of forage for sheep. If they were present in sufficient numbers this could negate a resting or "spelling" phase for paddocks in the arid zone and may point to the control of kangaroos in pastoral areas. Also at Lake Mere Station, Freudenberger's (1995) preliminary results from a long-term grazing study show that kangaroos and sheep at the same densities in a paddock have similar impacts on the vegetation and at high stocking rates both were capable of complete overgrazing.

Grazing is obviously a crucial part of Grubb's (1977) regeneration niche (CHAPTER 3). Suppression of regeneration by non-native and native vertebrate herbivores has been examined by several authors. In the Coorong National Park in South Australia, Cooke (1987) discovered that vigorous regeneration occurred in both *Allocasuarina verticillata* and *Melaleuca halmaturorum* in the 1950's when myxomatosis kept rabbit populations low; however, in recent times, unprotected seedlings have been quickly found and eaten by an expanding rabbit population. Friedel (1985) reported that the densities of smaller size classes of trees and shrubs in calcareous shrubby grasslands were *"severely depleted where rabbits were plentiful"*.

Lange, Coleman and Cowley (1992) measured the survivorship probabilities of seedling and adult saltbush (*Atriplex vesicaria*) in heavily stocked sheep enclosures. They found that seedlings were spared relative to shoots of adult plants. Lange and Willcocks (1980) reported on experiments in a 4,050 ha paddock using compressed cubes of fresh lucerne (*Medicago sativa)* as simulated seedlings. They concluded that a typical flock of sheep would extinguish most recruits in a few weeks. By contrast in the arid Karoo, South Africa (Milton, 1994) sheep had no effect on the survival of seedlings of three Asteraceae species (*Osteospermum sinuatum, Pteronia empetrifolia* and *P. pallens*).

Abbott and Van Heurck (1988) propose that changes in the abundance of kangaroos and wallabies may have been the partial cause of regeneration failure in *Persoonia elliptica* in the northern jarrah forest of Western Australia. On destocked portions of Yeelirrie Station in Western Australia areas were fenced to exclude kangaroos and the survival of six plant species (five shrubs and a perennial grass) was monitored (Gardiner, 1986a). He noted that kangaroo grazing reduced the regeneration of three of these.

At Koonamore Station in the north-east of South Australia, Crisp and Lange (1976) discovered that recruitment of *Acacia burkittii* was completely suppressed by the combined influences of sheep and rabbits; rabbits on their own reduced recruitment but did not eliminate it completely. The effect of sheep alone on this species was not determined. Woodell (1990) investigated *A. burkittii* at Middleback Station and found, however, that although some populations showed the same trends as those at Koonamore, others were recruiting quite vigorously in spite of the presence of both sheep and rabbits; populations of the latter were, however, heavily reduced by myxomatosis. Again at Koonamore, Crisp (1978) found that sheep and rabbit grazing completely prevented recruitment of *A. aneura*. Henzell (1991) discovered that although *A. aneura* germinated abundantly in 1979, 1984 and 1989 nearly all seedlings were eliminated from areas that were accessible to rabbits. and that feral goats had a relatively minor impact on recruitment.

At Kinchega National Park in NSW where domestic herbivores were not present, Auld (1990 and 1993) found that the regeneration of *A. carnei* was almost completely limited by rabbits and kangaroos but a small percentage of *A. oswaldii* recruits survived in spite of the rabbits and kangaroos. He concluded that the eradication of rabbits from *A. carneii* populations was essential for the plant's long-term survival. Further work at Kinchega National Park by Auld (1995a and 1995b) determined that *A. loderi* and *A. ligulata* recruits suffered the same fate and that the limited number of surviving *A oswaldii* recruits had avoided rabbit grazing by growing inside the canopy of shrubs such as *Maireana pyramidata*

It has been suggested that a combination of rabbits and sheep may cause profound changes in the dominance of the low chenopod shrubland and low woodland communities in the arid zone (Crisp, 1978). However, evidence accumulated by Tiver (1994) was interpreted to show that the grazing of several species of *Acacia* by rabbits, goats and kangaroos was much less important than that of sheep in the north east of South Australia.

There are however, no studies which clearly identify the rabbit, the sheep or the kangaroo as the single major suppressor of regeneration in the western myall. Lange and Graham (1983) examined the effects of rabbit grazing on seedling survival of *Acacia papyrocarpa* (western myall), *A. oswaldii*, *A. kempeana* and *A. burkitti* in enclosures. They also examined rabbits' ability to remove sparse seedlings by planting small cut shoots of adult western myall foliage (as a seedling surrogate) across 1000 ha of western myall woodland. They concluded that even with low rabbit populations such as those that are left after rabbit control programs (e.g. release of rabbit pathogens), rabbit grazing pressure would still be high enough to significantly suppress recruitment. The effects of sheep grazing were not addressed in their study. Moore (1984) found that rabbits prefer western myall seedlings over those of *A. oswaldii*; he also experimented with probes of western myall. His model showed that rabbits were capable of eliminating western myall seedlings in the absence of sheep.

There is abundant anecdotal evidence that western myall seedlings are protected by growing up inside individuals of other species (e.g. the chenopods, *Maireana sedifolia* and *M. pyramidata*) out of reach of herbivores (personal observation and R.T. Lange *pers. comm.*). Lange and Graham (1983) suggested that dense grass may have protected seedlings from rabbits in part of their experiment. O'Connor (1995) also found that *Acacia karoo* in South Africa established and survived within a dense grass sward for at least a year despite low irradiance and interference from browsers. In a completely different environment in the New Forest of southern England, Morgan (1991) demonstrated that seedlings of *Fagus sylvatica* and *Quercus* species are not found in heavily trampled, browsed areas but are associated with protective conditions. On the Golan Heights of Israel the establishment of tree and shrub seedlings is virtually prevented by the rapid desiccation of the soil in summer and by grass fires (Noy-Meir *et al.*; 1989), however tree seedlings do survive in stone mounds (Kaplan, 1984, quoted in Noy-Meir *et al.*; 1989).

Tree guard experiments, where different types of fencing are used to exclude rabbits and sheep from the western myall seedlings, have been used extensively on Middleback Station. Of those plants that have survived desiccation, unpublished results (R. T. Lange *pers. comm.*) generally show that the unfenced control (open to rabbit and sheep grazing) is more severely grazed than those fenced against sheep (open to rabbit grazing only) which in turn are more severely grazed than those fenced against sheep and rabbits (no access to either rabbits or sheep). These effects can be clearly seen in **Plate 6**.

Other than the experiments outlined above it would appear that the differing effects of rabbits and sheep on the recruitment of arid zone *Acacia* species has not been examined. Furthermore it has always been assumed that cut shoots of adult trees (probes) can be used as surrogates for seedlings in experiments with sheep and rabbits.

The relative palatability of western myall compared with other species in the landscape was considered by Murray (1937) who stated that unlike mulga, western myall *"is of little use as a fodder plant"* and Jessup (1951) who observed that although the foliage of western myall is grazed by stock as high as they can reach, it is only slightly palatable to them (on his palatability scale of 1-5, western myall scored a low 4).

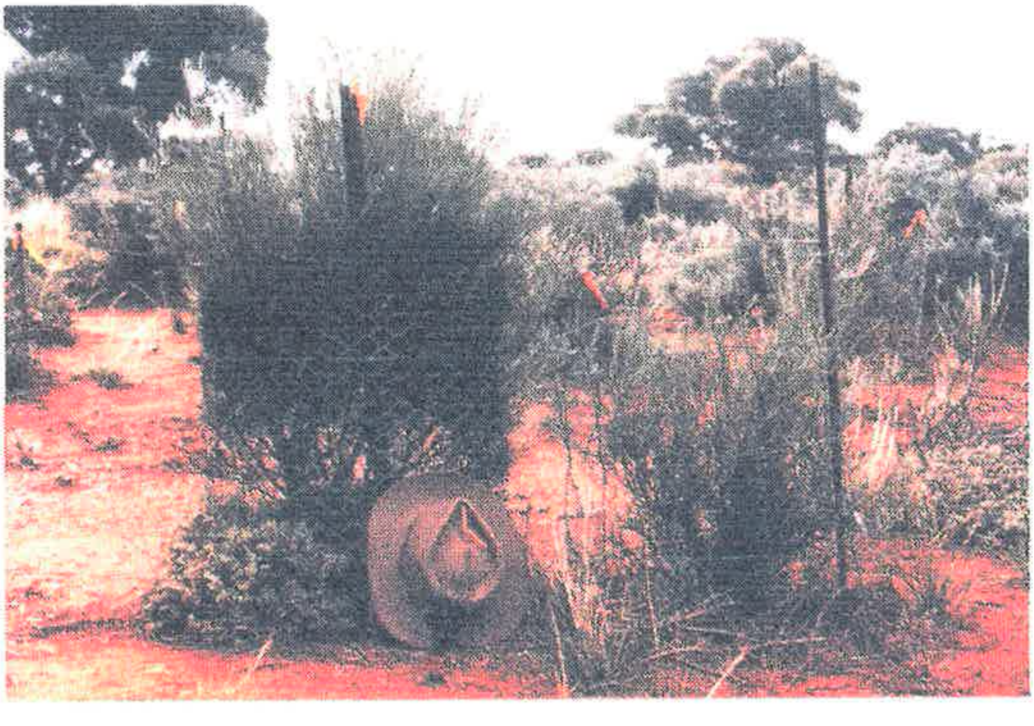

Plate 6: Tree guard experiment at Middleback (left: no access to sheep or rabbits, right: no access to sheep, foreground in front of hat: access to both rabbits and sheep)

It is well known that western myall displays ecotypic variation (CHAPTER 1). These variations are displayed not only in the gross morphology of the plant itself; differences have also been noted in colour, phyllode length and morphology, susceptibility to insect attack and conceivably in herbivory by native and exotic herbivores. If the latter holds, then not only does herbivory by domestic, feral and native species impact on western myall success but it may also discriminate between plant ecotypes.

This chapter reports the different impacts of sheep and rabbits on the recruitment of western myall obtained from grazing experiments of several kinds using seedlings and probes of western myall. From this I draw conclusions about:

- The validity of using cut shoots of adult western myall (probes) as a surrogate for seedlings in experiments with rabbits and sheep.
- The palatability of western myall to sheep compared with the palatability of other species in the landscape.
- The possible effects of ecotype on the palatability of adult western myall probes to both sheep and rabbits.

4.2 THE EFFECTS OF SHEEP AND RABBITS ON WESTERN MYALL RECRUITMENT

The numbers, density and uniformity of distribution of sheep, rabbits and kangaroos have all increased during the last 150 years. Each could be responsible for significant suppression of recruitment of western myall during the same period. Research into this suppression requires studying the loss of seedlings from the environment, but producing and field-placing seedlings is labour intensive. Few seedlings occur naturally in the field. Furthermore, it is logistically very difficult to propagate and artificially place in the field seedlings in large enough numbers for landscape scale experiments. Researchers have sought to substitute cut shoots (probes) of adult western myall plants as surrogates for seedlings. I have conducted experiments to test the validity of this technique.

As previously mentioned, it is interesting to note that seedlings of arid zone species have rarely been used in experiments to test their palatability to sheep. Lange and Graham (1983) used seedlings of four *Acacia* species (including western myall) and cut shoots of adult western myall trees (probes) as surrogates for seedlings of the species in an experiment to test the effect of rabbit grazing on the recruitment of *Acacia* seedlings. Moore (1984) used both seedlings and probes in his experiments with rabbits. Many University of Adelaide 3rd Year Rangeland Ecology classes at Middleback Field Centre have used probes as surrogates for seedling in their experiments. I decided not only to test the palatability of seedlings and probes to both sheep and rabbits, but also to test the acceptability of using probes as surrogates for seedlings. Jessup (1951) reported that the foliage of western myall is always grazed by stock as high as they can reach, however, it is actually only slightly palatable to them (Jessup, 1951; Mitchell et al., 1988). Similarly there is anecdotal evidence that attributes some browse lines on adult trees to both rabbits and kangaroos (D.A Nicolson and R.T. Lange, *pers. comm.*).

Two experiments were conducted with sheep to test the following hypotheses:

A1: That sheep eat western myall seedlings.

A2: That there is no difference in the preference shown by sheep for western myall seedlings or probes (i.e. that probes are acceptable surrogates for seedlings).

A3: That sheep will differentiate between probes taken from adult trees that may be different ecotypes.

A4: That all the forage species (including the western myall seedlings and probes) in the enclosure would be consumed in direct proportion to the amount they contributed to the total biomass on offer to the sheep (the "lawnmower hypothesis" of no selectivity).

Two experiments were undertaken with rabbits to test the following hypotheses:

B1: That unconfined rabbits (i.e. those that have their full dietary range available) eat western myall seedlings.

B2: That there is no difference in the preference shown by rabbits for western myall seedlings or probes (i.e. that probes are acceptable surrogates for seedlings).

B3: That rabbits will differentiate between probes taken from adult trees that may be different ecotypes.

4.2.1 METHODS

The sites chosen for these experiments were areas of western myall low open-woodland adjacent to Middleback Field Centre on Middleback Station on the northern Eyre Peninsula of South Australia (32°57'S, 137°24'E). Western myall is the dominant overstorey species; the understorey is characterised by the chenopods *Maireana sedifolia, Atriplex vesicaria* and *M. pyramidata* and an ephemeral flora of forbs and grasses.

Four treatment combinations were compared; two types of animals (rabbits and sheep) for each of two times of year (spring and summer). Each treatment combination is tested at 24 different sites, making 96 tests altogether. Each test is referred to as a pair, since at each there is a pair of pots, one containing a probe and one with a seedling (**Plate** 7). The most accurate comparisons are differences within pairs; essentially, was more of one eaten than the other? Direct comparisons of rabbits and sheep are less reliable since there is little control; the sheep (being enclosed) may have had less access to alternate food sources than did rabbits.

4.2.1.1 The sheep experiments

The two experiments with sheep were conducted in a similar manner to those described in Lange, Coleman and Cowley (1992). An area of typical chenopod shrubland was fenced with sheep mesh to form an enclosure 120m x 10m. At one end a separate holding pen was constructed and a watering trough installed halfway along one side of the enclosure. The enclosure was divided into 24 unfenced cells each 10m x 5m. The weight of available forage for *Atriplex vesicaria, Maireana pyramidata, M. appressa, M. georgii* and *Dissocarpus biflorus.* was estimated for each cell using the techniques of Andrew *et al.* (1979). Selected

Plate 7: A pair of pots; probe on the left and seedling on the right

shrubs of each of the species taken from adjacent to the experimental area were used to calibrate biomass estimates. The leaf-marking technique of Lange (1984) was used to follow shoot loss for the duration of both experiments.

I did two experiments in these enclosures with sheep with no rabbits present; eight merino sheep were given free access to graze for three days in September 1993 and six days in February 1994. Stocking rates were artificially high (67 sheep ha^{-1}) to simulate a “speeded-up” stocking pressure that would give meaningful results in a few days. There were 24 sites spread uniformly across the enclosure with ten pairs of each of seedlings and probes at each site. These were "planted" in identical black plastic pots which were buried flush with the ground. To maintain the freshness of the probes, those remaining each day were discarded and new probes from the same trees put in their place. An estimate of the total enclosure biomass was obtained by weighing 20 spare seedlings and 20 probes, averaging their weight and multiplying by 240.

As seeds were taken from a genetically varied stock, probes were taken from 10 widely scattered adult western myall trees (labelled A - J). Because fresh shoots had to be collected before each day's experiment could be recorded and re-set the area of collection was confined to approximately 10 square km. Likewise for logistical reasons, probes from Trees A - J were planted in the same order in each cell.

4.2.1.2 The rabbit experiments

I conducted two experiments with rabbits with no sheep present; seedlings and probes (identical to those used in the sheep experiments) were placed in natural rangeland vegetation around active rabbit warrens and exposed to grazing for four days in September 1994 and six days in February 1995. There were six active warrens with four sites at each (a total of 24 sites) with ten pairs of each of seedlings and probes at each site. For logistical reasons probes from Trees A - J were planted in the same order at each site.

4.2.2 RESULTS

4.2.2.1 The palatability of seedlings and probes to sheep and rabbits

Either a probe or seedling was eaten or it was not, giving a proportion out of ten for each site. The data (**Table 4.1**) were analysed as a split-plot design, both as an ANOVA (the Normal model) and as a Generalised Linear Model, which is more correct for these binomial data,. The conclusions from both these analyses were identical. The results of the Normal model are presented.

Table 4.1: Number of seedlings and probes eaten in the four experiments

	SHEEP				RABBITS			
	SEPTEMBER		FEBRUARY		SEPTEMBER		FEBRUARY	
SITE	SEEDLING	PROBE	SEEDLING	PROBE	SEEDLING	PROBE	SEEDLING	PROBE
1	3	5	2	7	6	9	2	3
2	7	8	1	7	2	4	6	9
3	6	5	1	3	4	8	6	6
4	6	5	2	4	1	5	6	6
5	2	8	2	7	9	5	4	3
6	1	5	1	4	8	9	2	4
7	0	3	1	4	5	6	5	3
8	0	5	3	4	3	7	4	6
9	2	4	1	6	1	2	1	4
10	2	7	0	7	3	4	2	4
11	3	8	1	8	2	3	2	2
12	3	6	1	7	4	5	3	3
13	3	4	1	8	0	0	0	0
14	3	7	3	7	4	4	3	3
15	2	7	2	8	3	5	2	2
16	3	6	1	3	2	3	3	3
17	0	3	0	7	6	9	6	5
18	3	4	2	3	5	6	6	6
19	0	4	2	7	4	3	3	3
20	2	0	1	4	0	1	5	7
21	0	5	3	4	2	2	7	10
22	2	1	2	5	3	5	8	8
23	1	8	4	8	2	3	4	4
24	2	4	0	4	3	1	3	4

Table 4.2: The analysis of variance

ERROR: PAIRS

Source	Df	Sum of Squares	Mean Square	F Value	Pr(F)
animals	1	8.7552	8.755208	1.324393	0.2527875
time	1	0.1302	0.130208	0.019697	0.8886948
animals:time	1	1.719	1.171875	0.177269	0.6747132
Residuals	92	608.1875	6.610734		

ERROR: WITHIN

Source	Df	Sum of Squares	Mean Square	F Value	Pr(F)
type	1	223.1719	223.1719	117.5345	0.0000000
type:animal	1	78.7969	78.7969	41.4987	0.0000000
type:time	1	2.2969	2.2969	1.2097	0.2742691
type:animal:time	1	10.5469	10.5469	5.5546	0.0205536
Residuals	92	174.6875	1.8988		

In **Table 4.2** "type" refers to the differences between the numbers of seedlings eaten and number of probes eaten. "Type:anim" and "type:time" ask whether the numbers eaten are dependent on time of year **or** on animal. "Type:anim:time" looks at interactions **between** numbers eaten, time of year and animal. The F ratios in the ANOVA indicate that there are large differences between consumption of seedlings and probes ($F=117.53$) and that the size of that difference depends strongly on each particular vertebrate herbivore ($F=41.50$). Overall, probes were preferred to seedlings ($P<0.001$), sheep preferred probes over seedlings and rabbits appeared not to discriminate between the two ($P<0.001$). The differences do not depend on time of year ($F=1.21$; $P>0.001$) although there is a small but significant interaction between animal and time of year ($F=5.55$; P only marginally >0.001). Sheep showed a stronger selection for probes in summer. Results are shown graphically in **Figure 4.1**.

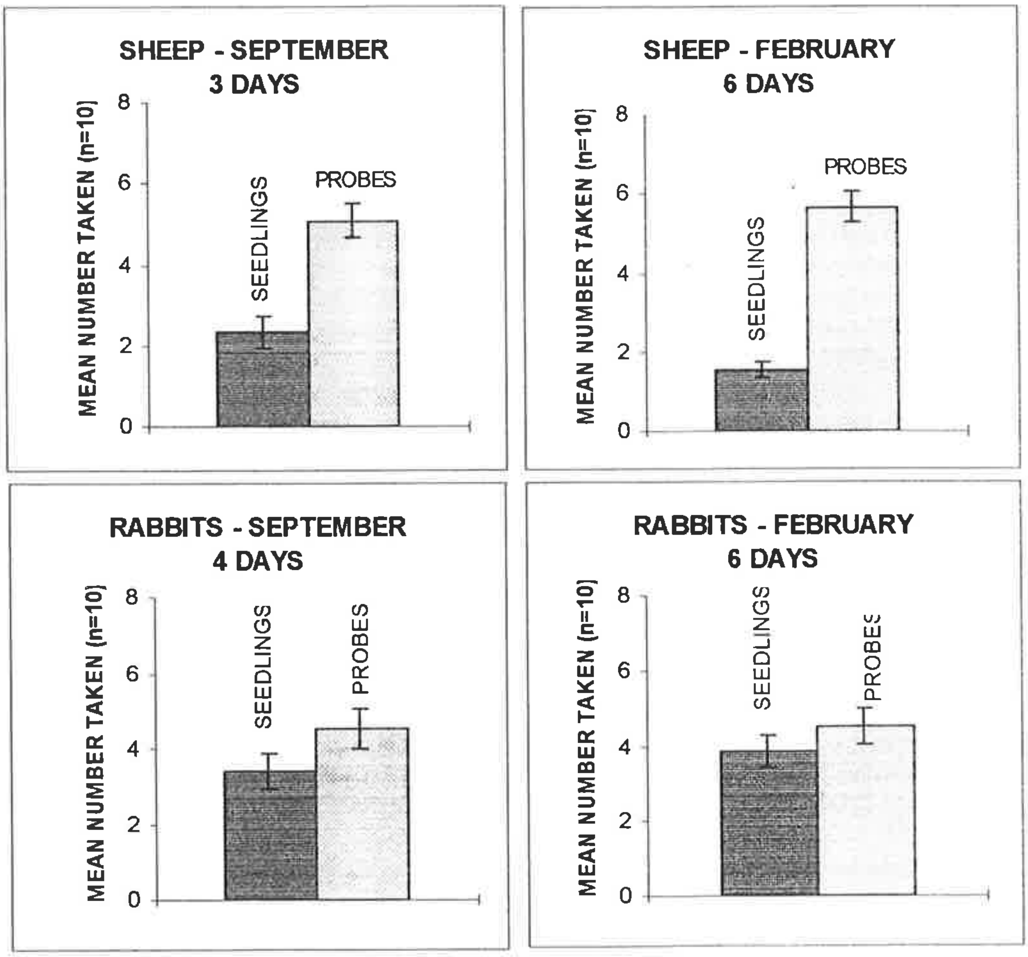

Figure 4.1: The results of the experiments with sheep and rabbits at Middleback Station, spring 1993 and 1994, summer 1994 and 1995

4.2.2.2 *An electivity index for the sheep experiment*

In order to measure diet selection a comparison of the relative abundance of species available must be made with the abundance of species consumed by the animal. High utilisation of a species and low availability indicates relatively high selection (Norbury and Sanson, 1992). Consumption of shoots for all forage species within the enclosure is shown in **Table 4.3**.

Table 4.3: Shoots remaining each day for each species in the experiment

SPECIES	START	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
Atriplex vesicaria	1200	956	736	608	459	360
Maireana appressa	220	161	140	112	88	65
M. pyramidata	1190	941	731	628	508	397
M. georgei	200	185	149	119	97	67
Disocarpus biflorus	285	173	91	59	48	34
Acacia papyrocarpa seedlings	238	215	185	168	159	153
Acacia papyrocarpa probes	239	221	151	125	109	93

To analyse these data I calculated Ivlev's electivity index (Ivlev, 1961). The formula is:

$$E = \frac{r-p}{r+p}$$

where r is the percentage contribution to the diet and p is the percentage abundance in the vegetation on offer. Ivlev's electivity index has a range from -1 for total rejection, 0 for indifference and will approach +1 (E will never be exactly +1) where a single species is exclusively eaten. These values for the forage species (including western myall seedlings and probes) within the sheep experiment conducted in summer 1994 are shown in **Figure 4.3**.

The results show that sheep appear to prefer almost any other forage on offer than western myall and that they particularly rejected the seedlings.

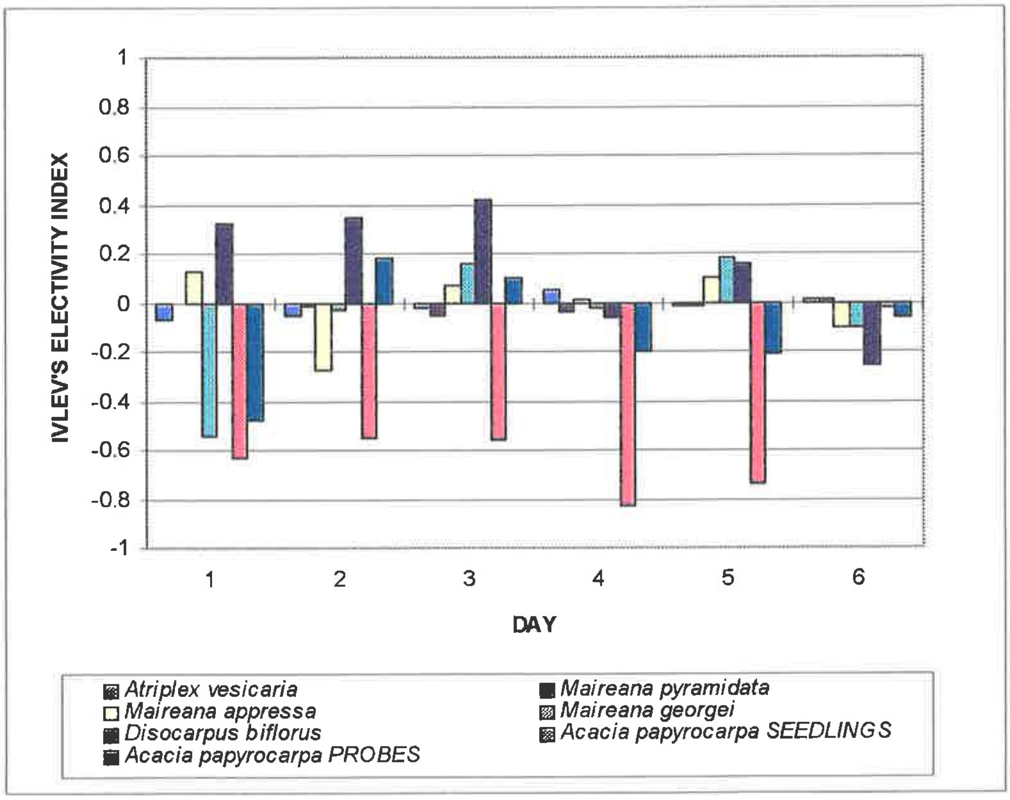

Figure 4.2: Dietary selection in the sheep experiment at Middleback Station, summer 1994

4.2.2.3 *The variability in palatability between individual trees*

I have only used the results of probe consumption from the sheep and rabbit experiments undertaken in summer over periods of 6 days each **(Table 4.4)**. Trees A-J were not used for the spring sheep experiment and the spring rabbit experiment only ran for 4 days; results from this experiment were not included in this analysis of palatability between trees.

For both sets of summer data (rabbit and sheep), a χ^2 goodness of fit test (assuming a Poisson distribution) showed that there was no evidence for the results being any different from random results, in other words there was no evidence of difference in palatability between trees.

Table 4.4: Number of probes eaten that originated from Trees A-J (n=24)

TREES	SHEEP	RABBITS
A	9	9
B	11	6
C	14	7
D	17	11
E	15	11
F	14	11
G	14	13
H	15	11
I	18	8
J	11	14

4.3 CONCLUSION AND DISCUSSION

The experiments clearly show that both western myall seedlings and cut shoots of adult plants (probes) are palatable to both rabbits and sheep.

Results of the Generalised Linear Model and the ANOVA on the seedling and probe data for rabbits and sheep indicate large differences in palatability depending on the type of material offered and that the size of these differences depends on the animals:

- sheep show a significant preference for probes over seedlings, and
- rabbits appear not to discriminate between the two.

From this I conclude that probes are not an acceptable surrogate for seedlings in sheep experiments but they are in experiments with rabbits. This has implications for sheep experiments that are undertaken using cut shoots of adult plants of western myall. Care should also be taken when experimenting with other plant species to determine whether or not probes may be used instead of seedlings.

The fact that sheep rejected seedlings relative to probes certainly substantiates the work done by other researchers on the palatability of other *Acacia* species. Unpublished results for mulga (*Acacia aneura*) in Queensland suggest that young trees contain more tannins than old trees (Sean Miller, *pers. comm.*) and the hypothesis is proposed that young trees need to protect themselves during their struggle to get started in life. Mulga phyllodes contain tannins and it has been suggested that this is the reason sheep do so poorly on an exclusive diet of mulga. It is thought that tannins may bind leaf protein and only a fraction is thus digested; the balance passing through the animal. Digestibility of mulga is only 45% and the species is considered to be only a drought maintenance ration (Wilson and Harrington, 1984). Bryant et al. (1991b) believe that the influence of tannins on digestibility is questionable and instead propose that tannins are toxic to the lining of the stomach and other internal organs. Unpublished results have also been recorded for gidgee *(A. cambagei)* in central west Queensland (David Cobon, *pers. comm.*); percentage condensed tannins in the phyllodes decreases as the tree grows taller - from about 13% in one metre high specimens to about 2% in three meter high specimens.

By calculating Ivlev's electivity index on the forage species contained in the summer 1994 sheep experiment an interesting and important implication can be seen - that sheep appear to reject western myall seedlings compared to probes. At Middleback sheep also reject saltbush (*Atriplex vesicaria*) seedlings (Lange *et al.*, 1992). This seems to be an example of a more general phenomenon that seedlings or juvenile growth shoots contain higher concentrations of plant secondary compounds and are thus less palatable than adult foliage of the same species Bryant et al. (1991a).

Elsewhere, examples of this phenomenon are found in several boreal tree species (paper birch, quaking aspen, green alder and balsam poplar) which have chemical defenses against the snowshoe hare (Bryant, 1981; Sinclair and Smith, 1984; Reichardt *et al.*, 1984; Clausen *et al.*, 1986; Sinclair *et al.* 1988; Reichardt *et al.*, 1990); in all cases snowshoe hares preferred mature growth over juvenile growth. Moose, like hares, feed preferentially on shoots from mature trees and shrubs even when younger plants of the same species are more freely available (Bryant and Kuropat, 1980). Grouse in Scotland select for older heather plants rather than juveniles (Moss et al., 1972; Savory, 1978). In the arid south west of the USA woodrats prefer mature leaves of creosote bush (Myer and Karasov, 1989). Juvenile-phase chemical defence has also been shown to influence the feeding behaviour of deer in Oregon (Dimock, 1974, quoted in Bryant *et al.*, 1991a) and California (Hall and Lagenheim, 1986), jackrabbits in California (Libby and Hood, 1976, quoted in Bryant *et al.*, 1991a), beaver in Nevada (Basey, 1987) and elephant in southern Africa (Jachmann, 1989).

None of the forage species in the sheep experiment conducted in summer 1994 was consumed in direct proportion to the amount that species contributed to the total biomass on offer. Sheep appear to prefer almost any other forage on offer e.g. saltbush or blackbush (note: this rejection is not an artefact - the electivity index is calculated taking into account the relative availability of probes, seedlings and other forage). Both seedlings and probes were rejected with a particularly clear rejection of seedlings (**Figure 4.2**). Although Lange and Wilcox (1980) concluded that sheep had the capacity to eliminate populations of small scarce plants in a short space of time, my results show that with western myall in a typical vegetation association at Middleback Station, this is unlikely to occur. Even at the artificially high stocking rates used in the experiments (67 sheep ha^{-1}) my results show that sheep favoured almost every other forage on offer over western myall seedlings. My methods, however, differed from those of Lange and Wilcox (1980) who used simulated seedlings (cubes of fresh mashed lucerne - *Medicago sativa*) as a substitute for seedlings and spread these out over a 4050 ha paddock. At Middleback sheep rejected these outright because, the authors assumed, they were unfamiliar with lucerne. Sheep at Morgan on the River Murray however, ingested the cubes because, Lange and Wilcox assumed, they had previously been weaned on lucerne.

As with the other parts of the experiments, when the consumption of Trees A-J is considered, direct comparisons between rabbits and sheep are not reliable. The only comparison that can be made is between trees within each individual experiment. It should also be remembered the purpose of the work was not to specifically examine this question but to allow gross differences in palatability between trees to appear if they were there; none was apparent. The χ^2 goodness of fit test showed that there was no apparent difference in the relative palatability of the 10 trees used for either the rabbit or sheep experiments. This suggests that although the trees may have been of varying genetic stock their palatability to sheep or rabbits is not affected, at least not in the immediate vicinity of the Field Centre at Middleback. Differences in palatability caused by genetic differences may, however, exist in other more spatially separated trees; also the apparently large range in both sets of results indicates that there may be scope for further work using higher numbers of samples to increase the precision.

Observations of flourishing individual juveniles on severely grazed land close to watering points (e.g. 400 m south of Majendie Dam on Parakylia Station, **Plate 17**) may infer that some ecotypes exist which are strongly unpalatable to major herbivores. Whilst my experiments cannot directly compare the effects of rabbits and sheep the individual results for each species of animal are revealing and conclusive. Both animals have the potential to damage western myall populations by suppressing recruitment. It is clear that rabbits will consume both seedlings and foliage from adult trees indiscriminately, but I have no way of knowing whether the lawnmower hypothesis of no selectivity applies to them with regard to other species of forage on offer. Lange and Graham (1983) and Moore (1984) also concluded that rabbits do graze both seedlings and probes. Sheep on the other hand, whilst they will consume both seedlings and adult foliage have a clear preference for adult foliage and will reject both (particularly seedlings) if other forage is available. It may be that the major impact of sheep is on young plants (up to 20 years old) with more palatable foliage rather than seedlings; these can be defoliated constantly **(Plate 8)** by either sheep or rabbits over a long period of time and it is thought that they will eventually die from stress (R.T. Lange, *pers.comm.*).

Plate 8: A young western myall (thought to belong to the 1973/74 cohort and photographed in 1992), which has been regularly defoliated by vertebrate herbivores

Unlike gidgee, however, it is not known when western myall seedlings lose the properties which make them less palatable than adult foliage, and while sheep may reject western myall seedlings in favour of probes, this does not necessarily mean that probes are not an acceptable surrogate for older suppressed juveniles.

Implications of these findings will be discussed further in CHAPTER 8.

CHAPTER 5

THE LIFE SPAN OF WESTERN MYALL

5.1 INTRODUCTION

Western myall is thought to be a long-lived species (Correll and Lange, 1966) - at least two hundred and fifty years (Lange and Sparrow, 1992) and possibly longer. Knowledge of its age structure is central to gaining an understanding of the species' population biology. As described in previous chapters it grows in an arid and unpredictable environment and reproduces almost exclusively from seed at infrequent intervals, apparently about once every 25 years. It seems then, that the species can recruit infrequently and still survive. If we know the age or life span then we could estimate the average recruitment needed at each recruitment event to ensure its survival. By comparing this with results collected in the field conclusions could be reached about the sustainability of the species under present land use. Furthermore, sensible suggestions for its management could be made.

Previous attempts to estimate a life span for western myall have placed the oldest trees at >250 years. Correll and Lange (1966) observed an extremely slow rate of growth in the western myalls photographed by Goode (1941) on the northern Eyre Peninsula and photos taken by themselves of the same trees 23 years later. They proposed that trees moved independently through all stages from seedlings to mature trees to disintegration. Assuming a steady state (i.e. input=losses) they argued that the ratio of live to dead trees near Hesso Railway Station would be the same as the ratio of the time taken from seedling to death (the life span) over the time it took for a dead tree to disintegrate. They sampled an area of woodland with a modified point-centre quarter method which gave them a ratio of live/dead trees. They then estimated from the matched pairs of Goode's (1941) photos and their own photos how long it takes to progress from death to disintegration and arrived at a conservative estimate of 50 years; believing this to be too conservative they finally chose a figure of 100 years. From this they calculated a conservative life span for western myall of >250 years.

Lange and Sparrow (1992) constructed a model of trunk growth from the 10-year increments in trunk diameter of 16 western myall trees at Middleback Station. On the assumption that annual trunk growth is linear they calculated a span of 160 years for a tree to progress from Lange and Purdie's (1976) Life Stage IV to Life Stage V (**Figure 2.7**). However a single decade may not be adequate for an estimation and from first principles it seems that growth rate probably declines with age and varies with conditions.

In this chapter three complementary techniques, dendrochronology, mortality studies and radiocarbon dating are assessed for their potential to provide information on the life span of western myall.

5.2 DENDROCHRONOLOGY

The utilisation of woody plants for dendrochronology requires that the species produces growth rings in most years (Flinn *et al.*, 1994). In many trees new vessels are added during each growth season following an inactive period during winter (Lowe and Walker, 1984). In the early part of the season these vessels are larger and thin-walled - the earlywood; in the latter part of the growing season they are smaller and thicker walled - the latewood. These vessels and walls often form a distinct line or annual growth ring and the tissue is described as ring porous. In species where the distinction between latewood of one season and earlywood of the next season is not so clear the tissue is described as diffuse porous. In these latter species rings are harder to distinguish and the technique is much less useful.

Arid zone trees have been assumed difficult to age by means of growth rings, as growth of most species is thought to respond to individual erratic rainfall events rather than seasonal cycles (Ogden, 1978; Adamson, 1982; Schweingruber, 1988). Western myall, however, produces a new flush of growth in early summer each year (Maconochie and Lange, 1970; Ireland, 1992), an event which appears to be independent of the pattern of rainfall. Hence western myall is a more likely candidate for the successful application of tree-ring counting techniques.

5.2.1 DENDROCHRONOLOGY AND ARID ZONE PLANTS

Dendrochronology has not received much attention in Australia as the climate was not thought to generally lend itself to the production of clear annual rings because of erratic rainfall and no distinct annual cold period (Francis, 1928). However, some researchers have found that useful annual growth rings are relatively common in the cooler, more humid south east of the Australian mainland and particularly in Tasmania (see **Figure 1** in **Appendix 6**. Many of the studies have been reviewed by Ogden (1978) and LaMarche *et al.* (1979). In his review, Ogden (1978) suggested that *Eucalyptus* and *Acacia* appeared to be generally unsuited to standard dendrochronological studies although, particularly for *Eucalyptus*, there were exceptions. He dismissed the two genera as generally not sufficiently long-lived to be useful for tree-ring dating, with the possible exception of *Acacia peuce* in the arid zone. However, Baillie and Pilcher (1987) successfully constructed the 7000 year Belfast "long chronology" for oak which has a lifespan of 200-300 years.

Studies of a variety of semi-arid and arid zone perennials around the world have shown that discernible annual growth rings do occur in some shrubs and trees. Fergusson (1962) found that about 10% of desert shrubs in Arizona contained annual growth rings including *Artemesia tridentata* and *Acacia greggii*. The latter flowers regularly in spring and has useable rings (Little, 1980). In 1963, Ferguson suggested that 18 individuals of known age of *Prosopis glandulosa* var. *glandulosa* (honey mesquite) in southern Arizona contained annual growth rings, that certain sequences of rings cross dated and some samples correlated with winter rainfall. Flinn *et al.* (1994) also identified annual rings in the same species at sites in Texas. They concluded that tree-ring analysis of this species may be useful for the reconstruction of climatic events, disturbance and successional history because some trees may have exceeded 200 years of age.

One study with particular relevance to my work is that of Wyant and Reid (1992) in the arid Turkana District of Kenya. They used tree-ring counts to age *Acacia tortilis*; whose wood appears to have a similar structure to western myall. Wyant and Reid each counted rings for two radii on each of 12 cross-sections and found their counts were highly consistent. In upland specimens of known age they showed a significant linear relationship between age and ring count. *Acacia tortilis* of known age from the riparian zone were found to have only half as many rings as years in age so the researchers concentrated on upland specimens. However, they considered that the slope of their regression suggested one ring appears to be missing for every 3-4 years. Their explanation was that a ring was not formed during drought years which happen about three times a decade. Gourlay (1995) examined individuals of several *Acacia* species of known age from Zimbabwe, Kenya, Zambia, Malawi, Somalia and South Africa. He found that the marginal parenchyma bands and crystalliferous chains found in samples could indicate seasonal growth patterns; he concluded that in some African acacias he was able to identify seasonal growth changes thus enabling age determination and some correlation with climatic and environmental factors.

There have been several attempts to use dendrochronology in the arid zone of South Australia. Examining the tree-rings of *Callitris columellaris* (Cupressaceae) at The Pines Station near Pimba, Lange (1965) and Jackson (1982) achieved limited success. They found an imprecise relationship between broad rings and large rainfall events and a differing number of narrow rings between these broad rings when comparing individual trees, however, they did find that rings tended to be produced about one every year. In Western Australia, Pearman (1971) found a similar relationship in *Callitris preissii*. More recently Read (1995) used tree-ring counts to assign ages to *Callitris glaucophylla* (formerly *columellaris*) specimens near Olympic Dam in South Australia. Schweingruber (1992) concentrated only on shrubs and found that in the Australian arid and semi-arid areas growth rings were indistinct and probably due to rainfall events rather than annual climatic influences.

5.2.2 DENDROCHRONOLOGY AND THE WESTERN MYALL

The age structures of western myall populations have so far been approximated by well defined, but arbitrary, life stages (CHAPTER 2). The use of life stages is clearly the most efficient means of characterising populations in the field. However, apart from life stages recruited within living memory (I, II and III) we do not know the age structure of populations of older individuals. With my colleague, Dr. Des Coleman, I am assessing the potential of tree-ring analysis for ageing individual specimens of western myall. We also wish to know if life stages are a reliable indicator of relative age within populations.

Acacia species in the arid and semi-arid zones of Australia appear to fall into two phenological groups, those with an irregular pattern of growth and reproduction and those which flower, fruit and produce a regular growth flush each year. *Acacia aneura* (mulga) is probably the most well researched of the first group; individual mulga trees may flower and produce new shoots at any time of year in response to rain - evidence from near White Cliffs in New South Wales (Preece, 1971), in the Musgrave Ranges, South Australia and near Alice Springs in the Northern Territory (Maconochie, 1973). At Mileura Station in Western Australia (Davies, 1976) the same phenomenon was observed over a period of about 20 years. Other members of this group are *A. kempeana* in the Musgrave Ranges and near Alice Springs (Maconochie, 1973), *A. georginae* studied by Robinson *et al.* (1990) for 3 years near Alice Springs in the Northern Territory and *A. harpophylla* near Emerald in Queensland (Wetherell, 1966).

In contrast western myall falls into the group which has a regular phenological pattern. *Acacia* species in this group flower and put on new growth once each year despite rainfall variability. However the timing differs between species. Sedgley (1989) attributes these responses to temperature regimes and photoperiod. Pedley (1978) stated that the majority of Queensland *Acacia* species flower at the same time every year regardless of weather conditions prior to flowering. He suggested that this was possibly a photoperiodic response. Friedel *et al.* (1993 and 1994) found over a period of 4 years that *Acacia* species in Central Australia flowered and fruited at a variety of times, not always in response to rainfall. Davies (1976) reported a *"remarkably regular calendar of flowering"* in 13 arid zone acacias at Mileura Station in Western Australia. He stated that photoperiod and other environmental variables at Mileura are fairly regular. *Acacia cambagei* in south western Queensland (John Reynolds, *pers. comm.*) has a regular flowering season; new shoot growth of *Acacia ligulata* and *Acacia murrayana* in the Musgrave Ranges, *Acacia papyrocarpa* (western myall) at Yudnapinna Station in South Australia (Maconochie and Lange, 1970) and *Acacia victoriae* near Alice Springs (Maconochie, 1973) is distinctly seasonal. Maconochie and Lange (1970) suggested that the apparent cycles of growth in *A. papyrocarpa* and other species over a period of 3 years coincide with the build-up and climax of high temperatures in summer and that they were related to water stress. They continued that despite the arid habitat most of the species they studied showed periods of activity unrelated to rainfall events.

This response is also seen in more temperate climates where rainfall, temperature and photoperiod display a more seasonal pattern. *Acacia myrtifolia* and *Acacia pycnantha* showed distinctly seasonal shoot growth in the Mount Lofty Ranges of South Australia (Maconochie, 1975). Floral buds were produced every month in *A. pycnantha* at Glen Osmond in South Australia but flowering occurred only once a year in December (Buttrose *et al.*, 1981).

Judging from the limited evidence available so far, western myall produces a new flush of growth in early summer each year (**Plate 9**), an event which appears to be independent of the pattern of rainfall (Maconochie and Lange, 1970; Ireland, 1992; Bob Lange, Don and Andrew Nicolson, *pers.comm.*). If cambial activity is linked to the periods of growth at the apices then I consider there is a good chance that growth rings correspond to years of age, which would make the western myall a potentially good candidate for tree-ring dating. Clear growth rings evident in polished sections may represent annual increments, with few missing or false rings (**Plate 10**).

Plate 9: A flush of new growth in early summer each year

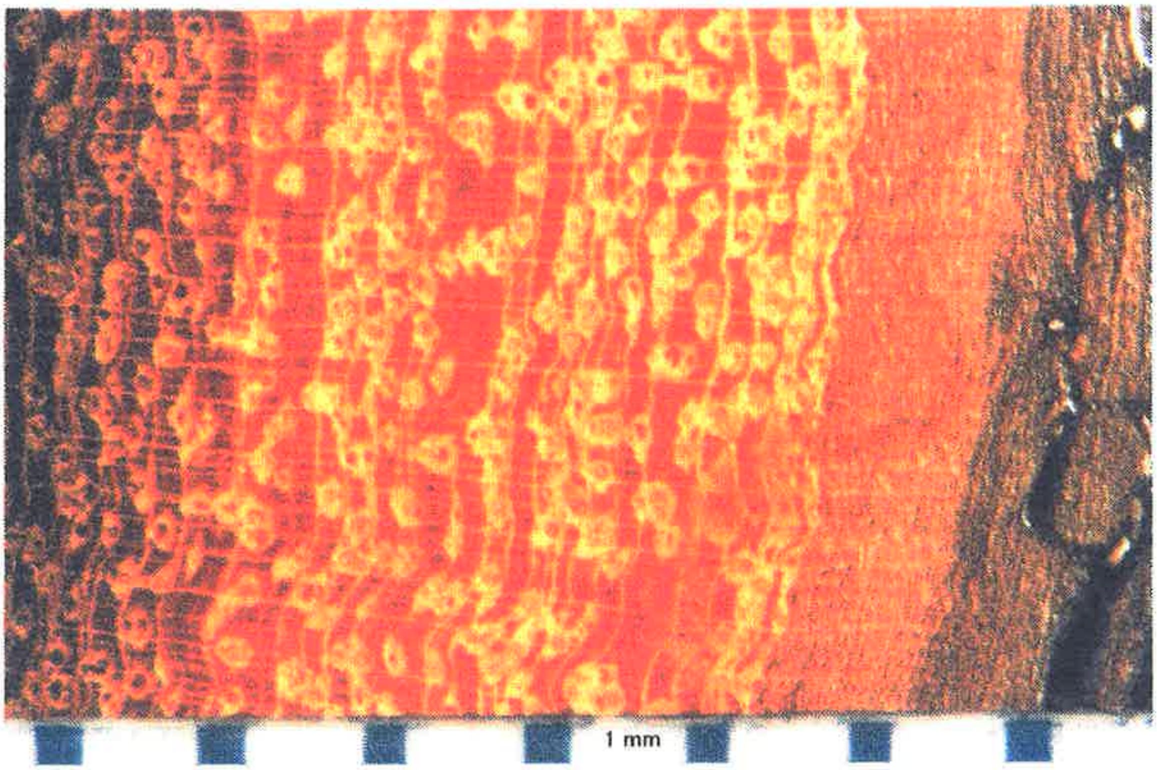

Plate 10: The internal structure of western myall wood x 20 (Photo: Trevor Ireland)

5.2.2.1 Methods

Sample trees of known age (72 years) were chosen from the fire scar at Yudnapinna Station (*Section 3.4.4.1*). Fire swept through the Bowen Hill area and other western paddocks of the station in 1922. Regeneration of most species was rapid and in 32 years (Jackson, 1958) western myall trees had reached heights of 5-8 ft (1.5 - 2.5 m). In 1995 a sample of known age (49 years) was also taken from Corunna Station. Samples were also taken at other sites where age could not be determined; these were North Well, Moonarie and Middleback Stations and also at other unburned sites on Yudnapinna Station **(Figure 2.1)**. Permission to take specimens was obtained from the South Australian Department of Environment and Natural Resources[1]. Because western myall wood is extremely hard and dense, samples could not be taken with a standard increment corer. For this preliminary work a single cross-section

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[1] Permits under the South Australian National Parks and Wildlife Act, 1972 were granted to enable the taking of samples both inside and outside a reserve. (W23275-03 to "Undertake Scientific Research in a Reserve" and A23276-03 to "Take for Scientific purposes (not in a reserve)")

was taken from near the base of multi-stemmed specimens; consequently a minimal number of branches were lopped from specimens at each site. A Life Stage was assigned to each tree (**Figure 2.8**) and photographs were taken before lopping commenced.

Cross-sections cut from the sample trees were polished with increasingly fine grades of sandpaper and fine steel wool until the internal structure of the wood could be clearly seen under a standard binocular microscope (**Plate 10**). Growth rings were counted along two radii for each sample. Five cross-sections were taken from one of the trees at intervals of 10, 50, 90, 130 and 174 cm above the ground on one stem; if the number of rings decreases with height then this may be another indication that rings are produced annually (this is a standard method of initial sampling recommended by Tom Harlan and Alex McCord *pers. comm.*[2]);. My findings (and those of my colleague Dr. Des Coleman) are the first for western myall. This approach shows promise and the work has triggered a new research thrust that may be expanded to include other arid zone tree species in Australia.

5.2.2.2 Results

Western myall wood is *"...diffuse porous, with vessels in clusters or short chains, surrounded by abundant, usually vasicentric, paratracheal parenchyma"* (Coleman and Ireland, 1992). The growth rings bounded by thin bands of parenchyma are largely continuous around each cross-section of wood examined to date. Most samples show an eccentric ring pattern due to tension wood formed in response to inclination of the stem; the amount of tension wood depends on stem angle and is accentuated as the tree assumes procumbency.

Results of ring counts for individual trees are shown in **Table 5.1**. Ring-counts for most of these sections have produced preliminary counts very close to expected ages not only for the trees of known age (Life Stage III at Yudnapinna and Life Stage II at Corunna) but for others with ages predicted from Life Stages. For example, cross-sections taken in 1994 from the 1922 cohort (i.e. 72 years old) in the Yudnapinna fire scar had mean ring counts of between 70 and 76 growth rings each and an individual taken on Corunna Station in 1995 that is known to

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[2] Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

have recruited in 1946 (i.e. 49 years) had a mean ring count of 51 rings. At North Well Station, a group of Life Stage IV trees of diverse size had mean ring counts of 140, 136 and 205 from smallest to largest and a young Life Stage V individual cut for fence posts in about 1970 had a mean ring count of 194 rings giving an approximate age of 219 years if 25 years are added. Sample MI0295, a Life Stage VII individual from Middleback Station (**Table 5.1**) had some unreadable rings halfway through the radius. The tree had a total of 236 readable rings; by measuring this readable portion and extrapolating from readable rings I conservatively estimated that the tree may have approximately 350 rings.

Table 5.1: Tree-ring counts for individual western myall trees.

SAMPLE NUMBER	LIFE STAGE	IN FIRE SCAR	GIRTH (cm)	NO. OF RINGS IN RADIUS 1	NO. OF RINGS IN RADIUS 2	COMMENTS
Y0894/6	III	Yes	30.1	70	70	
Y0894/7	III	Yes	36.5	76	75	
Y0894/8	II	Yes	22.3	70	74	Outer rim of Life Stage III grove
Y0894/10	III	Yes	20.1	74	72	
Y0995/1a	III	Yes	40.2	72	74	
Y0894/1	III	No	43.6	36	38	Likely a Life Stage II
Y0894/2	II	No	25.6	19	21	Likely a Life Stage I
Y0894/3	I	No	9.1	21	20	
Y0894/12	IV	Yes	61.0	168	174	Near drainage channel
NW0595/1	IV	No	27.0	140	141	
NW0595/2	IV	No	40.2	136	136	
NW0595/3	IV	No	47.2	199	210	Older Life Stage IV
NW0595/4a	V	No	45.7	192	196	Fence post cut 1970/add 25 years
MI0295/1	VII	No	93.0	approx 350		Part of ring series unreadable
C0095/1	II	No	34.6	52	51	Recruited in 1946

Y = Yudnapinna Station located in the central part of the study area (all samples taken at Yudnapinna were within the 1922 fire scar ; all Life Stage III trees should be approximately 72 years old at time of sampling in 1994)
NW = North Well Station located at the north western limits of the range of western myall
MI = Middleback Station located in the southern part of the woodlands
C = Corunna Station located in the southern part of the woodlands

Tree-ring counts for five cross-sections taken from a Life Stage III tree (Y0595/1a-e) that recruited in 1922 (i.e. 72 years) are shown in **Table 5.2**. There are 72-74 rings at the base of the tree and as expected these diminish with elevation to 54-56 at a height of 174 cm above ground.

Table 5.2: Tree-ring counts for western myall Sample Number Y0595/1a-e (all from one tree - recruited in 1922)

SAMPLE NUMBER	LIFE STAGE	HEIGHT ABOVE GROUND (cm)	NO. OF RINGS IN RADIUS 1	NO. OF RINGS IN RADIUS 2
Y0995/1a	III	0	72	74
Y0995/1b		50	72	71
Y0995/1c		90	62	62
Y0995/1d		130	60	63
Y0995/1e		174	54	56

A regression of girth on rings was calculated (as the true number of rings was not available for Sample MI0295 it was removed from this calculation). With an r^2 (adjusted) value 0.352 the regression was considered only weakly significant, only 35.2% of the variation in girth was explained by the number of rings. The regression analysis of variance showed an F value of 8.07 which was significant at the 5% level but not at the 1% level. The relationship between girth and rings is shown in **Figure 5.1**.

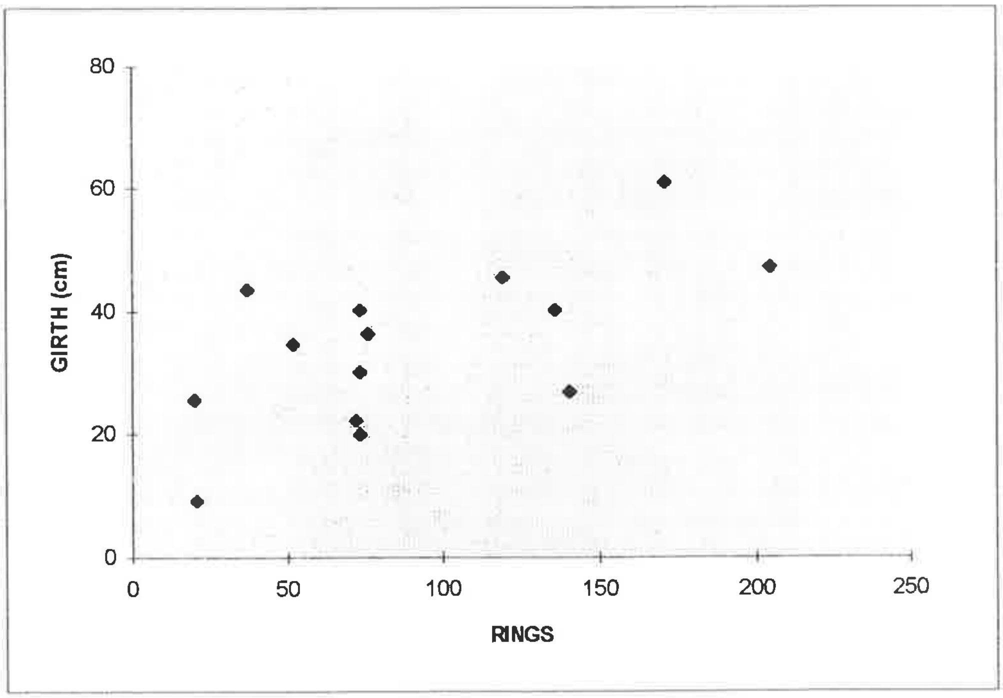

Figure 5.1: The relationship between number of rings and girth of the trees

5.2.2.3 Discussion

Our preliminary results indicate that tree-ring counts of western myall closely approximate age but that size of girth is unlikely to accurately reflect that age. Five trees sampled in the fire scar that would have recruited in 1922 (i.e. 72 years) have a mean ring count of 73 rings. One of those was placed in Life Stage II because of its small size, however it was growing on the edge of a grove of Life Stage III individuals and was probably in competition with its neighbours for resources (hence its smaller size). A Life Stage II tree recruited in 1946 (i.e. 49 years) on Corunna Station had approximately 50 rings. This is strong evidence that tree-rings can approximate age in the western myall, at least up to 200 years; thus dendrochronology provides a method for providing a life span for this species if we can find older trees with readable tree-rings. Thus, also, a tentative age range may be assigned to life stages (**Table 5.3**). A key finding of this study has been that western myall has a life span significantly greater then 360 years.

Table 5.3: A tentative age/life stage relationship for western myall

LIFE STAGE	MEAN TREE-RING COUNTS	APPROXIMATE AGE
I	21, 20	0-30
II	51	30-60
III	70, 76, 72, 73, 73	60-100
IV	171, 141, 136	100-170
V	220	170-250
VI	No ring counts available	250-320
VII	≈350	320-360
VIII	No ring counts available	>360
IX	No ring counts available	

Our ability to construct an accurately dated chronology for the region, based on western myall ring widths, will depend on three things:

- We need to have many more replicates of trees of known age so that we can confirm the relationship between number of years and number of rings.

- We need to find older trees to sample. This is hampered by the fact that the heartwood of older trees tends to decay with age and this has, to date, precluded the general use of dendrochronology to good effect on most aged individuals.
- The formation of tension wood produces highly eccentric growth rings, depending on stem angle, which may prevent easy recognition of "ring signatures" (distinctive patterns of wide and narrow rings) used for cross dating.

We intend to carry out extensive replication for all life stages in order to test our assumption that existing life stages represent even-aged cohorts recruited after exceptional summer rainfall, assign an age range to each life stage and obtain a conservative estimate for the longevity of individuals.

5.3 RADIOCARBON DATING OF WESTERN MYALL HEARTWOOD

Radiocarbon dating has been used successfully to assign dates to many organic materials including wood (Lowe and Walker, 1984; Taylor, 1987). The internal structure of some trees consists of a continuous series of annual growth layers (the tree-rings), and the carbon content of these can be ^{14}C dated and calibrated to calendar year. This technique was successfully used for the 8,000 year bristlecone pine (*Pinus aristata*) chronology in the White Mountains of California (Ferguson and Graybill, 1983; Suess and Linick, 1990), for the 11,000 year German oak (*Quercus robur*) and pine (*Pinus sylvestris*) chronology (Becker, 1993) and for the 7,400 year Tasmanian Huon pine chronology (McPhail *et al.*, 1983). If the centre heartwood of a western myall specimen could be found intact and uncontaminated by outside sources then a similar ^{14}C date might be possible.

Many of the oldest western myall specimens have rotten or hollow centres. The oldest western myall specimen found to date with intact heartwood to the centre of the tree is that of a Life Stage VII on Katunga Station about 40 km from Middleback. The innermost heartwood of this specimen was collected and prepared using the methods of Polach and Golson (1972). It was then submitted for radiocarbon (^{14}C) dating[3] of the cellulose fraction. Even this specimen had some rot in the centre which may have introduced modern ^{14}C into the sample submitted for dating thereby affected the date received from the laboratory (John Head *pers. comm.*). The age of this specimen was placed somewhere between 1850 A.D and 1700 A.D (i.e. not less than 140 years and probably not more than 300). Taylor (1987) and John Head (*pers. comm.*) argue that it is difficult to use ^{14}C data to assign unambiguous calendar ages to materials that date to less than 300 years B.P. This is because of several factors:

- Beginning in about 1650 A.D. (350 years ago), significant natural ^{14}C variations in the environment occurred creating a situation where it is not possible to assign a calendar age to any specimen that recruited in the last ≈300 years - the so-called *"de Vries effects"* (Taylor, 1987)
- ^{14}C activity in late 19th Century wood and other organic materials has been depleted. This phenomenon has been traced to the combustion of fossil fuels such as coal, oil and natural gas. These fuels contain no measurable ^{14}C and their burning over the last ≈100 years has released large quantities of "inert" ^{12}C into the atmosphere thus diluting the amounts of ^{14}C taken up in newly growing wood (Lowe and Walker, 1984; Taylor, 1987); this is referred to as the *"Suess"* or *"industrial effect"*.
- The detonation of atomic devices into the atmosphere over the last 50 years has resulted in the addition of significant amounts of artificial or *"bomb"* ^{14}C into the environment (Taylor, 1987).

Because of the difficulty of assigning calendar ages to wood of the ^{14}C age of my sample I have to date, unfortunately, been unable to use this method for aging western myall trees. However, as explained above, the specimen submitted for ^{14}C dating is unlikely to be older than 300 years. If I can find older specimens than the one already submitted for dating then some of the above problems with assigning a true age may be overcome, particularly those problems associated with the *"de Vries effects"* (Taylor, 1987).

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[3] Sample Number ANU - 10216 radiocarbon dated in 1996 by the Quaternary Dating Research Centre, Research School of Pacific Studies, The Australian National University, Canberra.

5.4 THE MORTALITY OF WESTERN MYALL

The population dynamics of various species have been studied in the South Australian arid zone. At the T.G.B. Osborn Vegetation Reserve at Koonamore, South Australia, Crisp and Lange (1976) studied the population dynamics of *Acacia burkittii*, and Crisp (1978) that of *Atriplex vesicaria, Maireana sedifolia* and *Acacia aneura* by analysing the measurement data that had accumulated in the long-term records since 1926. Again at Koonamore, Silander (1983) constructed age-specific life-tables for *Cassia nemophila* from 50 years of observations on mortality and recruitment. The data provided survival and recruitment data for four intervals.

To my knowledge there has been no attempt made to quantify the population dynamics and thus ascertain a natural adult mortality rate for western myall. Jessup (1951) reported that in his study area dead western myall trees amounted to 15-20% of the total populations and furthermore that tree death was equally severe in the unoccupied country. As early as 1864 John Lewis, who was droving cattle through the Gawler Ranges, noted:

> *"We crossed over the Saddle and got down to the Erina Plains and the second night from Moonaby came to a flat covered with dead myall."*
>
> John Lewis (1922)

Observing and taking a census of individual western myall trees from recruitment to death is difficult because of their lifespan. However, western myall are quite distinct on aerial photo images (**Plate 11**), and by comparing old aerial photography with the situation found on the ground today we can determine adult mortality rates.

5.4.1 USING AERIAL PHOTOGRAPHY FOR VEGETATION INTERPRETATION

"Plants stand still and wait to be counted."

John Harper(1977)

Aerial photography has long been established as a useful technique for many different types of vegetation survey and census (St. Joseph, 1966; Howard, 1970; Avery and Berlin, 1985). In particular, skilled interpreters can recognise many individual plant species (Avery and Berlin, 1985), particularly when they occur naturally in pure stands; aerial photography is thus used to complement, improve or reduce field work rather than replace it. Different species have distinctive crown shapes (Avery and Berlin, 1985); in my study area individual western myall are readily identifiable and are easily distinguished on the images from the species most similar in morphology and size such as mulga (*Acacia aneura*) and other tree canopies occurring in the area (**Plate 11**).

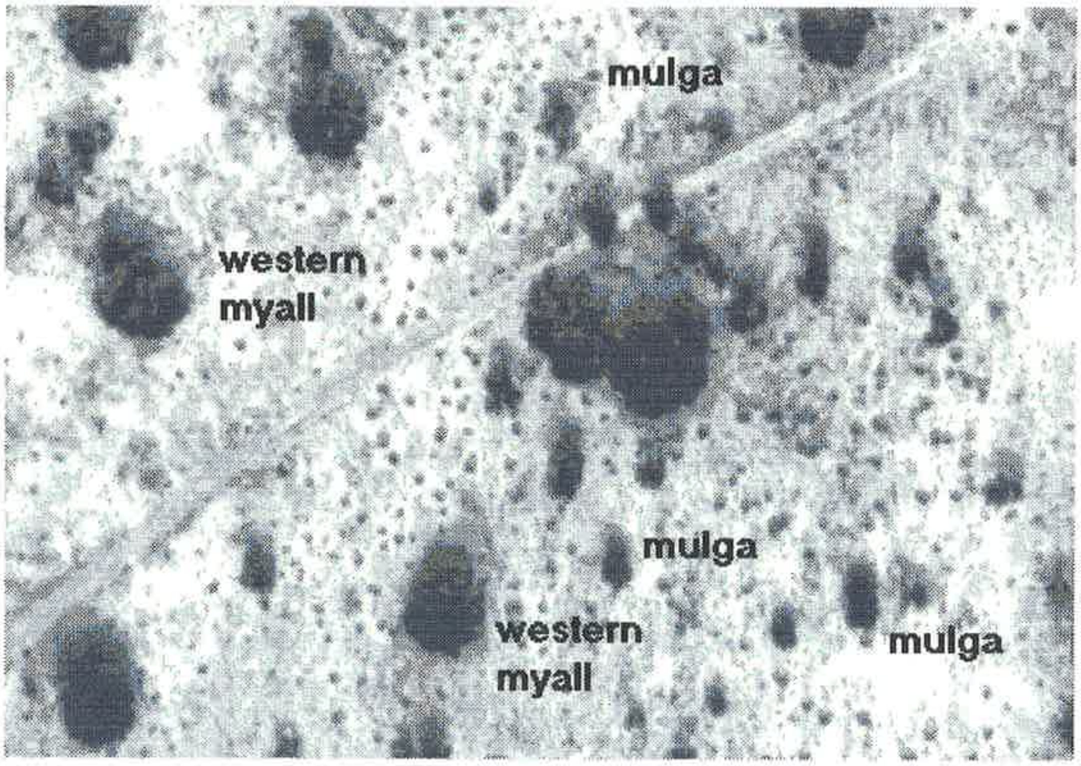

Plate 11: The crown shape of western myall and mulga (*A. aneura*) from above

Piggott (1966) stated that the advantage of aerial survey over ground survey was the rapidity with which it could be done; furthermore, he said, relatively fast changes over time could be followed if the photography was repeated at reasonable intervals. In South Australia there are many areas of the arid zone that have repeated aerial photo coverage, some dating back to the late 1930s.

Current aerial photography has been used for many vegetation surveys in Australia; few researchers have examined sequential years of aerial photography to determine vegetation dynamics. At Yeelirrie Station in Western Australia, Gardiner (1986b) compared low-level aerial photography from a short sequence of years (1973, 1976, 1979 and 1982) following the fate of individual plants of six arid zone plant species. Brown and Carter (manuscript) used aerial photography from the years 1960, 1974 and 1994 to quantify changes in the density and distribution of *Acacia nilotica* near Richmond in Queensland. Bowman *et al.* (1994) examined changes in the coverage of *Acacia aneura* shrublands and *Triodia* hummock grasslands in central Australia using aerial photography from 1950 and 1987. Scanlan and Archer (1991) used a transition matrix model coupled with changes detected on old aerial photographs to explore dynamics, rates and extent of change on a southern Texas *Prosopis* savanna. In contrast to these experiments I followed the fate of individual western myall trees by taking a census of western myall on old aerial photographs and comparing that with the situation on the ground in 1995.

For the purpose of this study I acquired the oldest aerial photography available for four sites within my study area, three of these were from 1948 and one from 1939 (**Table 5.4**). From these I was able to identify individual western myall trees, compare them with those that were still alive in 1995 and arrive at some estimation of the mortality that had occurred in the intervening period.

5.4.1.1 Methods

Four widely dispersed locations were chosen across the study area (**Figure 2.1** and **Table 5.4**). Two were at the southern edge of the study area (one adjacent to a northern fenceline - 2 Mile, and one adjacent to a southern fenceline - Cooks), one in the south central part of the study area (North Lambing) and the fourth in the northern area (Tolls). All four sites had areas of approximately 2 km x 2 km. The oldest aerial photography available for each location (1939 and 1948) was obtained and enlarged photographically to 1:3,000[4]; further enlargement to 1:1,500 was done by photocopier.

Table 5.4: The four sites and the photography used for the mortality study

SITE	LOCATION	LAT AND LONG	DATE	ORIGINAL SCALE
North Lambing	Yudnapinna	137° 10' E, 32° 06' S	1939	1:8,400
Cooks	Katunga	137° 12' E, 32° 57' S	1948	1:30,000
Two Mile	Middleback	137° 20' E, 32° 58' S	1948	1:30,000
Tolls	Parakylia	136° 03' E, 30° 29' S	1948	1:50,000

Western myall individuals on the aerial photographs were relatively easy to distinguish from other trees in the study area (**Plate 11**). Using this old aerial photography and ground census surveys conducted in 1995, I compared the presence or absence of trees for both time periods and calculated for each site a rate of mortality and a half life for different Life Stages of the species. I also estimated the number of recruits required to maintain the populations. The data, coupled with the ages calculated for some life stages with tree-ring dating, were applied to transition matrices constructed for each of the four sites across the woodlands.

A detailed description of the recording process is found in **Appendix 4**. During 1995, I carried out an on-ground census of approximately 2,000 western myall trees at each of the four sites. Individual trees were located and numbered on the enlarged (47 or 56 year old) aerial photograph (**Figure 5.2**). The census covered all mature living trees within each survey area at the date of photography. Each tree was then relocated on the ground and documented as follows: alive/dead and current Life Stage or Life Stage at death (skeletons of dead trees were invariably well-preserved). Recruits added to the population since photography were also documented. Based on the deaths observed, mortality rates were estimated for each Life Stage and for the entire population in each survey area. Other parameters collected were the number

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[4] Archival photographs were obtained from the Australian Surveying and Land Information Group (AUSLIG), P.O. Box 2, Belconnen, ACT, 2616.

of trees that had been chopped down or had limbs removed in the intervening years. All trees were recorded as either true western myall or water myall (See Section 6.2.5 for a description of these morphotypes).

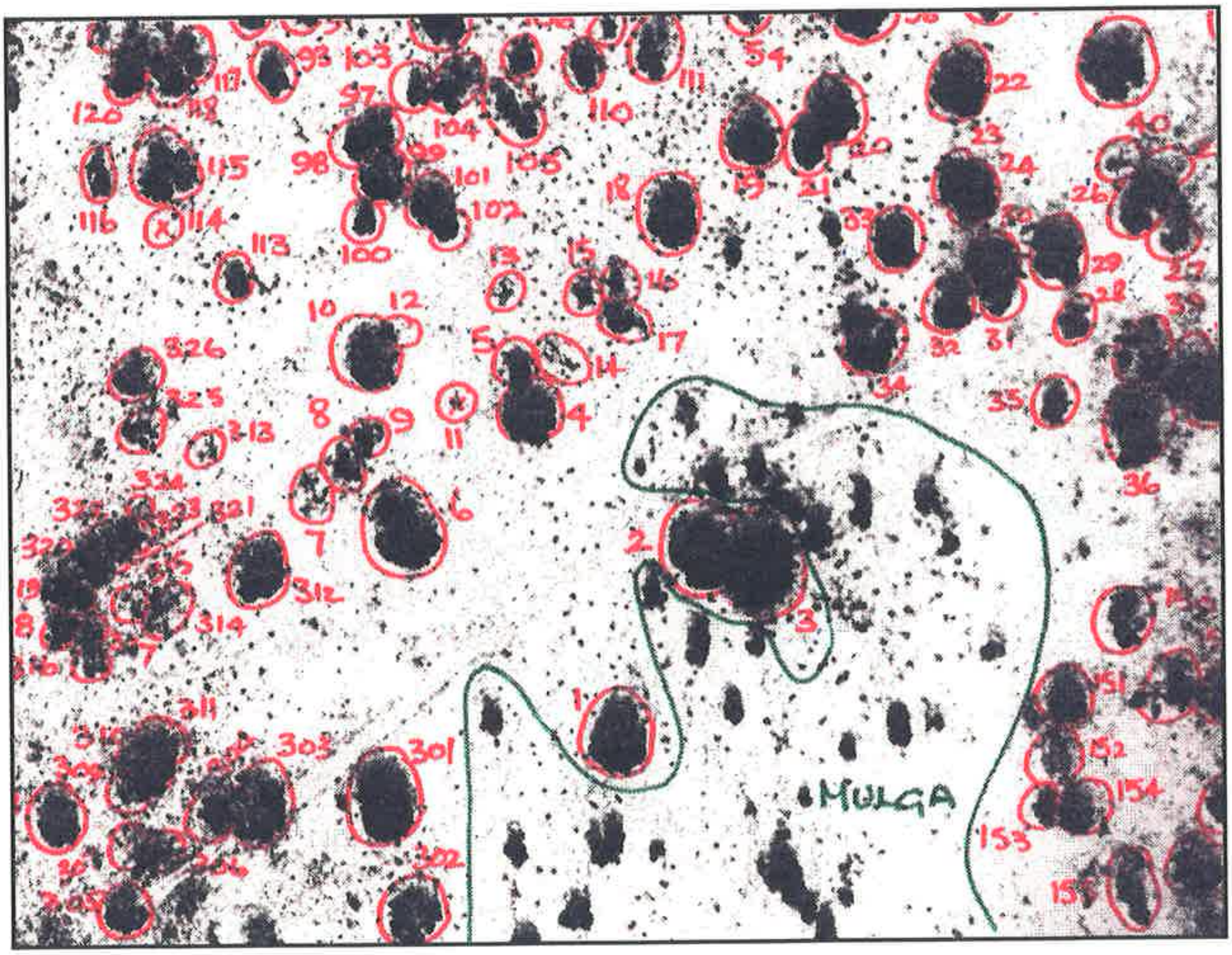

Figure 5.2: An example of an enlarged aerial photograph used for the mortality study

The transition matrix was constructed using the logic presented in the schematic model of the population dynamics of the western myall (**Figure 5.3**). Life Stages I-III were grouped as a Juvenile State, Life Stage IV as a Young State, Life Stages V-VII as a Mature State and Life

Stages VIII-IX as a Senescent State. The model illustrates inputs, movements from one State to another and deaths. Note that some individuals may not change State over the approximately 50 years of comparisons.

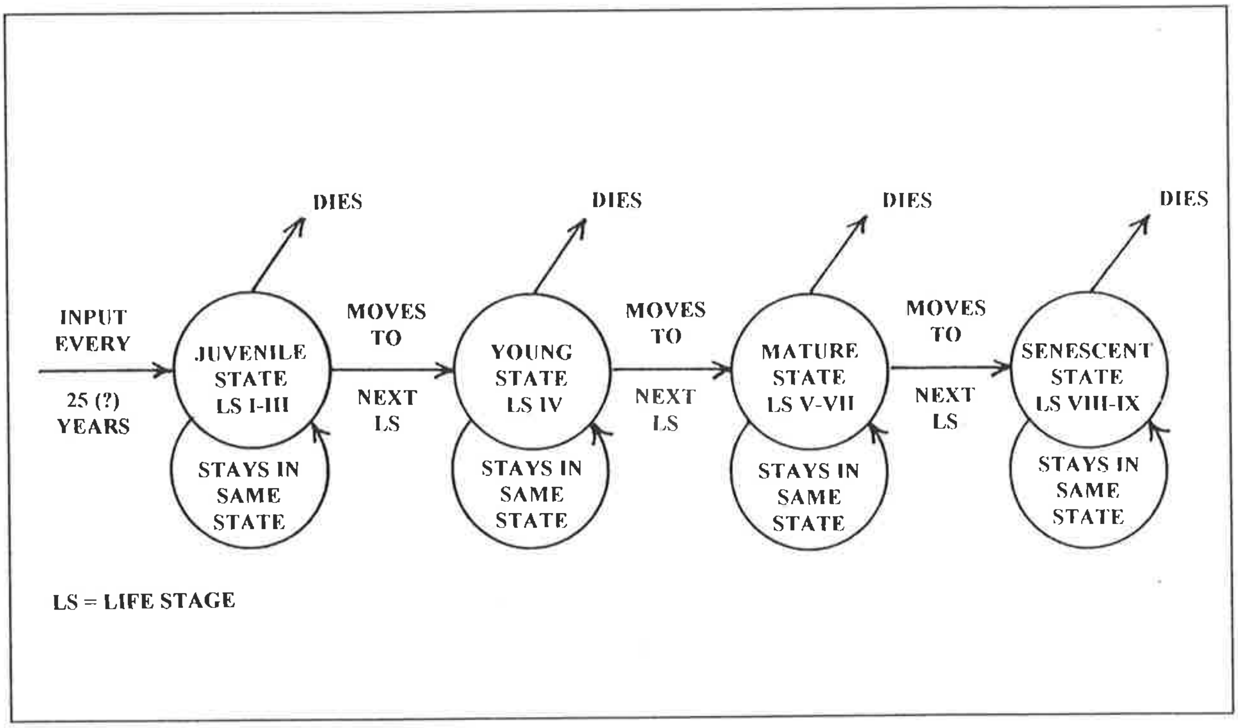

Figure 5.3: Schematic Model of the population dynamics of western myall

At the data collection stage each tree was placed in one of the nine Life Stages (**Figure 2.6**) based on its appearance in 1995. If a tree also appeared on the aerial photograph (1939 or 1948) then it is assumed, based on tree-ring evidence (Section 5.2.2.3), at that time it would have been either at its current Life Stage or at one Life Stage younger than that. This was dependent on the probability of it moving from a younger State to its current State in the intervening 56 or 47 years. These probabilities were calculated using the approximate age/life stage relationships determined by tree-ring counts as shown **Table 5.3**. They are detailed in **Table 5.5**. Trees that were dead in 1995 were relatively easy to place in Life Stages from the structure of standing skeletons. These observations confirm the estimate (Correll and Lange, 1965) that skeletons remain *in situ* for at least 50-100 years

Table 5.5: Probability of a tree which survives moving up from or remaining in a State between time of photography in 1948 and field census in 1995 (47 years) at Cooks, 2 Mile and Tolls. Slightly different probabilities apply at the North Lambing site.

	Juvenile State Life Stage I-III	**Young State Life Stage IV**	**Mature State Life Stage V-VII**	**Senescent State Life Stage VIII-IX**
Approximate number of yrs. spent in stage	100	70	190	140?
Probability of survivors staying in the same State	0.53	0.33	0.75	1.00 (All stay in same State unless they die)
Probability of survivors moving to the next State	0.47	0.67	0.25	0.00 (None can move to another State)

The following example shows how these probabilities were applied to all possibilities in all four paddocks:

COOKS PADDOCK

In 1995 there were 1052 individuals from Life Stages V-VII (Mature State)

- Probabilities shown in **Table 5. 5** indicate that 75% of these (789 individuals) had stayed in the Mature State throughout the intervening 47 years
- Therefore the remaining 25% (263 individuals) had moved from the Young State to the Mature State in the intervening 47 years
- There were 286 dead trees (Mature State) that were perceived on the aerial photograph to have still been alive in 1948 and must have died in the intervening 47 years
- 1052 + 286 = 1338 (the number of live trees on the 1948 aerial photograph)

Thus, of 1338 live trees in 1948

- We assume that 789 (59% of 1338) stayed in the Mature State
- We assume that 263 (20% of 1338) had moved from Young to Mature by 1995
- We know that 286 (21% of 1338) had died in the intervening period of 47 years

Using the probabilities of transition from one State to another, transition matrices were constructed for each site to examine the dynamics of western myall population structure and mortality. The probabilities of change between States were determined using the method outlined in the box above.

5.4.1.2 Results

Overall mortality rates (q_x) for each of the four paddocks and individual rates for each Life Stage and each State (Life Stages VI - Young, V-VII - Mature and VIII-IX - Senescent) were calculated using the standard formula:

$$q_x = \frac{d_x}{l_x}$$

where l_x is the number of individuals alive in 1939 or 1948 and d_x is the number dead from natural causes by 1995. All mortality rates for the four sites are shown in **Tables 5.6 to 5.10**.

Silvertown (1982) stated that the half life of a cohort is a useful statistic to describe some characteristics of survivorship. Although only truly appropriate as a measure of the rate of mortality in Deevey type II populations it may also be used for sections of the other types of curve where there is an exponential decline in numbers. The formula is:

$$\text{Half life in years} = \frac{t \ln 2}{\ln N_x - \ln N_{x+t}}$$

where N_x is the number of survivors at age x and N_{x+t} is the number remaining after a time interval of t years. Using this formula a half life for the population as a whole and for each individual Life Stage and State was calculated. This number was applied to the number of live trees in the population to calculate the approximate number of years to total extinction of the original population. These are also shown in **Tables 5.6 to 5.10**.

Table 5.6: Overall population mortality rates and half-lives for all four populations

PADDOCK	l_x Alive in 1948 (C, 2 AND T) or alive in 1939 (N)	d_x Dead from natural causes by 1995	q_x Natural mortality rate over 47 or 56 years (%)	Half life (years)	Time to extinction (years)
COOKS (C)	1999	426	21.31	136	1491
2 MILE (2)	1972	326	16.53	180	1973
N. LAMBING (N)	1939	419	21.61	159	1741
TOLLS (T)	1928	215	11.15	276	3007

Table 5.7: Data for Cooks Paddock

LIFE STAGE IN 1995	**l_x** Alive in 1948	**d_x** Dead from natural causes by 1995	**q_x** Natural mortality rate (%)	Half life (years)	Time to extinction (years)
IV - Young	328	109	33.23	81	674
V	665	118	17.74	167	1564
VI	405	110	27.16	103	890
VII	268	58	21.64	134	1077
VIII	190	28	14.74	204	1547
IX	92	3	3.26	983	6411
V-VII (combined) - Mature	1338	286	21.38	135	1407
VIII-IX (combined) - Senescent	282	31	10.99	280	2277
WHOLE POPULATION	1999	426	21.31	136	1491

Table 5.8: Data for 2 Mile Paddock

LIFE STAGE IN 1995	**l_x** Alive in 1948	**d_x** Dead from natural causes by 1995	**q_x** Natural mortality rate (%)	Half life (years)	Time to extinction (years)
IV - Young	250	73	29.20	94	752
V	667	85	12.74	239	2242
VI	313	68	21.73	133	1103
VII	375	56	14.93	201	1722
VIII	204	29	14.22	212	1630
IX	86	14	16.28	183	1178
V-VII (combined) - Mature	1355	209	15.42	194	2023
VIII-IX (combined) - Senescent	290	43	14.83	203	1660
WHOLE POPULATION	1972	326	16.53	180	1973

Table 5.9: Data for North Lambing Paddock

LIFE STAGE IN 1995	**l_x** Alive in 1939	**d_x** Dead from natural causes by 1995	**q_x** Natural mortality rate (%)	Half life (years)	Time to extinction (years)
IV - Young	453	143	31.57	102	903
V	687	116	16.89	210	1978
VI	282	61	21.63	159	1296
VII	369	69	18.7	188	1599
VIII	99	28	28.28	117	774
IX	19	2	10.53	349	1482
V-VII (combined) - Mature	1338	246	18.39	191	1984
VIII-IX (combined) - Senescent	118	31	25.42	127	877
WHOLE POPULATION	1939	419	21.61	159	1741

Table 5.10: Data for Tolls Paddock

LIFE STAGE IN 1995	l_x Alive in 1948	d_x Dead from natural causes by 1995	q_x Natural mortality rate (%)	Half life (years)	Time to extinction (years)
IV - Young	1152	110	9.55	325	3301
V	495	51	10.30	300	2682
VI	120	24	20.00	146	1008
VII	110	23	20.91	139	942
VIII	36	6	16.67	179	924
IX	6	1	16.67	179	462
V-VII (combined) - Mature	725	98	13.52	224	2132
VIII-IX (combined) - Senescent	42	7	16.67	179	964
WHOLE POPULATION	1928	215	11.15	276	3001

The majority of these data indicate the death of all existing adults within approximately 1,000 to 1,500 years although the at Tolls (the northernmost site) this number is considerably higher.

To maintain the populations, the number of recruits needed at every recruitment event for every 100 trees in the population is a simple calculation (given the mortality information). We divide $\mathbf{d_x}$ (number which died in the intervening period) by $\mathbf{l_x/100}$ (number alive at beginning of time period/100) to arrive at the number of dead individuals per 100 trees alive at the beginning of the time period (**a** in **Table 5.11**). As we know the time periods are either 47 or 56 years and that approximately two recruitment events may occur during that time, the number (**a**) is divided by two giving **b** (in **Table 5.11**). This will give us a very approximate estimation of how many recruits are needed at every event for every 100 trees in the population (**Table 5.11**); a calculation of the number of recruits needed at every event within each survey area is also shown (**c**). Other parameters collected at the time of census are shown in **Table 5.12**. These included numbers of water myall in each population, the number of trees that had died in the intervening period from non-natural causes (most likely chopped down by timber harvesters or for fence posts) and the number of live trees that had limbs removed (most likely taken for fence posts).

Table 5.11: Number of recruits required at every recruitment to maintain the populations

PADDOCK	**d_x** number dead in intervening period	**l_x/100** number alive at start of time period/100	**a** number of dead individuals per 100 trees during each time period	**b** approx. number of recruits needed at each event	**c** for population at each event
COOKS	426	19.99	21	11	219
2 MILE	326	19.72	17	8	158
NORTH LAMBING	419	19.39	21	11	213
TOLLS	215	19.28	11	6	116

Table 5.12: Other parameters collected during the census in 1995

PADDOCK	**Number of trees alive in 1995**	**Number of water myalls**	**Trees dead from non-natural causes**	**Live trees with limbs chopped off**
COOKS	1573	0	27	3
2 MILE	1648	0	79	1
NORTH LAMBING	1520	26	28	73
TOLLS	1713	18	11	23

Transition matrices were constructed for all four sites (**Appendix 5**). Probabilities were calculated from the tree-ring/age relationship data in **Table 5.3**; these are detailed in **Table 5.5**. The matrices also show a decline of the current populations to eventual extinction in 1,300 to approximately 2,000 years (except Tolls - 3,000 years) if there is zero input of recruits. However no allowance is made for future recruitment. The transition matrices (**Appendix 5**) include inputs of Juveniles that were recorded at each site (Cooks - 23; 2 Mile - 22; North Lambing - 12 and Tolls - 72) and probabilities were also applied to them in the matrices.

5.4.1.3 Discussion

The first and clearest finding is that observed rates of mortality vary greatly both between and within all four populations although some trends are apparent (**Tables 5.6 - 5.10**). Generally the southern and south central populations (Cooks, 2 Mile and North Lambing respectively) have higher overall mortality rates (21.31%, 16.53% and 21.61%) and lower half lives (136, 180 and 159) than does the population in the north (Tolls, 11.15% and a half life of 276). Results of other population studies reported in CHAPTER 6 also show that populations of western myall in the south are older and that they gradually change across the woodlands to younger in the north. Within the populations at Cooks, 2 Mile and North Lambing the highest rate of mortality was concentrated in the Young State - Life Stage IV (33.23%, 29.20% and 31.57%); in the north at Tolls this rate was much lower at only 9.55%. At Cooks, 2 Mile and North Lambing mortality rates generally declined with age however at North Lambing a steep rise in rates of mortality in the Senescent State were apparent. Many live trees at this site showed evidence of limb lopping for fence posts; this may have been reflected in the dead population in that trees were badly damaged enough by this practice to die.

Although years to total extinction in the transition matrices (**Appendix 5**) do not match exactly those calculated based on half-lives derived from observed mortality rates, the general trend of population decline is apparent in both calculations. It goes without saying that if sufficient inputs do not occur then the populations will eventually become extinct.

The number of trees that died in the intervening period from non-natural causes (**Table 5.12**) can be almost wholly attributed to the activities of timber gatherers and fence post cutters (the latter would also apply to live limbs lopped for fence posts). Timber gathering was particularly prevalent in the earlier part of this century (Goode, 1941) at Yudnapinna (which includes the North Lambing site) and to a lesser extent near Whyalla (includes the Cooks and 2 Mile sites). There is no history of this type of activity at Tolls. Fence post cutters may have had an impact on mortality at all four sites as each site was located near a fenceline for ease of access.

There were no water myalls found at Cooks and Two Mile; they constituted 1.7% of the population of western myall at North Lambing and 1.3% at Tolls (**Table 5.12**). This accords with observations made in other parts of the woodlands; there appear to be very few in the south and the numbers increase further north.

5.5 CONCLUSION

The foregoing work yields a fairly consistent picture of the age ranges represented by the various Life Stages in the western myall particularly in the younger groups by using tree-rings (although further replication is required to add confidence to this model). The oldest age so far discovered by this method is about 350 years for a tree of Life Stage VII and a likely life span for the species of greater than 500 years is indicated for some of the very oldest specimens. Tree-ring studies of later Life Stages (e.g. VIII and IX) may in the future reveal these older ages. A radiocarbon date from another Life Stage VII specimen has revealed equivocal evidence for an age that may be between 170 and 300 years B.P.

The age projection based on observed mortality (1,500 - 3,000 years) greatly exceeds the measurable ages of older individuals by the tree-ring or radiocarbon methods (>500 years). As neither of the direct dating methods have yet yielded an unequivocal result for the oldest specimens, and the age distributions projected from approximately 50 years of mortality observations entail substantial projection and involve acknowledged approximation, it is perhaps reasonable to conclude that the true length of individual lifespan lies between the two ranges - say, approximately 1000 years.

The mortality study revealed five interesting findings, these are:

1. The rate of mortality varies across the woodlands; it is generally higher in the south than in the north.
2. The rate of mortality also varies greatly within populations; in the south a greater proportion of younger trees are dying than in the north.
3. The number of recruits required to sustain the populations (i.e. to replace observed mortality) varies between six and eleven per 100 live adult trees at each recruitment event (**Table 5.11**). Fewer recruits would be required to maintain the populations in the north than in the south and central areas.
4. Water myalls appear to be more prevalent in the central and northern areas than the south.
5. Timber gatherers and fence post cutters have, in the past, had a significant effect on the population structure of the species where they have been active.

These findings will be further discussed in CHAPTER 8 when the results will be applied to suggestions for management of the species.

CHAPTER 6

BIOGEOGRAPHY

6.1 INTRODUCTION

Biogeography is the study of why species are distributed the way they are and whether they have always occupied the same space (Cox and Moore, 1993). Thus, biogeography is not only concerned with analysis and explanation of distribution patterns, but also with understanding the changes that have happened in the past and those that are currently taking place.

Sound, detailed descriptions of the size, location, structure and shape of species' ranges are commonly lacking, as are details of the dynamic aspects of those ranges (Cox and Moore, 1993). Ranges are often not as static as the boundaries on existing maps may suggest; long or short-term climatic fluctuations often explain shifts in distribution or changes in range size (Hengeveld, 1990). He describes these continuous changes in environmental conditions at different temporal and spatial scales as:

> *"...a permanent amoeboid creeping of species over the earth..."*

Acacia is the largest genus of higher plants in Australia (Maslin and Pedley, 1982; Whibley and Simon, 1992). The genus also occurs in Africa, the Americas and Asia and may be found in almost all environments; it is most common in arid and semi-arid areas. Few authors have attempted to study the biogeography of any *Acacia* species. Hnatiuk and Maslin (1988) reported on the kinds of geographic patterns encountered in the distribution of *Acacia* species across Australia and also examined some climatic correlates of those patterns. Nix and Austin (1973) analysed the distribution of mulga (*A. aneura*) in relation to selected environmental parameters at both continental and regional levels and Preece (1971) examined the climatic requirements for regeneration of the species. Booth (1988) computer matched the climatic requirements and distribution of *Acacia* species in Australia with areas in the world where

Australian fuelwood species are to be introduced; in this way the ideal *Acacia* species for a particular region might be selected.

This thesis has addressed the geographical extent of the western myall woodlands (CHAPTER 2), the distribution of recruitment in space and time (CHAPTER 3) and a life span and mortality rate for the species (CHAPTER 5).

There is no study of any aspects of the biogeography of the western myall recorded in the literature, although attempts have been made by various authors to map the distribution of the species (**Table 2.4**) and I have drawn a new map as a result of this study (**Figure 2.4**). Because of this, aspects of the biogeography of the species will be examined in this chapter by:

- Summarising the literature of the climatic and vegetation history of the western myall woodlands (**Appendix 6**). Some speculative proposals follow with regard to the temporal and spatial distribution of the species.

- Examining the distribution of the two related species, western myall and nealie and two of the three different morphotypes of the species (western myall and water myall).

- Reviewing the variation of population structure across the species' range in terms of mortality, recruitment and life stage patterns.

6.2 CLIMATE AND VEGETATION CHANGE IN THE AUSTRALIAN ARID ZONE

The glacial/interglacial cycles of the Quaternary Period (the last 2 million years) have had a particularly profound effect on the current distribution of the vegetation of Australia, not only in direct effects of changing climates but also in the indirect effect of rising and falling sea levels. By examining the wealth of literature that exists for Quaternary climate change in Australia (see **Appendix 6** which is also summarised in **Table 6.1**) we can look at patterns in

Years BP	TIME PERIOD AND CLIMATIC CONDITIONS	EVENTS
2,000,000	**THE TERTIARY/QUATERNARY BOUNDARY** A general increase in aridity as the stable climates of the Tertiary gave way to the unstable climate of the Quaternary	• Closed canopy rainforest declined towards the end of the Tertiary • Extensive series of Tertiary marine, fluviatile and lacustrine sediments abruptly overlain by Quaternary calcareous soils on the lower Murray River
2,000,000 to 130,000	**THE EARLY TO MID-PLEISTOCENE** Several 100,000 year cycles each comprising: • 15% warm interglacial • 85% cooler drier interval including a much colder, drier, windier glacial	• Vast areas of dunes and sandsheets formed during acutely arid glacials • Repeated fluctuations from dry to humid environments turned more and more of Australia permanently arid • Recurring pattern of vegetation migrating to and from refugia established
130,000 to 120,000	**THE LAST INTERGLACIAL** Warmer and wetter climate	• Polar ice caps smaller; higher sea levels than today • High sea level illustrated in the Woakwine relic coastal dune in the southeast of SA • Vegetation in Victoria and northern Queensland similar to today
120,000 to 60,000	**THE MID TO LATE PLEISTOCENE** Minor fluctuations in climate	• Sea level lower than today • Environments similar to present at about 120,000 • Vegetation at Lynch's Crater alternates between rainforest and sclerophyll elements • Substantial fluctuations in vegetation types at Lake George
60,000 to 10,000	**THE LATE PLEISTOCENE**	
	• The humid Lacustral Phase up to about 25,000 BP Much higher rainfall, warmer	• Highest lake levels at Lake George, Willandra Lakes (includes Lake Mungo), Lake Tyrell, Lake Frome, Lake Woods and Lake Gregory • Shoreline dunes at Lake Amadeus • Drier conditions at Lynch's Crater and palaeodrainage channels of Central Australia
	• The intensely arid Glacial Phase from 20-17,000 BP Rainfall less than half of today, maximum windiness, colder (5-8°C less)	• Correlates with the glacial maximum in the Northern Hemisphere • Sea level more than 100 m lower globally - large areas of continental shelf exposed forming land bridges between Australia and New Guinea and Tasmania • Extensive active dune systems mantle area from Gulf of Carpentaria to N. Tasmania • Trees excluded from 85% of continent
	• Abrupt amelioration of climate between 15-10,000 BP Warmer and wetter	• Warming of Southern Ocean by 8°C and rapid rise in sea level • Icesheets melted in Northern Hemisphere and ice gone from Tasmania by 10,000 BP • Continentality dramatically reduced as continental shelves flooded • Great Barrier Reef began to revive • Forests began to come back and vegetation became increasingly sclerophyllous
10,000 to 2,000	**THE EARLY TO MID-HOLOCENE** An extremely complex pattern of cyclic climate change over the whole period, however, of less amplitude than in former periods.	• Vegetation cover in Australia assumes its current form • **8,000 - 5,000 BP:** Dune building waned, warmer and wetter at Lake Keilambete and on the Nullarbor, cooler and drier at Lynch's Crater • **5,000 BP:** Sea level stabilises, coastal beaches and barriers begin to form, Great Barrier Reef reaches present height • **5,000 - 3,500 BP:** Warmer and wetter at Lynch's Crater, cooler and drier at Lake Keilambete, • **3,000 BP to Present:** dune building increases
2,000 to Present	**THE LATE HOLOCENE** Climate fluctuates as in early to mid-Holocene	• **1,900 BP Roman Period:** increase in warmth and dryness lead to the collapse of Saharan civilisations and the level of the Caspian Sea fell by four metres • **12th Century AD "Medieval Warm Period":** Vikings settled Greenland with an estimated population of 10,000 who planted woodlands and grazed sheep. Thirty eight vineyards were recorded in southern Britain. • **17th Century AD "Little Ice Age":** Temperatures fell worldwide and glaciers advanced. The Sahara was wetter, the Thames froze frequently, the tree line descended in California and Viking settlements were abandoned in Greenland. • **19th Century AD warming trend:** New Zealand glaciers retreated • **Early 1900s AD cold "snap":** Pack ice in Antarctica was known to have expanded. • **1,900 - 2,000 AD:** A warming and drying trend over the last 100 years. Lake levels have fallen in Australia. Mineshafts unworked for 600 years in Europe have once more become visible as glaciers have retreated.

Table 6.1: A summary of climate change over the past 2,000,000 years (All dates are approximate)

climatic fluctuation that may explain shifts in the distribution or changes in range size of western myall. The vegetation and soils that mantle the ancient and stable land mass of the Australian continent have undergone a series of substantial climate-related changes over the Quaternary period (Chappell, 1991).

The Pleistocene (2,000,000 BP[1] to 10,000 BP) was marked by a series of widely fluctuating climates culminating in an intensely arid phase between 20,000 and 17,000 BP followed by an abrupt amelioration of climate between 15,000 and 10,000 BP. This correlated with the last glacial maximum and waning of the glaciers in the Northern Hemisphere. During the arid phase sea levels fell more than 100 m globally. In Australia vast areas of the Continental Shelf were exposed around the continent; these formed land bridges to Papua New Guinea and Tasmania. Chapell (1991) argues that this huge increase in continentality would have greatly affected the climate at this time but cautions that precipitation was also much lower and average temperatures between 5-8°C lower than today. The result was an extensive dune system that mantled the continent (**Figure 6.1**) from the Gulf of Carpentaria to northern Tasmania (Bowler and Wasson, 1983). Rainfall in the desert areas is believed to have been less than half of the present-day amount: lakes dried up, many never to fill again (Bowler, 1976) and trees were excluded from 85% of the continent (Hope and Kirkpatrick, 1988).

The end of the Pleistocene is marked by a distinct warming and rapid rise in sea levels as the Northern Hemisphere ice sheets melted. Continentality was rapidly reduced as the continental shelves flooded (Chappell, 1991) and as conditions began to ameliorate forests began to recover (Kershaw, 1981). Evidence of climatic fluctuations from all over the world, however, show an extremely complex pattern of cyclic changes which operated on a very short time scale. The vegetation cover in Australia appears to have assumed its current form by the beginning of the Holocene although Bowler *et al.* (1976) indicate that between 8,000 and 5,000 BP conditions may have been warmer and wetter than present. The bulk of forests and woodlands have invaded new ground and changed in composition over the last 10,000 year (Hope and Kirkpatrick, 1988). Sea level appears to have stabilised at about 5,000 BP and Australia assumed its modern form with all the major regions of the continent and their specialised biotas in place (Clark, 1983; White, 1994).

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[1] BP = years before present

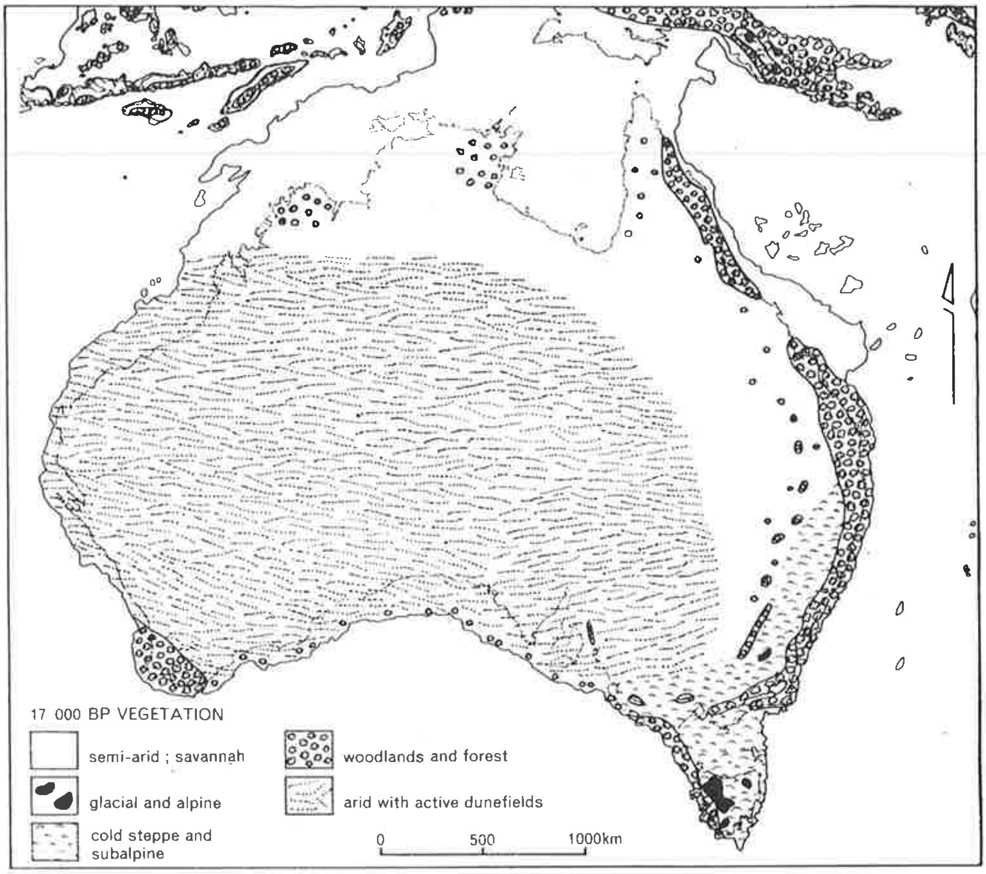

Figure 6.1: Possible limit of Australian forest and woodland at the time of their greatest contraction about 17,000 years BP (from: Hope and Kirkpatrick, 1988)

6.2.1 CLIMATE CHANGE AND THE WESTERN MYALL WOODLANDS

The western myall belongs to the section Plurinerves within the genus *Acacia*. Maslin and Hopper (1982) examined species distributions by comparing close relatives within the genus *Acacia* finding that a southern semi-arid predominance exists in about 25% of the groups of the genus. The elements are derived from speciation within the sections Phyllodineae and Plurinerves which probably occurred during a short period in the late Tertiary and Quaternary periods. It is suggested that other sections of the genus (e.g. Julliflorae) are older. This is backed up by phenological studies by Maconochie (1979) cited in Maslin and Hopper (1982) which show that the older sections are in phase with the current arid conditions in central Australia while species of the younger sections are out of phase. They hypothesise that the latter may reflect an invasion of the arid zone by these species such that insufficient time has elapsed to allow for an adaptive shift in phenology.

Maximum aridity in the late Pleistocene is now placed around 18,000 to 16,000 BP (Bowler, 1978) and drying started around 35,000 BP. Despite Crocker and Wood's (1947) placement of the *"Great Aridity"* at around only 5000 BP, their hypothesis of vegetation change in South Australia is not necessarily invalidated (Carolin, 1982). It must be remembered that they had no recourse to palynology or radiocarbon dating at the time of their study. Their work was the first serious attempt to integrate soils and geological data with the evolution and distribution of the Eremaean flora (Carolin, 1982). Crocker and Wood (1947) described the *"Great Aridity"* as a period of *"wholesale destruction of the native flora which in turn led to accelerated wind and water erosion"*. Remnants of the *"pre-arid"* flora survived the desiccation in specially favoured refugia (most often located in ranges such as the Flinders and Gawler Ranges[2]). When rainfall increased, recolonisation of the landscape could begin; this was mostly governed by the rapidity with which each species could produce and disseminate its propagules. Only seeds that arrived in suitable habitats survived, making it almost certain that the main migratory routes in the development of the present South Australian flora have been from the refugia out along a series of closely related soils. This hypothesis seems reasonable when the distribution of western myall is examined. Crocker and Wood (1947) suggest that the main refugia for the species were in the Gawler Ranges with minor survival centres in the Denison Range and also along the Neales River. Jessup (1951) observed that there are large areas of suitable soils where western myall has not colonised which lie to the north and west of its current range; in these areas species which normally associate with western myall occur but western myall itself is lacking. He implies that the restricted spread of the species following the lifting of climatic stress resulted from increased rainfall of too short a duration to enable it to migrate to all of the areas it is capable of colonising. The present rainfall remains below that of the moister period of colonisation. My own observations in the North West Pastoral District concur with these observations.

Crocker and Wood (1947) state that species of very restricted distribution can either be regarded as young endemics (new species) or old endemics (relict species); an example of a

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[2] Localities shown on Figure 1 in Appendix 6

true relict species is *Acacia peuce*, formerly widespread but now restricted by the onset of aridity to ecological niches in widely separated areas. During desiccation the dunefields built up between these niches making it impossible for *A. peuce* to recolonise. Western myall and its relative, nealie (*A. loderi*), display a special kind of discontinuity (Crocker and Wood, 1947) which is described in Section 6.2.2.

Evidence of past climatic change can be seen in the Cainozoic sediments and soils of the western myall woodlands of the Whyalla area in South Australia (Jessup and Wright, 1971). The Whyalla area today is located near the northern limit of the temperate winter rain systems and south of the regular influence of the northern monsoonal systems. The rare occurrence of monsoonal rain events and their influence on the recruitment of western myall has been discussed in CHAPTER 3. Jessup and Wright (1971) infer a series of historic climate oscillations which coincided with the glacial and interglacial periods of the Quaternary. Five major glaciations have been recognised during the Pleistocene in Europe (Schwarzback, 1963); Jessup and Wright (1971) correlate this evidence with a sequence of soils, sediments and erosional episodes at Whyalla which spanned, they say, the whole of the Quaternary. The soils, sediments and erosional episodes were formed by oscillations in the region between two very different climates:

1. Arid "non-pluvial" climates which coincided with a southward migration of both the westerly cyclonic (winter rainfall) and the monsoonal (summer rainfall) systems; true aridity, Jessup and Wright (1971) say, prevailed when the westerlies were too far south while the monsoons were too far north to bring significant rainfall. These episodes coincided with periods of erosion and subsequent deposition of sediments.
2. Humid "pluvial" climates which occurred when the southward migration of the systems was great enough to bring regular monsoonal rains or when the northward migration of the systems brought regular rain-bearing westerlies. These episodes were accompanied by periods of deep weathering and soil formation.

Jessup (1960a and 1960b) also examined and described two buried palaeosols (The Parakylia Layer and The Bookaloo Layer) located several hundred kilometres to the north and east of Whyalla. Soil formation takes time; periods of soil formation of the two were associated

(Jessup, 1960a and 1960b) with humid climates with a relatively stable landscape well protected by vegetation which prevented large-scale erosion.

Around the Great Australian Bight vegetation belts of mallee scrub near the coast give way to tall open shrubland with western myall and *Myoporum* sp. further inland, this in turn becomes the true Nullarbor low shrubland of *Atriplex vesicaria* and *Maireana sedifolia*; these zones are clearly controlled by the rainfall gradient which in turn is controlled by the distance from the coast. Martin (1970) provides palynological evidence that at about 18,000 BP when sea levels were about 160 m below their present level. the treeless Nullarbor Plain extended far south of its present day position. Parsons (1969) considers that the mallee belt which formerly consisted of a continuous distribution of *Eucalyptus diversifolia* and *E. incrassata* was fragmented by rising sea levels in the Quaternary. Furthermore these sea level changes may explain other disjunct species distributions on the Nullarbor and Roe Plains.

It appears then that the western myall woodlands, far from being a stable landscape, were, in all probability, subjected to the same retreats and advances that other types of vegetation experienced in response to relatively frequent climatic fluctuations that have occurred over the past millennia. The most extreme time of forest retreat across Australia was between 23,000 and 14,500 BP (Hope, 1989) and there is no reason to believe that the western myall woodlands escaped this fate. The woodlands as we currently see them can have been in existence for only the past 10,000 years or so.

6.2.2 THE RELATIVE DISTRIBUTIONS OF WESTERN MYALL AND ITS CLOSE RELATIVE, NEALIE

A related species, *A. loderi* Maiden (Common name: "nealie" or "nelia"), is described by Crocker and Wood (1947) as occurring *"south of Cockburn along the NSW border and extending into that State"*. Western myall and nealie are almost identical in habit, appearance and morphology; they occur in the same climatic zone on similar soil types with similar vegetation associations. Nealie has been observed growing as far east as Wilcannia in NSW. Whibley and Simon (1992) confirm Crocker and Wood's (1947) distribution in South Australia and further state that intermediate forms between *A. loderi* Maiden and *A. papyrocarpa* Benth. have been recorded from Tarcoola, Kingoonya and the Copper Hills area east of Mount Willoughby. Ising (1922) states that the dominant tree species of the Tarcoola area and the Kingoonya plain was *A. loderi.* He was assisted with his identification by J.H. Maiden, J.M. Black and T.G.B. Osborn, all well regarded botanists of their time. It is extremely difficult to imagine that all four wrongly identified *A. loderi* Maiden, however from my observations and identification of specimens, those found to the west of the Flinders Ranges all appear to be either *A. papyrocarpa* Benth. or they may truly be the intermediate form of Whibley and Simon (1992). Unconfirmed sightings of an intermediate form (Tony Robinson and John MacDonald *pers comm.*) have also been made south of Yunta to the east of the Flinders Ranges in South Australia. Crocker and Wood (1947) describe the two taxa as "almost identical in habit, appearance and other morphological characters." Whibley and Simon (1992) and Crocker and Wood (1947) describe the differences between the two species; *A. loderi* Maiden has narrower but thicker phyllodes and narrower moniliform legumes.

Species that differ slightly morphologically but are widely separated geographically are referred to as vicarious. Crocker and Wood (1947) were of the opinion that the two taxa descended from the same parent which was once very widespread and they are the result of biotypical isolation within the parent species. It is likely, they say, that western myall developed from refugia in the Gawler Ranges and that nealie was distributed from another refuge, probably in New South Wales. Crocker and Wood state that the two can be considered as both relic and as new species.

6.2.3 THE DISTRIBUTION OF DIFFERENT MORPHOTYPES

Ogden (1985 and 1989) states that the expansion and contraction of tree populations that occurred during the climatic oscillations of the past 2,000,000 years implies changes in both survival and mortality rates at different times and in different parts of the species' range. He coins the term *"coenospecies"* to describe a *"group of related, more or less frequently hybridising species forming a common gene-pool"* and explains the evolutionary significance of this. Different genotypes, he says, are favoured in expanding versus contracting populations; rare or more intermediate forms may have been more common at other times as the geographical range of the coenospecies fluctuates in response to climate change.

I have observed that there are at least three distinct and easily recognised morphotypes of western myall (*Acacia papyrocarpa* Benth.) in the woodlands of the North West Pastoral District of South Australia (and probably many more ecotypic varieties among those). By far the most common is the "true" western myall; it has stiff, upright terminal branches (**Plate 12**). A second, much less common, form existing sympatrically with western myall is the "water" myall which has, in contrast, pliable, pendulous terminal branches (**Plate 13**). Both forms key to *A. papyrocarpa* Benth. using Jessop and Toelken (1986). The water myall, whilst growing within populations of true western myall, has fewer individuals in the southern part of the range and its numbers increase generally in a northerly direction (my personal observation and results presented in **Table 5.12** and described in Section 5.4.3). A particularly attractive population of this morphotype intermixed with true western myall can be observed along both sides of the Stuart Highway on Oakden Hills Station (approximately 90 km north of Port Augusta) in South Australia (**Plates 12** and **13**).

An allopatric population grows in the gullies that flow into the western side of Lake Torrens in South Australia; this is a more stunted form of western myall (my personal observation; Barry Durman and Frank Badman *pers. comm.*). Having examined the duplicate specimen from Kew of *A.* sp. aff. *papyrocarpa* Benth. which is housed in the Western Australian Herbarium, I believe that the Lake Torrens populations may be synonymous with Koch's specimen from Mount Lyndhurst. Confirmation of this hypothesis is not possible until new specimens have been gathered in both locations for identification.

Morphological variation within *Acacia* species has been recognised by researchers. Even within local populations of *Acacia aneura*, Cody (1991a and 1991b) found that morphological variability is high and that maintenance of this variability is regulated mainly by intraspecific biotic selection which segregates different morphotypes into self-determined (autogenic) niches. Some morphotypes may eventually be described as official varieties if a basis can be established for recognising a formal entity (Bruce Maslin *pers. comm.*). *Acacia cyperophylla* var. *omearana* from the Pilbara in Western Australia is a case in point (Maslin, 1991).

Plate 12: True western myall

Plate 13: The water myall

6.2.4 VARIATION OF WESTERN MYALL POPULATION STRUCTURE ACROSS ITS RANGE

I have observed that the population structures of the western myall differ across the woodlands, as do the rates of mortality and recruitment. Is this variability a response to oscillations in climate during the Pleistocene? As western myall is a such a long-lived tree, populations register the effects of recruitment events hundreds of years ago. The species presents fewer generations than other shorter-lived species, to adjust and respond to each new stage of the climatic cycle. To see if the observed differences are significant from north to south I have calculated a population structure index with which to sample the populations; from the results obtained I make some speculative hypotheses about the effects of long-term climate change on the populations across the study area.

6.2.4.1 Methods

A total of 226 separate and randomly chosen populations of western myall were examined across the woodlands of South Australia for other studies described elsewhere in this thesis (CHAPTERS 3 and 7). At each of the 226 locations the life stage array of a minimum 100 trees was scored (totalling approximately 23,000 trees). Here, I have used this data set to investigate the population structures that occur across the study area. I derived the following formula as an index of population structure (calculated for each of the 226 populations):

$$\mathrm{PSI} = \frac{\Sigma_i (n_i \times i) - N}{8N}$$

where PSI is the population structure index, n is the number of individuals in a category (i) and N is the number in the total population. The nine categories used are the nine Life Stages shown in **Figure 2.6**. If there are all Life Stage I individuals at a site then that site will have an index of zero; if there are all Life Stage IX individuals at a site then it will have an index of one. The index is a proportional representation of the life stage structure at a site.

6.2.4.2 Results and discussion

To determine the strength of the relationship between the two variables PSI and latitude I calculated Pearson's product-moment correlation coefficient (r). This calculation demonstrated a significant relationship with a correlation coefficient of -0.671 (df 222) and I was able to reject the null hypothesis of no relationship (H_O:p=0 at P<0.01). The significance of r was tested; reference to Student's t showed that with 222 df, t must exceed 2.58 at the 0.01 level. The calculated value greatly exceeded this so the relationship is highly significant. The age of populations decreased in a northerly direction (**Figure 6.2**).

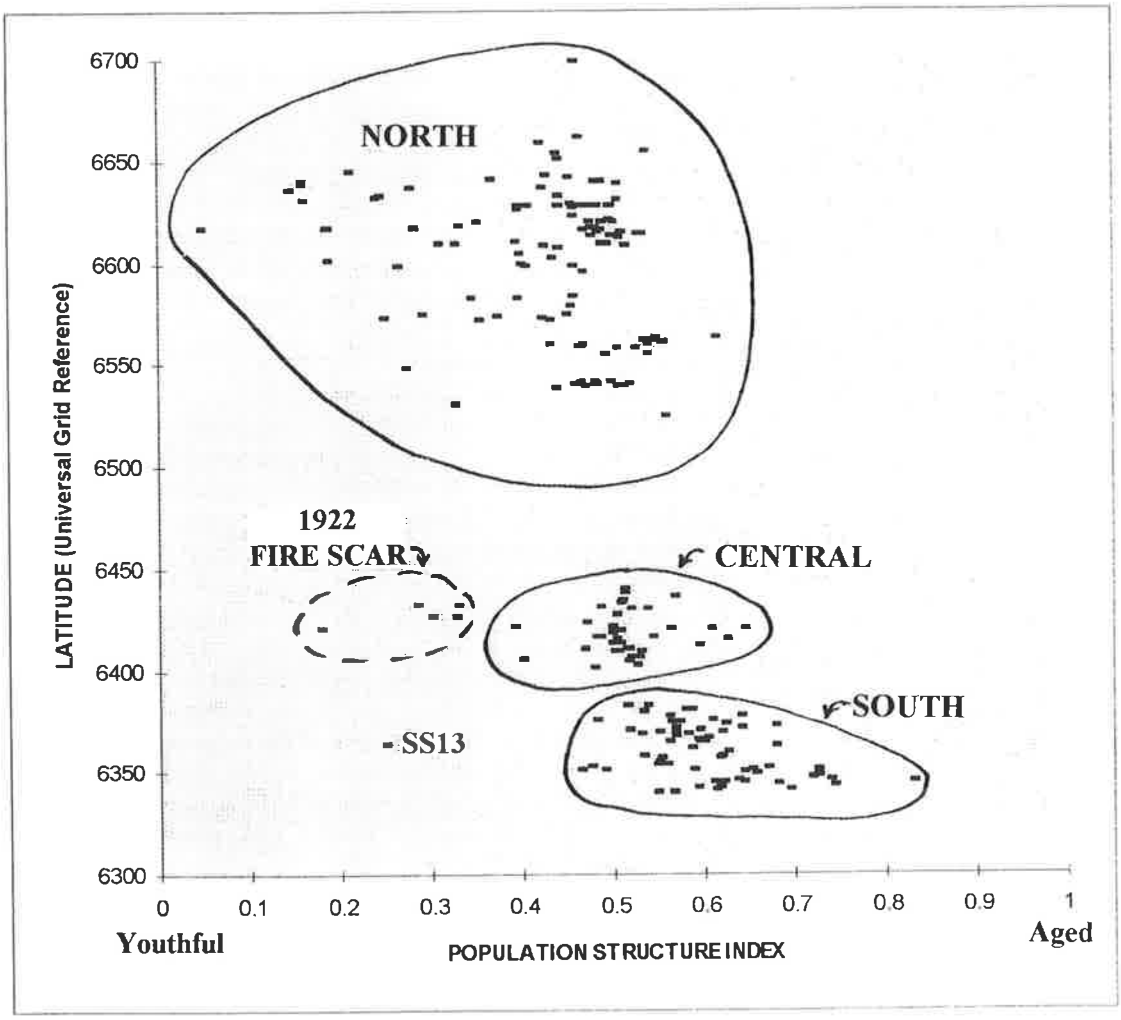

Figure 6.2: Population structure from north to south across the study area

Figure 6.2 clearly shows that the populations in the northern part of the species range generally have a higher proportion of the juvenile and young adult life stages whereas populations in the south have a higher proportion of mature and aged life stages. Populations in the central region appear intermediate between the two. As in the recruitment study in Section 3.4.2 there is a trend of populations falling naturally into 3 regions - north, central and south (described in Section 3.4.2.2). Results for each region are shown in tabular form in **Table 6.2** and graphically in **Figure 6.3**.

Table 6.2: Number and percentage of western myall trees at sites in three regions

LIFE STAGE	SOUTH (66 populations)		CENTRAL (43 populations)		NORTH (116 populations)	
	No. of trees	%	No. of trees	%	No. of trees	%
I	29	0.4	107	2.3	1249	10.8
II	28	0.4	73	1.6	172	1.5
III	43	0.6	333	7.2	154	1.3
IV	1320	19.8	1262	27.2	4943	42.6
V	1825	27.4	1623	35.0	2952	25.4
VI	1481	22.3	658	14.2	1126	9.7
VII	1062	16.0	377	8.1	626	5.4
VIII	732	11.0	177	3.8	340	2.9
IX	137	2.1	27	0.6	49	0.4
TOTAL	6657	100	4637	100	11611	100
REGIONAL PSI	*0.59*		*0.49*		*0.42*	

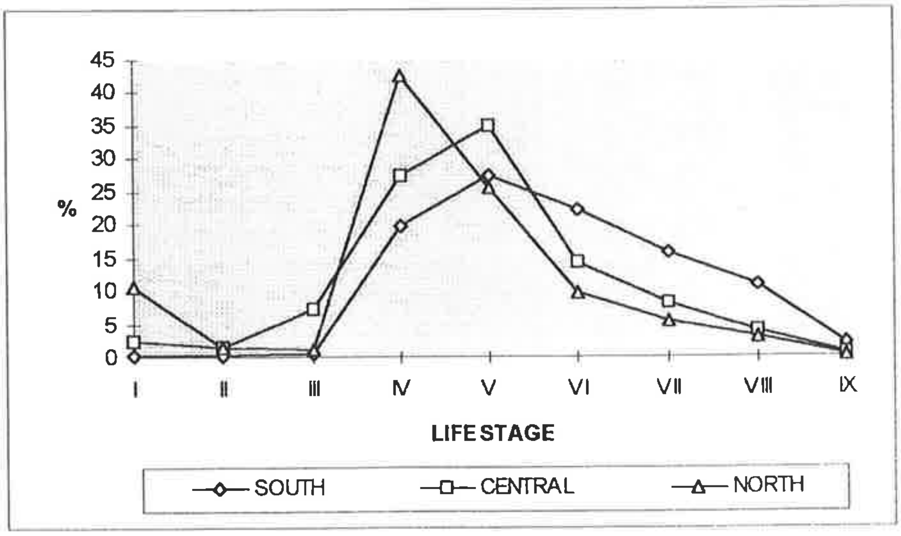

Figure 6.3: Percentage of trees in each life stage by region

The most obvious differences are:

- The life stages containing the highest proportion of trees in each region are:
    - SOUTH Life Stages V (27.4%) and VI (22.5%)
    - CENTRAL Life Stages IV (27.2%) and V (35.0%)
    - NORTH Life Stages IV (42.6%) and V (25.4%)

If Life Stages reflect the ages of western myall (Section 2.4 and CHAPTER 5) then it can be seen from the results that the populations in the South may be generally older than those in the Central area which in turn may be older than those in the North

- The proportion of trees that occur in the Stage I cohort (new recruits) in each of the populations:
    - SOUTH Life Stage I (0.4%)
    - CENTRAL Life Stage I (2.3%)
    - NORTH Life Stage I (10.8%)

New recruits make up a larger proportion of the population in the northern part of the species' range than they do in the south and central.

- The proportion of trees that occur in the oldest Life Stages (VII, VIII and IX) in each of the populations:
    - SOUTH Life Stages VII, VIII and IX (29.0%)
    - CENTRAL Life Stages VII, VIII and IX (12.5%)
    - NORTH Life Stages VII, VIII and IX (8.7%)

More of the oldest trees are found in the south than in the north.

6.2.4.3 Conclusions

As stated in Section 2.4, trees must grow successively through each life stage from seedling to juvenile, adulthood, senescence and death. If we can apply these life stages to a population as an approximate substitute for true age structures then the data indicate the following general trends:

- Populations are older in the south and gradually change across the woodlands to younger in the north and west.

- Recruitment is less frequent in the south and much more common in the north and west.

- Mortality rates (CHAPTER 5) are higher in the south than they are in the north.

A picture emerges of an aging population at the southern edge of the western myall's range with older trees, higher mortality and little recruitment and a younger, more vigorous population at the northern and western edges with lower mortality and much higher recruitment. Inconsistencies in these trends can be explained by examining individual circumstances; an abundance of Life Stage III that recruited in 1922 in the burned areas of the south central region and Site SS13 containing a high percentage of recruits in the southern region (these are described in more detail in Section 3.4 and highlighted in **Figure 6.2**).

6.3 DISCUSSION

> *"In geological time the few thousand years that separate us today from the desert land of yesterday is not even the blink of an eye...what we inherited 200 years ago was a land convalescing from the most horrendous climax of aridity."*
>
> (White, 1994)

The findings make sense when interpreted against the climate data. Fluctuating climates in the past have given rise to a distribution of native trees in South Australia that does not follow patterns that are simply explained by modern soil and rainfall associations (Boardman, 1986). This is certainly so for the western myall (Jessup, 1951); there are many areas outside the range of western myall which are well suited by soil and climate to the species. The woodlands as we currently see them can have been in existence for no more than 10,000 years or so. In the history of a long-lived species such as the western myall this is a very short time given the relatively small number of cohorts (a cohort is a group of individuals all recruiting to the population at the same time interval) that must have occurred within those 10,000 years.

The results of my study into population structure described above shows an aging population at the south of the species' range with a younger, more vigorous population to the north. I propose, then, that the western myall woodlands that may have existed prior to the glacial maximum retreated to refugia during the extreme arid period of 23,000 to 14,500 BP. Expansion out from those areas (and there may have been numerous refugia scattered throughout the area covered by the current woodlands) would have begun almost immediately once the climate ameliorated. Progression would have been slow in a long lived species with seeds that are not readily dispersed. The north-south migration of climatic belts containing the summer monsoons to the north and the winter rain-bearing westerlies to the south during the Holocene would have initiated a pattern of retreat and advance by a western myall population likely in disequilibrium with its environment for much of the time. The populations, I hypothesise are still generally expanding out into the suitable soils identified by Jessup (1951) to the north and north-west of its range. If climatic conditions are favourable in the future than the western myall will expand its range; if unfavourable, it will contract closer to the refugia in the Gawler Ranges, the Denison Range and along the Neales River.

CHAPTER 7

HISTORICAL ECOLOGY AND THE CONCEPT OF "FOSSIL PADDOCKS"

7.1 INTRODUCTION

Clark (1990) and Wasson and Clark (1985) state that management of ecosystems requires a knowledge of their history.

> *"Environmental pattern at any one time is both the outcome of preceding interactions between processes and what was there, and the template on which processes act in the immediate future."* (Clark, 1990)

Clark (1990) highlights the value of historical ecology research using natural experiments to bridge the gap between palaeoecology and present-day monitoring and experimentation. It can provide answers to specific management questions. Deevey (1969) stated that experimental method in ecology is necessarily restricted to those situations that history has already provided; he uses the metaphor of "coaxing history to conduct experiments". Other authors have used natural experiments and historical ecology to investigate ecological problems - a literature review of these investigations will be found later in this chapter. Because western myall is so long lived and establishes only episodically, historical ecology approaches are likely to be effective tools for studying western myall ecology.

The impact of domestic stock on the landscape is an important factor in any study of vegetation dynamics. In Australia domestic stock have been present for less time than some cohorts of many of the perennial plant species; the impact of stock is thus still a relatively recent phenomenon compared with the lifespan of some plants in ecological terms. Australia provides many good opportunities to study such phenomena (Crisp and Lange 1976; Moore

1976). Plant populations are dynamic in the Australian rangelands; they are affected by domestic, native and feral herbivores and the climate is erratic and unpredictable which further confuses the picture. The interpretation of the vegetation present at any time is unusually difficult. Westoby (1988) believes that Australia is a "key laboratory" for natural experiments - most of the biota have evolved separately from the rest of the world. Australians lie at the forefront of ideas and understanding of the interactions between domestic stock and natural land systems (Walker 1988; Westoby, Walker and Noy-Meir 1989).

The introduction of sheep grazing across the arid rangelands of southern Australia was not sudden but progressive as water points were gradually created and large areas subdivided into smaller and smaller paddocks. It is widely recognised that sheep rarely graze more than five km from water, thus there are areas grazed today that were beyond the range of grazing sheep in the past. Sheep are presumed to be capable of destroying new cohorts of many perennial arid zone plants including the western myall which, as shown in CHAPTERS 2 and 3, recruits only episodically (about four times a century after extreme rains). Thus if sheep were the sole destroyers of western myall seedling cohorts, past populations should have survived in sites where sheep did not then graze. Preliminary investigations using a new idea (the "fossil paddock" concept) indicate that whole cohorts of western myall failed to persist *even in the absence of sheep grazing* and that at some sites western myall may recruit *even in the presence of sheep*. The "fossil paddock" or historical ecology approach should be widely applicable to discovering the responses of other long-lived species to the effects of herbivores in the arid zone.

This chapter reports the historical effects of herbivore grazing on the western myall woodlands as revealed by:

- Reviewing other authors' use of natural experiments and historical ecology observations.
- Using the new concept of "fossil paddocks".

Insights into the ecology and management of western myall woodlands provided by these results are described. (These will be further expanded in CHAPTER 8).

7.2 NATURAL EXPERIMENTS AND HISTORICAL ECOLOGY

7.2.1 LITERATURE REVIEW

By looking at experiments that have already been conducted in the past, ecological theory can be tested (Deevey, 1969). Ellenberg's (1988) seminal work on the vegetation ecology of central Europe contains numerous examples of the integration of phytosociology with historical ecology and experimental work in the Northern Hemisphere. The work is based fundamentally on humanity's overwhelming impact on most facets of that landscape; central Europe is an *"ancient cultivated landscape"* and there are few areas where the original landscape has remained unaltered. Chambers (1993) introduces various pieces of research that attempt to discriminate between effects caused by climate change and those caused by human impact. He states that human impact may exacerbate or delay the effects of climate change and uses the examples provided by Huntley, Moore, Barber *et al.* and Warner (Chambers, 1993) to illustrate this.

Hastings and Turner (1965) used historical and recent photographs combined with historical records to illustrate and describe vegetation change in Southern Arizona; they also reviewed and threw light on the principal explanations that have been advanced to account for change and evaluated the evidence. Historical and quantitative assessments throughout the world indicate that in arid and semi-arid grasslands the abundance of woody plants has increased substantially over the past 50-300 years (Archer, 1989). However in southern Texas arguments that these woody plants have contributed to the decline of prairie and savanna have been derived from indirect, historical sources coupled with only limited quantitative data. As Archer (1989) states, the results are equivocal.

In Australia, Wasson and Clark (1985) proposed that from sequences of past events we can explain past changes and how the present came to be. They stated that a greater knowledge of environmental history (or historical ecology) can expand our understanding of what may happen in the future. Clark (1990) recorded several reasons for studying what he describes as *"environmental history"* and supported the notion that reconstructions of the historical past are needed in order to understand the changes that have occurred and how these may impact on future management. He cited the following examples of research undertaken in Australia:

- A study of the Magela floodplain in Kakadu National Park, Northern Territory. Pickup *et al.* (1987) predicted the likely fate of uranium mill tailings stored above ground when the Ranger Mine stops operating.
- An examination of the pollen record in Rotten Swamp in the Brindabella Ranges, Australian Capital Territory revealed the fire history of the area, providing past analogues of present day conditions (Clark, 1986).
- Wasson and Galloway (1986) calculated pre- and post-European settlement erosion rates near Broken Hill.
- Reservoirs and farm dams have been used (Wasson and Clark, 1985) to study past land use changes in a range of variables in areas where natural surface water is rare.

Williams and Oxley (1979) examined the historical aspects of the use of chenopod shrublands using such tools as time trends in livestock numbers, the wool-growing economy, rainfall and rabbits in western New South Wales; they predicted that the chenopod shrublands there are a vanishing resource. Norris *et al.* (1991) used climatic data, archival records and the biology and ecology of component parts of the flora and fauna of the Pilliga forests in northern New South Wales to examine change or stability of the vegetation. In the semi-arid rangelands of western New South Wales Mitchell (1991) reviewed the history of settlement to gain an understanding of changes to the vegetation and soil; he concluded that in some cases traditional wisdom was faulty and in danger of becoming accepted fact.

Noble (1977) used the long-term photographic record of the TGB Osborn Vegetation Reserve at Koonamore Station to examine the biomass dynamics in chenopod shrubland and found a system dominated by large pulses of input followed by slow declines in biomass. At Momba Station in New South Wales, Pickard (1990) analysed stocking records and subdivision of the property from 1884 to 1988. Not surprisingly he found that over 100 years of grazing had initiated substantial changes to the ecosystem; more interesting was his observation that there were insufficient data to determine which combinations of pastoral management, weather and fire are mostly responsible for those changes. Similarly, vegetation changes at a property in south west Queensland were documented using historical records combined with a field survey (Oxley, 1987). Barnes (1996) attempted to use techniques "*to extract quantitative data from qualitative sources*" (i.e old photos, diaries etc.) for her study of the historical changes in the North East Pastoral District of South Australia, finding that land condition in this area has improved markedly since the 1940s.

7.2.2 HISTORY OF PASTORALISM IN THE STUDY AREA

Matthew Flinders first visited the head of Spencer Gulf in 1801; indeed his botanist, Robert Brown, collected the type specimen of western myall during that voyage, (Jessop and Toelken, 1986). Other early explorers (Stuart, Babbage, Warbuton and Giles) travelled through the study area and reported on its potential for settlement. In the early 1860s settlers had begun to take up Pastoral Leases in the southern part of the Gawler Ranges (**Figure 7.1**) but most of the study area remained unoccupied.

> *The western side of Spencer's Gulf from Mount Laura on the south to Yudnapinna and Euro Bluff on the north, and west through the Gawler Ranges was very little known in the early 'sixties. The country to the north-west, beyond the northern boundaries of Euro Bluff, Yudnapinna, and Carriewerloo, and west of Lake Torrens, was unoccupied."*
>
> Richardson (1925)

In South Australia's Centenary year, Richardson (1936) showed the distribution of sheep in 1866 (**Figure 7.1**); from this it can be seen there were very few sheep in the study area in those very early years - each dot on the map represents 2000 sheep. Davidson (1938) also wrote of the extensive unoccupied country available for grazing at that time.

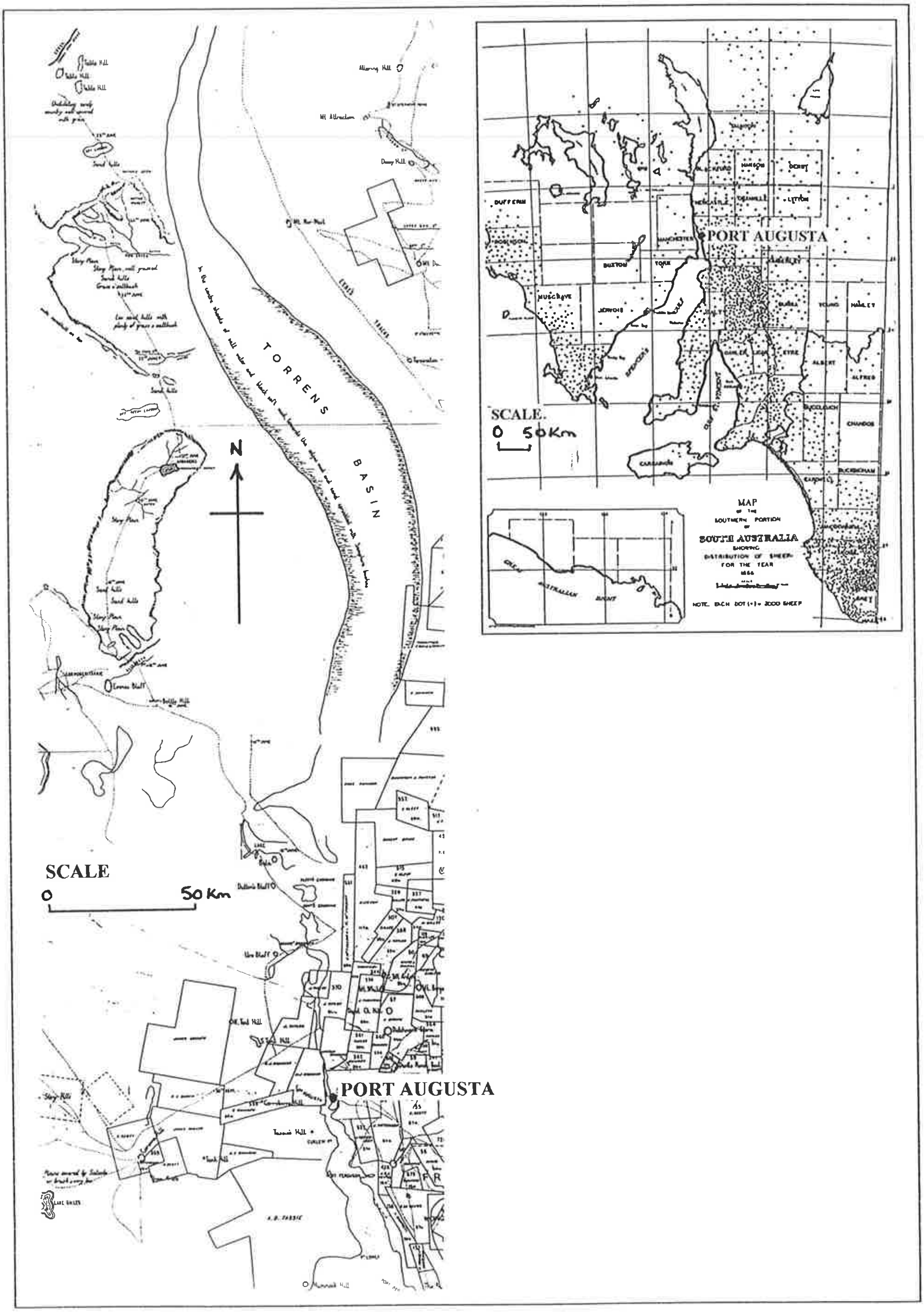

Figure7.1: Pastoral map for the north west - 1865 (Inset: Distribution of sheep in 1866)

The lack of surface water in the region was highlighted in July of 1865 by Mr. A.T. Woods, an Inspector of Pastoral Claims. He wrote of the Gawler Ranges in his notebook:

> *"In the Gawler Ranges it appears to be proved that the low ground will only yield salt water, and it is only to be regretted that so many thousands have been spent to discover what should not be done, to find out the places that are not favourable for drinking.*
>
> *The fact that all persons have followed the same system, with the like want of success, leads me to trust that when other places are tried, the country will eventually, although slowly become watered."*
>
> Woods (1865)

It was not until September 1866 that G.W. Goyder recommended to Parliament that fencing of pastoral runs was a necessity if South Australia wished to keep its place in the wool markets of the world (PSA, 1866).

It is well accepted that in the chenopod shrublands in most seasons, sheep will not graze beyond about five km from water. Evidence was collected by Osborn *et al.*, (1932) that most sheep grazing in chenopod shrublands took place within 2.4 km of water and country beyond 6.4 km was hardly ever visited; this work was confirmed by Barker and Lange (1969). In similar terrain, Jessup (1951) found that sheep rarely grazed beyond 4 km from water and Squires (1970, cited in Lynch, 1974) showed that sheep averaged a total of 6 km travelling in any one day. Landsberg and Gillison (1995) used a figure of 10 km as a buffer zone around water points across Australia to determine the distribution of areas lying beyond the influence of all water-dependent animals (including cattle, kangaroos, goats, horses, donkeys and camels which range much further from water than sheep). For the purpose of this study I have used a 5 km radius from water as the area that is grazed on any regular basis by sheep, however many of the areas investigated were beyond this range and frequently well beyond 10 km. Researchers with the Pastoral Management Branch of South Australia (Craig Baulderstone *pers. comm.*) consider that 5 km is a "drought" zone; beyond that distance sheep travel infrequently and only when seasons are good; then they tend to concentrate on new grass (the "green pick") and ignore perennials. This occasional but significant use of the paddock beyond 5 km from water was confirmed by Cridland and Stafford Smith (1993) for western myall woodland with an understorey dominated by *Maireana sedifolia* and *A. vesicaria* on the perimeter of the Nullarbor plain in Western Australia.

It must be remembered that sheep are literally "tied" to the watering point because of the absence of alternative water sources and confined by fences which often truncate the natural piosphere; in other places the fences may lie well beyond the natural limit (Lange, 1971a). Kangaroos, which proliferated with the introduction of stock watering supplies (Wilson *et al.*; 1984), need to return to this water to drink but can range much further and are not confined by fences. Rabbits obtain the moisture necessary for their survival from the plants they eat (Linton, 1994) and are thus not dependent on water supplies; they can live permanently beyond the piosphere.

In the early days of the occupation of the study area most land was beyond the range of sheep. Thus the small flocks of sheep were shepherded between widely scattered, very scarce ephemeral surface water locations (Richardson, 1925; Don Nicolson *pers. comm.*). In an era before wire fences and the also due to the presence of dingos, the sheep were pounded (enclosed in pounds or pens) each night (Lange, 1971b). Thus their impact on the country was concentrated within 5 km of water and the pounds. As time progressed however, wells were sunk and huge flocks watered. These were as much as 60 miles (96 km) apart. For example Wizzo Well on Roopena Station was the sole watering point for 15,000 sheep before 1919 (**Plate 14**); this compares with 250-300 per water today!. On Yudnapinna Station, stocking policy in the 1890s was based on carrying the maximum number of sheep (Jackson, 1958). An average of 53,000 sheep were run on Yudnapinna over a period of 14 years at only eight wells. This led to severe overgrazing of the bush in the immediate vicinity of these wells; by 1958 these areas were still highly degraded and Jackson predicted that recovery would probably never take place. He also stated that many other parts of Yudnapinna, away from the eight wells, were virtually ungrazed.

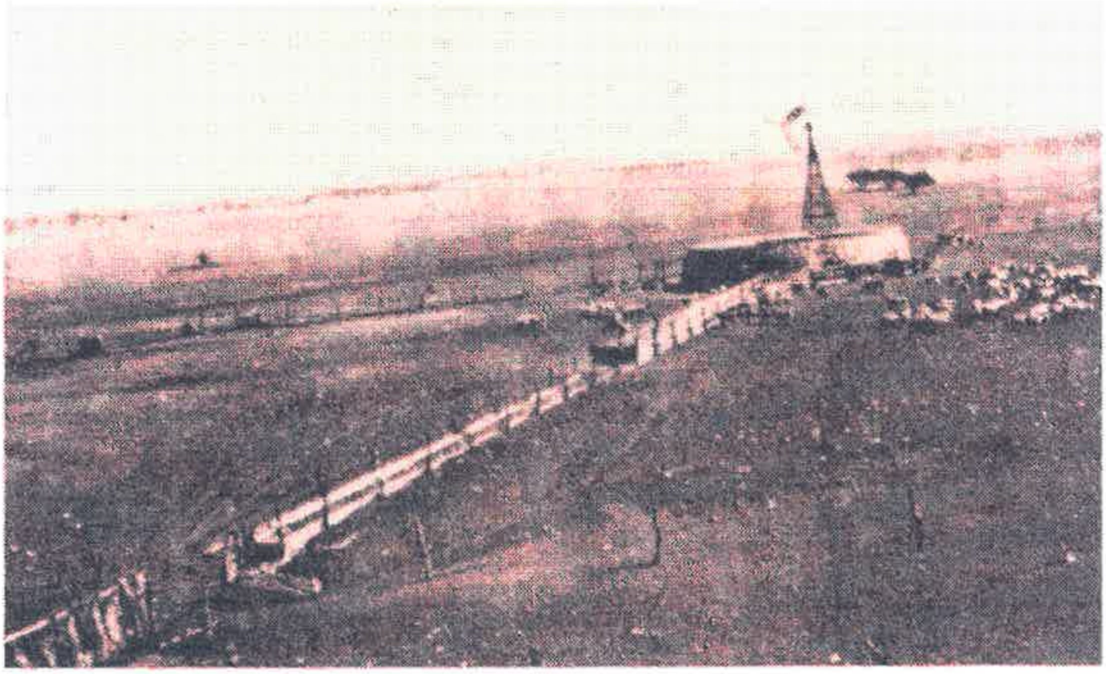

Plate 14: Wizzo Well in 1921

By the 1880s and 1890s, much fencing had been done, particularly around the perimeter of each run (**Figure 7.2**). Internal fencing of each run progressed slowly and will be discussed in Section 7.3. Davidson (1938) wrote of improvements in water storage and management of pastoral properties in the arid zone of South Australia that enabled the pastoralist to carry his sheep through drought years more successfully. More complete histories of the stocking and pastoral settlement of the study area can be found in Tynan (1991), Heathcote (1991), Donovan (1995), Gawler Ranges Soil Conservation Board (1996) and Kingoonya Soil Conservation Board (1996).

Lange, Nicolson and Nicolson (1984) describe the progressive subdivision of paddocks and water-point proliferation on Roopena Station in South Australia which still continues today after almost 70 years (**Figure 7.3**). The idea of paddock subdivision was originally advanced by Peter Waite (1895) and its initiation at Ophara Station in Western New South described by Whitington (1897). Similar progressive subdivision and watering of paddocks has occurred on most South Australian pastoral properties and is well documented in station records and in the files of the Pastoral Management Branch of the South Australian Government.

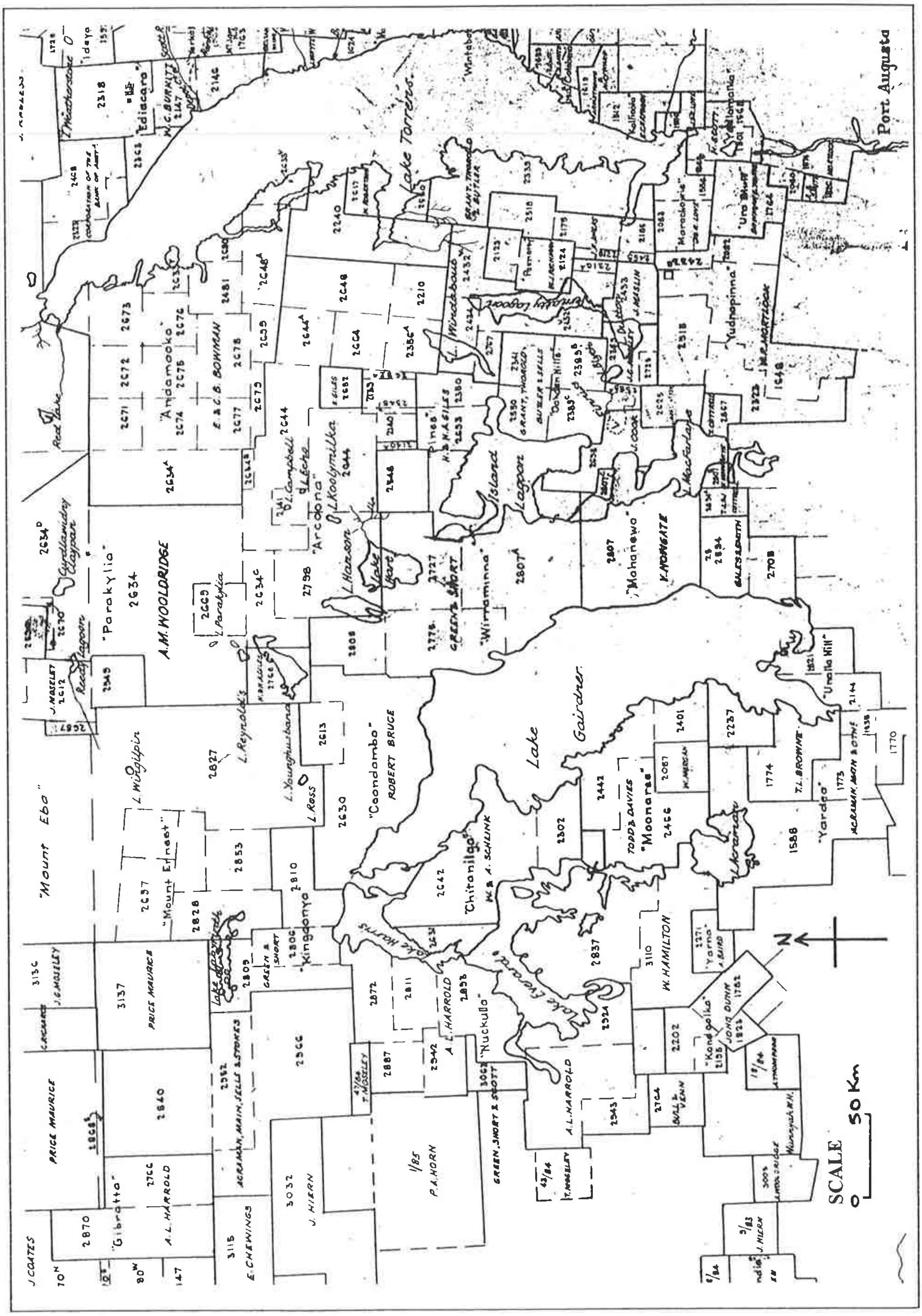

Figure7.2: Pastoral map for the north west - 1888

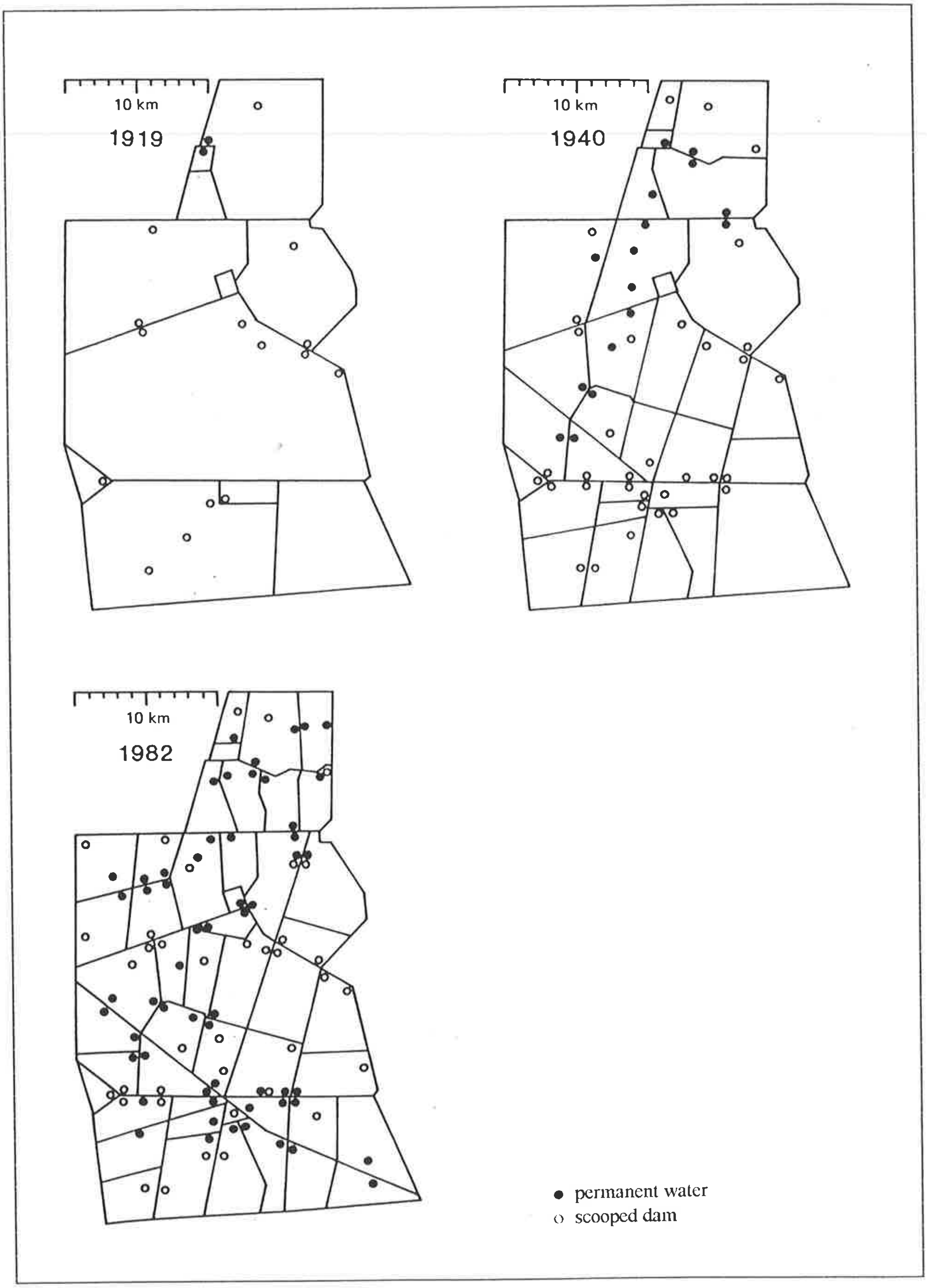

Figure7.3: Subdivision and proliferation of watering points on Roopena Station 1919-1982 (from: Lange *et al.*, 1984)

7.3 "FOSSIL PADDOCKS": A NEW IDEA FOR DISCERNING THE HISTORICAL EFFECTS OF DOMESTIC STOCK ON THE LANDSCAPE

In the rangelands of Australia, then, two things are important for the analysis of current vegetation patterns in terms of their recent historical development:

- the impact of domestic stock was progressive, not sudden; in any one landscape plant communities can be found that have been grazed for different lengths of time, and
- The duration of impact from domestic stock is often less than the lifespan of some long-lived plants.

With this in mind, I began to examine the effects of domestic stock (and sheep in particular) on the landscape as a whole and, more importantly, over the complete span of time they have occupied the pastoral zone in the study area.

7.3.1 WHAT ARE "FOSSIL PADDOCK" SYSTEMS?

Because introduced herbivores can destroy whole cohorts of perennial plants, their impact, and its timing, is evident in population structures of arid zone plants (*Acacia burkittii*, Crisp and Lange, 1976; the western myall, Lange and Graham, 1976). However, domestic stock did not impact all of the landscape simultaneously. At the start, much of the landscape was beyond the reach of stock due to water and paddock restrictions as described in 7.2 above. Thus, the impact of stock was progressive - not sudden.

One of the definitions of fossil in the Concise Oxford Dictionary (Fowler and Fowler, 1964) is:

> *"...recognisable as remains or impressions of plant or animal of past ages..."*

I have thus coined the term "fossil" paddock to describe any paddock that has had a new pattern of smaller paddocks and new watering points superimposed upon it. Thus the situation at Middleback and Roopena comprises a number of fossil paddock systems. I will show how the long-lived Australian arid zone species, the western myall, can be used as an indicator of past grazing by native, domestic and feral herbivores within a "Fossil Paddock" System (Ireland and Andrew, 1994 and 1995).

7.3.2 APPLICATION OF THE "FOSSIL PADDOCK" APPROACH

As we have seen in earlier chapters, a characteristic of Australian arid zone perennials such as the western myall is the episodic nature of recruitment events after major inundations or "flood years" (Lange, 1971c; Noble, 1986). Lange, (1971c) predicted that western myall recruitment can only occur in years that contain a month with rainfall over 100 mm. These events occur approximately four to six times per century in the western myall woodlands of South Australian. The most widespread and universal "floods" within the study area in living memory were in 1921, 1946, 1973/74; towards the northern area of the species' range, 1968 and 1989 are also considered flood years (**Figure 2.3**). Each of these "floods" resulted in a major emergence of western myall seedlings; in the intervening years, little if any recruitment occurred in the open paddocks (Lange and Purdie, 1976; R.T. Lange. D.A. Nicolson, and A.D. Nicolson *pers. comm.).* Three cohorts are recognised and I have grouped Life Stage I recruits (most likely germinated following 1989, 1973/74 or 1968 rains) as the late century cohort. Life Stage II recruits (most likely 1946) comprise the mid-century cohort, and Life Stage III trees (1921) are the early century cohort. Examples of these cohorts can be found throughout the region.

Within eight to ten years of recruitment, juvenile western myalls should have grown too tall for sheep to suppress them; e.g. western myall recruits from the 1921 cohort (and other perennial tree species) on Yudnapinna Station, South Australia were not suppressed by the introduction of sheep some ten years after a major fire destroyed most of the original vegetation (Crocker and Skewes, 1941; Jackson, 1958; A.D. Nicolson *pers. comm.*). Given the above, and given that most sheep grazing impact is concentrated within 5 km of the waterpoint other than in exceptional seasons, then if sheep are the prime cause of non-recruitment in the western myall, the appropriate life stages will be present in areas of the "Fossil Paddocks" that were beyond the grazing range of sheep when that cohort was establishing and will be absent within the grazing range of those sheep then. Thus, the early century cohort (Life Stage III) should be present around waters opened in the late 1920's, the mid and early century cohorts (life Stages II and III) should both be present for waters established in the mid to late 1950's. The late century cohort (Life Stage I) should be scarce in most places because few would have escaped sheep grazing other than in areas that were not watered until the late 1970's or not watered at all. Evidence for these cohort dates is shown in **Table 2.1** and CHAPTER 3. If sheep are the culprits, this sort of pattern may recur continuously across the pastoral zone with different permutations. However if sheep are not the prime destroyers of western myall seedling cohorts, then this pattern will not be found.

With this in mind, I investigated the historic effects of sheep on the recruitment of western myall using the "Fossil Paddock" System.

7.3.3 GENERAL METHODS USED AT EACH "FOSSIL PADDOCKS" SITE

The investigations were undertaken at 18 locations in the western myall low open-woodland that lie within the Kingoonya and Gawler Ranges Soil Conservation Board Districts of South Australia (**Figure 7.4**), an area of some 80,000 square kilometres comprising about 50 pastoral runs. Western myall is the dominant overstorey species; the understorey is characterised by the chenopod shrubs *Maireana sedifolia* (or alternatively the composite, *Cratystylis conocephala* known as the false bluebush because of its striking similarity to *Maireana sedifolia*), *M. pyramidata* and *Atriplex vesicaria* and an ephemeral flora of forbs and grasses. Each "Fossil Paddock" (FP) was identified by research into archival maps, government files, pastoral property files and personal communication with pastoralists. Within the western myall woodlands I located about 25 FPs that held potential for analysis; some proved unsuitable once field reconnaissance had been carried out (e.g. in cases where the dates of paddock subdivision and watering were not known). **Appendix 7** contains maps showing the outlines of the old FPs used within the study area; on these maps the current paddock system has been overlaid on the old paddock system that existed in the late 19th Century. Eighteen FPs have now been investigated in this study (**Table 7.1**). **Appendix 8** gives a vegetation description taken verbatim from the old surveyor's maps for each FP. **Figures 7.5, 7.6, 7.7** and **7.8** are examples of four individual cases.

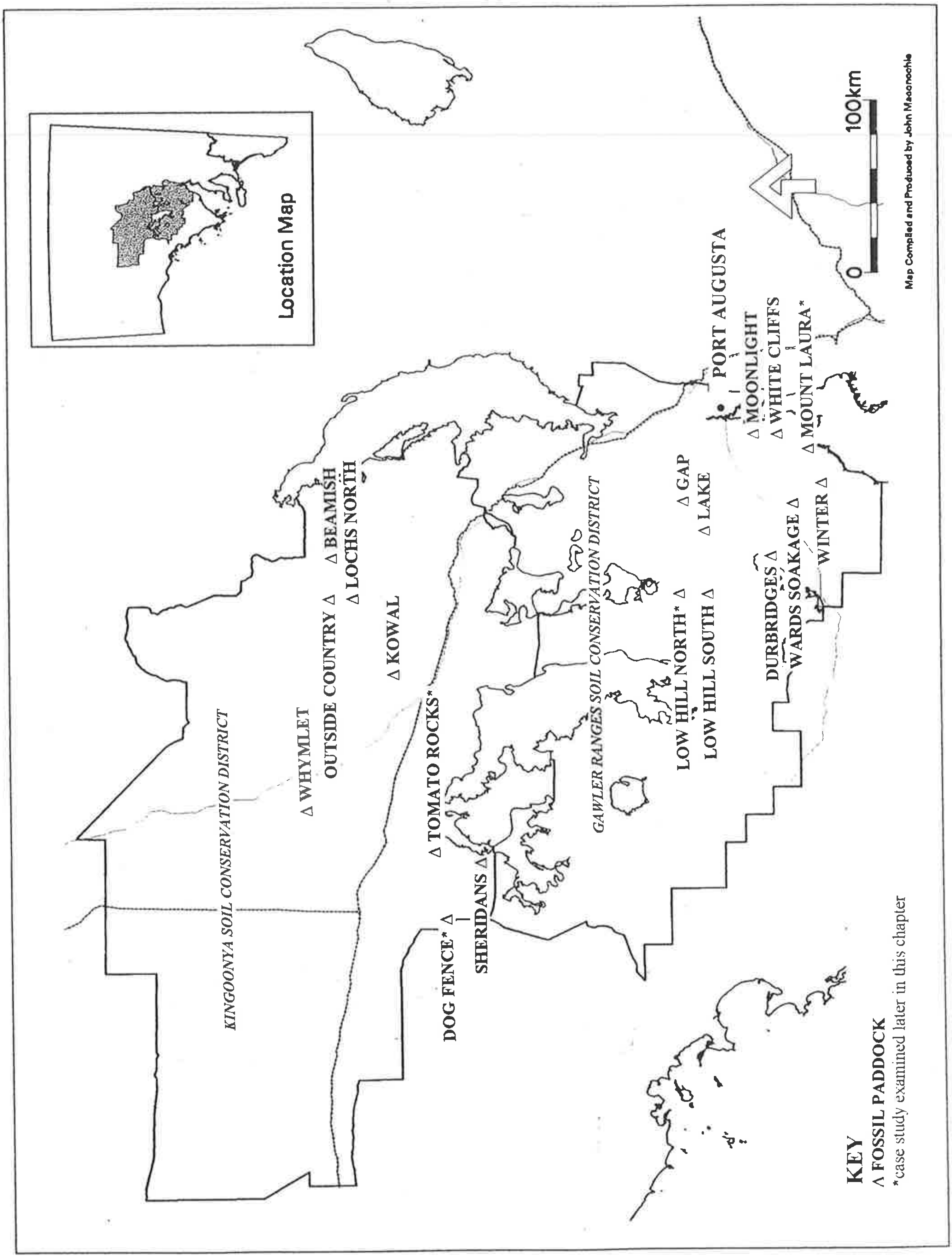

Figure 7.4: Fossil Paddocks within the study area

Table 7.1: Fossil Paddocks used for this study

FOSSIL PADDOCK	STATION
Beamish	Parakylia
Dog Fence*	North Well and Wilgena
Durbridges	Corunna
Gap	Cariewerloo
Kowal	Mount Vivian
Lake	Wartaka
Lochs North	Parakylia
Low Hill North*	Siam
Low Hill South	Siam
Moonlight	Tregalana
Mount Laura*	Middleback
Outside Country	Parakylia
Sheridans	North Well
Tomato Rocks*	North Well
Wards Soakage	Katunga
White Cliffs	Tregalana
Whymlet	North Well
Winter	Nonowie

*case study examined later in this chapter

I established a map of each FP with all known dates of original fencing and watering points (examples of these are at the foot of **Figures 7.5, 7.6, 7.7** and **7.8**). Internal fences and new water points were also established on the plan, verified wherever possible by document from several sources and personal communication with participants in the subdivision concerned (or their descendants). Location of all known western myall woodland occurrences were plotted through an initial field reconnaissance of the FP and between eight and fifteen sites each containing at least 100 western myall trees were chosen semi-randomly (using the SERM method[1]) within the woodlands along the known tracks and fencelines. At each site a modified random walk procedure (described in Section 2.4.1) was carried out 50 m away from each track or fence (to minimise edge effects) scoring at least 100 trees into one of the nine Life Stages (**Figure 2.6**). Using this simple technique, individual trees can be assigned to one of the nine stages providing a fair approximation of population structure at that site. As a control I used sites (scored for previous experiments) that have been heavily grazed by sheep since at least 1920 or before, i.e. an area where the maximum impact of sheep on all twentieth century cohorts could be assured. Furthermore, whilst driving around the paddock I also looked

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[1] SERM - the Sheep Egesta Randomisation Method. Ten to twenty pieces of dry sheep egesta are thrown onto a map of the fossil paddock. Pencil marks are made on the map if the egesta lands in an area close to an access track within western myall woodlands in the FP. The method is repeated until the required number of sites have been selected.

carefully for any western myall trees from these younger cohorts as a qualitative control to identify patchy recruitment which may have been missed by the sampling of the FP in 10-15 sites; this process confirmed the site sampling in every instance.

In order to interpret my data, a number of covariate data were collected. A key covariate was the use of the site by major vertebrate herbivores (sheep, kangaroos and rabbits) for reasons given earlier in CHAPTERS 3 and 4. Dung was used as one index of herbivore activity. As early as 1969 Lange noted that sheep dung (egesta) found per unit area in any paddock closely indexed the average sheep time spent per unit area. This idea was further refined by Lange and Wilcocks (1978) Lange (1983). Andrew and Lange (1986) used the technique at Middleback for sheep and kangaroos; more recently Landsberg *et al.* (1992) used it in north western New South Wales for sheep, goats and kangaroos. The abundance of rabbits has also been investigated using this method by generations of students at Middleback Field Centre.

These relatively ephemeral signs of recent occupation by sheep, rabbits and kangaroos should reflect the propensity of the local environment to sustain populations of the particular herbivores and **may** therefore be indicative of past populations, particularly those that may have impacted on the late century cohorts and it is for this reason that the data were collected.

These data were collected at the same time as western myall trees were scored into Life Stages. At each site I estimated the abundance of sheep, rabbit and kangaroo dung using a modified rank-order procedure - the ACFOR (abundant, common, frequent, occasional, rare) scale as described by Kent and Coker (1992). Abundance refers to the relative amounts found along each of the random walk transects. Where an area is being studied as a whole site rather than by using a series of quadrats they consider these methods to be more useful than assigning frequency with a one to five Braun-Blanquet scale. Estimates using the same scale were also made for the frequency of sheep tracks, rabbit warrens (old and new) and the amount of cryptogamic or lichen crust found at each site. My modified scale (abundant, common, occasional, none) used to collect this data is shown in **Table 7.2**.

Table 7.2: Scale for measuring abundance of various variables at each Fossil Paddock site;.

SCORE	ABUNDANCE
3	Abundant
2	Common
1	Occasional
0	None

The results of this "fossil paddock" investigation are best understood by first examining some case studies chosen to illustrate the methods and results; this provides a basis for understanding the total data set presented later in the chapter. Four individual FPs - Mount Laura and Low Hill South are located in the southern and central part of the western myall woodlands and Dog Fence and Tomato Rocks are located in the north west.

7.3.3.1 Mount Laura "Fossil Paddock" - a case study

The site chosen for the initial investigation was an area of western myall low open woodland between the homestead at Middleback Station and the city of Whyalla on the northern Eyre Peninsula of South Australia (32^{o}57'S, 137^{o}24'E). I refer to this FP by its former name of Mount Laura (**Figure 7.5**) using it to test the hypothesis for the first time. Mount Laura FP, although fenced around its perimeter and bisected by the unfenced Whyalla to Iron Knob ore haul tramway, remained ungrazed until 1929 when two new waters were added to the north-western corner and to the western boundary. During the period 1958/60 Mount Laura FP was subdivided into four smaller paddocks - Rainbow, Koleroo, Moonee and Wanga; other dams and pipelines were added at about this time. **Figure 7.5** and Page 209 show the configuration of the paddock in 1919 (no internal fences or watering points) and in 1994 (fully developed). Thus, the 1921 cohort should have escaped sheep grazing and occur throughout the entire paddock; and in areas more than 5 km from the original two watering points the 1946 cohort should also have escaped sheep grazing.

Along the internal tracks of Mount Laura FP ten sites were chosen at locations where there were between 50 and 100 adult western myall trees. Three of these sites were located in the

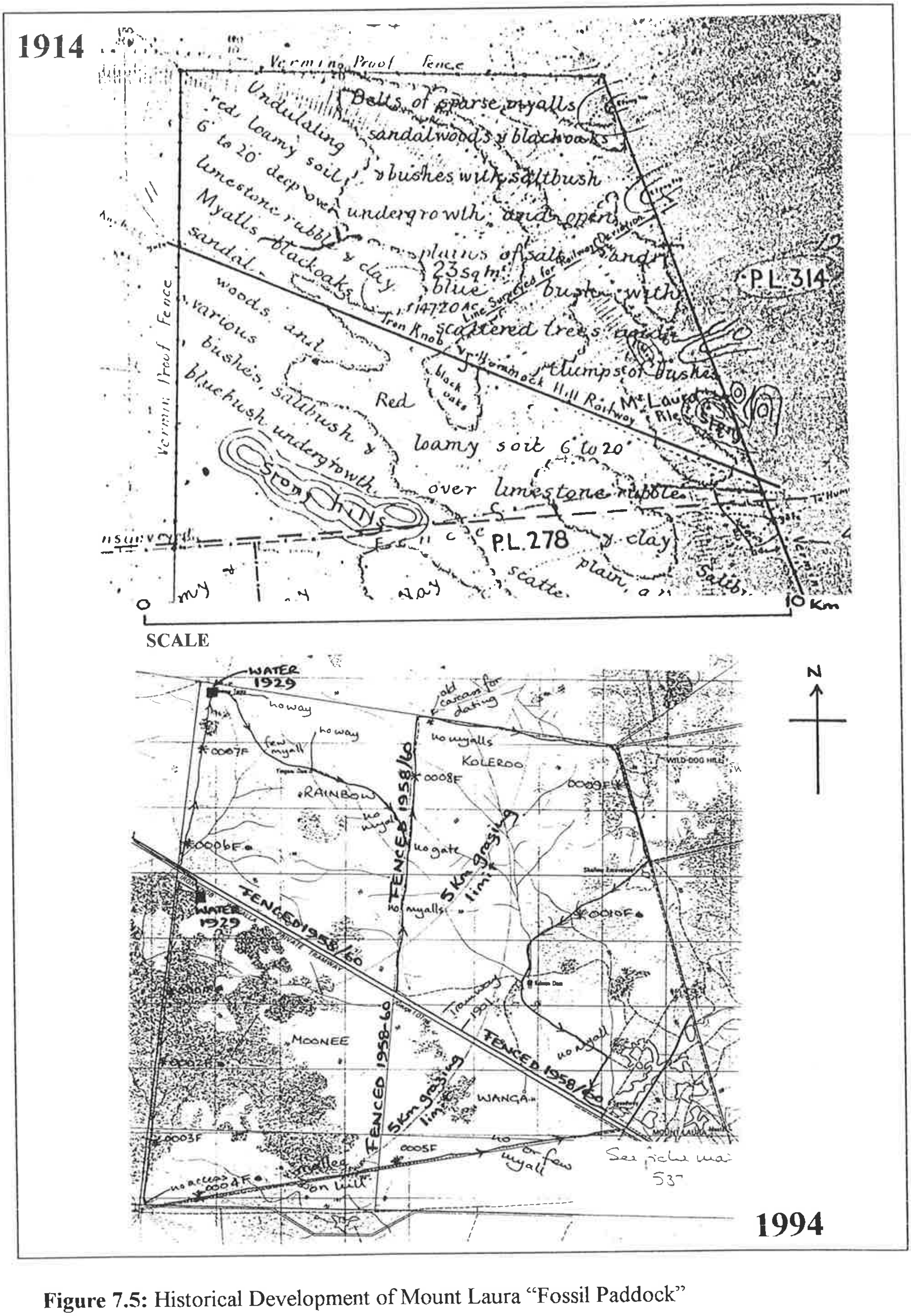


Figure 7.5: Historical Development of Mount Laura "Fossil Paddock"

part of the paddock that was more than 5 km from the original water points. As a control I used three sites (scored for a previous experiment) in an adjacent paddock that has been heavily grazed by sheep since at least 1919 (A.D. Nicolson *pers. comm.*). At each of nine sites in Mount Laura FP (**Figure 7.5**), life stages were scored for 100 or more trees, at the remaining site only 65 were located. A total of 994 trees was scored and 331 for the control. Whilst driving around the paddock I also looked carefully for western myall trees from Life Stages II and III (approximating the 1946 and 1921 cohorts). It has been noted previously from anecdotal evidence that germination of western myall was widespread in this general area following the 1921, 1946 and 1973/74 rains.

At the ten sites in Mount Laura FP virtually none of the 1921 cohort were found - of the 988 trees scored across ten sites, only 7 were of Stage III (**Table 7.3**). This was a similar proportion to the control sites (**Table 7.3**) grazed since at least 1919. Similarly only one individual from the 1973/74 cohort was found and none from the 1946 cohort.

Table 7.3: Life Stages at ten sites in Mount Laura FP and at three sites in the control paddock (located at Middleback Station)

LIFE STAGE	MT. LAURA - 10 SITES - NUMBER (AND PERCENTAGE) OF TREES	CONTROL - 3 SITES - NUMBER (AND PERCENTAGE) OF TREES
I	1 - (0.1%)	0 - (0.0%)
II	0 - (0.0%)	0 - (0.0%)
III	7 - (0.7%)	3 - (0.9%)
IV to IX	980 - (99.2%)	328 - (99.1%)
TOTAL	988 - (100%)	331 - (100%)

If sheep were the culprits you would expect to find the trees from the 1921 cohort everywhere in the FP because they would have grown tall enough to escape grazing. Virtually none were found. This was similar to the control sites grazed since at least 1919. However, you would expect to find the mid century (1946) cohort only in the further parts of the paddock remote from the original (1928) watering points. None were found at any site. Indeed, during the two days I spent in Mount Laura FP I saw very few western myall trees which could be assigned to Life Stages I, II or III. Thus, assuming significant numbers of the 1921 and 1946 cohorts germinated, it seems that most failed to persist even in the absence of sheep grazing.

It appears then, at least for Mount Laura FP, the 1921 and, 1946 (and 1973/4) cohorts are essentially missing from the record. No sheep were grazed in this paddock until 1929, eight years after the 1921 cohort recruited to the population. Western myall recruits from this cohort on Yudnapinna Station some 100 km to the north were not suppressed by the introduction of sheep some ten years after a major fire destroyed most of the original vegetation (A.D. Nicolson *pers. comm.*). Thus it seems unlikely that sheep introduced into Mount Laura Paddock in 1928 would have been able to destroy the 1921 cohort of western myall, or all of the 1946 cohorts in the three sites then beyond the range of grazing sheep. Assuming the cohorts emerged (which is almost certainly true), some other agent must have been responsible.

7.3.3.2 Low Hill North "Fossil Paddock" - a case study

Low Hill North FP (**Figure 7.6**) is located on Siam Station in the Gawler Ranges of South Australia (32°15'S, 136°45'E). Until the 1960s Low Hill North and Low Hill South FP were designated Siam North and run as part of Carieweloo Station. The external boundary fence of the FP was erected before 1893 and watered from Low Hill Well on the southern boundary of the paddock. North Dams, some 3 km from Low Hill Well were installed in 1900. Until 1955 these were the only improvements (other than north-south fence dividing the paddock) and a large proportion of the FP remained unwatered. During 1955 major developments were undertaken. A report and map in the newspaper outlined the work done and described it *as "symbolic of the post-war progress made by sheep stations in the North West"*. Mr John Edkins, the manager of Cariewerloo, stated that *"the basis of the programme was to provide more watering points for sheep and to subdivide so that paddocks would be greatly reduced in size. This would be followed by reducing the number of sheep in the mobs in each paddock"*. Low Hill North FP was subdivided into 6 paddocks (West and East Fiddle Hill, Dingo Hill, Tanfield, Rankins and Jungle) each with one or two new watering points. Sheep now had access to more that 95% of the total area of the old FP. **Figure 7.6** and Page 206 show the configuration of the paddock in 1893 (no internal fences or watering points), in about 1950 (an

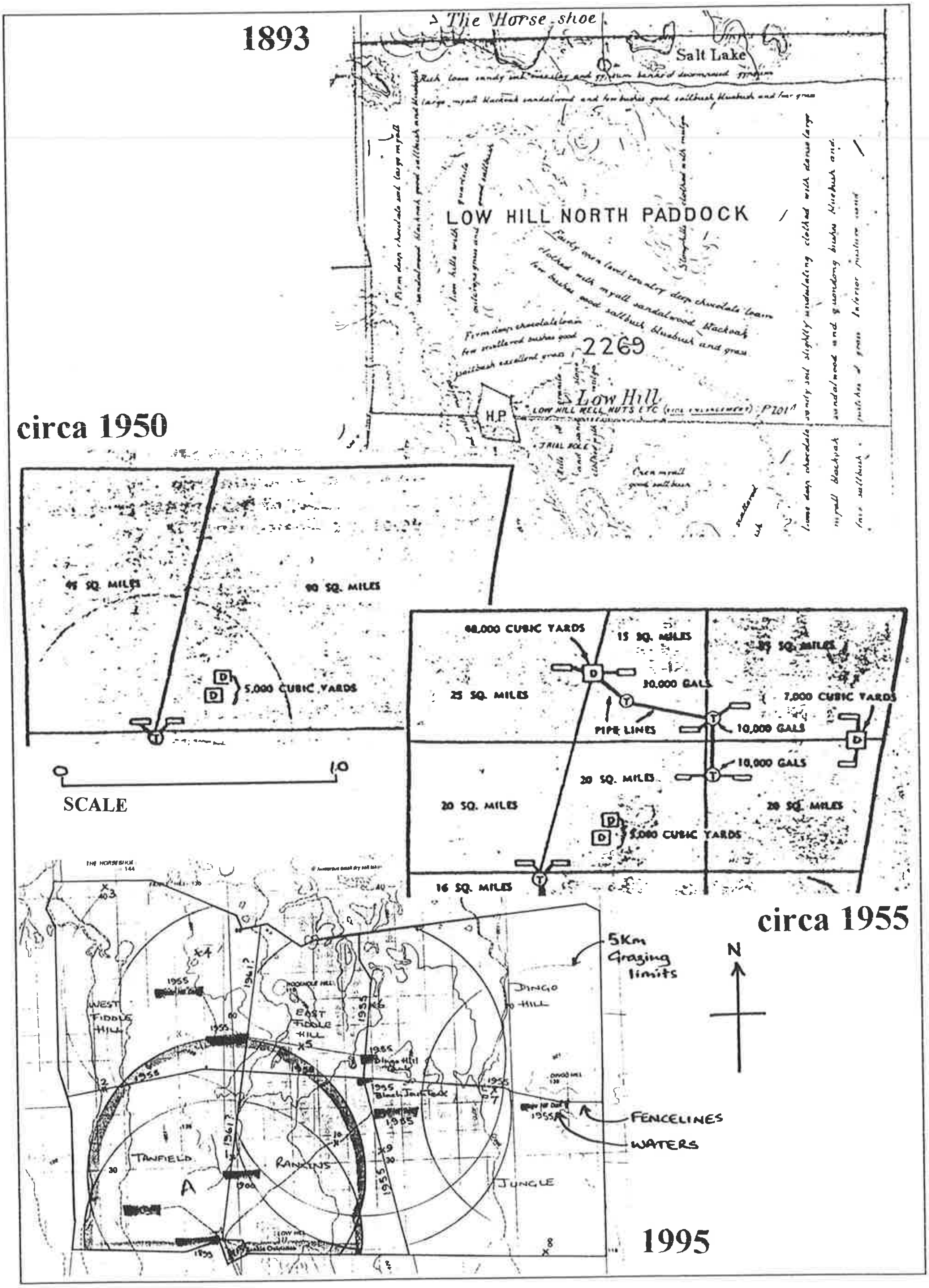


Figure 7.6: Historical Development of Low Hill North "Fossil Paddock"

internal north-south fence and one watering point), in 1955 (showing the development reported in the newspaper at the time) and in 1994 (virtually unchanged since 1955).

I examined 10 FP sites in Low Hill North FP scoring a total of 1068 western myall trees (**Table 7.4**); these are compared with the control site grazed continuously since 1919. At eight of the sites few of the early century cohort were found. Of the 1068 trees scored across those eight sites, only one was Life Stage III. This was similar to the control sites grazed since at least 1919. At the two remaining sites (7 and 8) relatively high numbers of Life Stage III were found; these sites were within the scar of the fire that swept through adjacent Yudnapinna Station and other surrounding stations in 1922 (see Section *3.4.1.1*) and were beyond the grazing range of sheep in the paddock at the time of recruitment. Across the paddock only 25 Life Stage I individuals from the late century cohort were found and only 18 Life Stage II individuals from the mid century cohort.

Table 7.4: Life Stages at ten sites in Low Hill North FP and at three sites in the control paddock (located at Middleback Station)

LIFE STAGE	LOW HILL NORTH - 10 SITES - NUMBER (AND PERCENTAGE) OF TREES	CONTROL - 3 SITES - NUMBER (AND PERCENTAGE) OF TREES
I	23 - (2.2%)	0 - (0.0%)
II	18 - (1.7%)	0 - (0.0%)
III	116 - (10.8%)	3 - (0.9%)
IV to IX	913 - (85.3%)	328 - (99.1%)
TOTAL	1070 - (100%)	331 - (100%)

At all sites sheep dung was occasional to abundant. Rabbit dung was similarly occasional to abundant except at sites containing western myall of Life Stages I, II and III; at these sites there was no rabbit dung. Kangaroo dung was common at most sites.

Because no internal fence and water point development took place in the FP until the mid 1950s the early century cohort would be expected to occur everywhere in the paddock; few were found except at sites that had been burned in 1922. Similarly, mid century cohort (Life Stage II) would be expected to occur in all parts of the paddock more than 5 km away from Low Hill Well and North Dams. Very few were found. Because no sign of rabbits (including dung and <u>old</u> or new warrens) were found at the sites that contained young western myall it is likely that rabbits were not present during the time of recruitment. Again, as in Mount Laura FP, assuming significant numbers of young myall of each cohort germinated it seems that most failed to persist even in the absence of sheep grazing, however, they may have persisted in the absence of rabbits.

7.3.3.3 The Dog Fence "Fossil Paddock" - a case study

The Dog Fence FP is located on North Well Station near Kingoonya in the north west pastoral district of South Australia (31°05'S, 134°40'E). The Dog Fence is a term coined in Australia for the vermin-proof fence that separates the sheep and cattle pastoral lands of Southern Australia. It was built to prevent the wild dog or dingo (*Canis familiaris dingo*) from destroying stock in the sheep pastoral lands of the State. It has also been very effective for most of this century in keeping other large mammals (including kangaroos) on one or other side of the fence. Arcoordaby Station (as it was then known) was taken up in 1882 (Richardson, 1925) and the original vermin proof netting fence in this area was erected in 1901 just before the Station was abandoned; a fence containing Arcoordaby Paddock some 16 km to the east had already been erected in 1899. The only waterpoints between the two were Tunkillia Rockhole (large shallow holes for short periods of time), Tunkillia Well (which proved unviable), and Arcoordaby Rockhole (holding about 4000 gallons in a good season). No water was available to the west of the Dog Fence. The whole area remained ungrazed by stock until 1924 when the McBride family took up the Wilgena and North Well leases. The Dog Fence and Arcoordaby fence were repaired and new fences surrounding the Tunkillia Paddocks constructed in 1924. Again Tunkillia Well proved disappointing and a new well was sunk on the North/South Tunkillia Paddocks fence. The area between the two fences (now some 8 km wide) was not stocked with sheep. In about 1970 a pipeline from the Arcoordaby Wells was installed to the Tunkillia Paddocks and also into the newly fenced North and South Sandalwood Paddocks (Michael McBride, *pers. comm.*). The Dog Fence FP with its progressive subdivision and installation of waterpoints is illustrated in **Figure 7.7** and Page 214. This shows the configuration of the paddock in 1899 (no internal fences and scarce ephemeral water holes) and in 1994 (fully developed). A band of western myall woodland

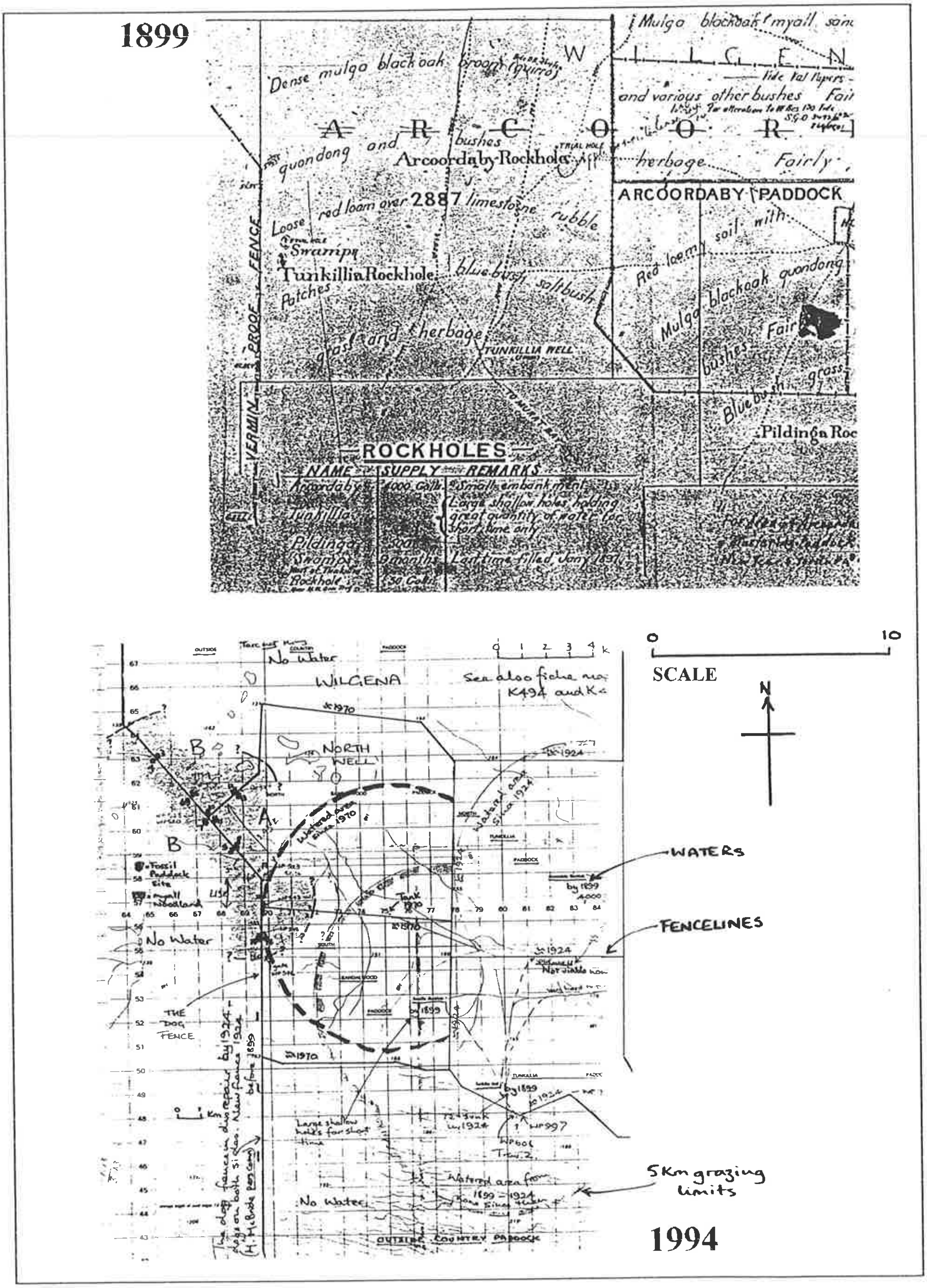


Figure 7.7: Historical Development of The Dog Fence "Fossil Paddock"

some 10 kilometres north to south straddles the Dog Fence; the east to west extent of this band is not known. Fifteen sites within this woodland were examined and western myall cohorts were scored at each site by the method described above; a total of 1512 trees were scored (**Table 7.5**); these are compared with the control site grazed continuously since 1919.

Table 7.5: Life Stages at fifteen sites in and around The Dog Fence FP and at three sites in the control paddock (located at Middleback Station)

LIFE STAGE	DOG FENCE - 15 SITES - NUMBER (AND PERCENTAGE) OF TREES	CONTROL - 3 SITES - NUMBER (AND PERCENTAGE) OF TREES
I	1 - (0.1%)	0 - (0.0%)
II	2 - (0.1%)	0 - (0.0%)
III	14 - (0.9%)	3 - (0.9%)
IV to IX	1495 - (98.9%)	328 - (99.1%)
TOTAL	1512 - (100%)	331 - (100%)

Few of the early century cohort were found on either side of the fence either inside or outside The Dog Fence "Fossil Paddock"; only 14 of the 1512 trees scored to Stage III. Only one and two trees respectively were found of Life Stage I and Life Stage II. Indeed, in the Dog Fence "Fossil Paddock" as a whole, few western myall were observed which could confidently be placed in Life Stages I, II or III. These results were similar to the control sites grazed since at least 1919. There also appeared to be no difference in the occurrence of the three youngest cohorts between the east and west side of the Dog Fence.

Evidence of rabbits was present at all sites and abundance varied from occasional to common; evidence of kangaroos was common to abundant on the eastern side of the Dog Fence but only occasional or absent on the western side; few sites showed the presence of sheep on either side of the fence. Thus, assuming significant numbers of the Life Stage III and Life Stage II cohorts germinated, it seems that most failed to persist in the Dog Fence FP even in the absence of sheep. Interestingly, they also failed to persist on the western side of the fence which has never been watered or grazed. That the Life Stage I cohort is missing on the eastern side of the fence could be attributed to the presence of sheep, at least at the southern sample sites, however, its absence from the ungrazed western side of the fence is not easily explained if sheep are the primary destroyers of western myall seedlings. Some other agent must have been responsible for the scarcity of these 20th century cohorts where sheep were absent, possibly rabbits or kangaroos. At the time of the survey rabbits were certainly plentiful on both sides of the fence. An examination of Landsat Imagery (Scale 1:100,000) clearly shows the effects of grazing on the eastern side of The Dog Fence north of Tunkillia fence. Why should this be so if no sheep have ever been present in this area? Preliminary dung counts taken on both sides of the Dog Fence reveal that grazing pressure visible from space may be due to the presence of high numbers of kangaroos.

7.3.3.4 *Tomato Rocks "Fossil Paddock" - a case study*

Named after the brilliantly ochre-red coloured granite inselberg in the south eastern corner of the paddock, Tomato Rocks FP is also located on North Well Station (30°57'S, 135°05'E). The perimeter fence was erected before 1899 and the only water was a rockhole at Tomato Rocks. All fences on North Well fell into disrepair between abandonment of the lease in 1899 and 1924 when the lease was taken up by the McBride family; no sheep were present during those years. In 1924 the perimeter fences were repaired and in 1927 the fence that divides the FP into Rentons and Tomato Rocks Paddocks was built (**Figure 7.8**); a pipeline carrying water from the north to a tank installed on the northern boundary was finished at the same time. **Figure 7.8** and Page 219 show the configuration of the paddock in 1899 (no internal fences and scarce ephemeral water holes) and in 1994 (fully developed). About one half of the paddock is western myall woodland; eight sites within this woodland were examined in which a total of 825 trees were scored (**Table 7.6**); these are compared with the control site grazed continuously since 1919.

Table 7.6: Life Stages at eight sites in Tomato Rocks FP and at three sites in the control paddock (located at Middleback Station)

LIFE STAGE	TOMATO ROCKS - 8 SITES - NUMBER (AND PERCENTAGE) OF TREES	CONTROL - 3 SITES - NUMBER (AND PERCENTAGE) OF TREES
I	160 - (19.4%)	0 - (0.0%)
II	5 - (0.6%)	0 - (0.0%)
III	19 - (2.3%)	3 - (0.9%)
IV to IX	643 - (77.7%)	328 - (99.1%)
TOTAL	827 - (100%)	331 - (100%)

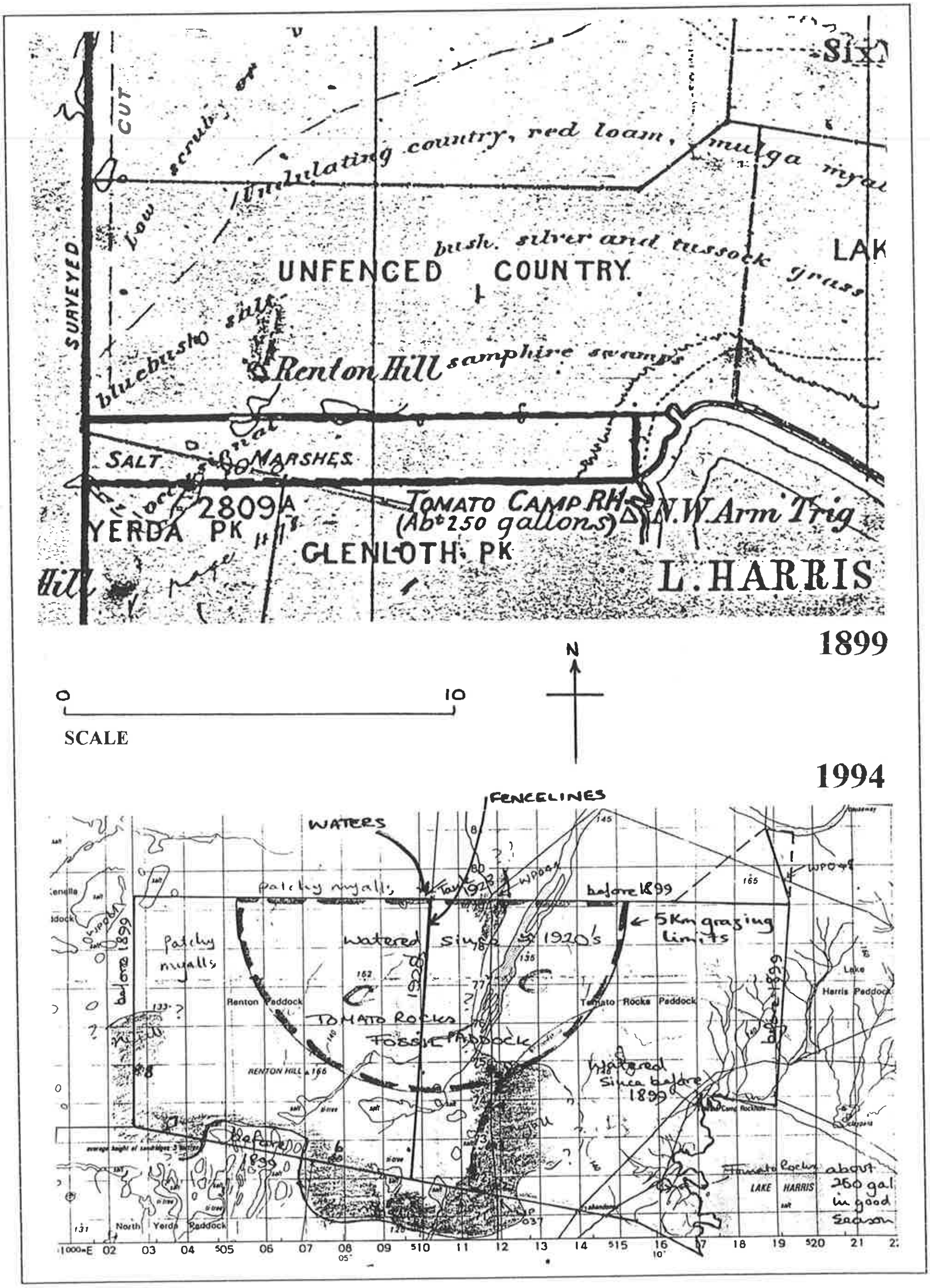


Figure 7.8: Historical Development of Tomato Rocks "Fossil Paddock"

The most obvious finding is the large amount of recruitment that has occurred in the latter part of this century in spite of the occasional to abundant presence of sheep and kangaroos at all sites where that recruitment occurred. Rabbits however, were not present at any of these sites. Sheep, kangaroos and rabbits were also common at sites where no recruitment occurred. Few of the earlier cohorts survived, however where they did, sheep were also present and rabbits were not.

The Life Stage I cohort appears to be composed of two distinct size groups. This may be a reflection of two recruitment events, one in 1973/74 and a further one in 1989. Large rainfall events were certainly recorded for these years at both Coondambo Station 70 km to the east and Tarcoola 60 km to the west.

7.3.4 RESULTS ACROSS THE STUDY AREA

Within any FP western myall trees were of quite similar age structure as expected. This was demonstrated by calculating χ^2 contingency tables for sites by life stages to ensure that there was a reasonable degree of uniformity across the populations of mature trees within each individual FP. The χ^2 analysis showed that the populations were remarkably uniform; 91% of all sites tested across the woodlands were similar within their own FP. Thus, differences in the three youngest life stages between sites within each FP were more likely to be caused by some external factor.

Results from the 18 FPs studied are shown in **Table 7.7** and the data are summarised in **Table 7.8** (the original count of trees for each FP is shown in **Appendix** 7). If a site was more than 5 km from water (i.e. sheep were absent from that part of the paddock at the time of recruitment and for about ten years thereafter) I have predicted that young western myalls of the relevant cohort will be present. Similarly, if a site was less than 5 km from water (i.e. sheep were present in that part of the paddock at the time of recruitment) I have predicted that young western myalls of the relevant cohorts will be absent. In some cases sheep were either present or absent in all parts of the paddock and these are noted in **Table 7.7**.

Table 7.7: Percentage of trees sampled in twentieth century cohorts of western myall in relation to predictions from the hypothesis that sheep will exterminate western myall seedlings (the cases which do not conform with the prediction are highlighted in ***bold italics***)

FOSSIL PADDOCK	**LIFE STAGE**	**PREDICTION - sheep *ABSENT* at time of recruitment based on historical records** Therefore expect western myall of these cohorts to be present (**yes** in Table 7.7)		**PREDICTION - sheep *PRESENT* at time of recruitment based on historical records** Therefore expect western myall of these cohorts to be absent (**no** in Table 7.7)	
		No. of sites	**No. of trees (% of total population)**	**No. of sites**	**No. of trees (% of total population)**
Beamish	I	7	40 (3.7%)	***3***	***28 (2.6%)***
"	II	9	9 (0.8%)	***1***	***1 (0.1%)***
"	III	***9***	***0 (0.0%)***	***1***	***1 (0.1%)***
Dog Fence	I	***10***	***0 (0.0%)***	***5***	***1 (0.1%)***
"	II[2]	15	2 (0.1%)	0	N/A
"	III[2]	15	14 (0.9%)	0	N/A
Durbridge's	I[2]	6	***0 (0.0%)***	0	N/A
"	II	***5***	***0 (0.0%)***	1	0 (0.0%)
"	III	***5***	***0 (0.0%)***	1	0 (0.0%)
Gap	I[1]	0	N/A	***10***	***44 (3.9%)***
"	II[1]	0	N/A	***10***	***8 (0.7%)***
"	III	5	5 (0.4%)	***5***	***3 (0.3%)***
Kowal	I	3	167 (15.7%)	***7***	***267 (25.2%)***
"	II	6	12 (1.1%)	4	0 (0.0%)
"	III	***9***	***0 (0.0%)***	1	0 (0.0%)
Lake	I[1]	0	N/A	***10***	***15 (1.4%)***
"	II	***3***	***0 (0.0%)***	***7***	***8 (0.7%)***
"	III	***5***	***0 (0.0%)***	5	0 (0.0%)
Low Hill North	I[1]	0	N/A	***10***	***23 (2.2%)***
"	II	8	17 (1.6%)	***2***	***1 (0.1%)***
"	III	8	115 (10.7%)	***2***	***1 (0.1%)***
Low Hill South	I	***1***	***0 (0.0%)***	***11***	***25 (2.0%)***
"	II	10	37 (3.0%)	2	0 (0.0%)
"	III	10	155 (12.2%)	2	0 (0.0%)
Moonlight	I[1]	0	N/A	10	0 (0.0%)
"	II	***6***	***0 (0.0%)***	4	0 (0.0%)
"	III	***6***	***0 (0.0%)***	***4***	***1 (0.1%)***
Mount Laura	I[1]	0	N/A	***10***	***1(0.1%)***
"	II	3	***0 (0.0%)***	7	0 (0.0%)
"	III[2]	10	7 (7.8%)	0	N/A
North Lochs	I	3	2 (0.2%)	***7***	***25 (2.3%)***
"	II	5	2 (0.4%)	5	0 (0.0%)
"	III	***5***	***0 (0.0%)***	5	0 (0.0%)
Outside Country	I	2	10 (0.8%)	***9***	***222 (18.3%)***
"	II	2	1 (0.1%)	***9***	***1 (0.1%)***
"	III	***8***	***0 (0.0%)***	3	0 (0.0%)
Sheridans	I	6	1 (0.1%)	***4***	***3 (0.3%)***
"	II[2]	10	2 (0.2%)	0	N/A
"	III[2]	10	20 (1.9%)	0	N/A
Soakage	I[1]	0	N/A	***13***	***28 (2.1%)***
"	II	***5***	***0 (0.0%)***	***8***	***21 (1.6%)***
"	III	***7***	***0 (0.0%)***	***6***	***13 (1.0%)***
Tomato Rocks	I	3	67 (8.1%)	***5***	***93 (11.2%)***
"	II	5	5 (0.6%)	3	0 (0.0%)
"	III	5	11 (1.3%)	***3***	***8 (1.0%)***

Table 7.7 continued overleaf

Table 7.7: (Continued)

White Cliffs	I[1]	0	N/A	10	0 (0.0%)
"	II	7	2 (0.3%)	3	0 (0.0%)
"	III	7	6 (0.8%)	***3***	***1 (0.3%)***
Whymlet	I[1]	0	N/A	***11***	***99 (9.3%)***
"	II[1]	0	N/A	***11***	***8 (0.8%)***
"	III	10	24 (2.2%)	***1***	***5 (0.5%)***
Winter	I[1]	0	N/A	10	0 (0.0%)
"	II[1]	0	N/A	10	0 (0.0%)
"	III[2]	10	6 (0.7%)	0	N/A

[1] Uncontrolled - sheep present in all parts of paddock

[2] Uncontrolled - sheep absent in all parts of paddock

The survival of each cohort in each FP is considered relative to prediction. In the summary **Table 7.8**, surviving cohorts are split between those comprising more than 5% and those comprising less than 5% of their particular populations; the 5% cut-off was arbitrarily chosen on the basis that chance events may mean that some small percentage of seedlings had been grazed or had survived. The numbers of recruits of each Life Stage found are shown as a percentage of the total population at all sites in the relevant part of the paddock and the exceptions to these predictions are shown in ***bold italics***.

Key findings from the 18 FPs (**Table 7.7**) show clearly cases where recruitment of cohorts was completely suppressed even when sheep were not present:

- Life Stage I in Durbridges, Dog Fence and Low Hill South FPs
- Life Stage II in Durbridge's, Lake, Moonlight, Mount Laura and Soakage FPs and
- Life Stage III in Beamish, Durbridge's, Kowal, Lake, Moonlight, North Lochs, Outside Country and Soakage FPs.

Table 7.7 also shows cases where western myall established in the presence of sheep:

- high percentages of Life Stage I in Kowal, Outside Country, Tomato Rocks and Whymlet FPs (low percentages of Life Stage I in Beamish, Dog Fence, Gap, Lake, Low Hill North, Low Hill South, Mount Laura, North Lochs, Sheridans, Soakage and Whymlet FPs)
- Life Stage II in Beamish, Gap, Lake, Low Hill North, Outside Country, Soakage and Whymlet FPs, and
- Life Stage III in Beamish, Gap, Low Hill North, Moonlight, Mount Laura, Soakage, Tomato Rocks, White Cliffs and Whymlet FPs

Table 7.8 summarises the information in **Table 7.7** regarding the survival of cohorts in the presence or absence of sheep. The similarity between the two data sets **(a)** and **(b)** in **Table 7.8** clearly shows that the neither the presence nor absence of sheep at the time of recruitment is a predictor of cohort survival.

Table 7.8: Survival of cohorts according to predictions (Note: the shaded areas of this table are the cases that do not conform to the predictions - these are highlighted in ***bold italics*** in **Table 7.7**)

(a) **SURVIVAL OF WESTERN MYALL COHORTS *ACCORDING TO PREDICTION* (absence of sheep i.e. > 5 km from water)**			**(b)** **SURVIVAL OF WESTERN MYALL COHORTS *CONTRARY TO PREDICTION* (presence of sheep i.e. < 5 km from water)**		
Number of cases with *surviving* cohorts		**Number of cohorts *not surviving***	**Number of cases with *surviving* cohorts**		**Number of cohorts *not surviving***
< 5% of population	**> 5% of population**		**< 5% of population**	**> 5% of population**	
21 (**Range:** cohort 0.1% to 4.4% of pop'n)	**5** (**Range:** cohort 13.5% to 52.4% of pop'n)	**16**	**25** (**Range:** cohort 0.1% to 4.4% of pop'n)	**4** (**Range:** cohort 8.8% to 36% of pop'n)	**18**

Abundance scores for sheep, rabbit and kangaroo dung at sites where there were more than 5 recruits are displayed in **Figure 7.9** and the raw data are contained in **Appendix 7.** It is assumed that the presence of rabbits now may indicate the presence of rabbits in earlier times when cohorts were establishing. There is good evidence for this which is presented in Section 7.4. From the graph in **Figure 7.9** it can be seen that evidence of rabbits was absent or only very occasionally present where recruitment had occurred. Evidence of the presence of sheep and kangaroos, on the other hand, ranged from none to abundant; sheep were always present to some degree at each of the sites and were in fact more frequently in evidence than were kangaroos. Conversely in **Figure 7.10** the data set shows that in sites with no young trees of Life Stages I, II and III rabbits were always present in numbers that ranged from abundant to occasional. Sheep and kangaroos were not always present; sheep were more likely to be common or occasional whereas kangaroos were more likely to be common.

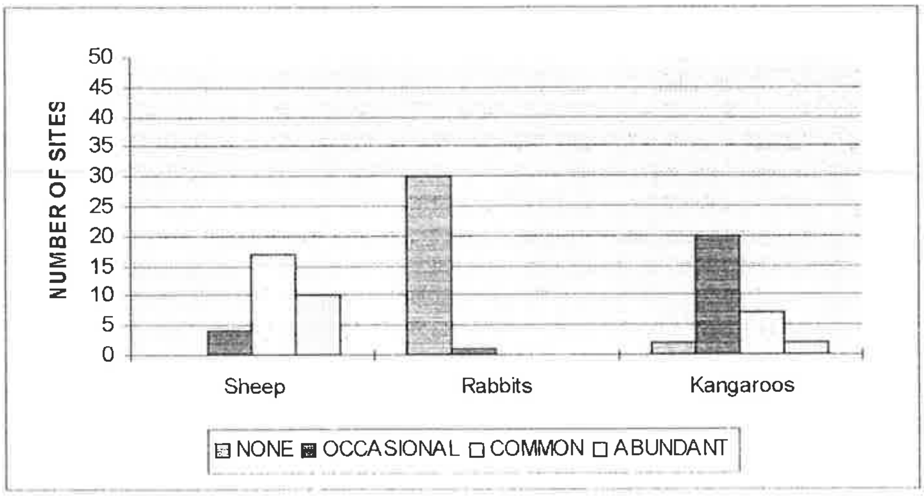


Figure 7.9: Abundance of the three major vertebrate herbivores at sites containing >5 young individuals

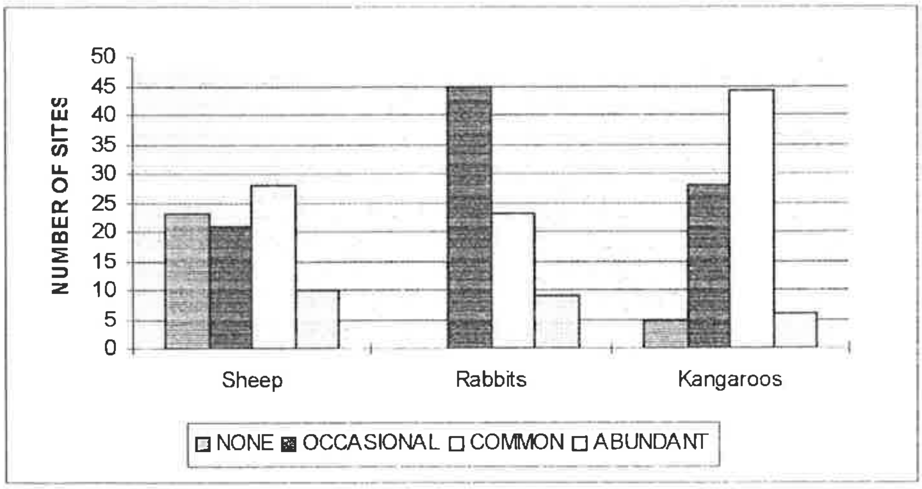


Figure 7.10: Abundance of the three major vertebrate herbivores at sites containing no young individuals

For all sites (**Table 7.9**), 3 x 2 χ^2 contingency tables were constructed for each herbivore - sheep, rabbits and kangaroos. The hypotheses were that the three major vertebrate herbivores (rabbits, sheep and kangaroos) were present or absent equally at sites with or without recruits. In the case of rabbits the χ^2 value was very large (101.36) implying that the expected frequencies did not reflect the presence or absence of rabbits equally at either type of site. In the case of sheep the χ^2 value was much smaller although still significant (14.50), implying that the expected frequencies also did not reflect the presence or absence of sheep equally at either type of site (although this was to a much lesser extent than the rabbit). In the case of kangaroos the χ^2 value was very small (0.60) implying that the expected frequencies may reflect the presence or absence of kangaroos equally at either type of site.

Table 7.9: Presence or absence of rabbits, sheep and kangaroos at sites containing more than five young western myall individuals (recruits) or no young individuals (recruits)

	RABBITS PRESENT	**RABBITS ABSENT**	**SHEEP PRESENT**	**SHEEP ABSENT**	**KANGAROOS PRESENT**	**KANGAROOS ABSENT**
>5 recruits present	3	37	41	0	39	2
<5 recruits present	27	10	27	10	35	1
No recruits present	93	6	58	23	78	5
χ^2	101.36		14.5		0.60	
p	highly significant at the 1% level		barely significant at the 1% level		not significant at the 1% level	

7.4 CONCLUSIONS AND DISCUSSION

Firstly, my evidence suggests that assuming there was significant germination (and this seems likely), the cohorts that should have recruited during the last 80-90 years whilst domestic stock progressively colonised the landscape are missing from many paddocks, even in areas where sheep did not graze. Jessup (1951) also observed that regeneration (of western myall) was equally poor in the unoccupied country west of the pastoral country that he worked in.. Secondly, my studies also indicate that recruitment is occurring in the presence of sheep. It seems unlikely then that sheep are suppressing western myall recruitment.

If this so, then what is suppressing recruitment? Assuming significant numbers of the various cohorts germinated in the FP's (and there is much anecdotal evidence to suggest this premise is reasonable), then something other than sheep has been suppressing them, probably rabbits, kangaroos or possibly desiccation (Section *4.2.1.2*).

Desiccation and insect attack are forms of death for which we have no covariate data and they may form ubiquitous and non-FP type patterns. Desiccation has certainly been implicated in the death of *Callitris glaucophylla* seedlings at Roxby Downs in South Australia (Read, 1995) and my model of western myall recruitment (Section 3.3) requires follow-up rains to promote onward growth in that species. It would seem reasonable then, that desiccation may be a factor in the suppression of western myall recruitment. Notwithstanding this, what does the data say about the other major herbivores, kangaroos and rabbits, neither of which are greatly affected by sheep fencing or regular placement of watering points?

There is no evidence that points strongly to kangaroos; they were present at many sites where recruitment had occurred. It is not known whether kangaroos eat western myall seedlings; however, they are less constrained than sheep by distance from water and they are present in much larger numbers now than before settlement (Wilson *et al.*, 1984; D.A. Nicolson and M.P. McBride *pers. comm.*). Assuming that the presence of kangaroos now may indicate their presence in the past, they were present both in areas where recruitment had taken place and also where it had not.

From the evidence accumulated to date, rabbits were certainly implicated as the primary predator of western myall seedlings; both currently and historically they were present where there was no recruitment and largely absent from areas where recruitment had occurred. Rabbits populate independently of watering points and they certainly eat western myall seedlings (CHAPTER 4 and Lange and Graham, 1983). They appeared to be mostly absent from sites where recruitment had occurred and they possibly were also absent at the time of recruitment (evidence for this was provided not only by the absence of dung but also by the absence of new or even old warrens from any of these sites). Conversely, rabbits were always present at sites where recruitment had not occurred (evidence provided by the presence of dung and or warrens, both new and old).

If rabbits are one of the major causes of suppression of recruitment in the western myall, then the effects of the recently released rabbit calicivirus on emerging populations of western myall must be closely monitored. It may be that this biological control agent has important implications for management of the western myall.

Finally a comment on the FP method itself as a tool for studying historical ecology. Deevey (1969) held that in experiments where time was needed to see results that there was no substitute for history. His exhortation to *"coax history to conduct experiments"* was and has been used by many researchers particularly in the field of palaeoecology. His approach was to regard historical disturbance whether through climate change or culture as a *"quasi-experimental"* way of placing stress on systems in order to infer the nature of their stability. Indeed, he further states that the only two significant sources of disturbance may have been climate change and culture and that it is also *"unexpectedly difficult"* to distinguish between those two sources.

In Britain, areas of land commonly regarded as natural landscapes are often a more complex product of growth and husbandry (Mabey, 1980). Most of the moorland of the Scottish Highlands was created by forest clearance some centuries ago, the southern chalk downs the product of intensive sheep grazing and ploughing and the waterways of the Norfolk Broads the remains of medieval open-cut peat mines now flooded.

The results in this Chapter indicate the usefulness of the "Fossil Paddock" idea and the historical ecology approach; it is an approach which should be widely applicable for discovering the responses of other long-lived perennials to the effects of herbivores in the arid zone.

CHAPTER 8

GENERAL DISCUSSION

8.1 INTRODUCTION

The western myall (*Acacia papyrocarpa* Benth.) is a characteristic and very attractive part of the landscape over its entire range. Although aspects of its biology and ecology had been well studied in the Whyalla area at the extreme south of its range, there had been no previous attempt to investigate the species over the rest of its range. This study was conceived to address various aspects of western myall recruitment, lifespan, distribution and the effects of major vertebrates on the species' ecology over the major part of its range in South Australia; findings are discussed in detail in the relevant sections of this thesis. From this we may be able to develop practical and appropriate management strategies for the maintenance of viable populations in the rangelands of Australia.

8.2 A REVIEW OF THE STUDY

This review will briefly summarise my work under four broad headings:

- Firstly, a study of the population dynamics of the species was done to assess the adequacy of net recruitment (seedling establishment less seedling losses); the focus of that study was on the various factors that eliminate seedlings.
- Secondly, studies were undertaken to gain an understanding of the lifespan of mature individuals as a prerequisite to estimating the rate of recruitment needed to maintain the populations and to formulating strategies for the management of the species.
- Thirdly, population structure was examined across the woodlands.
- Finally, the new concept of "fossil paddocks", was adopted to investigate the historical impact of introduced herbivores on the landscape.

8.2.1 RECRUITMENT CHARACTERISTICS

CHAPTER 3 examines an updated model of recruitment originally proposed by the author in 1992, discusses the role played by episodic events on recruitment and analyses the occurrence of recruitment across the study area and some of the variables that may affect it. The results of the analysis of recruitment across the study area show conclusively that in contrast to previous findings at the southern extreme of the species' range, recruitment of western myall does occur across the woodlands in South Australia. The rate of recruitment, however, varies quite markedly between north and south - in the north 31% of sites examined contained more than 10% of juvenile trees; in the central areas this number fell to 19% and at sites on the southern margins of the range the proportion of sites was only 2%. This finding is verified by similar results gleaned from other sources. These levels of recruitment can be compared with recruitment rates estimated to be required from observations of mortality discussed in Section 8.2.2. My study thus confirms a much more widespread pattern of recruitment across the woodlands than has previously been assumed. The association of western myall recruitment with the absence of rabbits and its apparent independence of the presence or absence of sheep is also an important finding and will be discussed in more detail in Section 8.4.

CHAPTER 4 takes another approach by examining the palatability of western myall seedlings and adult plants to both sheep and rabbits. Both herbivores have the potential to damage western myall populations by suppressing recruitment. The palatability experiments (Section 4.2) clearly show that western myall seedlings and the cut shoots of adult plants (probes) are palatable to both rabbits and sheep, however sheep show a clear preference for adult foliage over seedlings and will reject both (particularly seedlings) if other forage species are available. Rabbits appear not to discriminate between adult foliage and seedlings. From this I concluded that probes are an acceptable surrogate for seedlings in experiments with rabbits but may not be in experiments with sheep (results obtained from this type of experiment will be conservative). Although it is clear from this and other studies that rabbits can rapidly eliminate populations of seedlings it may be that the major impact of sheep is on juvenile plants with foliage more palatable than seedlings which can be consumed over long periods of time by both sheep and rabbits before eventually dying from stress (**Plate 8**).

8.2.2 LIFE SPAN

As stated before, the estimation of a life span for the species is critical to an understanding of population dynamics and trends over time. The three complementary methods used to assess the age of the oldest individuals - mortality studies, dendrochronology and radiocarbon dating - are examined in CHAPTER 5. The dendrochronology and radiocarbon studies are still very much in their infancy and only preliminary investigations are presented - Sections 5.3 and 5.4.

I have found that dendrochronology is a valid tool to use in the estimation of a life span for western myall and that the oldest age so far discovered by this method is about 350 years for a Life Stage VII specimen. The implication of this is that trees of Life Stage VIII and IX must be older and I propose a conservative life span for the species of at least 500 years (an possibly as high as 1,000 years) for the oldest specimens. A single radiocarbon date from another Life Stage VII specimen provided equivocal results.

Water myalls are more common in the central and northern areas and timber gatherers and fence post cutters have had a great effect on populations. My studies of natural mortality also revealed several interesting findings. Rates of mortality varied across the woodlands and were higher in the south than in the north. These rates also varied greatly within populations with a greater proportion of young trees dying in the south compared with the north. The study also enabled me to calculate the number of recruits that would be required at each recruitment event; in the south at least 11 recruits for every 100 adult trees in the population are required at each event whereas in the north the number required is only six. While these levels of recruitment are observed in some parts of the range, particularly in the north, it is clear that in many areas of the woodlands the required rate of recruitment is not being sustained.

8.2.3 POPULATION STRUCTURE

Drawing on all of the aspects of western myall distribution addressed in previous chapters, CHAPTER 6 takes up the theme of the biogeography of the species by examining temporal and spatial change and population structures across the woodlands. As an adjunct to this, a review of the possible impacts of historic climate change on the range of the species was undertaken.

The results of the population structure study show an aging population in the south of the study area with a younger, more vigorous, population to the north. Fluctuating climates during the late Pleistocene and Holocene periods have given all species of plants in arid Australia a chequered history. Huntley (1991) stated that *"The palaeoecological evidence of the response, especially of plants, to past climate change indicates that evolutionary adaptation has played no more than a minor role and that migration is the usual response of an organism to climate change"*. The woodlands we can see today can have been in existence for only about 10,000 years. I propose that in a long-lived species that recruits infrequently this is a very short time frame for full expansion from refugia out into all suitable habitats. Given the pattern of retreat and advance initiated by north-south migration of climatic belts, the populations may still be expanding northwards. This provides a possible explanation for the relative youth of the populations in the north of the species' range.

8.2.4 "FOSSIL PADDOCKS" AND THE HISTORICAL EFFECTS OF STOCK ON THE LANDSCAPE

In CHAPTER 7, the idea of the "Fossil Paddock" is presented - a new concept devised by me for discerning the effects of domestic stock on the landscape; it addresses the historical ecology of sheep grazing in the western myall woodlands. The concept is explained and the results of field testing are discussed.

Evidence from the study suggests that many cohorts of western myall that emerged this century are essentially missing even in the absence of sheep grazing. The study also indicates that recruitment has occurred in the presence of sheep. It would appear that something other than sheep have been suppressing recruitment in the populations. There is no evidence that points strongly to kangaroos, they were present at many sites where recruitment has occurred.

Desiccation may play an important role; evidence from other species of woody perennial show that this is a large factor in suppression of recruitment. Rabbits are certainly implicated; my study showed that they are present where no recruitment occurred in the past and largely absent where it has occurred.

The concept of "fossil paddocks" and the historical ecology approach has shown its usefulness in this study; it should be widely applicable for discovering the responses of other long-lived species to the effects of vertebrate herbivores in the arid zone.

In aggregate, the results of all these investigations tend to contradict the conventional view that the current pastoral sheep-grazing regime is unsustainable in the western myall woodlands. The occurrence of episodic events plays a major role in recruitment; this would be expected to cause significant patchiness in patterns of recruitment which could persist over centuries in the absence of intervention by pastoralism or feral herbivores. Rabbits, when present, remain a threat to both seedlings and juveniles, sheep on the other hand, whilst consuming both in small quantities, appear to have less of an impact on seedlings. Furthermore the species is responding differently in different parts of its range apparently caused by long-term biogeographic trends. A summary of current population structure is presented in **Table 8.1**.

Table 8.1: Population structure in the woodlands

REGION	POPULATION STRUCTURE
North	Lower mortality Younger trees High recruitment
Central	Medium mortality Mixture of ages High recruitment
South	Higher mortality Older trees Low recruitment

The fundamental aim of management of the western myall woodlands must be to maintain the populations by promoting the recruitment of enough individuals and by maximising the survival opportunities of adults. Are current management practices allowing this to happen?

8.3 ECOLOGICAL IMPLICATIONS AND MANAGEMENT STRATEGIES

Episodic rainfall inundations stimulate recruitment of new individuals to the western myall woodlands and this has been discussed in detail in Section 1.2.2. Desiccation on the other hand, most likely plays a role in suppressing the ultimate survival of those seedlings. In arid and semi-arid areas good follow up rains are crucial to ensure the successful onward growth of new seedlings. Brown (1985) found that death of young mulga in south west Queensland occurred after protracted droughts in the early 1980s and that grazing had little or no effect on death rates. Read (1995) found that rabbit grazing had no impact on *Callitris glaucophylla* recruitment. All his monitored seedlings died from desiccation within 18 months of germination despite above average rainfall. He concluded that successful recruitment in this species was dependent on extended periods of consistently above average rainfall. Similarly, in south-west Queensland, Johnston (1991) found that in spite of massive germination events, insolation, not grazing, was the major cause of death in recruits of white cypress pine; grazing had, however, stunted growth at all levels of grazing. He further stated that soil disturbance prior to seed fall gave increased germination. This has also been observed by others with regard to western myall recruitment (A.D. Nicolson, *pers. comm.*; Lay, 1972).

Is fire a major influence on western myall populations? Do western myall trees recruit preferentially in a “parent” patch? An hypothesis model for recruitment after fire emerged from observations made during my study. It is more likely that western myall seeds fall to a safe site under the canopy than out in the open. Fire kills the parent tree, litter burns, seed is scarified and germination is triggered by follow up rainfall. Onward growth is more effective under the canopy because of higher nutrient levels of nitrogen, phosphorous and organic carbon (Brock, 1993). Because of the patchy nature of the vegetation cover, burning is also patchy. Over time many parent trees are missed each time the country burns (Lay, 1976) and this is not surprising when the woodlands are viewed from above (**Plate 15**). Each tree or grove is surrounded by a "halo" of open ground virtually bare of ephemeral species. Gaps created by successive fire events are filled by recruits of that time (provided there is follow up rain of sufficient magnitude). Over hundreds of years this patchiness increases; most or all patches will burn at some time and some will burn several times resulting eventually in a mixed age woodland. Stands containing mostly very old trees (Life Stage VII, VIII and IX) may never have burned, those with life Stage IV or V may have burned more recently than those with Life Stage VI or VII. The question remains - is fire a major influence on recruitment in the western myall woodlands? Might it be the main influence on recruitment? Aboriginal patterns of fire have been much suppressed since the onset of pastoralism. It would appear that mass recruitment after fire would need to be accompanied by sufficient rain to promote germination and onward growth. Thus I hypothesise, fire may be a significant agent in recruitment and provide an alternate model of the recruitment process, however its primary impacts are a different method of seed scarification and a possible explanation for the structure of the mixed age woodland. A careful study of the effects of fire was, unfortunately, beyond the scope of this thesis.

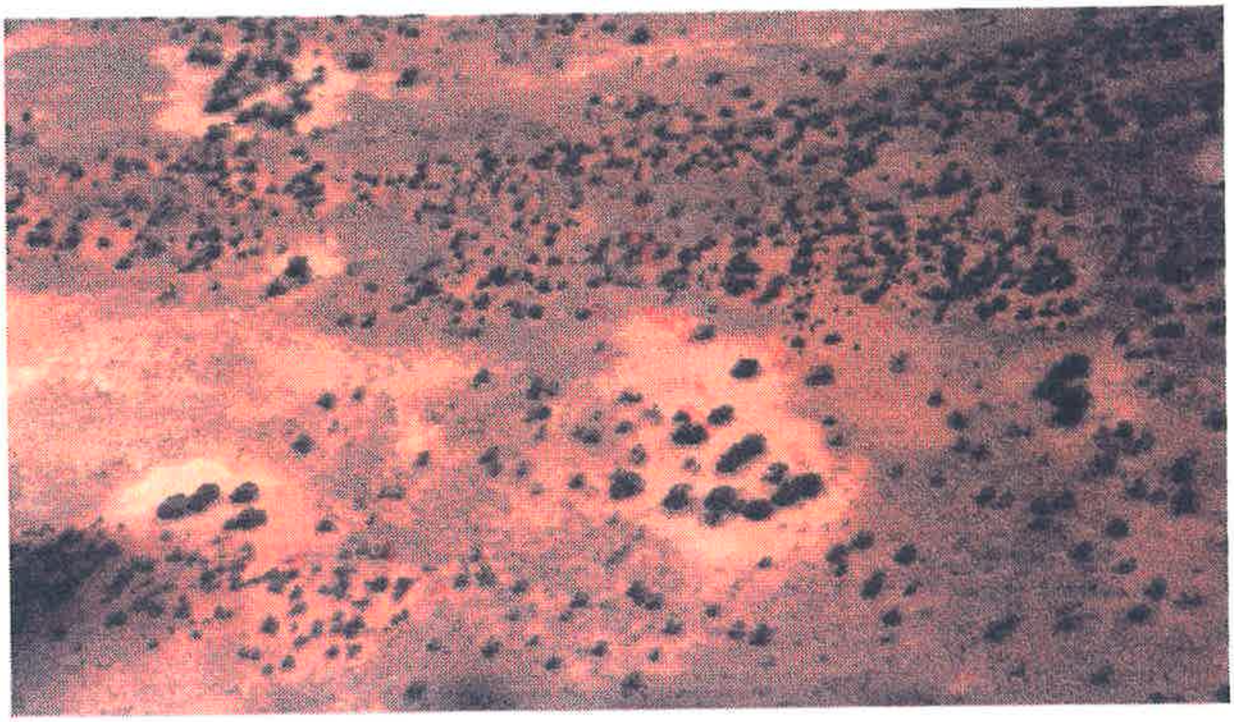


Plate 15: The woodlands from above. Western myall trees are surrounded by a bare "halo"

The occurrence of extreme rainfall events in successive years can also have very powerful effects on recruitment (Austin and Williams, 1988). These sequential events can initiate changes in the long-term population dynamics of a community which result in circumstances that are quite different to dynamics driven by rare individual rainfall events. Austin and Williams (1988) postulate that it was the interaction between climate events of these types, the historical impacts of cattle, sheep and rabbits and the myxoma epizootic that resulted in substantial recruitment of several different species in arid Western Australia, Queensland and the Northern Territory. A similar sequence of events may have occurred across the western myall woodlands driven by the two years of extremely heavy rainfall in 1973 and 1974.

The threat of recruitment suppression from other sources however, remains. Rabbits undoubtedly play a role. They populate country independently of watering points, certainly eat western myall seedlings, suppress growth in juveniles (**Plate 6)** and are currently not present where western myall has recruited in the past. More importantly, evidence of their presence was almost always apparent at sites where no recruitment occurred. When we look at the history of the rabbit in the South Australian arid zone we begin to understand the sorts of likely impacts that the species may have had on western myall recruitment. While it can only be speculative at best, a tentative history of rabbits and western myall recruitment in the Whyalla area has been constructed in **Table 8.2**. It remains to be seen whether the recent release of rabbit calicivirus has impacts on the next and subsequent recruitment events of the species.

Table 8.2: A history of the western myall, the rabbits and myxomatosis at Middleback

DATE	HISTORY
1880's	Rabbits arrived in the Middleback area
1893	Large rains, little if any recruitment of western myall
1919	Nicolson's purchased Middleback .Progressive fencing and watering of paddocks commenced
1921	Large rains, little if any recruitment of western myall
1946	Large rains, little if any recruitment of western myall
1955-6	Widespread rabbit death from myxomatosis
1961	Iron Baron road fenced and graded. Verges disturbed and often cleared up to fence. Recruitment of seedling myall on road verges due to accumulation of water in gutters. Few rabbits observed.
1972/73	Large rains, sparse and patchy recruitment of western myall. Rabbits beginning to build up again but not in such numbers as previously

Although it seems unlikely that sheep are the main culprits because so much recruitment is found where sheep commonly graze (**Plates 16** and **17**) they can have an effect on the ultimate survival of juveniles (**Plate 6**).

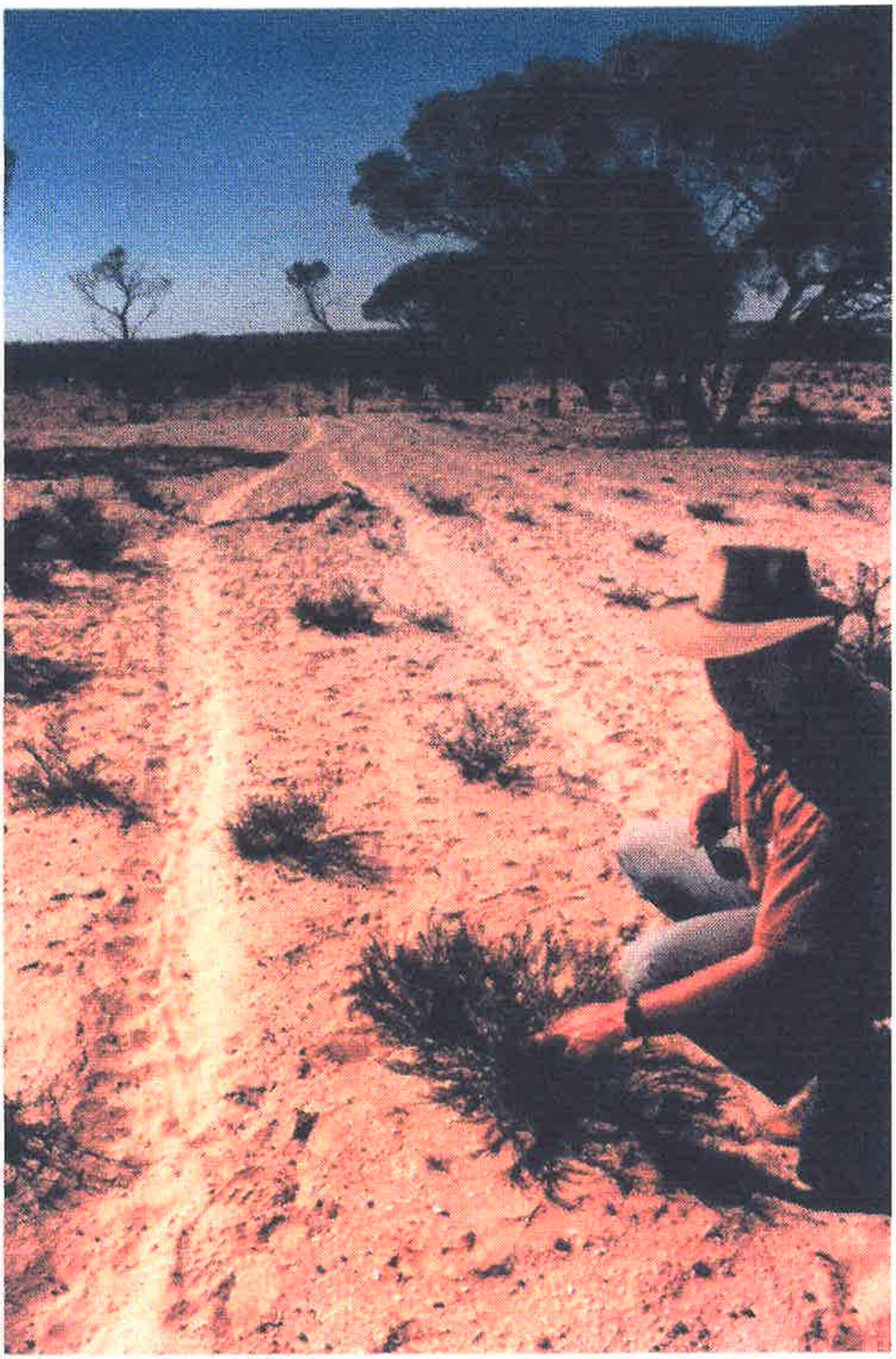


Plate 16: Recruits (aged about 10-20 years) located 700 m south of Moondiepitchnie Bore, Parakylia Station (note heavily used sheep tracks)

Plate 17: Recruits (aged between 25 and 50 years) located 400 m south of Majendie Dam (in background), Parakylia Station

A picture begins to emerge from this study of a species that is recruiting in the arid zone in spite of the impact of some vertebrate herbivores. This is however an over simplification of the facts. Whilst the species is recruiting well in some areas (and this rate of recruitment does vary both between and within populations across the range), mortality and life span studies show that in many areas not nearly enough recruits survive at each event in order to maintain the populations. What practical and appropriate management strategies can be developed for the maintenance of viable populations?

Management of plant species in the arid zone based on a regular annual cycle is clearly inappropriate due to the high variability of climatic conditions from year to year (Foran *et al.*, 1990). Episodic climate events (e.g. extreme rainfall events, follow up rains and insolation that may cause desiccation) and fire have an over-riding effect on the recruitment of new individuals to the populations; recruitment and onward growth is intermittent. These episodic rainfall events are often followed by the growth of a dense cover of ephemerals, which in turn sustain large increases in the rabbit populations and also wildfires (Friedel *et al.*, 1990). Management of both rabbits and wildfire after large rainfall events is critical to the survival of newly recruited perennial seedling populations. Western myall is no exception. The state and transition model of Westoby, Walker and Noy-Meir (1989) applies well to this method of management.

There are few management strategies that could be suggested to mitigate the effects of climate or wildfire. Similarly during the intervening or normal years referred to in the recruitment model (Section 3.3) there are few appropriate management strategies available. It is however, important not to remove litter or fallen logs which provide safe sites for seeds and thus promote consequent recruitment in the abnormal years of extreme rainfall events.

At Middleback, the most important forage shrub species have been able to recruit to their populations in the face of the stocking levels imposed by the pastoralists (Lange *et al.*, 1984) and this may also apply to tree species such as western myall across the woodlands. Several researchers have pointed out, however, that rabbits, over which the pastoralist has little control, are a major factor in the suppression of the perennial shrubs and non-forage trees such as *Acacia* and *Eremophila* spp. which are associated with the chenopod shrubland (Lange and Purdie, 1976; Crisp and Lange, 1976; Lange *et al.*, 1984). Control of rabbits is vital for the survival of perennial species in the arid zone.

Once recruitment occurs the opportunistic spelling of some paddocks from sheep grazing may assist in promoting onward growth of juveniles although as we have seen before, recruitment does occur in the presence of sheep. Protecting juveniles from continual defoliation by constructing tree-guards may also improve the chance of an individual surviving to maturity. However, this measure would not be successful unless the tree-guards were also rabbit proof. Both spelling paddocks and protection of juveniles would be costly to the pastoral community both in terms of lost production for the former and by increased capital and labour costs for the latter, however the erection of sheep and rabbit proof fencing around populations of established recruits until they assume heights that are out of reach of grazing would be cheaper and less labour intensive than erecting individual tree guards. Although recruitment rates that have occurred in the past century are not adequate to maintain the populations, it is apparent that western myall recruitment can occur under the current sheep stocking rates in the absence of rabbits. Stocking rates as determined from time to time by the Pastoral Board of South Australia and most recently during the recent assessment process should therefore remain at the current conservative levels if western myall is to be conserved. Whether rates of recruitment would be higher in the absence of sheep is not known; the precautionary principle should thus prevail and no attempt should be made by the Pastoral Board to raise the current stocking rates. The removal of pastoralism at its current rates of stocking would not obviously improve the situation for western myall.

An active program of rabbit control, either biologically (through the release of the myxoma or calici viruses), mechanically (warren destruction) or by a combination of the two would obviously have a large and possibly devastating impact on the populations of rabbits in the western myall woodlands. This in turn would have a very beneficial effect on the survival not only of western myall seedlings but also on the juveniles that are continually defoliated by rabbits. It remains to be seen whether the current release of the rabbit calicivirus has the desired effect of destroying rabbit populations. Even reduced numbers such as those that followed the introduction of myxomatosis would provide benefits for western myall. Whatever the results of the calicivirus release, a comprehensive follow-up program of warren ripping should be implemented to destroy the rabbits' refuges.

8.4 OPPORTUNITIES FOR FUTURE RESEARCH

While my research has been conducted over a large and I believe, fairly representative portion of the western myall woodlands of southern Australia, care should be taken when extrapolating the results to other areas such as Western Australia; the species inhabits a highly variable and unpredictable environment. As such the results and trends reported here may not represent the situation in parts of the woodlands not studied for this thesis. Furthermore, research is needed in other aspects of the species biology and ecology.

Ongoing studies about the western myall are currently being undertaken by myself and other researchers. In Section 1.2.1 a long-term flowering study is described. I intend to collect data for at least ten years; the first report will be made in 2001. Dr. Des Coleman and I are undertaking an expanded and enlarged study on the dendrochronology of the species as discussed in CHAPTER 5.

At the smaller scale of stands of trees within populations the western myall woodlands are very distinctive, particularly when viewed from the air (**Plate 15**). With the exception of work undertaken by Brock (1993) the influence of western myall on plant community structure has not been investigated. This aspect has been investigated for other arid zone species such as *Acacia tortillis* and *Adansonia digitaria* (baobab) by Belsky (1992). Patch dynamics in isolated savanna trees has been looked at by Belsky and Canham (1994) and many studies have been conducted on patterns observed in other desert perennials (Grieg-Smith and Chadwick, 1965; Barbour, 1969; Anderson, 1971; Belsky, 1989; Joffre and Rambal, 1993). I suggest that a study of both "halos" and the patterning of trees and groves in the landscape would constitute an interesting study.

The effects of fire on western myall populations also warrants further investigation. Although rare in the chenopod shrublands that form the understorey for this vegetation assemblage, high levels of herbage do grow after good rains and provide adequate fuel to carry fires. Even rare fires may be common enough to influence western myall population dynamics. What effect does this fire have on the populations other than killing the adult trees (Lay, 1976) and scarifying seeds (Section 3.4 and 8.3)?

As reported in Section 6.2.3 there are large areas of soils which Jessup (1951) suggested were suitable for western myall to the north and west of current populations. A study of the actual suitability of these soils to western myall may add to my hypothesis that the woodlands are still expanding out from refugia established thousands of years ago.

Studies of the chemical bases, not only for the variation in palatability already observed between trees that may be of varying genetic provenance (touched on in Section 4.2.2.3), but also for the differences noted between seedlings and juvenile trees could be undertaken.

Increased levels of harvester ants in the arid zone since European settlement (Andersen, 1990) may also have a major effect on reducing the successful recruitment in the western myall (Ireland, 1992), and possibly other perennials. I suggest that a study into the effects of pastoral herbivore species on the ant fauna of the woodlands needs to be undertaken.
Other areas of further research are also suggested in **Table 1.1**. Examples are the palatability of seedlings and adults to kangaroos, ecopysiology studies, pollination ecology and genetics of the species.

The Pastoral Management Branch data base referred to earlier in Section 3.5 contains (along with the simple presence/absence data for western myall and its recruitment) many other environmental variables. An analysis of these data, whilst time consuming, may provide more insight into the patchy recruitment of the species.

This study has attempted to answer some of the questions about the ecology of western myall populations in order to make practical and appropriate suggestions for the long-term survival of the species. Given some of the findings of this study some management strategies can be implemented immediately. The rabbit calici virus has finally been officially released and is spreading through the woodlands with increasingly devastating effects on the rabbit populations. However, we will have to wait for another large-scale recruitment event to ascertain what effect this potential lack of rabbits actually has on recruitment success. After such a time, another "fossil paddock" study will be particularly revealing.

APPENDIX 1: PASTORAL LEASES IN THE KINGOONYA AND GAWLER RANGES SOIL CONSERVATION DISTRICTS

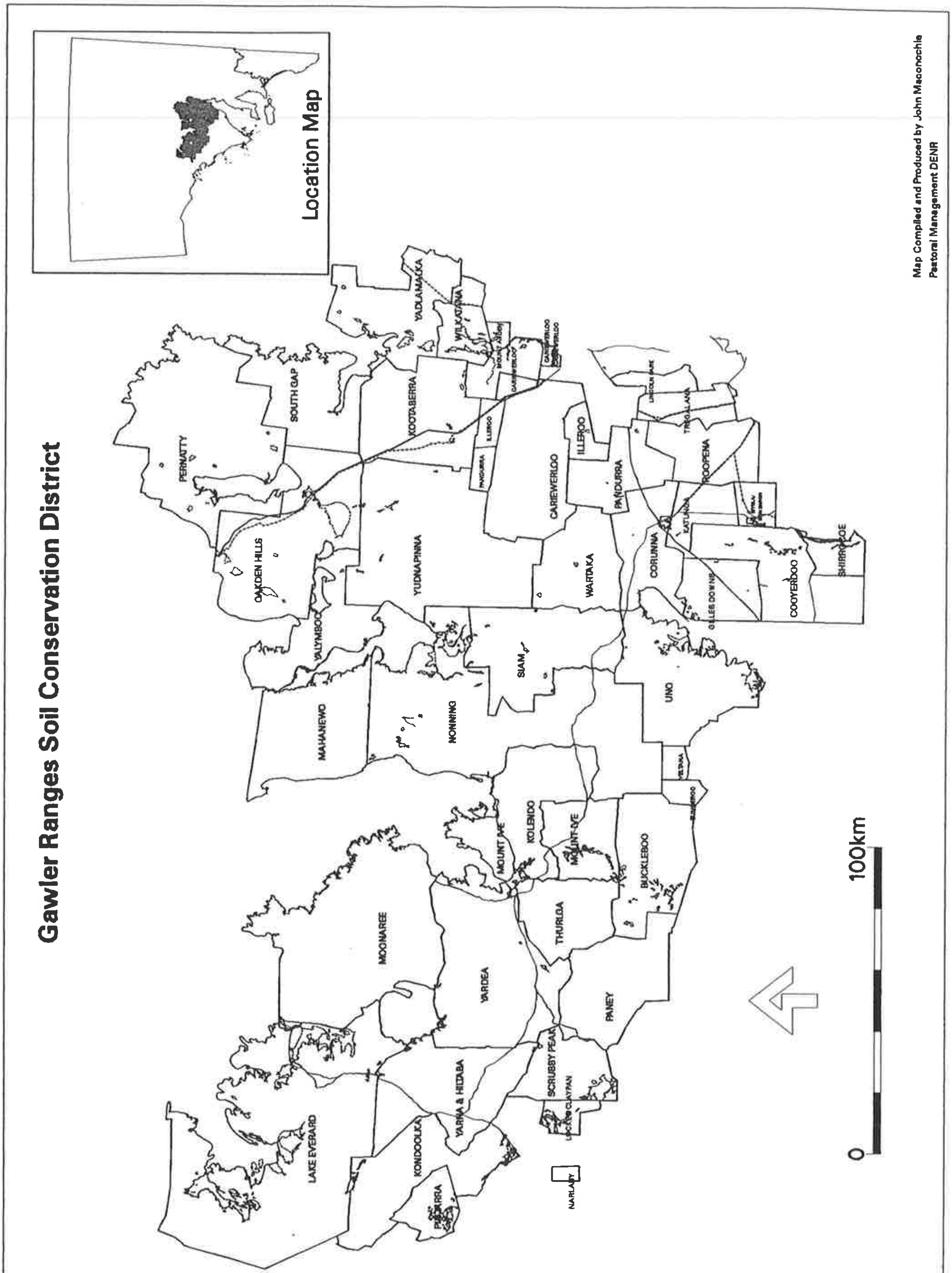
GAWLER RANGES SOIL CONSERVATION DISTRICT

Buckleboo
Cariewerloo
Cooyerdoo
Corruna
Giles Downs
Illeroo
Katunga
Kolendo
Kondoolka
Kootaberra
Lake Everard
Lincoln Park
Lockes Claypan
Mahanewo
Moonaree
Mount Arden
Mount Ive
Myola
Part Narlaby
Nonning
Oakden Hills
Pandurra and Myall Creek
Paney
Pernatty
Pinjarra
Roopena and Middleback
Scrubby Peak
Shirrocoe
Siam
South Gap
Thurlga
Tregalana
Uno
Wartaka
Wilkatana
Yadlamalka
Yalymboo
Yardea
Yarna and Hiltaba
Yeltana
Yudnapinna

KINGOONYA SOIL CONSERVATION DISTRICT

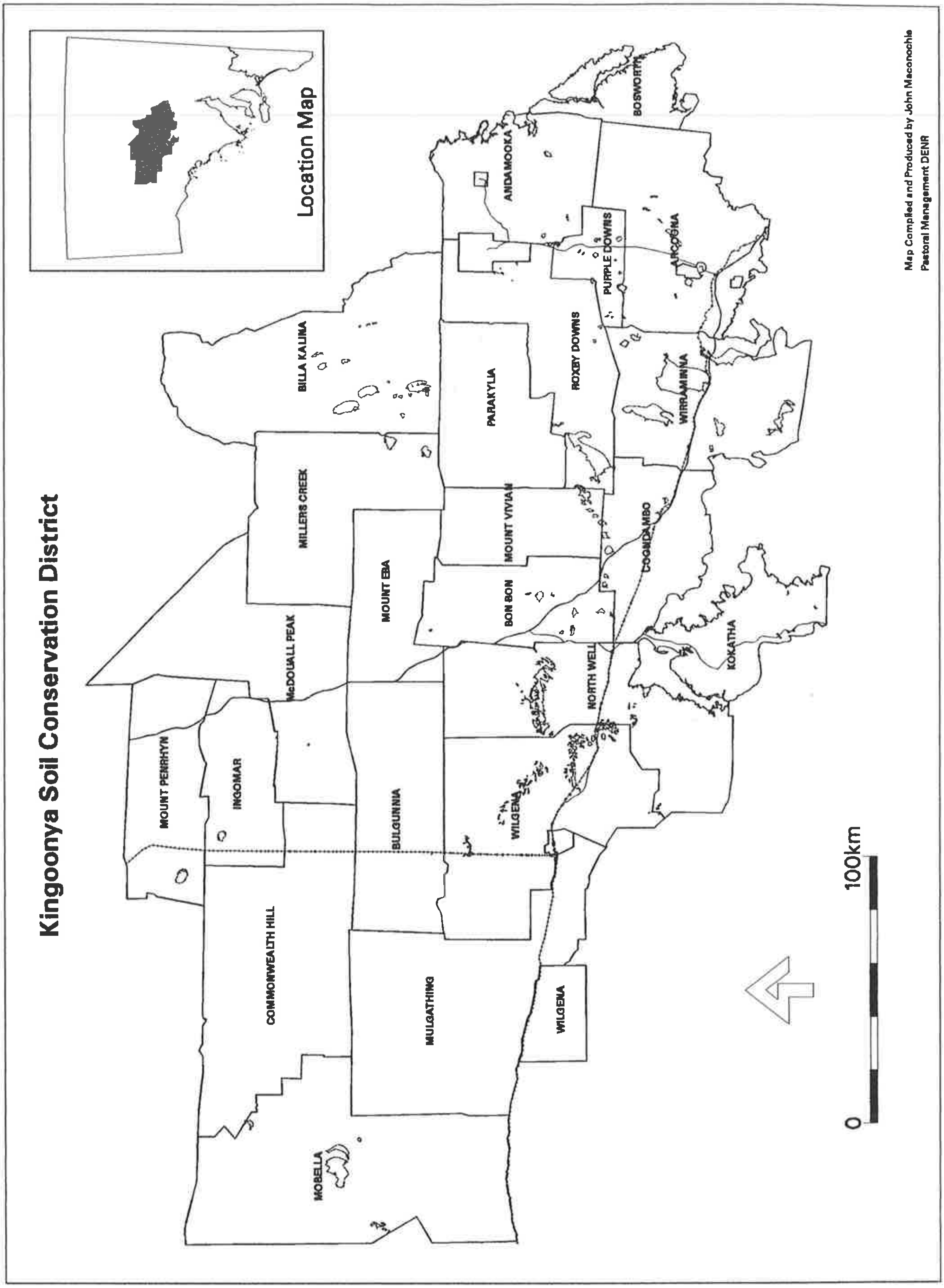
Andamooka
Arcoona
Billa Kalina
Bon Bon
Bosworth
Bulgunnia
Commonwealth Hill
Coondambo
Ingomar
Kokatha
McDouall Peak
Millers Creek
Mobella
Mount Eba
Mount Penrhyn
Mount Vivian
Mulgathing
North Well
Parakylia
Purple Downs
Roxby Downs
Wilgena
Wirraminna

APPENDIX 1: PASTORAL LEASES IN THE KINGOONYA AND GAWLER RANGES SOIL CONSERVATION DISTRICTS



Map Compiled and Produced by John Maconochie
Pastoral Management DENR

APPENDIX 1: PASTORAL LEASES IN THE KINGOONYA AND GAWLER RANGES SOIL CONSERVATION DISTRICTS



APPENDIX 2: GEOLOGY, LANDFORMS AND LAND SYSTEMS OF THE STUDY AREA

GEOLOGY[1] AND LANDFORMS

The southern part of the study area is dominated by the 1600 million year old Gawler Range Volcanics, which outcrop as rounded rocky hills. Outliers of these volcanics are also found further north in the study area. The Corunna Conglomerate is of about the same age as the Gawler Range Volcanics and forms the Corunna and Uno Ranges. The Hiltaba Granite intruded into the volcanics a few million years later. Fracture zones which formed in a criss-cross pattern in the volcanics have eroded to form the flat floored valleys typical of the Gawler Ranges landform.

Older sedimentary, metamorphic, volcanic and igneous rocks (formed between 2640 and 1600 million years ago) that underlie the volcanics are exposed as hills to the south and south east (e.g. The Middleback Ranges) and as a large number of low rocky rises and hills to the north of the Gawler Ranges into the Kingoonya District. A few outcrops of iron formation (e.g. Wilgena Hill) near Tarcoola are remnants of a younger sedimentary phase. Granite was intruded into these older rocks north of the Gawler Ranges about 1700 million years ago. Near Tarcoola and Kingoonya a number of low quartzite ranges dating to 1660 million years ago are are found.

Younger rocks are mostly sediments; the red sandstone of the Pandurra Formation was deposited by erosion of the Gawler Range Volcanics along their eastern margin. Prominent flat topped mesas at the south east and eastern margins of the study area are remnants of the flat-lying Adelaidian sandstone, siltsone and shale formed 750-650 million years ago. These rocks are also seen as the base of a west-tilted plateau stretching from Lake Hanson to Lake Torrens, capped by Andamooka Limestone and shale, about 550 million years old. Together these rocks correlate with those that later formed the Flinders Ranges.

In the low-lying area north of Lake Gairdner deposition of sediments resumed about 150 million years ago in the Eromanga Basin; included in these sediments are the river-deposited Algebuckina Sandstone, a marginal marine sandstone and siltstone and finally the marine mudstone of the Bulldog Shale. Throughout their occurrence in the study area these sediments have been bleached by a weathering event 65 million years ago.

Since that time the rocks have remained mostly undisturbed, weathering, slow erosion and subsequent deposition being the only significant processes that have taken place. Most of these younger sediments are less than 2 million years old and have been deposited in increasingly arid conditions in three major environments as follows:

- Aprons of reddish gravel, sand silt and clay were deposited around most of the outcrops of older rocks.
- Salt lakes containing gypsum-rich and salty sand, silt and clay formed in the lower lying areas.

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[1] This description was summarised from information supplied by Mines and Energy of South Australia

- To the west and north of the study area during the last Northern Hemisphere glacial episode around 18,000 years ago, sand blown in from areas to the west formed longitudinal sand dune fields and sand spreads.

LAND SYSTEMS

Areas of land that reflect recurring patterns of topography, soils and vegetation are referred to as land systems; a change in this pattern determines the boundary of a land system (Christian and Stewart, 1953 and 1964). Land systems are described as a useful way of dividing the landscape into logical groups. Each of these land systems is made up of a number of closely related land units (uniform areas of vegetation, soil type and landform). Boundaries are based in visual recognition of recurring patterns on air photos and satellite imagery combined with geology and topographic maps; these boundaries are then checked in the field (Paul Gould *pers. comm.*). Maps and lists of the dominant overstorey and understorey plant species and soil types which typify each of the land systems for the KSCD and for the GRSCD are reproduced in this **Appendix**. Land systems that contain western myall are listed in the following table.

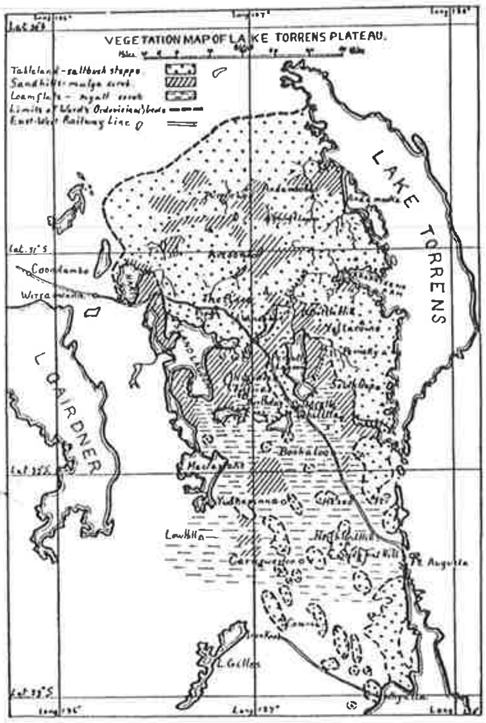
LAND SYSTEMS CONTAINING WESTERN MYALL

LANDFORM	LAND SYSTEM	DESCRIPTION
PLAINS	• **Gl** - Glendambo	Calcareous earthy sands and rises with western myall and mulga open woodland over pearl bluebush and bladder saltbush shrubland; the western myall overstorey is absent on heavier soils
	• **Ya** - Yarna	Black oak or western myall open woodlands with pearl bluebush, bladder saltbush, spiny goosefoor and Australian boxthorn in the shrub layer
	• **Ho** - Horseshoe	Western myall woodland over blackbush and bladder saltbush; mixed chenopod shrubland
	• **Pp** - Peter Pan	Mallee woodland; western myall woodland; bladder and bitter saltbush shrubland
	• **Pt** - Peterlumbo	Mixed woodland of western myall/mallee and black oak
	• **Rp** - Roopena	Bluebush/saltbush shrubland and saltbush plains; commonly with scattered western myall, blackbush and samphires
SAND PLAINS	• **Be** - Beacon	Western myall woodland over pearl bluebush and daisy bluebush; dunes with horse mulga and mallee tall shrubland
	• **He** - Hesso	Western myall/sugarwood woodland over pearl bluebush and bladder saltbush
	• **Jd** - Jungle Dam	Mixed woodland with dense mid-storey of cassia and pinbush wattle
	• **Yk** - Yorkey	Mixed woodland on dunes; interdunes with bladder saltbush/black bush and samphire with scattered western myall
DUNE FIELDS	• **Ro** - Roxby	Dunes with northern cypress pine, mulga and horse mulga open woodlands; swales with bladder saltbush and Sturt's pigface; calcareous plains and rises with western myall overstorey and pearl bluebush, low bluebush and bladder saltbush shrub layer; canegrass and lignum swamps
	• **Wa** - Waulalumbo	Dunes with open woodland of northern cypress pine, red mallee, mulga and horse mulga with speargrass understorey; swales with open woodland of western myall, mulga and black oak; skeletal soils with mulga and Tarcoola wattle scrub
UPLANDS	• **Bo** - Bowen	Bladder saltbush/samphire shrubland; scattered mulga and western myall over pearl bluebush shrubland; plain with low bluebush/bladder saltbush
	• **Eb** - Ebunbannie	Hills with skeletal soils and mulga scrub with Tarcoola wattle, dead finish and porcupine grass; valley plains with western myall open woodlands and bladder saltbush and low bluebush and black bluebush
	• **Lo** - Lookout	Plains with calcareous soils supporting chenopod low shrubland with pearl bluebush, bladder saltbush, spiny goosefoot and silvertails; western myall and low bluebush occur on rises
DRAINAGE AREAS	• **Ac** - Acraman	Salt lakes fringed by chenopod shrubland and black oak/western myall woodland

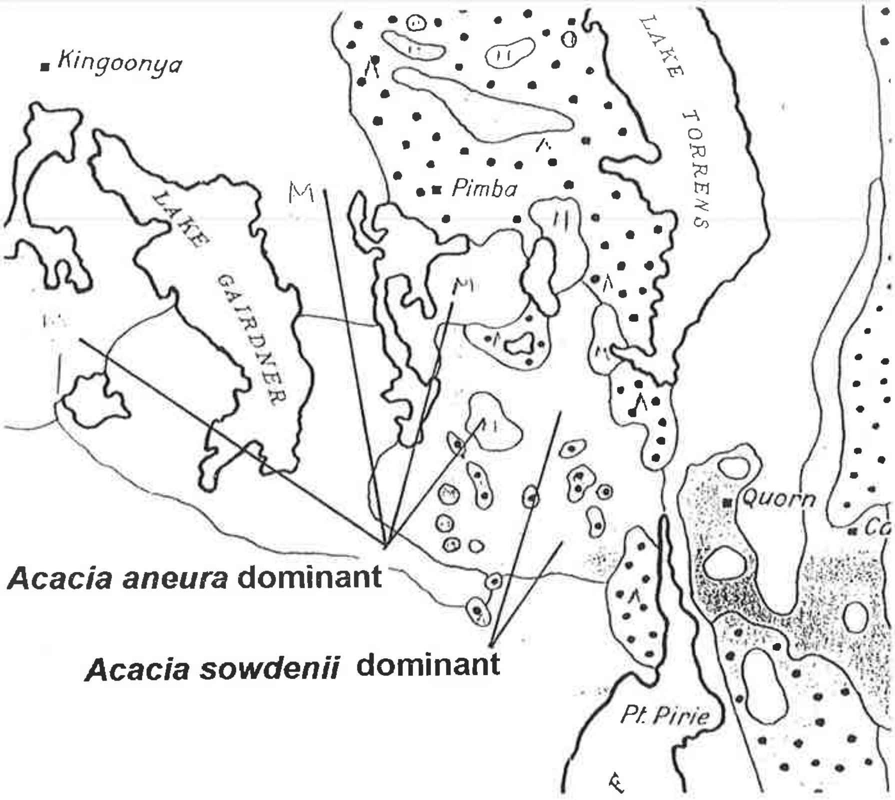
APPENDIX 3: DISTRIBUTION SURVEYS OF WESTERN MYALL

Author	Year	Method	Area
Murray	1931	Field surveys	Lake Torrens Plateau
Wood	1937	Field surveys	South Australia
Crocker and Skewes	1941	Aerial surveys	Yudnapinna Station
Crocker	1946	Field differentiation of major communities combined with survey diagrams	Northern Eyre Peninsula
Crocker and Wood	1947	Not known	North West Pastoral
Jessup**	1951	Field surveys along tracks	Kingoonya Soil Conservation District
Lay**	1972	Field surveys along tracks	Kingoonya Soil Conservation District
Specht	1972	Literature survey and other existing information and	South Australia
Nature Conservation Society of South Australia	1972	Field Survey	Gawler Ranges
Beard	1975	Air photos and field surveys	Nullarbor Mapsheet, Western Australia
Laut *et al.*	1977a	LANDSAT imagery	Eyre Peninsula
Laut *et al.***	1977b	LANDSAT imagery	Western Pastoral
Laut *et al.***	1977c	LANDSAT imagery	Northern Arid
Hnatiuk and Maslin	1980	Herbarium specimens	Western Australia
Boomsma and Lewis	1980	Not known	South Australia
Boomsma	1981	Not known	South Australia
Maslin and Hopper	1982	Herbarium specimens	Australia
Maslin and Pedley	1982	Herbarium specimens	Western Australia
McKenzie and Robinson**	1987	Field surveys	Nullarbor Region
Mitchell. McCarthy and Hacker	1988	Air photos and field surveys	Part of Nullarbor region in Western Australia
Robinson *et al.***	1988	Field surveys and herbarium specimens	Gawler Ranges
Simmons	1988	From existing information	Australia
Young**	1988	From existing information	Far west coast
Beard	1990	Field survey and aerial photography	Western Australia
Commonwealth of Australia	1990	Landsat imagery and existing information	Australia
Whibley and Simon**	1992	Herbarium specimens	South Australia
Copley and Kemper**	1993	Field surveys	Yellabinna Region
Mitchell and Wilcox	1994	From existing information	Western Australia
Biological Survey and Research, DENR**	1996	From existing information	South Australia
Maconochie and Lay**	1996	Field surveys along tracks	Kingoonya Soil Conservation District

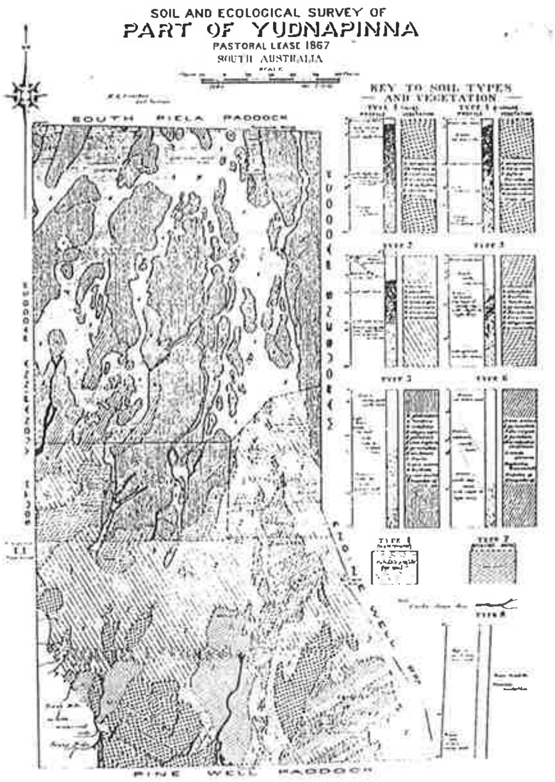
Note: All studies in South Australia unless otherwise stated.
**Surveys incorporated in Figure 2.4



Murray (1931)



Wood (1937)



Crocker and Skewes (1941)

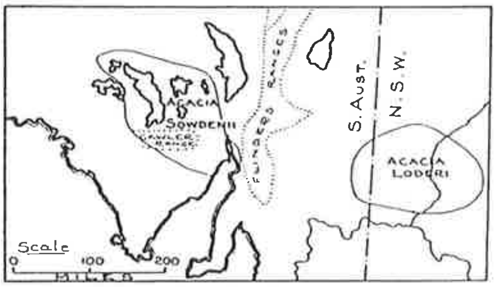
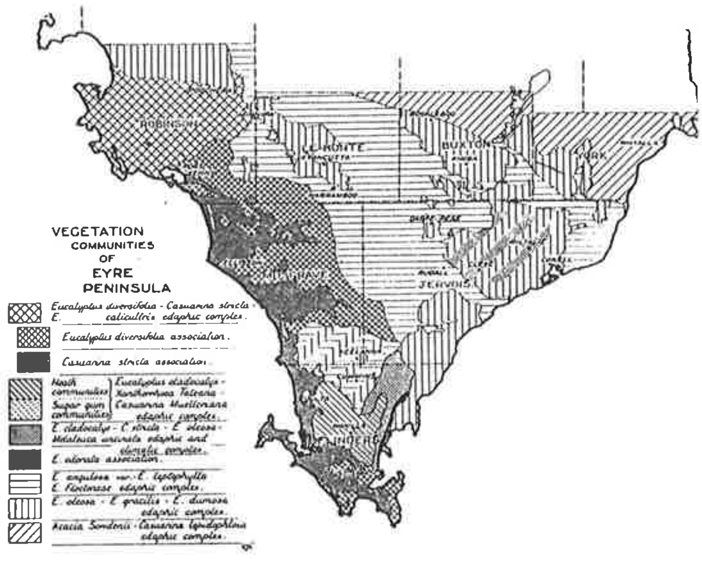
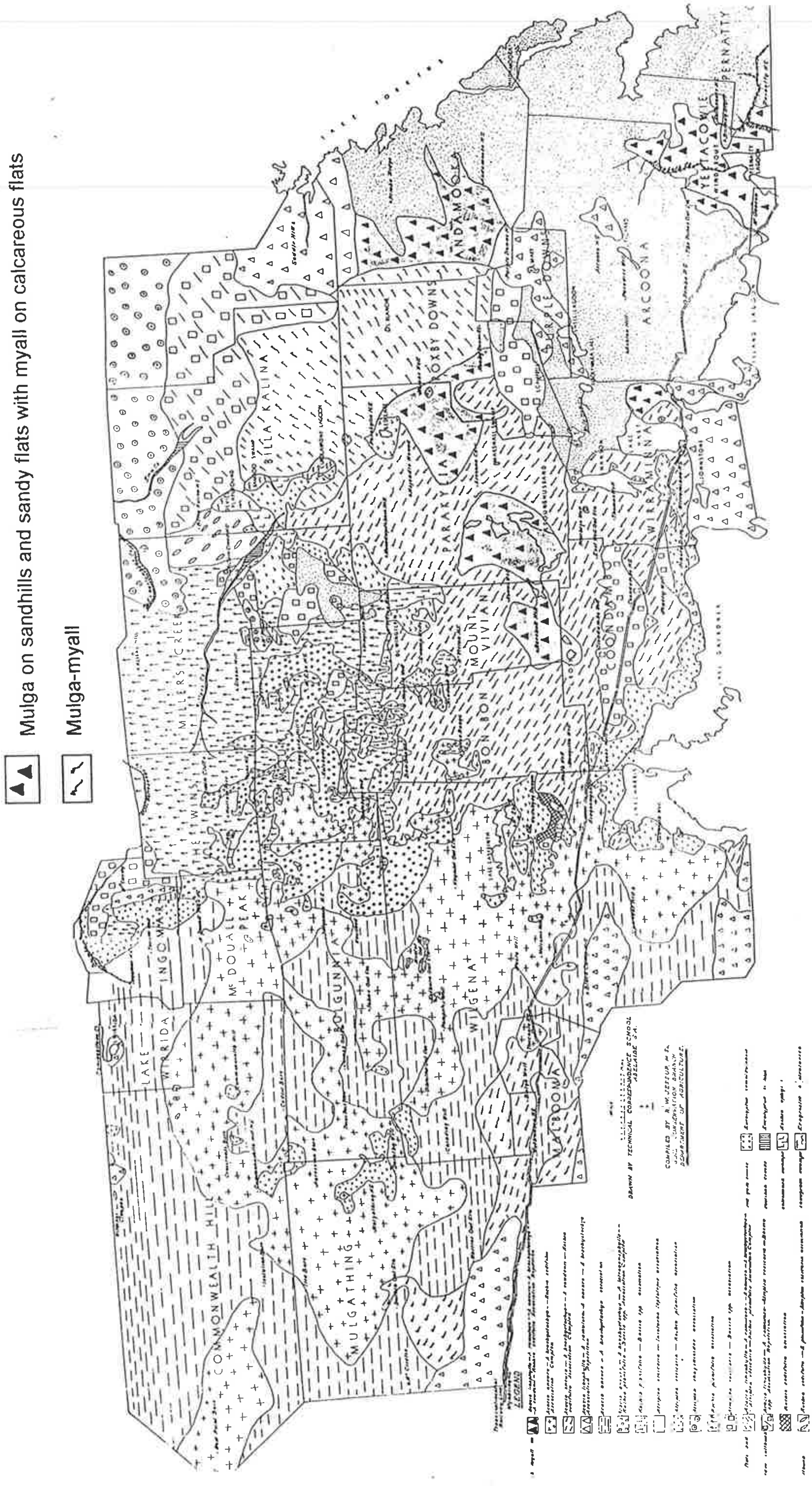


Fig. 11
The disjunction between the vicarious species *Acacia Sowdenii* and *Acacia Loderi*.

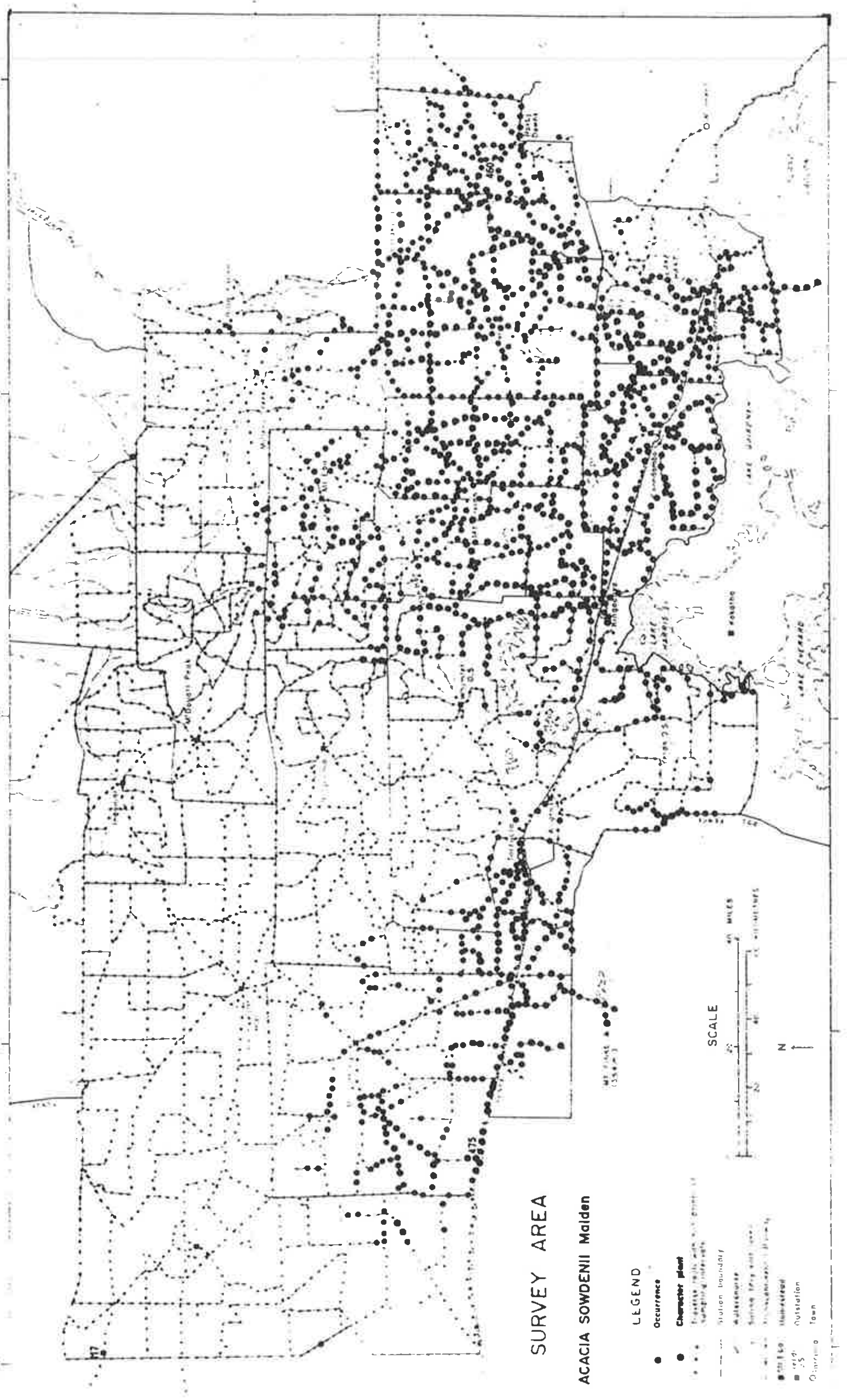
Crocker and Wood (1947)



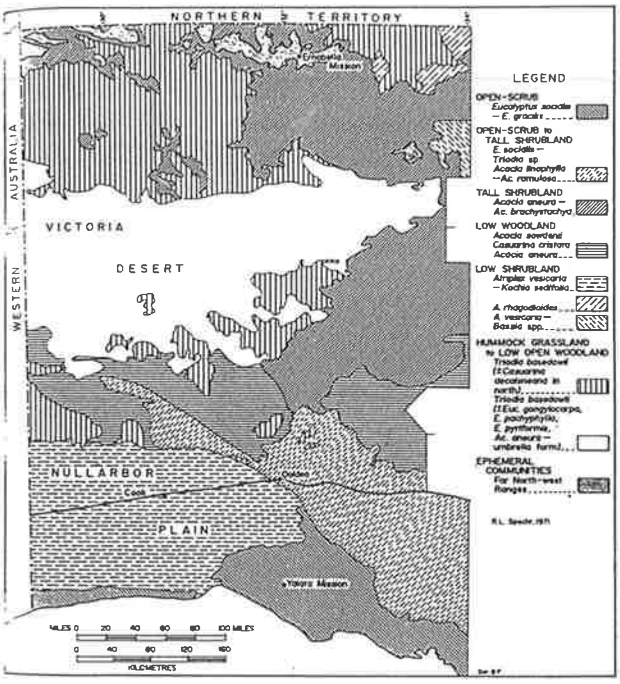
Crocker (1946)


Mulga on sandhills and sandy flats with myall on calcareous flats
Mulga-myall
COMMONWEALTH HILL
LAKE WIRRIDA
INGOMAR
McDOUALL PEAK
THE TWINS
MILLERS CREEK
MULGATHING
BOIGUNDA
WILGENA
MALBOOMA
BON BON
MOUNT VIVIAN
COONDAMBO
PARAKYLIA
BILLA KALINA
ROXBY DOWNS
PURPLE DOWNS
ANDAMOOKA
ARCOONA
WIRRAMINNA
YELTACOWIE
PERNATTY
LEGEND
DRAWN BY TECHNICAL CORRESPONDENCE SCHOOL ADELAIDE S.A.
COMPILED BY R.W. JESSUP M.Sc. SOIL CONSERVATION BRANCH DEPARTMENT OF AGRICULTURE

Jessup (1951)


SURVEY AREA
ACACIA SOWDENII Maiden
LEGEND
Occurrence
Character plant
Station boundary
Watercourse
Homestead
Outstation
Town
SCALE
MILES
N

Lay (1972)



Specht (1972)

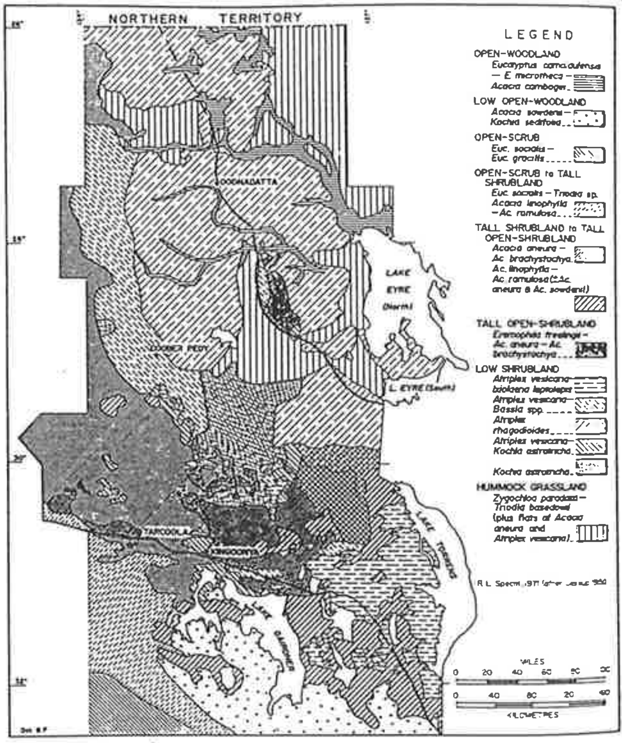
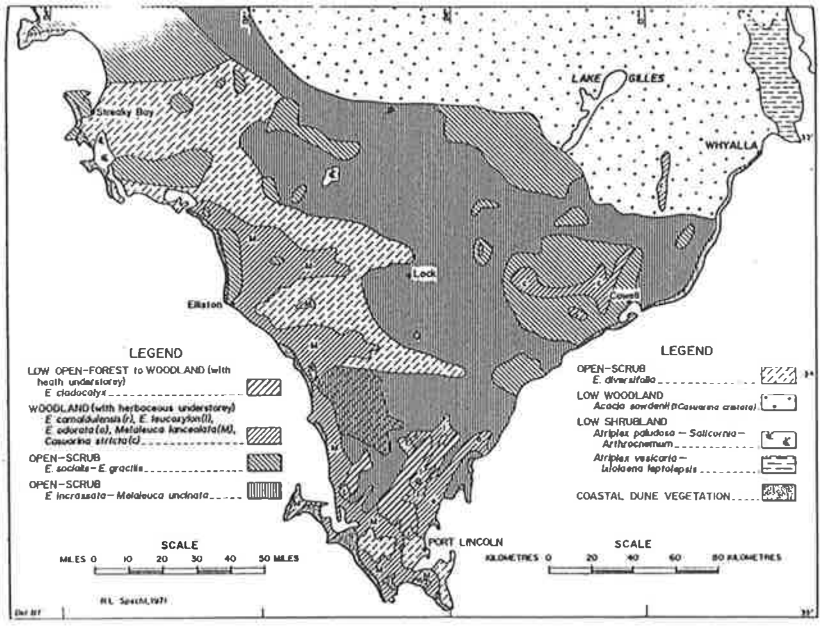
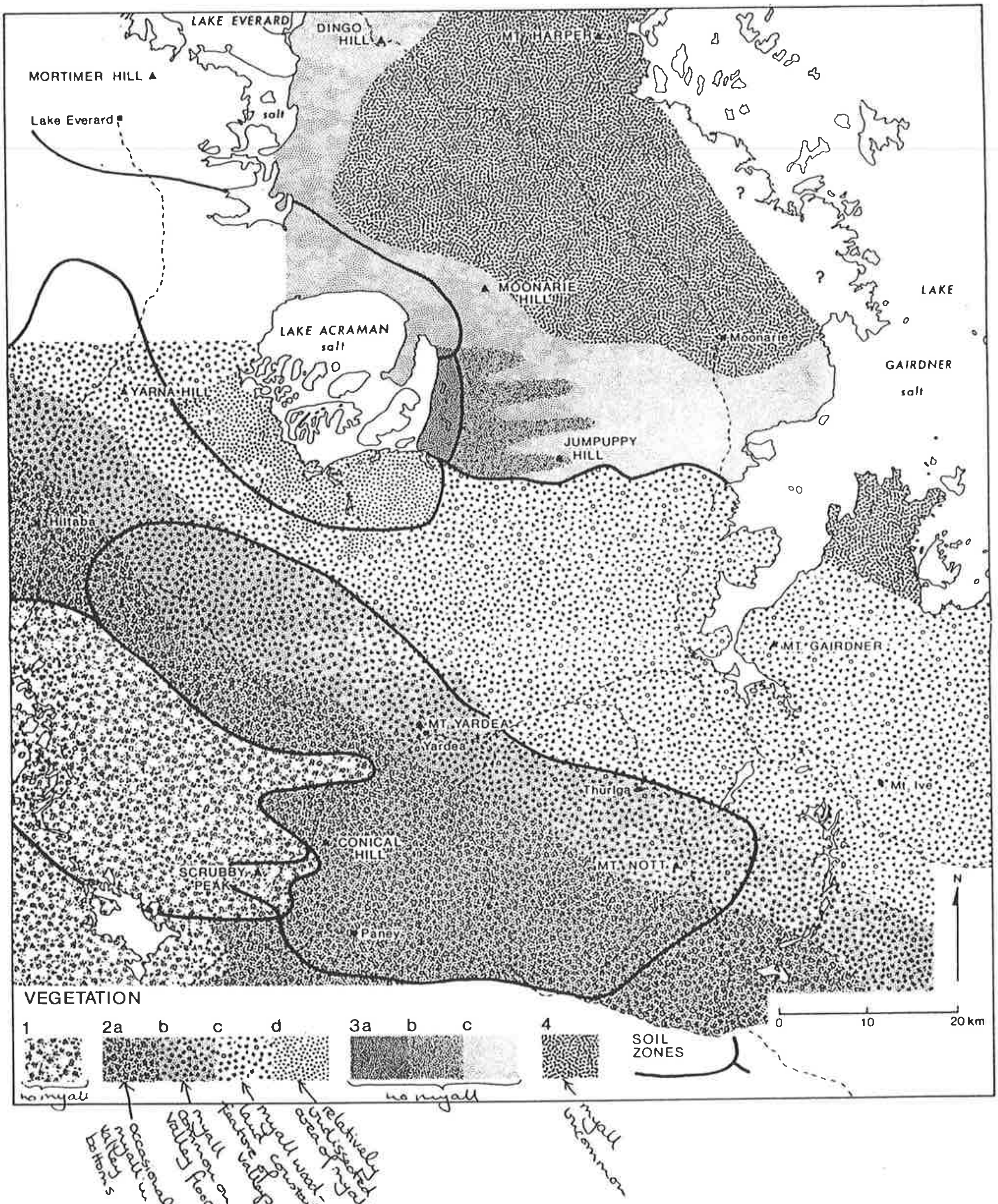


Figure 121. Vegetation map of North-Western South Australia. (Based on Jessup 1951; supplemented with information from Crocker 1946b; Crocker and Skewes 1941; Jackson 1958; Murray 1931; Northcote *et al.* 1968; Perry 1962; and R. W. Rogers, pers. comm. for the area south of the East-West Railway.)

Specht (1972)



Specht (1972)



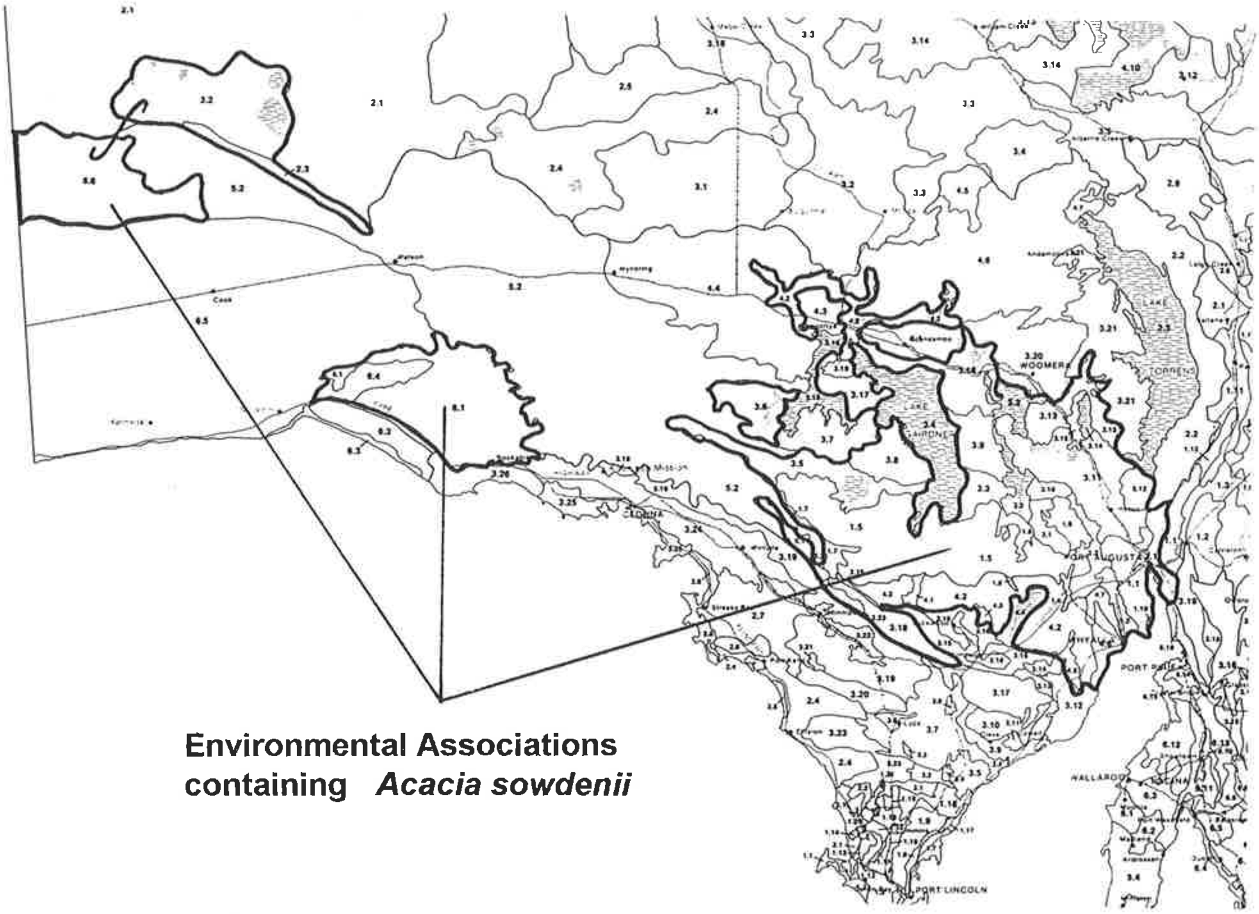
Map 3. The vegetation zones of the study-area. The heavy lines indicate the boundaries of the soil zones nominated on map 4. Note the correspondence between the topographic zones shown on map 1 and the distribution of soils and vegetation.

Nature Conservation Society of South Australia (1972)

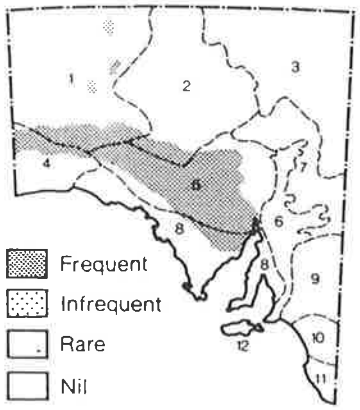
Maps too large to reproduce

Please see reference for details

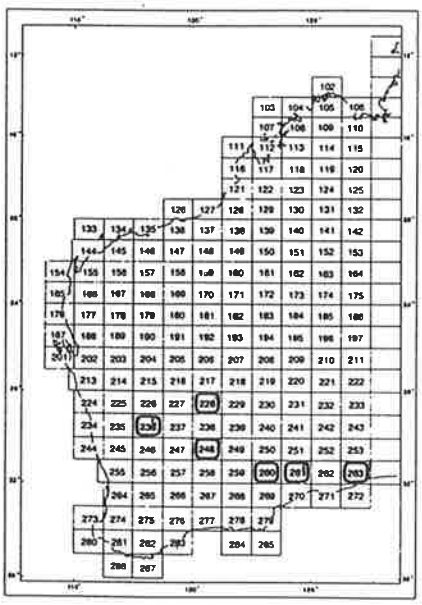
Beard (1975)



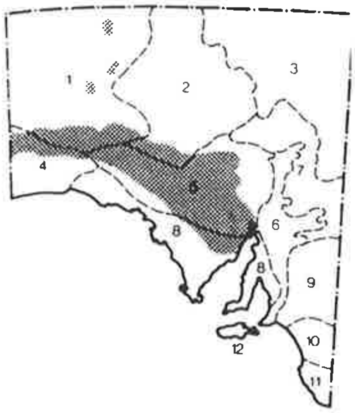
Laut *et al.* (1977)



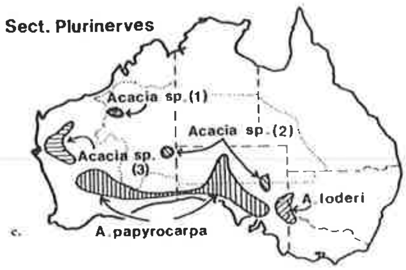
Boomsma and Lewis (1980)



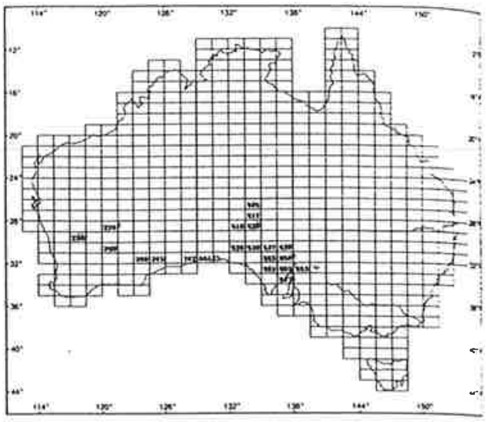
Hnatiuk and Maslin (1980)



Boomsma (1981)



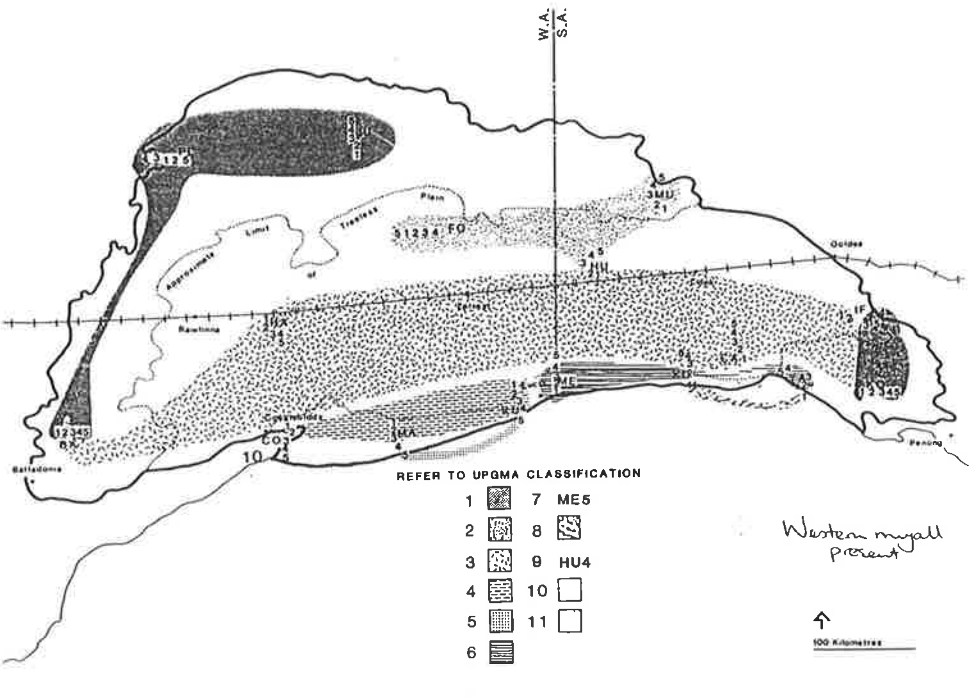
Maslin and Hopper (1982)



A. papyrocarpa Benth.

Maslin and Pedley (1982)

Figure 34
GEOGRAPHICAL INTERPRETATION OF PERENNIAL PLANT SPECIES QUADRAT GROUPS (UPGMA) ACROSS THE NULLARBOR STUDY AREA



Western myall present

UPGMA CLASSIFICATION - Groups with western myall ***(Acacia papyrocarpa)***

2: Western myall woodlands and the treeless plain interface with the northern myall woodlands of the Carlisle Plain
4: Southern low western myall, melaleuca or mallee woodlands of western coastal sites on the Hampton tableland
6: Southern coastal western myall or mallee woodlands of South Australia

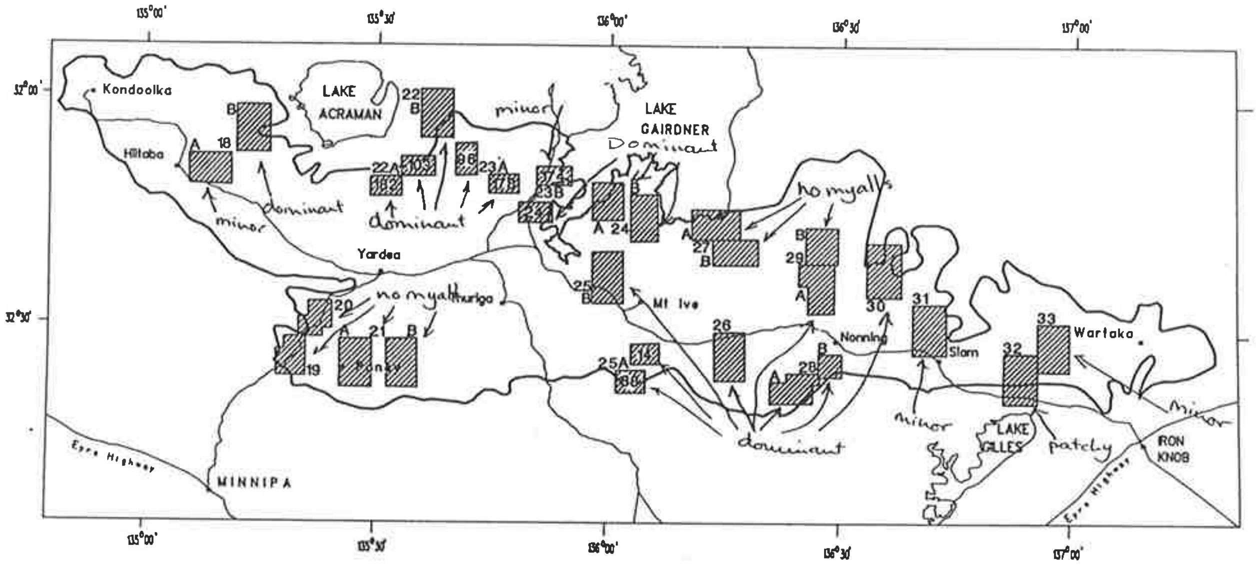
McKenzie and Robinson (1987)

Maps too large to reproduce

Please see reference for details

Mitchell, McCarthy and Hacker (1988)

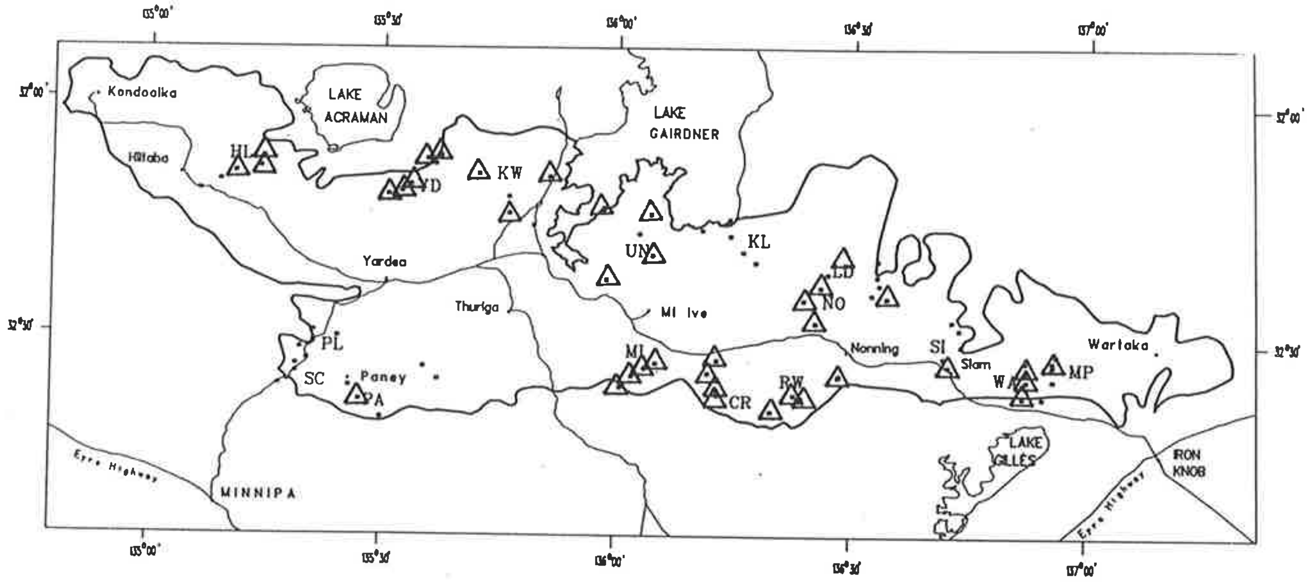
Simmons (1988)



Enlargement of study area ▨

(All enlargements from 1: 40 000 Aerial Photos)

Robinson *et al.* (1988)



CAMPSITES with western myall △

SC	Scrubby Peak
PA	Paney
YD	Yardea
KW	Kowerida
UN	Unalla
MI	Mt. Ive
CR	Coralbignie
RW	Rockwater
LD	Larry Dam
SI	Siam
WA	Wartaka
MP	Mac Paddock
HL	Hiltaba
PL	Pine Lodge
KL	Kolendo
NO	Nonning

0 km 50

Robinson *et al.* (1988)

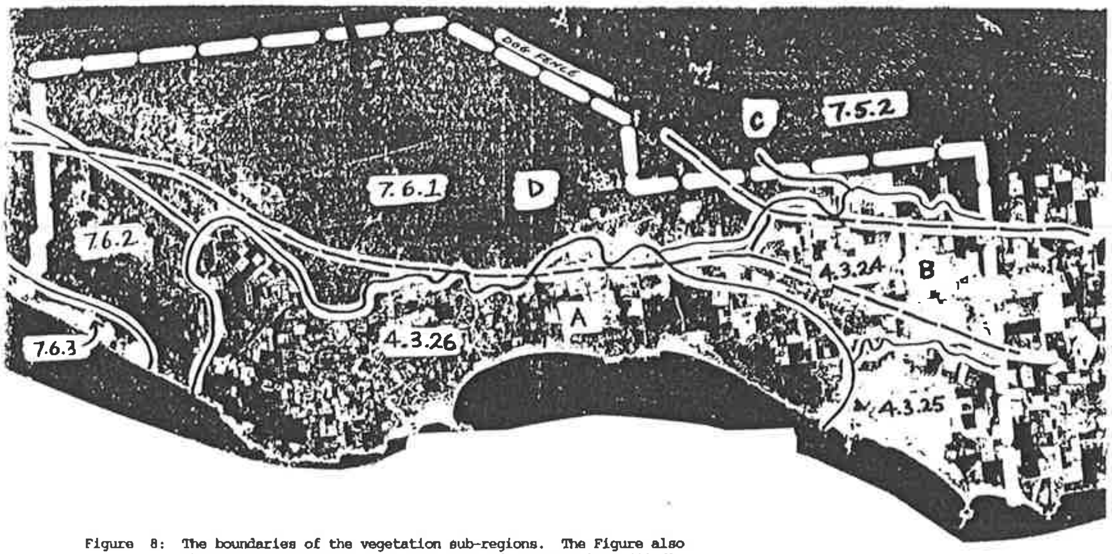
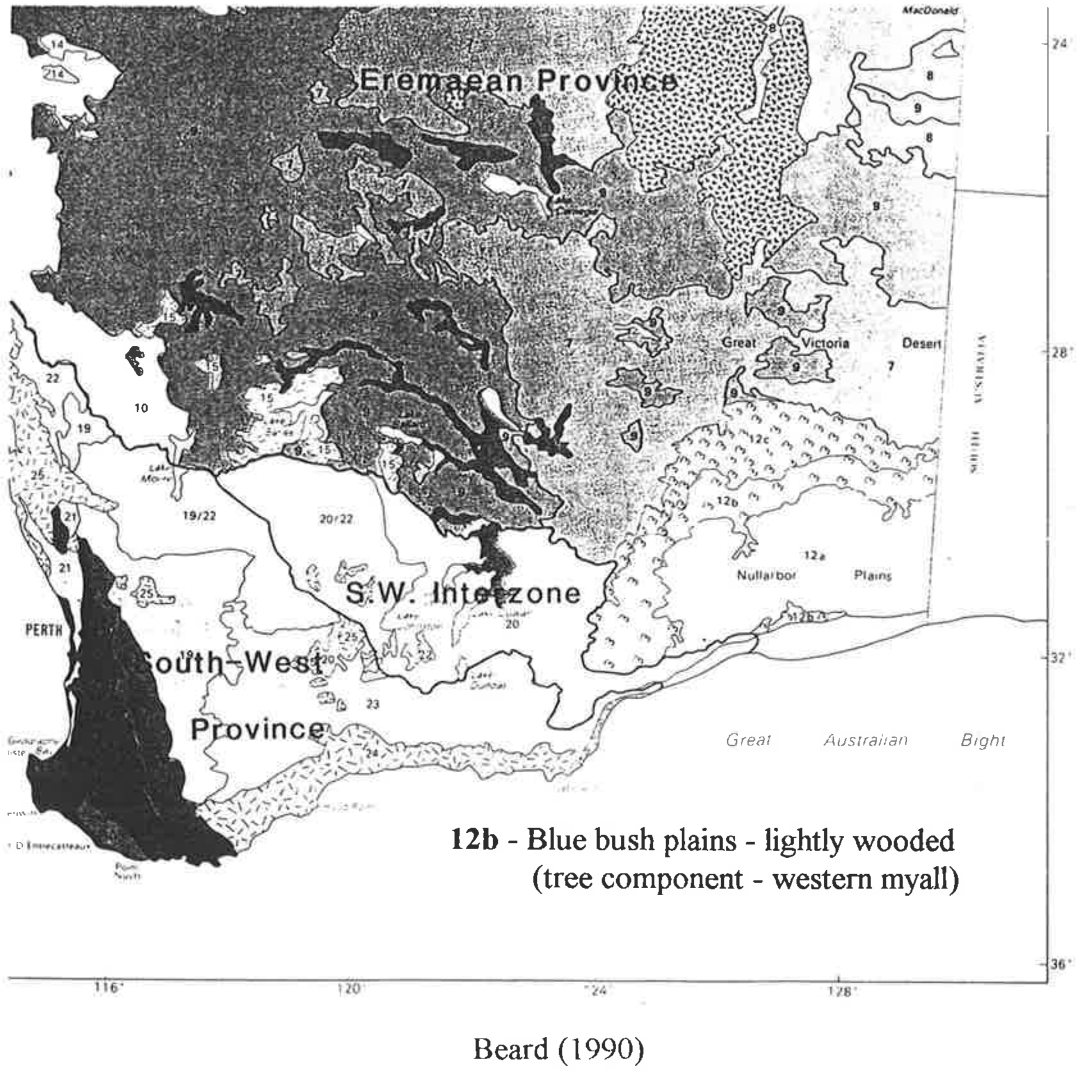


Figure 8: The boundaries of the vegetation sub-regions. The Figure also shows, for comparison, the boundaries of Laut et al.'s (1977) Environmental Associations

Vegetation sub-regions — — —
Environmental Associations ————

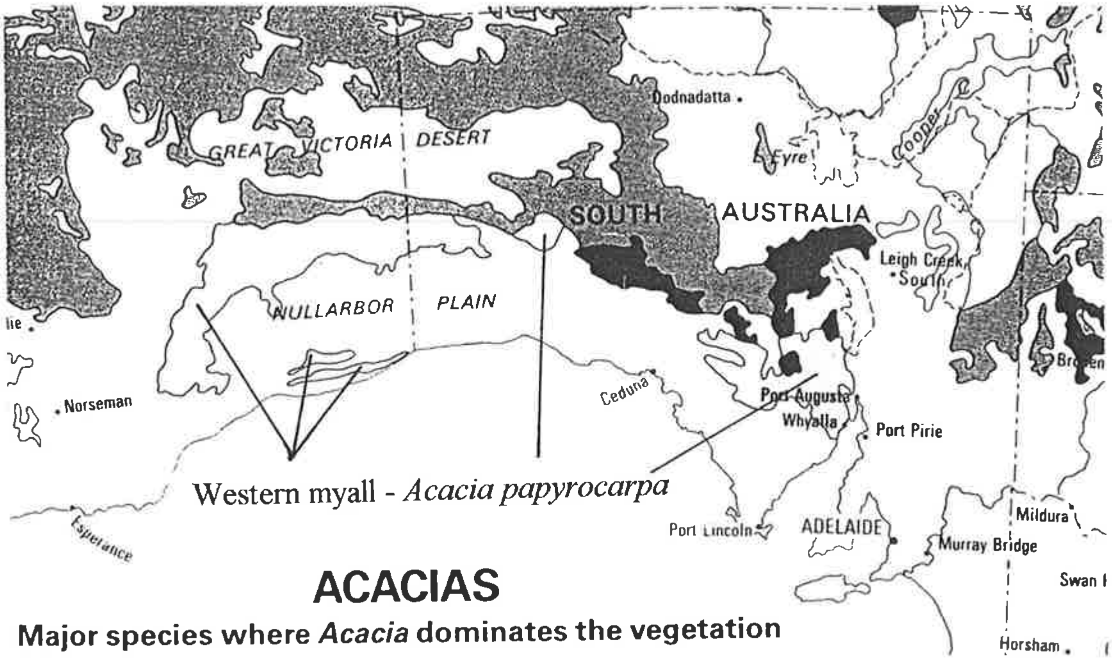
A: The coastal calcareous sand belt
B: The eastern agricultural belt
C: The siliceous sand ridge system
D: The mallee/myall belt

Young (1988)

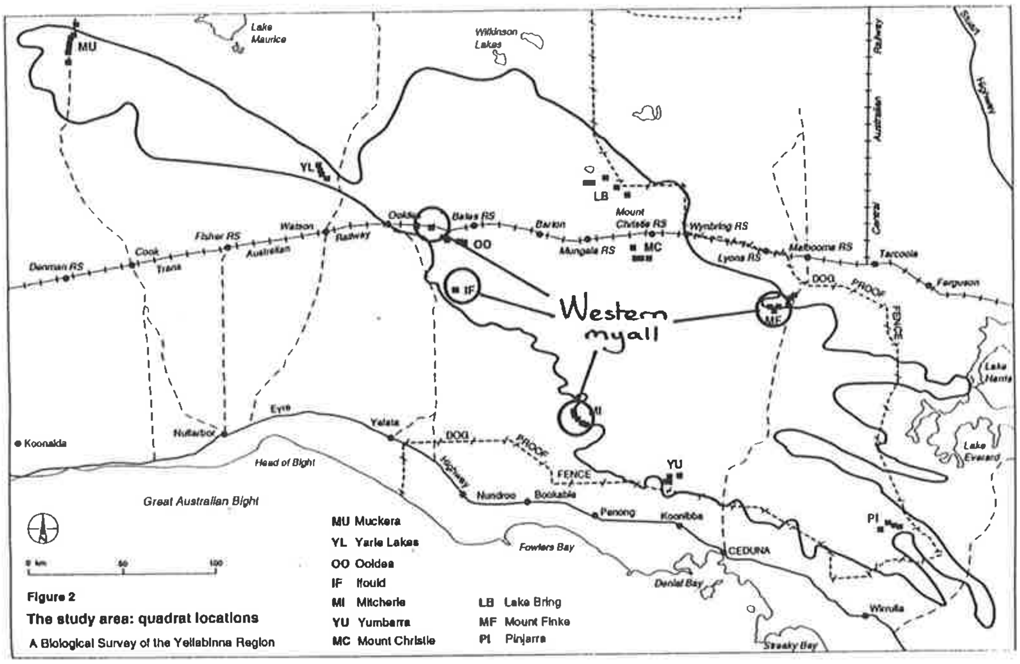


12b - Blue bush plains - lightly wooded (tree component - western myall)

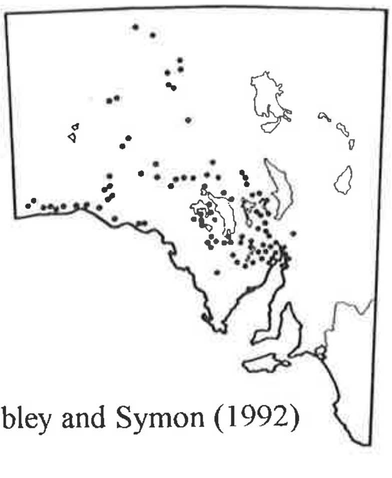
Beard (1990)



Commonwealth of Australia (1990)



Copley and Kemper (1993)

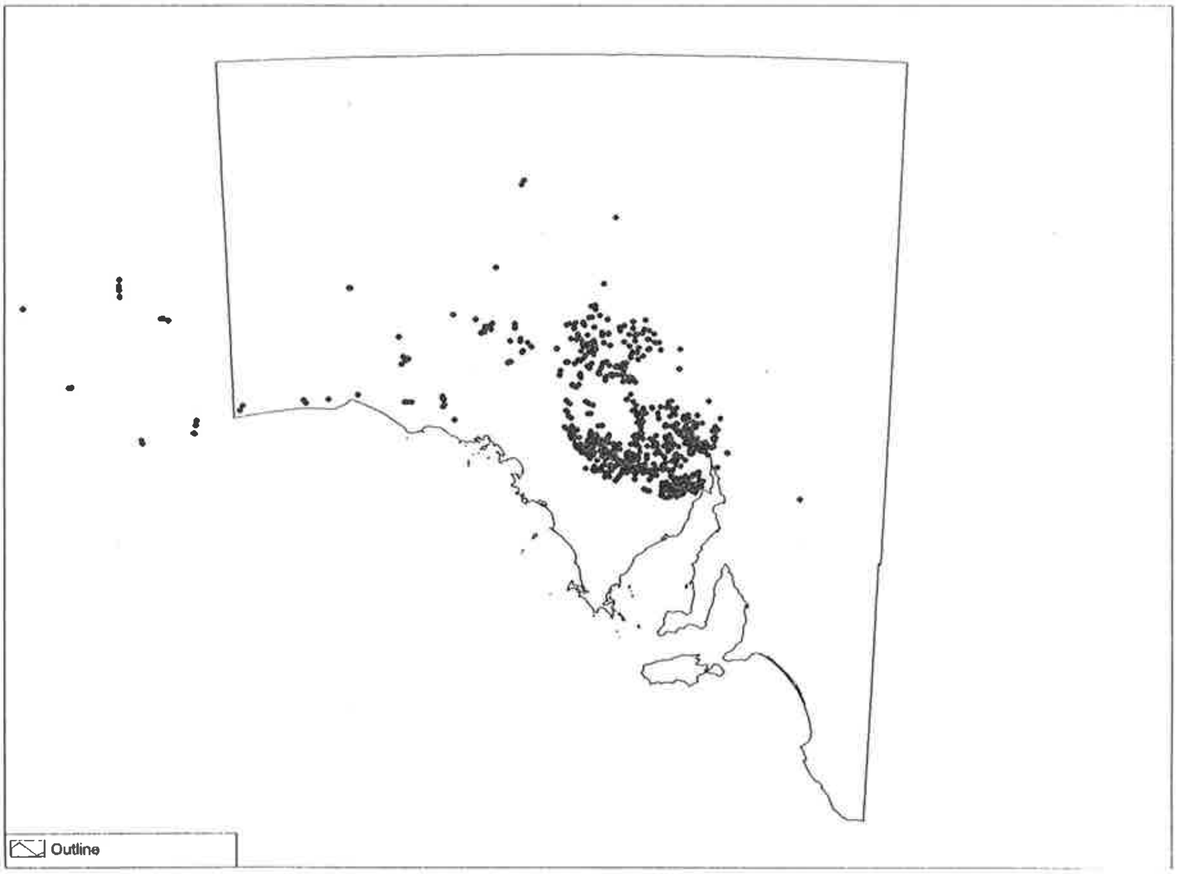


Whibley and Symon (1992)

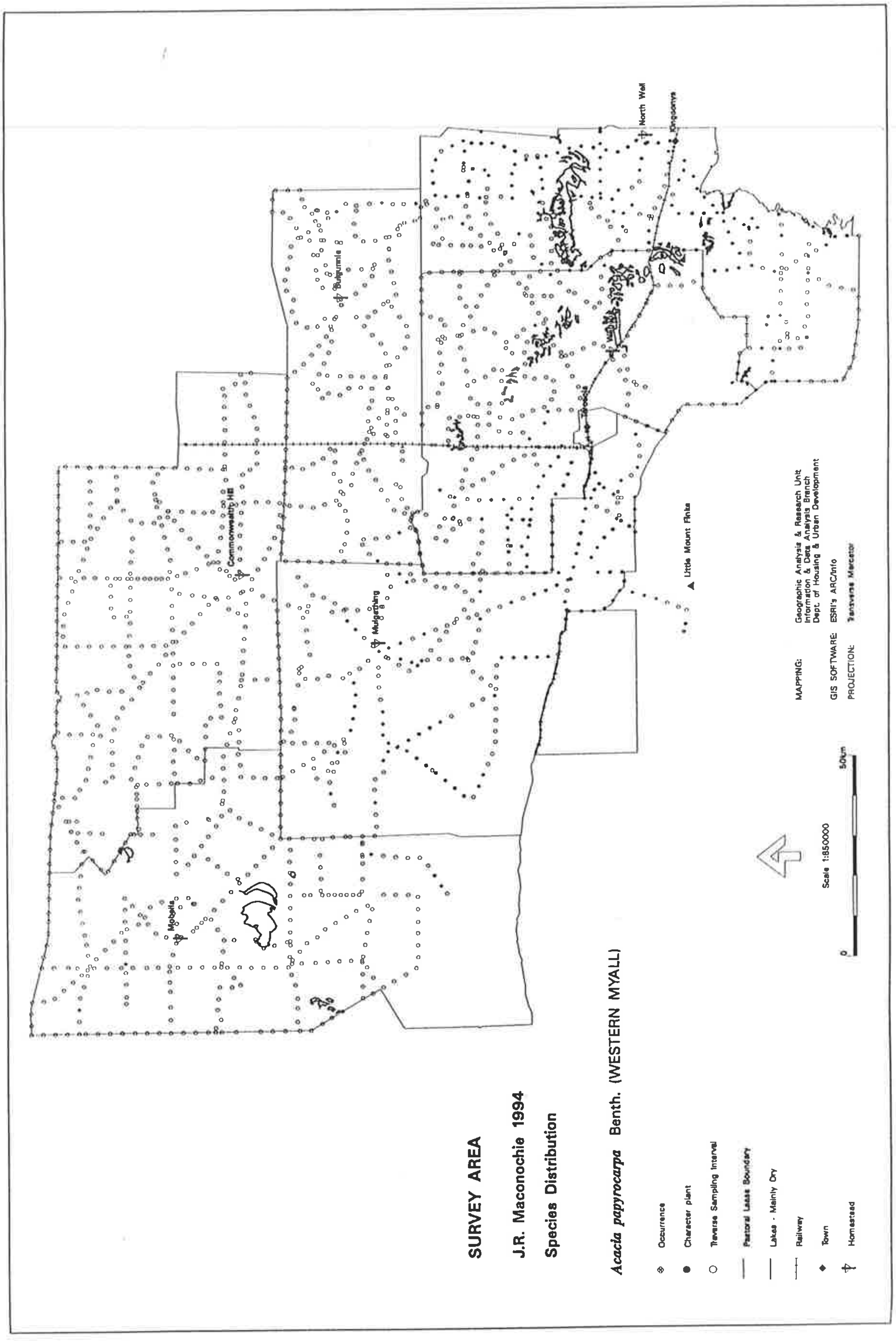
Mitchell and Wilcox (1994)

Acacia papyrocarpa

western myall



Biological Survey and Research, DENR (1996)

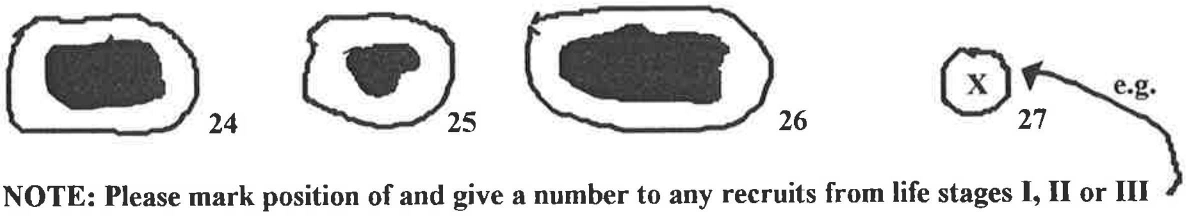


Maconochie and Lay (1996)

APPENDIX 4: FILLING IN THE DATA SHEETS FOR THE MORTALITY STUDY

- Walk into the woodlands and orient yourself on the ground and on the enlarged photocopy of the 1948 air photo. Many of the trees on the air photo are still alive; those that have died in the interim may still have standing carcasses or they may have been cut down.

- Assign each western myall tree that was alive in 1948 a number (in consecutive order) and ring the position of that tree in red texta along with its unique number on the enlarged photocopy as shown below: Ignore all western myall trees that were dead on the 1948 photo.



- **NOTE: Please mark position of and give a number to any recruits from life stages I, II or III that are not visible on the 1948 photo**

- On the data sheet assign a LIFE STAGE (**I, II, III, IV, V, VI, VII, VIII** or **IX**) to each of the trees that were alive in 1948. As you cannot tell the Life Stage from the 1948 photo, give it the Life Stage that it is today even if it has died in the intervening period (dead standing trees are relatively easy to assign to a Life Stage, those that have been chopped down are, of course, impossible!)

- Remember for this exercise that you are only looking at trees that were alive in 1948 (add the code **A** to all the spaces in the *Dead or Alive Then Column*). Decide whether each tree is alive or dead now and add the appropriate code letter **A** or **D** to the *Dead or Alive Now Column* on the data sheet:

A	Alive then (in 1948)
A	Alive now (in 1996)
D	Dead now (in 1996)

- If the tree is a weeping myall, shows signs that branches have been cut off or if only a stump remains record the following details in the *Dead or Alive Now Column* on the data collection sheet.

W	Weeping myall (Tree still alive)
B	Branches cut off (tree still alive)
C	Whole tree cut down (tree now dead)

- If you have any comments please use your notebooks or the border of the data collection sheets.

EXAMPLE:

TREE	LIFE	Dead or alive		TREE	LIFE	Dead or alive		TREE	LIFE	Dead or alive	
NO	STAGE	THEN	NOW	NO	STAGE	THEN	NOW	NO	STAGE	THEN	NOW
1	VI	A	A	51	VI	A	DC	101	VIII	A	D
2	V	A	D	52	IV	A	AB	102	IV	A	A
3	V	A	DC	53	V	A	A	103	IV	A	A
4	IX	A	D	54	VI	A	A	104	VI	A	A
5	IX	A	A	55	VII	A	AW	105	VII	A	A

APPENDIX 5: TRANSITION MATRICES FOR THE MORTALITY STUDY

TRANSITION MATRICES FOR MORTALITY STUDY															
COOKS PADDOCK, KATUNGA STATION															
	TRANSITION MATRIX				**TARGET**	**RESULT**									
	Juven.	**Young**	**Mature**	**Senesc.**	**1995**	**2042**	**2089**	**2136**	**2183**	**2230**	**2277**	**2324**	**2371**	**2418**	**2465**
No of years						*47*	*94*	*141*	*188*	*235*	*282*	*329*	*376*	*423*	*470*
Juven.	0.23	0	0	0	23	5	1	0	0	0	0	0	0	0	0
Young	0.27	0.22	0	0	219	54	13	3	1	0	0	0	0	0	0
Mature	0	0.45	0.59	0	1052	719	449	271	161	96	56	33	20	12	7
Senesc.	0	0	0.2	0.89	251	434	530	561	554	525	486	444	402	362	324
TWO MILE PADDOCK, MIDDLEBACK STATION															
	TRANSITION MATRIX				**TARGET**	**RESULT**									
	Juven.	**Young**	**Mature**	**Senesc.**	**1995**	**2042**	**2089**	**2136**	**2183**	**2230**	**2277**	**2324**	**2371**	**2418**	**2465**
No of years						*47*	*94*	*141*	*188*	*235*	*282*	*329*	*376*	*423*	*470*
Juven.	0.23	0	0	0	22	5	1	0	0	0	0	0	0	0	0
Young	0.27	0.23	0	0	177	47	12	3	1	0	0	0	0	0	0
Mature	0	0.48	0.63	0	1146	807	531	340	216	136	86	54	34	22	14
Senesc.	0	0	0.21	0.85	247	451	552	581	565	526	476	422	370	322	278
NORTH LAMBING PADDOCK, YUDNAPINNA STATION															
	TRANSITION MATRIX				**TARGET**	**RESULT**									
	Juven.	**Young**	**Mature**	**Senesc.**	**1995**	**2042**	**2089**	**2136**	**2183**	**2230**	**2277**	**2324**	**2371**	**2418**	**2465**
No of years						*47*	*94*	*141*	*188*	*235*	*282*	*329*	*376*	*423*	*470*
Juven.	0.23	0	0	0	12	3	1	0	0	0	0	0	0	0	0
Young	0.27	0.14	0	0	310	47	7	1	0	0	0	0	0	0	0
Mature	0	0.55	0.57	0	1092	793	478	276	158	90	51	29	17	10	5
Senesc.	0	0	0.25	0.75	87	338	452	458	413	349	284	226	177	137	105
TOLLS PADDOCK, PARAKYLIA STATION															
	TRANSITION MATRIX				**TARGET**	**RESULT**									
	Juven.	**Young**	**Mature**	**Senesc.**	**1995**	**2042**	**2089**	**2136**	**2183**	**2230**	**2277**	**2324**	**2371**	**2418**	**2465**
No of years						*47*	*94*	*141*	*188*	*235*	*282*	*329*	*376*	*423*	*470*
Juven.	0.27	0	0	0	72	19	5	1	0	0	0	0	0	0	0
Young	0.23	0.3	0	0	1042	329	103	32	10	3	1	0	0	0	0
Mature	0	0.61	0.65	0	627	1043	879	634	432	287	188	123	80	52	34
Senesc.	0	0	0.22	0.86	35	168	374	515	582	596	576	536	488	438	388

TRANSITION MATRICES FOR MORTALITY STUDY (CONT.)

COOKS PADDOCK, KATUNGA STATION (CONT.)

2512	**2559**	**2606**	**2653**	**2700**	**2747**	**2794**	**2841**	**2888**	**2935**	**2982**	**3029**	**3076**	**3123**	**3170**	**3217**	**3264**	**3311**	**3358**	**3405**
517	*564*	*611*	*658*	*705*	*752*	*799*	*846*	*893*	*940*	*987*	*1034*	*1081*	*1128*	*1175*	*1222*	*1269*	*1316*	*1363*	*1410*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
290	259	231	206	183	163	145	129	115	103	91	81	72	64	57	51	45	40	36	32

TWO MILE PADDOCK, MIDDLEBACK STATION (CONT.)

2512	**2559**	**2606**	**2653**	**2700**	**2747**	**2794**	**2841**	**2888**	**2935**	**2982**	**3029**	**3076**	**3123**	**3170**	**3217**	**3264**	**3311**	**3358**	**3405**
517	*564*	*611*	*658*	*705*	*752*	*799*	*846*	*893*	*940*	*987*	*1034*	*1081*	*1128*	*1175*	*1222*	*1269*	*1316*	*1363*	*1410*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	5	3	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
239	205	176	150	128	109	93	79	67	57	49	41	35	30	25	22	18	16	13	11

NORTH LAMBING PADDOCK, YUDNAPINNA STATION (CONT.)

2512	**2559**	**2606**	**2653**	**2700**	**2747**	**2794**	**2841**	**2888**	**2935**	**2982**	**3029**	**3076**	**3123**	**3170**	**3217**	**3264**	**3311**	**3358**	**AD**
517	*564*	*611*	*658*	*705*	*752*	*799*	*846*	*893*	*940*	*987*	*1034*	*1081*	*1128*	*1175*	*1222*	*1269*	*1316*	*1363*	*years*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
80	61	46	35	26	20	15	11	8	6	5	4	3	2	2	1	1	1	0	

TOLLS PADDOCK, PARAKYLIA STATION (CONT.)

2512	**2559**	**2606**	**2653**	**2700**	**2747**	**2794**	**2841**	**2888**	**2935**	**2982**	**3029**	**3076**	**3123**	**3170**	**3217**	**3264**	**3311**	**3358**	**3405**
517	*564*	*611*	*658*	*705*	*752*	*799*	*846*	*893*	*940*	*987*	*1034*	*1081*	*1128*	*1175*	*1222*	*1269*	*1316*	*1363*	*1410*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	14	9	6	4	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0
341	298	260	225	195	169	146	126	108	93	80	69	59	51	44	38	33	28	24	21

TRANSITION MATRICES FOR MORTALITY STUDY (CONT.)

COOKS PADDOCK, KATUNGA STATION (CONT.)

3452	**3499**	**3546**	**3593**	**3640**	**3687**	**3734**	**3781**	**3828**	**3875**	**3922**	**3969**	**4016**	**4063**	**4110**	**4157**	**4204**	**4251**	**4298**
1457	*1504*	*1551*	*1598*	*1645*	*1692*	*1739*	*1786*	*1833*	*1880*	*1927*	*1974*	*2021*	*2068*	*2115*	*2162*	*2209*	*2256*	*2303*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	25	23	20	18	16	14	13	11	10	9	8	7	6	6	5	4	4	3

TWO MILE PADDOCK, MIDDLEBACK STATION (CONT.)

3452	**3499**	**3546**	**3593**	**3640**	**3687**	**3734**	**3781**	**3828**	**3875**	**3922**	**3969**	**4016**	**4063**	**4110**	**4157**	**4204**	**4251**	**4298**
1457	*1504*	*1551*	*1598*	*1645*	*1692*	*1739*	*1786*	*1833*	*1880*	*1927*	*1974*	*2021*	*2068*	*2115*	*2162*	*2209*	*2256*	*2303*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	8	7	6	5	4	4	3	3	2	2	2	1	1	1	1	1	1	1

TOLLS PADDOCK, PARAKYLIA STATION (CONT.)

3452	**3499**	**3546**	**3593**	**3640**	**3687**	**3734**	**3781**	**3828**	**3875**	**3922**	**3969**	**4016**	**4063**	**4110**	**4157**	**4204**	**4251**	**4298**
1457	*1504*	*1551*	*1598*	*1645*	*1692*	*1739*	*1786*	*1833*	*1880*	*1927*	*1974*	*2021*	*2068*	*2115*	*2162*	*2209*	*2256*	*2303*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	15	13	11	10	8	7	6	5	5	4	3	3	3	2	2	2	1	1

TRANSITION MATRICES FOR MORTALITY STUDY (CONT.)

COOKS PADDOCK, KATUNGA STATION (CONT.)

4345	**4392**	**4439**	**4486**	**4533**	**4580**	**4627**	**4674**	**4721**	**4768**	**4815**	**4862**	**4909**	**4956**	**5003**	**5050**	**5097**	**AD**
2350	*2397*	*2444*	*2491*	*2538*	*2585*	*2632*	*2679*	*2726*	*2773*	*2820*	*2867*	*2914*	*2961*	*3008*	*3055*	*3102*	*years*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	0	

TWO MILE PADDOCK, MIDDLEBACK STATION (CONT.)

4345	**AD**
2350	*years*
0	
0	
0	
0	

TOLLS PADDOCK, PARAKYLIA STATION (CONT.)

4345	**4392**	**4439**	**4486**	**4533**	**4580**	**AD**
2350	*2397*	*2444*	*2491*	*2538*	*2585*	*years*
0	0	0	0	0	0	
0	0	0	0	0	0	
0	0	0	0	0	0	
1	1	1	1	1	0	

APPENDIX 6: CLIMATE AND VEGETATION CHANGE IN THE AUSTRALIAN ARID ZONE

CLIMATE CHANGE IN AUSTRALIA: THE LAST 2 MILLION YEARS

The glacial/interglacial cycles of the Quaternary Period (the last 2 million years) have had a particularly profound effect on the current distributions of the vegetation of Australia not only in direct effects of changing climates but also in the indirect effect of rising and falling sea levels. By examining the wealth of literature that exists for Quaternary climate change in Australia we can look at patterns in climatic fluctuation that may explain shifts in the distribution or changes in range size of western myall. The Quaternary is made up of the Pleistocene (2,000,000 BP[1] to 10,000 BP) and the Holocene (10,000 BP to Present). It was preceded by the Tertiary Period. **Table 6.1** (in CHAPTER 6) is a brief summary of the climate changes that have occurred since 2,000,000 BP (the information contained in this table has been compiled from the literature cited in this section). **Figure 1** (in this **Appendix**) shows the localities in Australia where evidence for climate change has been gathered.

Although Australia is geologically a very ancient and stable land, the vegetation and soils that mantle it have undergone a series of substantial changes over the Quaternary period (Chappell, 1991). In the last 15,000 years alone warmth and humidity have replaced the cold and aridity of the previous glacial period and sea levels have risen dramatically. These changes are reflected in the formation and growth to its present size of the Great Barrier Reef, the stabilisation of previously active dunefields over much of the continent, the formation of the modern shoreline of beaches and sandbars, and the disappearance of glaciers from Tasmania.

The Tertiary/Quaternary transition (approximately 2M BP)

The transition from the Tertiary to the Quaternary was marked by a general increase in aridity as the continent drifted into lower latitudes. The close of Tertiary time ended a period of relative climatic stability in which the oceans had acted as a heat storage that buffered the planet against small temperature oscillations. The oceans cooled and the planet entered a long period of meta-stable climatic mode where small temperature changes became capable of triggering both glaciations and the interglacial periods between them; this situation continues to the present day. The rapid change in climatic mode is most clearly illustrated in the sediments along the Murray River in South Australia where an extensive series of Tertiary marine, fluviatile and lacustrine sediments are abruptly overlain by Quaternary calcareous soils (Bowler, 1986).

An examination of palynological data for southeastern Australia by Kershaw *et al.* (1991) has allowed a reconstruction of vegetation and associated environmental conditions for the Late Tertiary and Quaternary Periods. Their studies have shown that at least in south eastern Australia a closed-canopy rainforest forest dominated much of the Tertiary and a major decline appears to have occurred at about 2,800,000 BP.

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[1] BP = years before present

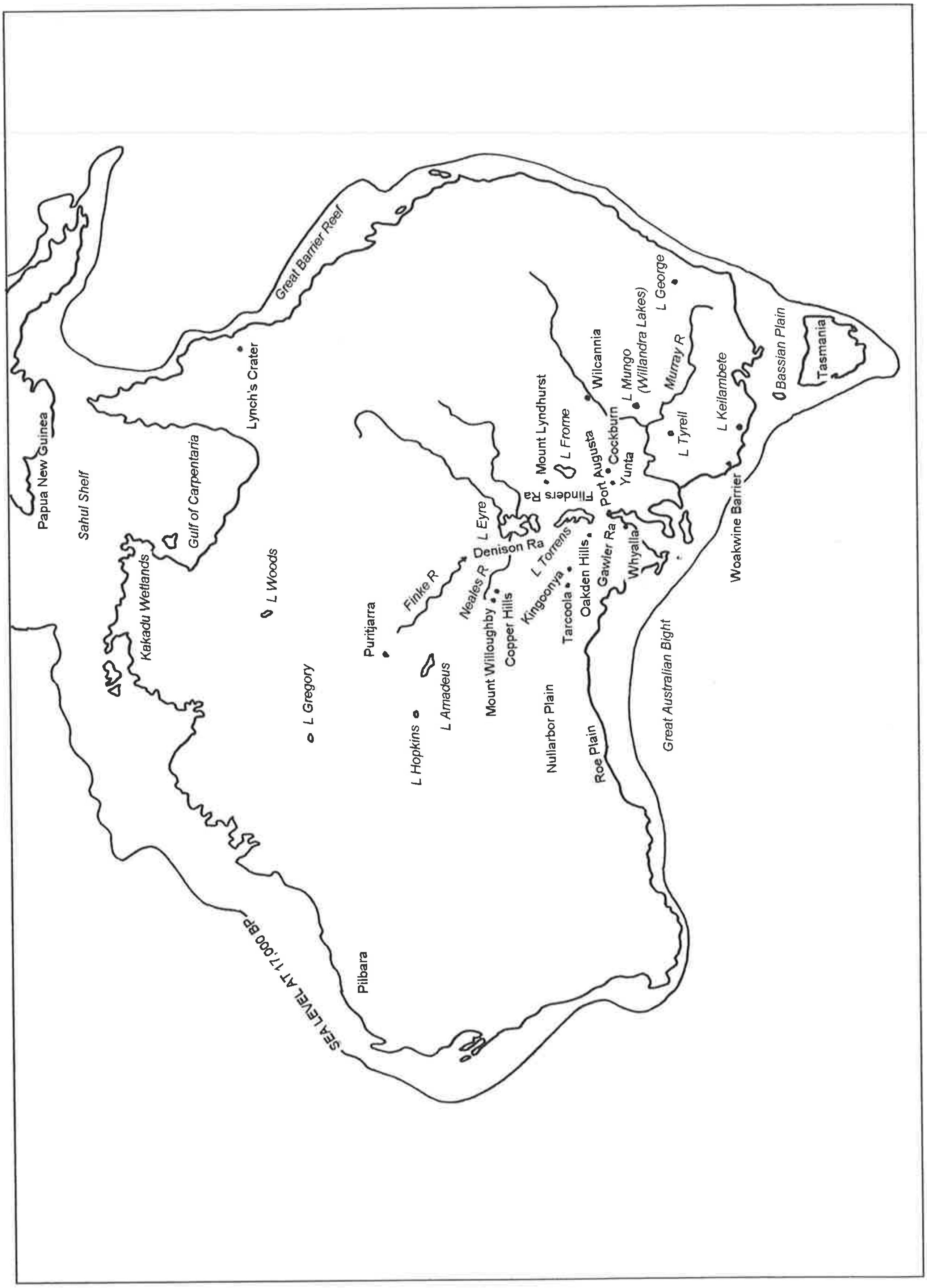


Figure 1: Localities mentioned in the text

The early to mid-Pleistocene (2M BP to 130,000 BP)

Increasing aridity in the early Pleistocene (Bowler, 1986) in south eastern Australia was characterised by a dominance of *Casuarina* with an understorey of Asteraceae and few eucalypts and grasses. Later in this period glacial/interglacial oscillations brought an alternation of this type of vegetation with cool-temperate forest elements and herbaceous understorey with grasses, patchy Asteraceae and poorly represented eucalypts (Kershaw 1981; Kershaw *et al.*, 1991). The repeated fluctuations from dry to humid environments appear to have turned more and more of Australia permanently arid. With the arrival of each glacial stage many communities of plants and even entire ecosystems were destroyed and when conditions ameliorated with the onset of warmer moist interglacials the landscape had to be recolonised by individuals that had retreated to refugia (White, 1994). One of the results of this was speciation; new forms arose that were suited to the new niches that evolved. Unable to recolonise their original ranges, many taxa established disjunct patterns during these oscillations in climate. The great radiation of the *Acacia,* which happened during these fluctuating Pleistocene climates, was enabled by the genetic ability of the genus to adapt coupled with the isolation of small populations; today there are more than 700 distinct species of *Acacia*. The recurring pattern of migration to and from refugia was established and continues to this day. From about 300,000 BP large areas of Australia were arid (Bowler, 1976). Blown sand dunes and sand sheets formed during the acutely arid glacial periods (Bowler, 1982; Gardner *et al.*, 1987). These coincide with lowered sea levels and thus a significantly expanded exposed continental land area.

The last interglacial (130,000 BP to 120,000 BP)

This period marks the climax of the last interglacial defined by Oxygen Isotope (OI) Substage 5e in deep sea cores (Shackleton and Opdyke, 1973). Polar ice caps were smaller and sea levels higher. This is well illustrated in the south east of South Australia in the Woakwine barrier, one of the younger of the great belt of relic coastal dune ridges that Chappell (1991) says are one of the finest Quaternary landscapes in Australia. Vegetation both at Lake George in southeastern Australia and Lynch's Crater in northern Queensland was similar to that of today (Kershaw, 1986; Chappell, 1991).

The mid to late Pleistocene (120,000 BP to 60,000 BP)

Relative sea level appears to have been below present day levels throughout this period (Chappell, 1991). The chronology of events is, however difficult to establish because it is too old for the precise measurements possible by the ^{14}C dating method which is limited to events <40,000 BP (the "^{14}C window"). There is some evidence that the climate across Australia changed in direct proportion to sea level variations (Chappell and Shackleton, 1986; Shackleton, 1987). Throughout the Lynch's Crater records (Kershaw, 1986), which arguably run unbroken through this period, rainforest and sclerophyll elements alternate; substantial fluctuations are also found at Lake George (Singh and Geissler, 1985).

APPENDIX 6: CLIMATE AND VEGETATION CHANGE IN THE AUSTRALIAN ARID ZONE

The late Pleistocene (60000 BP to 10000 BP)

This period is the richest and best documented episode of the Pleistocene in Australia (Chappell, 1991). The beginning of the high lake level period, or Lacustral Phase, is beyond the ^{14}C window at Lake Mungo in the Willandra Lakes (Bowler 1981) and was paralleled by the expansion of many lakes throughout Australia. Thermoluminescent (TL) dating carried out on shoreline dunes formed during higher lake levels at Lake Amadeus has given ages of between 50,000 to 60,000 BP (Chen *et al.*, 1990).

It appears that some intensely arid periods may have occurred in Central Australia from about 80,000 BP until the Lacustral Phase of the Late Pleistocene, in fact Jacobson *et al.* (1988) put the end of the period at 35,000 BP which conflicts with dates (Chen *et al.*, 1990) for the high lake levels at Lake Amadeus. Evidence comes from the dating of groundwater calcrete deposits of a palaeodrainage system that flowed from Lake Hopkins in Western Australia through Lake Amadeus into ancestral Finke River and thus to Lake Eyre (Arakel, 1991).

The highest lake levels occurred at or before 25,000 BP at Lake George; other lakes in the interior of Australia were so extensive during this period that clearly a different hydrological regime is indicated. Lakes Tyrell, Frome, Woods and Gregory all have Pleistocene shorelines far beyond their present margins. Bowler (1986) argues that although dating is sketchy it is reasonable to postulate that they were all full around the same time. Pollen records at Lynch's Crater, however, recorded drier conditions through at least part of the wetter period that occurred over the rest of the continent (Kershaw, 1986).

For millions of years prior to this period many large animal species, the so-called megafauna (e.g. *Diprotodon, Protemnodon, Sthenurus, Macropus giganteus*, the enormous flightless bird *Genyornis* and the carnivorous marsupial lion, *Thylacoleo carnifex*), had occupied Australia. By the time of the glacial maximum at 20,000 to 17,000 BP all of these animals had become extinct (White and Flannery, 1992). Debate is continuing as to the cause of these extinctions, but desertification of habitat and predation by Aboriginal populations appear the most likely.

Probably the driest period in the last 120,000 years occurred after the Lacustral Phase. The Australian continent had its greatest land area when sea level was at its lowest at 20,000 to 17,000 BP, again corresponding to the maximum extent of the Northern Hemisphere ice sheets. The Sahul shelf which formed a land bridge between Australia and New Guinea (Torgeson *et al.*, 1988) contained Lake Carpentaria (now the Gulf of Carpentaria). A similar land bridge joined Tasmania to the mainland forming the Bassian Plain. Vast areas of the Continental Shelf all around the margins of Australia were exposed and it is estimated that in the Great Australian Bight the coastline was 160 km south of its present alignment (Martin, 1973). Chappell (1991) argues that this huge increase in continentality would have greatly affected the climate at this time. He cautions, however, that this may not have been the only cause; precipitation was much lower and average temperatures between 5-8°C lower than today.

Wasson (1986) has compiled ^{14}C and TL dates for 50 sites throughout the western, southern and central parts of the continent which show that the extensive dunes which mantle vast areas of the continent were formed between 31,000 to 9,000 BP with a peak around 20,000 BP during a period of increasing cold, aridity and windiness (Bowler and Wasson, 1983). This peak correlates well with the climax of the Northern Hemisphere glacial maximum at 18,000

BP (Chappell, 1991). Active dunes stretched from the Gulf of Carpentaria in the north to Northern Tasmania in the south (Bowler and Wasson, 1983) and extended onto the exposed continental shelves of the western and southern margins. At Lakes Eyre and Frome huge gypsum dunes were produced, a phenomenon not seen before or since and indicative of extreme aridity. Rainfall in the desert areas is believed to have been less than half of the present-day amount; lakes dried up, many never to fill again (Bowler, 1976) and trees were excluded from 85% of the continent (Hope and Kirkpatrick, 1988).

The end of the Pleistocene is marked by a distinct warming and rapid rise in sea levels as the Northern Hemisphere ice sheets melted. Timing is not precisely known but ice had completely gone from the mountains in Tasmania by 10,000 BP (Colhoun, 1985). A warming of the Southern Ocean by 8°C and retreat of sea ice to its present position is believed to have occurred within 1,000 years (Hays, 1983). Increased rainfall resulted from the increased water budget of the planet. Continentality was rapidly reduced as the continental shelves flooded (Chappell, 1991); sediments were transported landwards forming transgressive coastal dunes and the Great Barrier Reef was revived (Hopley, 1982). As conditions began to ameliorate forests began to recover (Kershaw, 1981). During the late Pleistocene and into the Holocene (10,000 BP to Present) vegetation in southeastern Australia became increasingly sclerophyllous and associated with a grassy understorey (Kershaw, 1991), as the predominantly *Casuarina* forests were gradually replaced with more fire-tolerant *Eucalyptus* communities. At Lynch's Crater Araucarian forest was replaced with open woodland (Kershaw, 1981), on the Nullarbor chenopods replaced eucalypts and closed forest was replaced by herbaceous vegetation at Lake George.

The Holocene (10000 BP to the Present)

During the Holocene the amplitude of changes in the palynological record of the vegetation are markedly less than in the preceding period (Kershaw, 1988); they may also be affected by the impact of humans. Evidence of climatic fluctuations from all over the world, however, show an extremely complex pattern of cyclic changes which operated on a very short time scale. The vegetation cover in Australia appears to have assumed its current form by the beginning of the Holocene although Bowler *et al.* (1976) indicate that between 8,000 and 5,000 BP conditions may have been warmer and wetter than present. The bulk of forests and woodlands have invaded new ground and changed in composition over the last 10,000 year (Hope and Kirkpatrick, 1988). Lake levels at Lake Keilambete were at their highest during approximately the same time (De Deckker, 1982) and work by Wyroll (1979) on the Nullarbor Plain confirms this warmer wetter period. In north east Queensland however, the wetter warmer period appears to have occurred later between 5,000 and 3,500 BP (Kershaw, 1983) when Lake Keilambete was lower and more saline (Bowler, 1981). Dune building waned during the early Holocene and rose again over the last 3,000 years (Wasson, 1986).

Sea level appears to have stabilised at about 5,000 BP and Australia appears to have assumed its modern form with all the major regions of the continent and their specialised biotas in place (Clark , 1983; White, 1994). In the last 750 years lake levels have fallen and salinity levels have risen, a trend that has increased dramatically in the last 100 years. Dendrochronological studies of Huon pine, King Billy pine, pencil pine and celery top pine in Tasmania show that temperature has risen more rapidly in the last 25 years than at any other time since 900 AD

(Cook *et al.*, 1991). The tree-ring record is also consistent with some of the following events:

- The Roman period at about 1,900 BP when increasing warmth and dryness lead to the collapse of Saharan civilisations and the level of the Caspian sea fell by 4 m.

- The "Medieval Warm Event" of the 12th Century. Vikings settled Greenland with an estimated population of 10,000 who planted woodlands and grazed sheep. Thirty eight vineyards were recorded in southern Britain.

- The "Little Ice Age" of the 17th Century. Temperatures fell worldwide and glaciers advanced. The Sahara was wetter, the Thames froze frequently, the tree line descended in California and Viking settlements were abandoned in Greenland.

- The warming trend in the 19th Century when New Zealand glaciers retreated.

- The cold "snap" in the early 1900s when pack ice in Antarctica was known to have expanded.

- The warming trend over the last 100 years. Lake levels have fallen in Australia and mineshafts unworked for 600 years in Europe have once more become visible as glaciers have retreated.

Chappell (1991) sums up that the Great Barrier Reef, the Kakadu Wetlands and all of Australia's coastal barriers and beaches, some of our most valued natural resources, did not reach their equilibrium until many thousands of years after sea levels and climatic conditions had stabilised. All of these then are very recent phenomena. He continues that we must:

> *"...carefully separate the effects of our own species, in both the prehistoric and historic periods, from those which climatic changes have had on the limited and fragile environmental resources of Australia."*

THE EFFECTS OF CLIMATE CHANGE ON THE VEGETATION OF THE AUSTRALIAN ARID ZONE

The full geographic range of a single plant species comprises the sum of the ranges of a series of populations; the range itself is a reflection of the breadth of tolerance between its composite populations (Cox and Moore, 1993). When conditions change over time some species' ranges may expand or migrate, and others may contract or vanish (Hengeveld, 1990). Ranges may also be disjunct and populations lose contact with one another. Huntley (1991) stated that:

> *"The palaeoecological evidence of the response, especially of plants, to past climate change indicates that evolutionary adaptation has played no more than a minor role and that migration is the usual response of an organism to climate change".*

In the Northern Hemisphere the realised maximum migration rates of most trees are in the range of about 100 to 150 metres per year (Huntley, 1991) and there is a remarkable consistency between species. Communities of plants tend to respond to climate change by dissociating and reassociating into different assemblages. The major changes in climate that have occurred in the past have resulted then, in changes in broad scale vegetation patterns, vegetation gradients and ecotones. Davis (1986) describes climatic variability as an important exogenous factor that affects community structure. She says climatic parameters change in a directional way through time and have a profound effect on the structure of biological communities, furthermore, both the magnitude and timing of the change are different for each plant species, changing the pattern of relative species abundance in each assemblage. Complex patterns of plant distribution are difficult to decipher unless temporal and spatial climatic variations are taken into account. Many species are slow to respond to climate change and many will remain in a state of disequilibrium continually lagging behind or adjusting to new climatic trends. Davis (1986) believes that interpretations about community structure and the abundance of individual species within each community cannot be made without considering responses to directional climate change.

Bowler (1982) emphasises that the last 400,000 years of climate change is the most important in terms of its ecological significance. For the previous 6 million years the biota had adapted to relatively slow sequences of climatic change. Rapid hydrological fluctuations during the past 400,000 years affected large areas of Australia and placed significant stress on the plants and animals; essentially these processes produced a rapidly changing mosaic landscape (Boardman, 1994). As a result of a tree's requirement for greater amounts of water and nutrients for the formation and sustenance of a bole or trunk, Boardman (1994) suggests that they are much more likely to suffer climate change than are shrubs. He describes this as a cost for keeping the tree in a lofty position in the ecosystem and states that there is no difficulty in maintaining this in a stable climate. Even small fluctuations in climate are sufficient to alter the dominance of a particular tree species (Boardman, 1986). Results of these swings in stressful conditions can be seen in the distribution of trees in South Australia which do not follow a pattern that can be simply explained by present-day soil or climate associations. There have also been edaphic and geographic barriers to plant migration; both of these factors have resulted in a considerable but unknown number of species being unable to colonise and compete with other species in newly established niches (Boardman, 1994). Conversely species already present in those niches may have suffered intense selection pressures in their refugia and have *"a limited intrinsic adaptability to change in directions not already encountered"*. He describes much of the uncleared vegetation outside of settled areas in South Australia as *"ancient secondary vegetation"*.

The degree of aridity that occurred in any of the more climatically severe periods may affected a plant's ability to survive (Beard, 1982). Formation of aeolian landscapes requires considerable air movement, little protective vegetation and a large supply of incoherent surface materials. Given the abundance of dunes, sand ridges and sand sheets in Australia that have formed during more arid periods there must have been extensive extinctions and migrations of plant species during the Quaternary period. The existence of the sand sheets Beard (1982) postulates, seems to require the virtual absence of vegetation at the time of formation, however, the formation of linear sand ridges does not require complete absence but merely that the vegetation be relatively sparse. Seif (longitudinal) dunes could coexist with vegetation unlike barchan (crescent-shaped) dunes which destroy the plant cover as they roll across the country. Beard (1982) cautions that this does not imply that the Australian dune systems were necessarily built in the presence of vegetation, only that they may have been, however he continues that the existence of seif dunes well outside the present day arid zone (e.g Esperance Plains, WA) reveals the extreme climatic changes that took place.

At the period of maximum sea lowering (20,000 - 17,000 BP) a picture of an extremely arid continent emerges (Hope, 1989) and **Figure 6.1** shows the extent of the major vegetation assemblages at 17,000 BP; Hope (1989) continues that the whole period from 23,000 to 14,500 BP was the most extreme time for forest retreat. He describes the arid "treeline" as more diffuse than the altitudinal treeline in Australia but states that it appears to correlate well with the 400 mm isohyet in the sub-tropics and with the 200-250 mm isohyet in the temperate regions.

Following the destruction of much of the vegetation of the arid zone during the dune forming phase, the land was repopulated by species which had survived in refugia (Crocker and Wood, 1947; Burbidge, 1960); these refugia may have been scattered within the arid zone. Without doubt there has been an almost concentric succession of retreats and advances in vegetation as the climates alternated between wet and dry phases. With the return of wet conditions after each arid phase Burbidge (1960) hypothesises that winter rainfall may have influenced a greater area of southern Australia than today, allowing not only some east-west migrations but also a northward movement of some southern elements.

Evidence of human occupation of the very centre of the arid area during the glacial maximum comes from Puritjarra Rockshelter in the Northern Territory (Smith, 1989). Although the productivity of the land per unit area from a human perspective would have been considerably lower at 18,000 BP than today, people still managed to exist in the area. Smith (1989) paints a picture of a long frost season together with a heightened summer drought substantially reducing the growing season of many plants and completely restricting the survival of many others. The mulga (*Acacia aneura*) woodland which today is one of the most productive ecosystems in the region cannot set seed and thrive without both summer and winter rainfall (Nix and Austin, 1973; Davies, 1986). Mature trees, Smith (1989) says, are deep rooted enough to tap groundwater and survive protracted drought, however seedlings and saplings would be very vulnerable. He thus postulates that a widespread reduction of plant cover would be inevitable under such circumstances.

Pearson and Dodson (1993) present palynological evidence from two stick-nest rat (*Leporillus* spp.) middens in Western Australia which suggests a trend towards diminishing wooded vegetation from 900 to 300 BP in central Australia. Traditional sources of evidence for reconstructing past vegetation assemblages such as lake and swamp sediments (e.g. Lake Frome) are rare and often poorly preserved (Head, 1993). Techniques for analysis of the remains of pack-rat (*Neotoma* spp.) middens in the arid United States are well developed; some records span the last 40,000 years. Head suggests that stick-nest rat middens may provide a rich source of vegetation history and climatic implications for the Australian arid zone.

In South Australia one of the few attempts at reconstruction of past climates was undertaken by Singh and Luly (1991) for a pollen core from the bed of Lake Frome on the eastern side of the Flinders Ranges. Results of pollen analysis, stratigraphy and radiocarbon dates from this core show a striking pattern of changing vegetation types stretching from the present back to 18,000 BP.

APPENDIX 7: FOSSIL PADDOCKS IN THE STUDY AREA

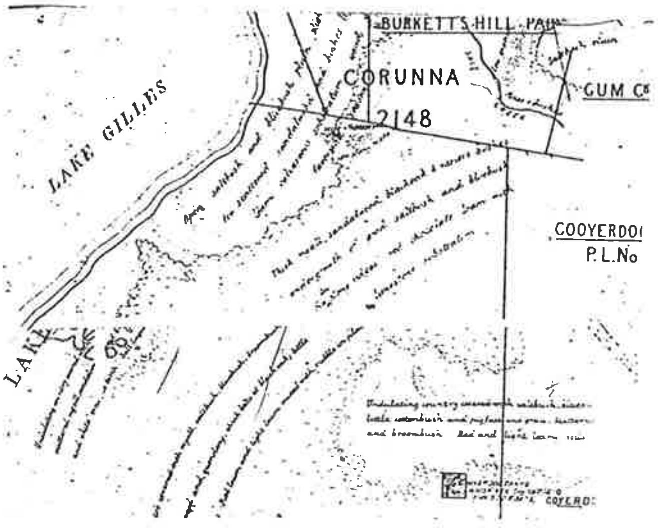
GAWLER RANGES SOIL CONSERVATION DISTRICT

FOSSIL PADDOCK	STATION	MODERN PADDOCKS THAT MAKE UP EACH FOSSIL PADDOCK
Durbridges	Corunna	Durbridges
Gap	Cariewerloo	New Well, North and South Poutchina and North and South Gap
Lake	Wartaka	Jungle North, Jungle South and Lake
Low Hill North	Siam	West and East Fiddle Hill, Dingo Hill, Tanfield, Rankins and Jungle
Low Hill South	Siam	Edkins, Jarret Hill, JD, Paullaloo and Courting Road.
Moonlight	Tregalana	Moonlight, Well and Creekwell
Mount Laura	Middleback	Rainbow, Koleroo, Moonee and Wanga
Wards Soakage	Katunga	Cooee, Corio, Parwingee, Moores, Broombrush, Tip Top, Centenery, Yanaby, Cooks, Malachi and Groves
White Cliffs	Tregalana	White Cliff North and South, Tassie, Cavanagh, Barretts and Gilmour
Winter	Nonowie	Kirani and Winter

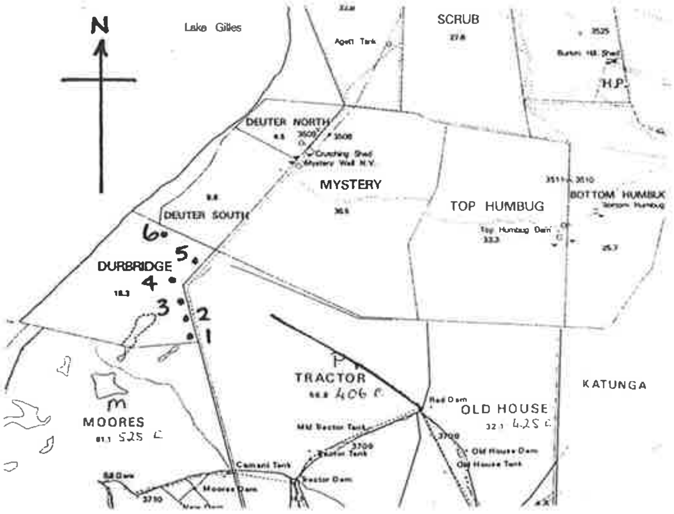
KINGOONYA SOIL CONSERVATION DISTRICT

FOSSIL PADDOCK	STATION	MODERN PADDOCKS THAT MAKE UP EACH FOSSIL PADDOCK
Beamish	Parakylia	Tolls, Nobles, Beamish, Gambier and Chermside
Dog Fence	North Well and Wilgena	North Outside Country (Wilgena), North and South Sandalwood, North Tunkillia, Tunkillia and South Outside Country (North Well)
Kowal	Mount Vivian	Rankin, Clemens, North Kowal and Kirby's
Lochs North	Parakylia	WJP, KKK and Middle Lochs
Outside Country	Parakylia	30 Mile North and South, 23 Mile, 13 Mile, Home, Rickaby, Prairie and Majendie
Sheridans	North Well	Mindruba Well, Sheridans and Outside Country
Tomato Rocks	North Well	Renton and Tomato Rocks
Whymlet	North Well	Number 1-22, Lake Labyrinth, North Survey, Survey, Mt. Eba Hill, Eba Dam, North Hicks, Hicks, Big Tank, Middle, West Wallabyng, Wallabyng, Government Wells, Kingoonya, No 2, Gilberts and West Gilberts

DURBRIDGES FOSSIL PADDOCK - CORUNNA STATION GAWLER RANGES SOIL CONSERVATION DISTRICT



1892



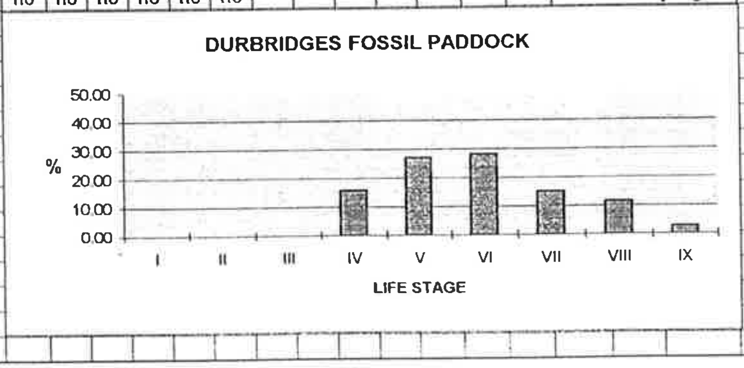
1995

0 5 Km
SCALE

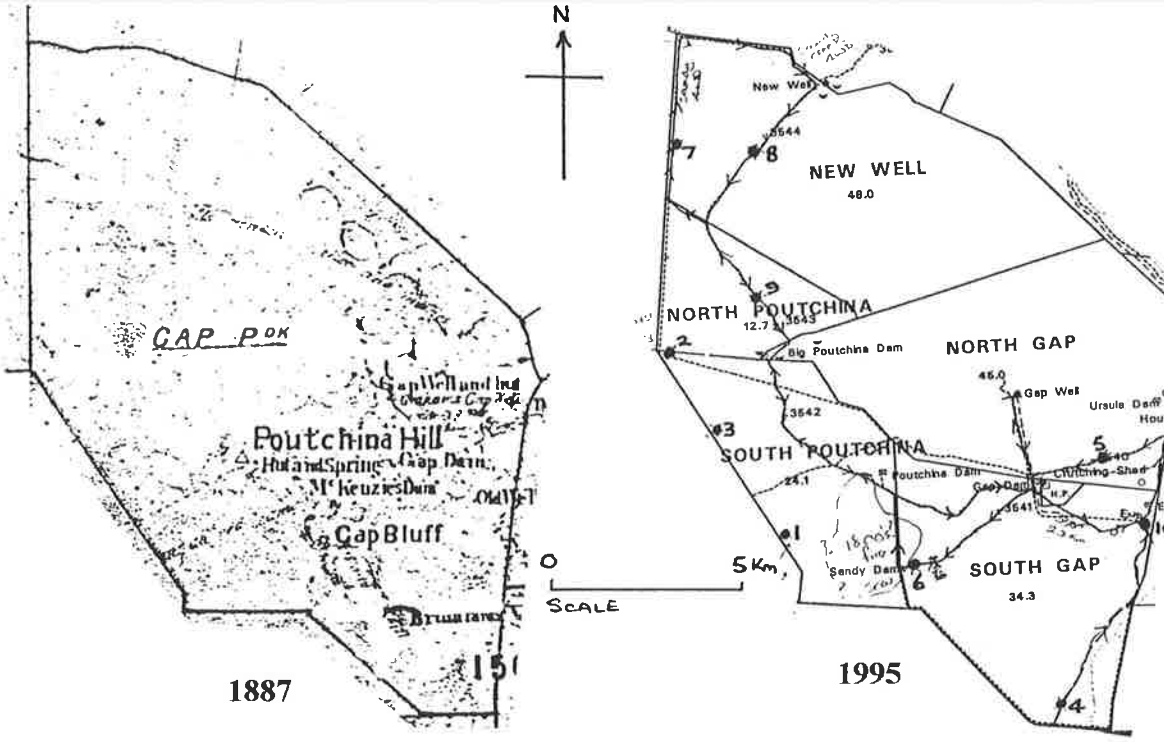
DURBRIDGES FP											
LIFE STAGE	SD1	SD2	SD3	SD4	SD5	SD6			TOTAL		% OF TOTAL
I	0	0	0	0	0	0			0	I	0.00
II	0	0	0	0	0	0			0	II	0.00
III	0	0	0	0	0	0			0	III	0.00
IV	27	9	24	20	11	8			99	IV	15.74
V	26	32	34	32	22	23			169	V	26.87
VI	28	30	26	36	34	23			177	VI	28.14
VII	11	18	10	14	24	18			95	VII	15.10
VIII	9	9	9	9	11	25			72	VIII	11.45
IX	4	2	1	3	3	4			17	IX	2.70
TOTAL	105	100	104	114	105	101			629	629	100.00
I Expected	yes	yes	yes	yes	yes	yes					
II Expected	yes	yes	yes	yes	no	yes					
III Expected	yes	yes	yes	yes	no	yes					
Sheep	0	0	0	0	0	0	**0**	low			
Rabbits	3	2	2	1	4	2	**14**	med			
Roos	2	2	2	2	2	2	**12**	med			
Lichen	3	3	3	3	3	2	**17**	high			
Fire	no	no	no	no	no	no					

yes = sheep absent, cohort expected
no = sheep present, cohort not expected

Dung Counts
0=none
1=occasional
2=common
3=abundant
4=extremely high!



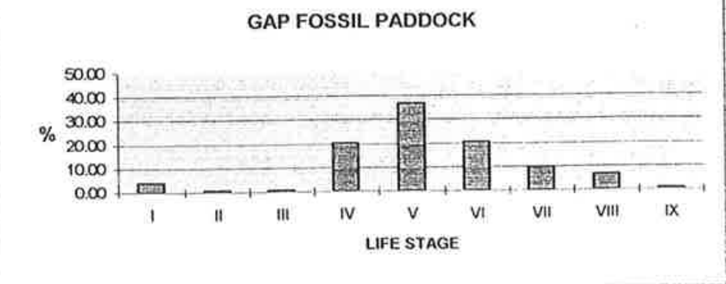
GAP FOSSIL PADDOCK - CARIEWERLOO STATION
GAWLER RANGES SOIL CONSERVATION DISTRICT



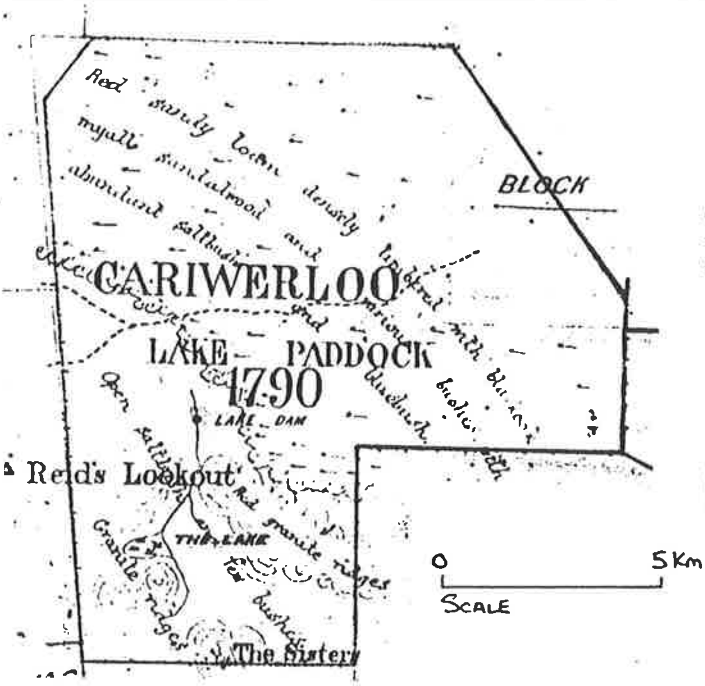
1887

1995

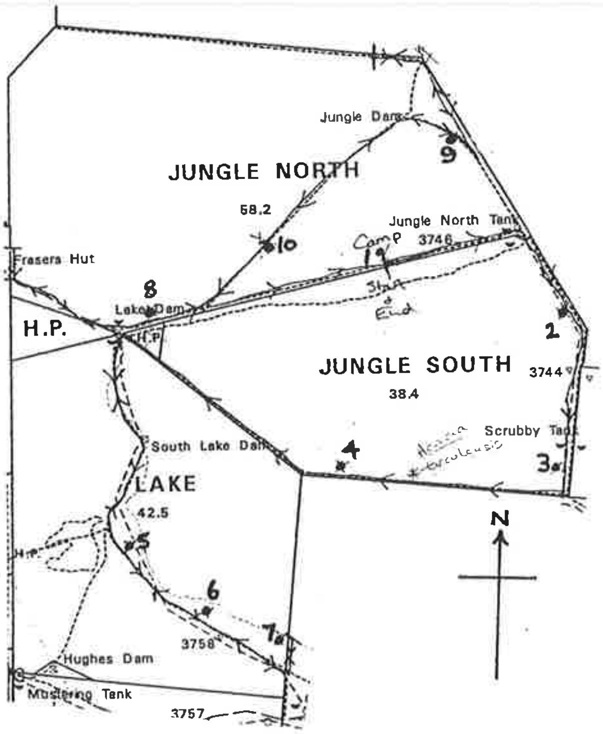
GAP FP																% OF
LIFE STAGE	CG1	CG2	CG3	CG4	CG5	CG6	CG7	CG8	CG9	CG10				TOTAL	LS	TOTAL
I	5	0	5	24	0	2	0	0	0	8				44	I	3.90
II	1	5	0	2	0	0	0	0	0	0				8	II	0.71
III	0	0	0	5	0	2	0	0	0	1				8	III	0.71
IV	29	30	30	24	13	21	11	16	35	21				230	IV	20.39
V	43	47	51	41	43	52	28	32	40	37				414	V	36.70
VI	22	24	25	17	30	20	27	23	18	25				231	VI	20.48
VII	12	7	6	5	16	9	16	15	13	12				111	VII	9.84
VIII	6	2	3	3	10	6	17	13	8	5				73	VIII	6.47
IX	0	0	0	0	1	0	5	2	1	0				9	IX	0.80
TOTAL	118	115	120	121	113	112	104	101	115	109				1128	1128	100.00
I Expected	no	no	no	no	no	no	no	no	no	no		yes = sheep absent, cohort expected				
II Expected	no	no	no	no	no	no	no	no	no	no		no = sheep present, cohort not expected				
III Expected	no	yes	no	yes	no	no	yes	yes	yes	no						
														Dung Counts		
Sheep	1	3	2	2	2	3	0	0	2	2	**17**	med		0=none		
Rabbits	0	0	1	0	1	0	1	1	1	0	**5**	low		1=occasional		
Roos	2	2	3	2	2	2	3	2	2	1	**21**	high		2=common		
Lichen	2	2	1	2	2	1	1	1	1	1	**14**	med		3=abundant		
Fire	no	no	no	no	no	yes	no	no	no	no	**0**					
Goats							yes	yes	yes							



LAKE FOSSIL PADDOCK - WARTAKA STATION
GAWLER RANGES SOIL CONSERVATION DISTRICT

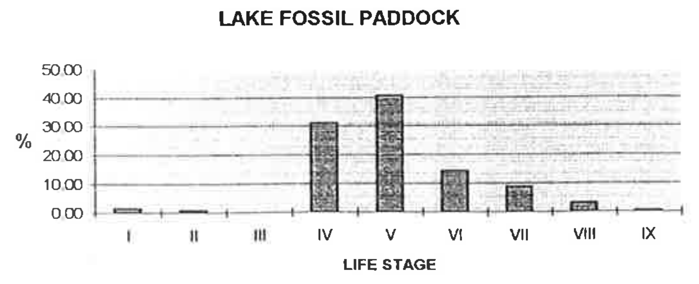


1889

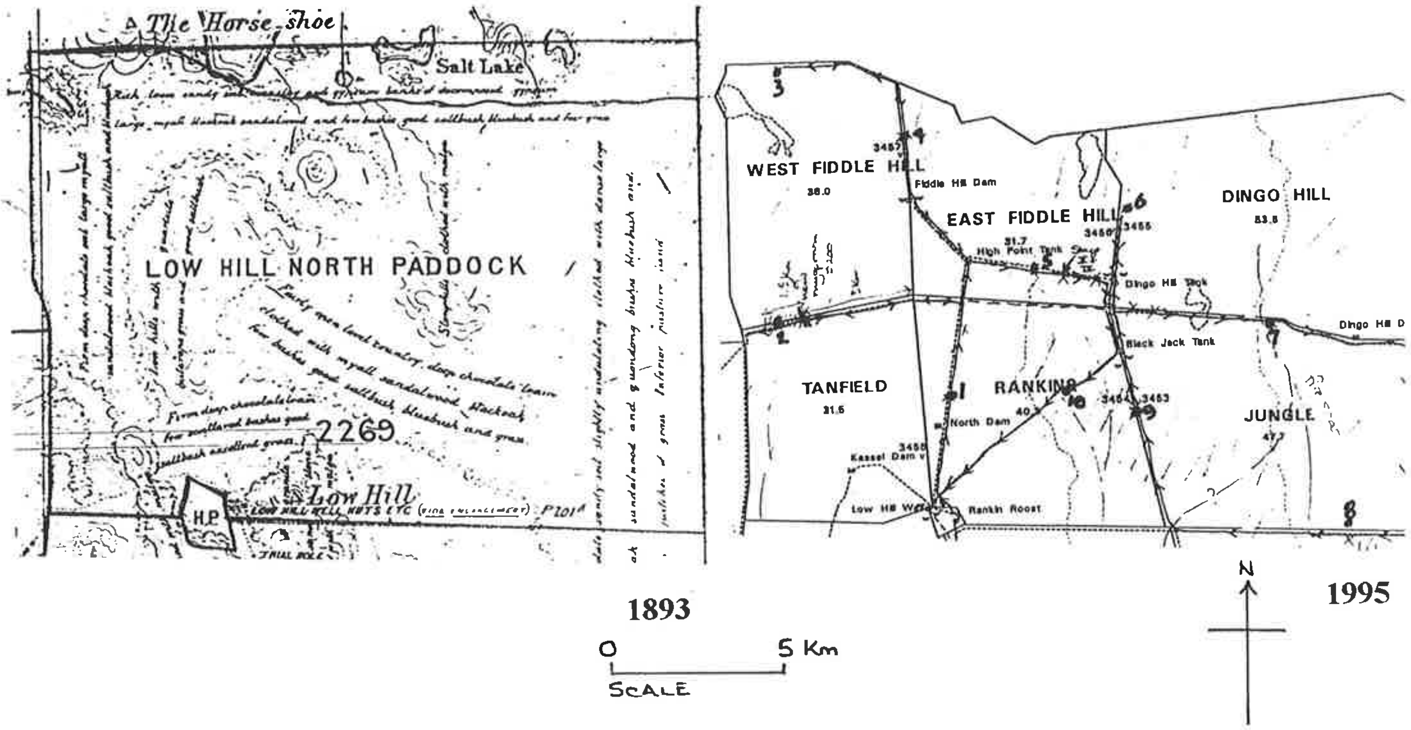


1995

LAKE FP																% OF
LIFE STAGE	CLK1	CLK2	CLK3	CLK4	CLK5	CLK6	CLK7	CLK8	CLK9	CLK10				TOTAL	LS	TOTAL
I	0	0	0	1	0	0	0	0	2	12				15	I	1.41
II	0	0	0	0	0	0	0	0	3	5				8	II	0.75
III	0	0	0	0	0	0	0	0	0	0				0	III	0.00
IV	36	38	31	28	31	28	46	40	30	23				331	IV	31.02
V	40	45	48	43	44	51	42	45	43	33				434	V	40.67
VI	14	10	17	15	16	18	10	18	19	15				152	VI	14.25
VII	12	9	12	11	8	7	5	7	11	10				92	VII	8.62
VIII	3	3	1	5	3	4	2	2	3	6				32	VIII	3.00
IX	0	0	0	0	0	1	0	1	0	1				3	IX	0.28
TOTAL	105	105	109	103	102	109	105	113	111	105				1067	1067	100.00
I Expected	no	no	no	no	no	no	no	no	no	no		yes = sheep absent, cohort expected				
II Expected	no	yes	yes	no	no	no	yes	no	no	no		no = sheep present, cohort not expected				
III Expected	yes	yes	yes	no	no	no	yes	no	yes	no						
														Dung Counts		
Sheep	2	3	3	3	2	1	1	3	2	2	22	high		0=none		
Rabbits	1	0	0	1	2	2	1	2	0	0	9	low		1=occasional		
Roos	1	1	1	1	2	2	2	0	2	1	13	med		2=common		
Lichen	1	1	2	1	2	3	1	1	2	2	16	med		3=abundant		
Fire	no	no	no	no	no	no	no	no	no	no						



LOW HILL NORTH FOSSIL PADDOCK - SIAM STATION
GAWLER RANGES SOIL CONSERVATION DISTRICT

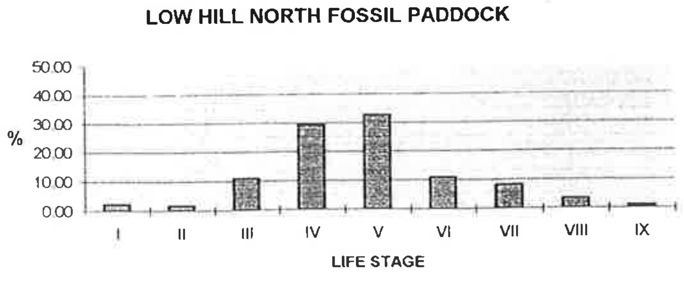


LOW HILL NORTH FP

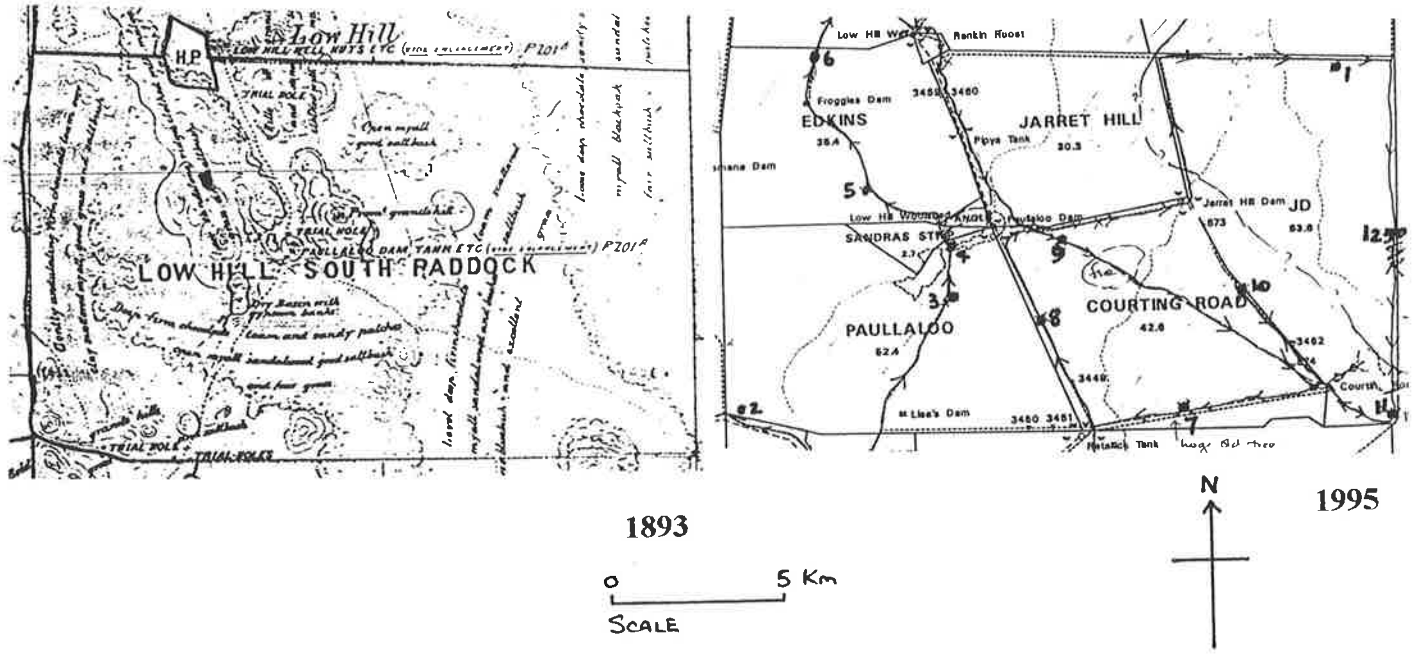
LIFE STAGE	CLN1	CLN2	CLN3	CLN4	CLN5	CLN6	CLN7	CLN8	CLN9	CLN10		TOTAL	LS	% OF TOTAL
I	0	6	0	0	0	0	14	3	0	0		23	I	2.15
II	0	0	0	0	0	0	16	1	0	1		18	II	1.68
III	0	0	0	0	0	0	45	70	0	1		116	III	10.84
IV	34	33	37	38	34	29	18	14	36	41		314	IV	29.35
V	44	39	43	40	41	40	15	11	39	37		349	V	32.62
VI	13	14	9	14	13	18	4	2	13	16		116	VI	10.84
VII	12	16	8	9	9	17	2	1	9	5		88	VII	8.22
VIII	5	4	4	3	3	8	1	0	6	2		36	VIII	3.36
IX	3	1	2	1	0	3	0	0	0	0		10	IX	0.93
TOTAL	111	113	103	105	100	115	115	102	103	103		1070	1070	100.00
I Expected	no	no	no	no	no	no	no	no	no	no				
II Expected	yes	no	yes	yes	yes	yes	yes	yes	yes	no				
III Expected	yes	no	yes	yes	yes	yes	yes	yes	yes	no				
Sheep	3	2	1	3	3	3	2	3	3	2	**25**			
Rabbits	1	0	4	2	3	2	0	0	2	1	**15**			
Roos	3	1	2	2	2	2	2	2	2	2	**20**			
Lichen	2	2	1	2	2	1	2	1	2	1	**16**			
Fire	no	no	no	no	no	no	yes	yes	no	no				

yes = sheep absent, cohort expected
no = sheep present, cohort not expected

Dung Counts
0=none
1=occasional
2=common
3=abundant



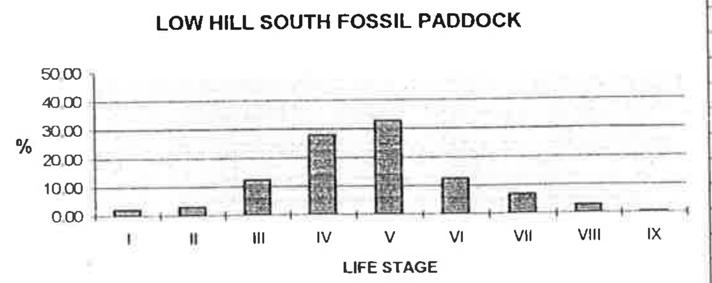
LOW HILL SOUTH FOSSIL PADDOCK - SIAM STATION
GAWLER RANGES SOIL CONSERVATION DISTRICT



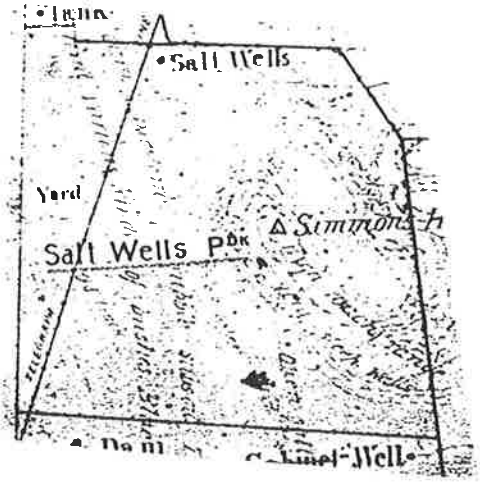
1893

1995

LOW HILL SOUTH FP																% OF
LIFE STAGE	CLS1	CLS2	CLS3	CLS4	CLS5	CLS6	CLS7	CLS8	CLS9	CLS10	CLS11	CLS12		TOTAL	LS	TOTAL
I	4	0	0	0	0	0	0	0	0	0	0	21		25	I	1.97
II	1	0	1	0	0	0	0	0	16	1	0	18		37	II	2.91
III	60	2	2	0	0	0	0	4	24	0	0	63		155	III	12.20
IV	15	42	36	40	46	35	16	36	22	19	47	0		354	IV	27.87
V	20	51	42	47	41	48	31	44	23	38	31	0		416	V	32.76
VI	6	11	15	18	10	12	21	15	12	22	15	0		157	VI	12.36
VII	0	7	11	6	3	7	18	8	7	12	7	0		86	VII	6.77
VIII	0	0	3	2	1	3	14	3	0	8	1	0		35	VIII	2.76
IX	0	0	0	0	0	0	5	0	0	0	0	0		5	IX	0.39
TOTAL	106	113	110	113	101	105	105	110	104	100	101	102		1270	1270	100.00
I Expected	no	yes	no	no	no	no	no	no	no	no	no	no		yes = sheep absent, cohort expected		
II Expected	yes	yes	yes	yes	no	no	yes	yes	yes	yes	yes	yes		no = sheep present, cohort not expected		
III Expected	yes	yes	yes	yes	no	no	yes	yes	yes	yes	yes	yes				
																Dung Counts
Sheep	1	1	2	3	2	2	2	3	3	2	1	2	**24**	med		0=none
Rabbits	0	2	1	2	1	1	1	0	0	2	2	0	**12**	low		1=occasional
Roos	3	2	2	2	2	2	2	2	3	2	1	1	**24**	med		2=common
Lichen	3	2	2	0	2	1	3	2	1	2	2	3	**23**	med		3=abundant
Fire	yes	no	no	no	no	no	no	no	no	no	no	yes				



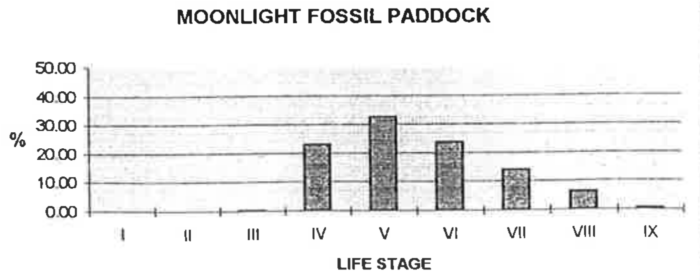
MOONLIGHT FOSSIL PADDOCK - TREGALANA STATION GAWLER RANGES SOIL CONSERVATION DISTRICT



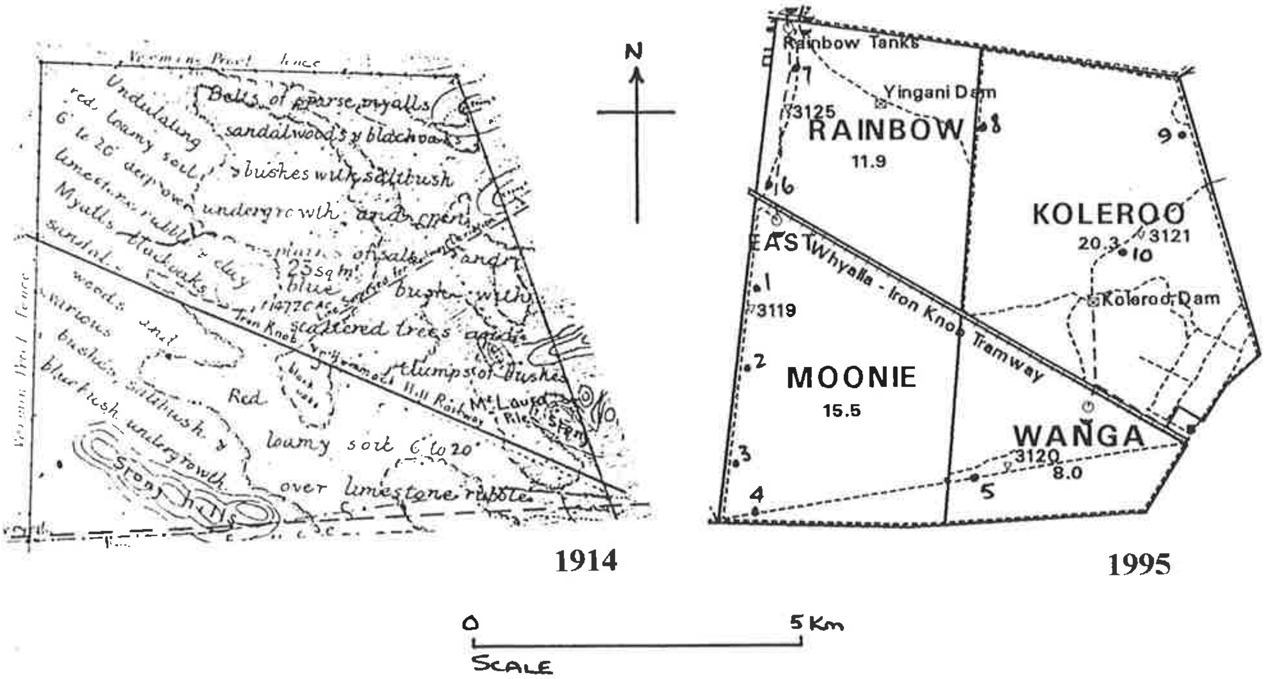
1887

1995

MOONLIGHT FP																% OF
LIFE STAGE	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	SM9	SM10				TOTAL	LS	TOTAL
I	0	0	0	0	0	0	0	0	0	0				0	I	0.00
II	0	0	0	0	0	0	0	0	0	0				0	II	0.00
III	0	0	1	0	0	0	0	0	0	0				1	III	0.09
IV	21	27	22	39	41	27	17	21	12	20				247	IV	23.02
V	53	43	33	32	29	34	33	26	32	34				349	V	32.53
VI	22	18	23	25	24	29	32	12	32	37				254	VI	23.67
VII	13	10	19	9	10	11	14	29	21	13				149	VII	13.89
VIII	8	4	12	2	2	1	6	19	7	6				67	VIII	6.24
IX	1	0	0	0	0	0	0	4	1	0				6	IX	0.56
TOTAL	118	102	110	107	106	102	102	111	105	110				1073	1073	100.00
I Expected	no	no	no	no	no	no	no	no	no	no		yes = sheep absent, cohort expected				
II Expected	yes	yes	no	no	yes	no	no	yes	yes	yes		no = sheep present, cohort not expected				
III Expected	yes	yes	no	no	yes	no	no	yes	yes	yes						
														Dung Counts		
Sheep	1	2	1	1	1	2	1	1	2	2	**14**	med		0=none		
Rabbits	1	2	1	1	3	1	1	1	1	1	**13**	med		1=occasional		
Roos	2	1	2	1	1	2	2	1	1	1	**14**	med		2=common		
Lichen	2	1	2	0	2	1	3	2	1	1	**15**	med		3=abundant		
Fire	no	no	no	no	no	no	no	no	no	no						



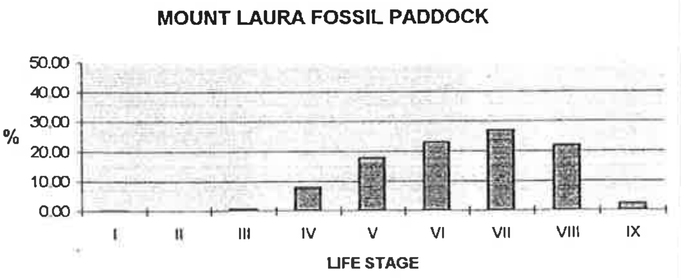
MOUNT LAURA FOSSIL PADDOCK - MIDDLEBACK STATION GAWLER RANGES SOIL CONSERVATION DISTRICT



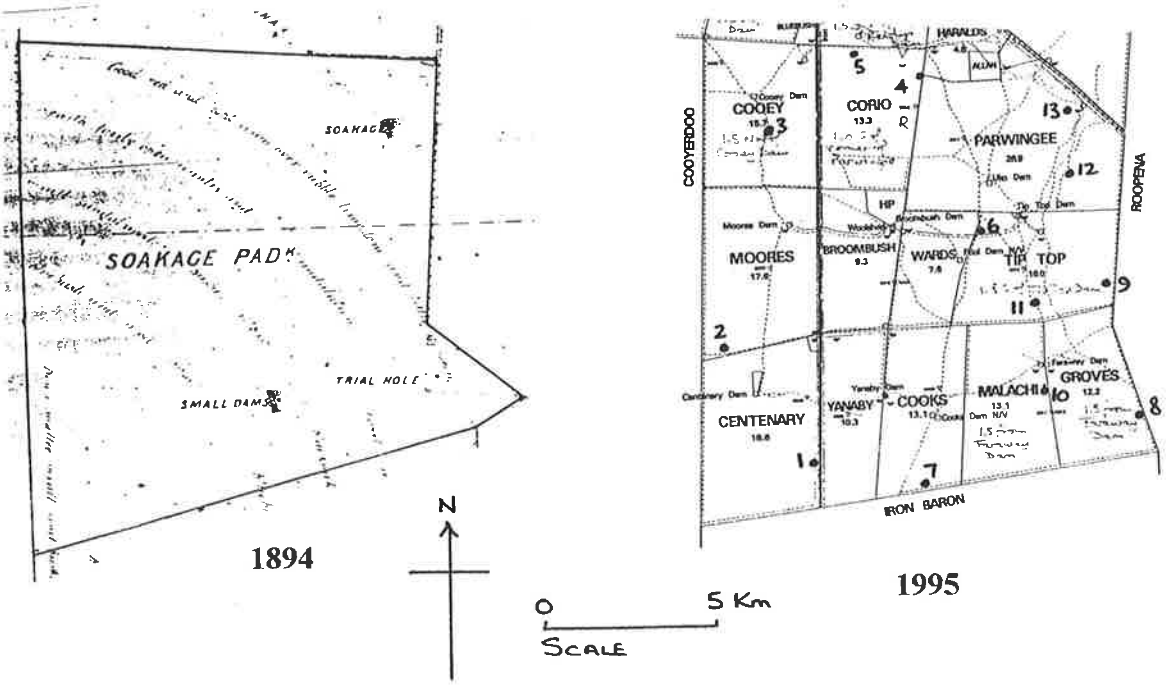
MOUNT LAURA FP													% OF
LS	SL1	SL2	SL3	SL4	SL5	SL6	SL7	SL8	SL9	SL10	TOTAL	LS	TOTAL
I	1	0	0	0	0	0	0	0	0	0	1	I	0.10
II	0	0	0	0	0	0	0	0	0	0	0	II	0.00
III	2	1	0	1	0	2	0	0	0	1	7	III	0.71
IV	7	7	7	16	3	12	4	11	4	6	77	IV	7.79
V	13	10	10	26	17	20	22	22	14	21	175	V	17.71
VI	12	21	17	26	22	23	33	27	18	27	226	VI	22.87
VII	23	31	23	22	17	26	25	29	35	33	264	VII	26.72
VIII	37	30	43	12	5	17	12	18	29	13	216	VIII	21.86
IX	7	4	2	0	0	1	5	0	3	0	22	IX	2.23
TOTAL	102	104	102	103	64	101	101	107	103	101	988	988	100.00
I Expected	no	no	no	no	no	no	no	no	no	no			
II Expected	no	no	no	no	yes	no	no	no	yes	yes			
III Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes			
Sheep	Data not collected at this site												
Rabbits	Data not collected at this site												
Roos	Data not collected at this site												
Lichen	Data not collected at this site												
Fire	no	no	no	no	no	no	no	no	no	no			

yes = sheep absent, cohort expected
no = sheep present, cohort not expected

Dung Counts
0=none
1=occasional
2=common
3=abundant



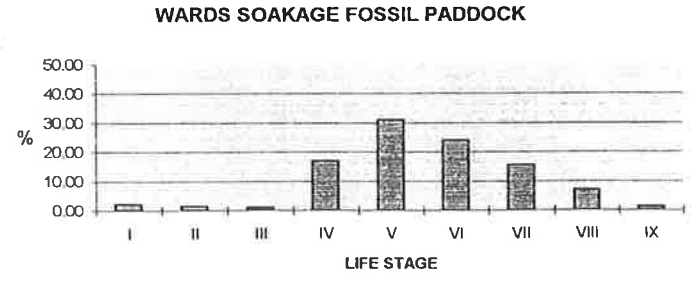
WARDS SOAKAGE FOSSIL PADDOCK - KATUNGA STATION
GAWLER RANGES SOIL CONSERVATION DISTRICT



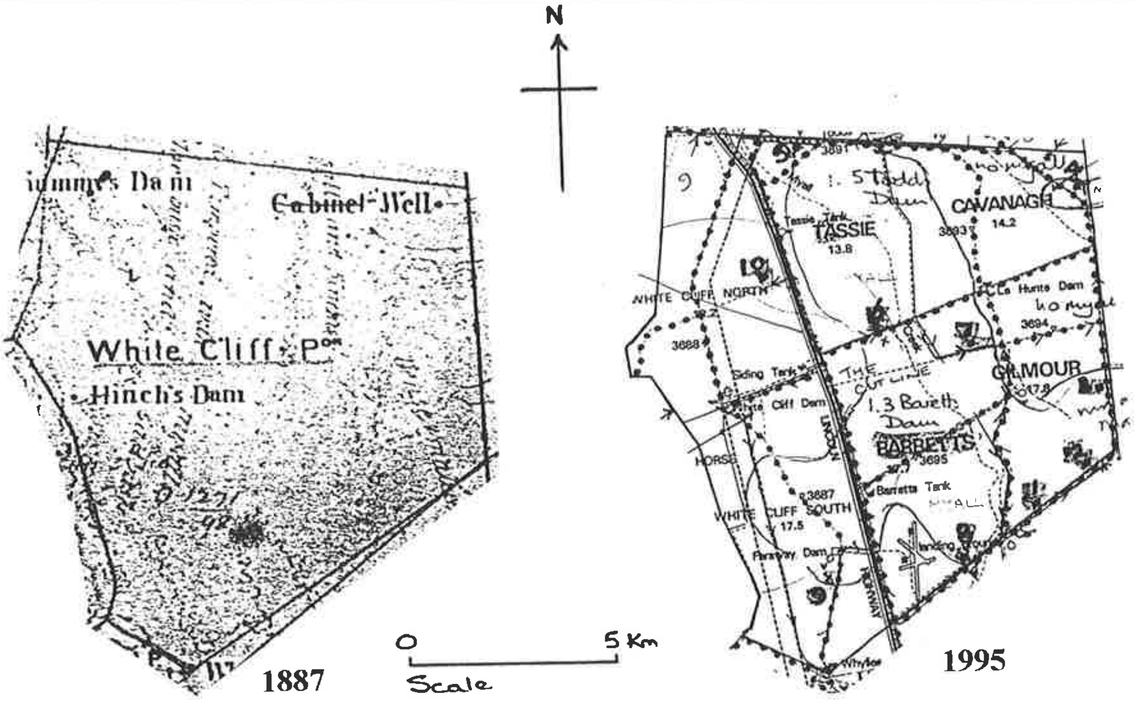
1894

1995

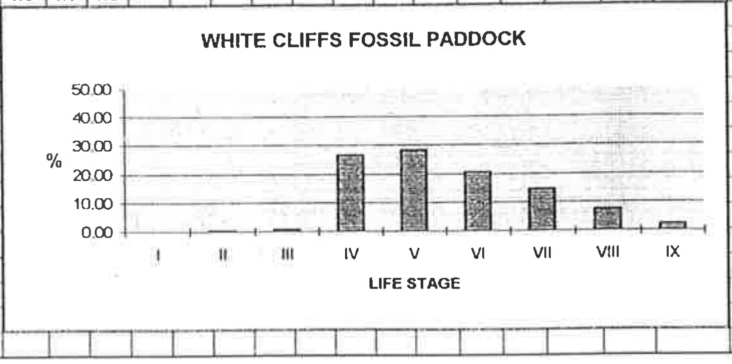
WARDS SOAKAGE FP																		% OF
LIFE STAGE	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	SS11	SS12	SS13			TOTAL		TOTAL
I	3	0	0	0	0	0	0	0	0	0	0	0	25			28	I	2.07
II	1	0	0	0	0	0	0	0	0	0	0	0	20			21	II	1.55
III	0	0	0	0	0	0	0	0	0	0	0	0	13			13	III	0.96
IV	21	27	4	16	13	8	7	26	12	26	26	21	21			228	IV	16.86
V	32	38	31	33	36	30	39	36	31	30	41	31	10			418	V	30.92
VI	21	24	24	27	31	33	26	21	27	30	22	36	3			325	VI	24.04
VII	13	14	22	13	18	23	15	12	30	16	9	20	3			208	VII	15.38
VIII	7	6	18	11	7	7	11	6	7	4	3	7	1			95	VIII	7.03
IX	1	0	8	2	0	2	2	0	1	0	0	0	0			16	IX	1.18
TOTAL	99	109	107	102	105	103	100	101	108	106	101	115	96			1352	1352	100.00
I Expected	no	no	no	no	no	no	no	no	no	no	no	no	no		yes = sheep absent,			
II Expected	no	no	no	yes	yes	yes	no	yes	yes	no	no	no	no		cohort expected			
III Expected	no	yes	yes	yes	yes	yes	no	yes	yes	no	no	no	no		no = sheep present,			
															cohort not expected			
																	Dung Counts	
Sheep	2	1	2	2	2	2	2	2	1	2	2	2	2	**24**	med		0=none	
Rabbits	0	1	1	1	1	2	1	0	2	2	1	1	1	**14**	med		1=occasional	
Roos	2	2	3	1	2	2	2	2	2	2	2	2	2	**26**	high		2=common	
Lichen	1	2	2	2	1	1	2	3	2	1	2	1	1	**21**	med		3=abundant	
Fire	no	no	no	no	no	no	no	no	no	no	no	no	no					



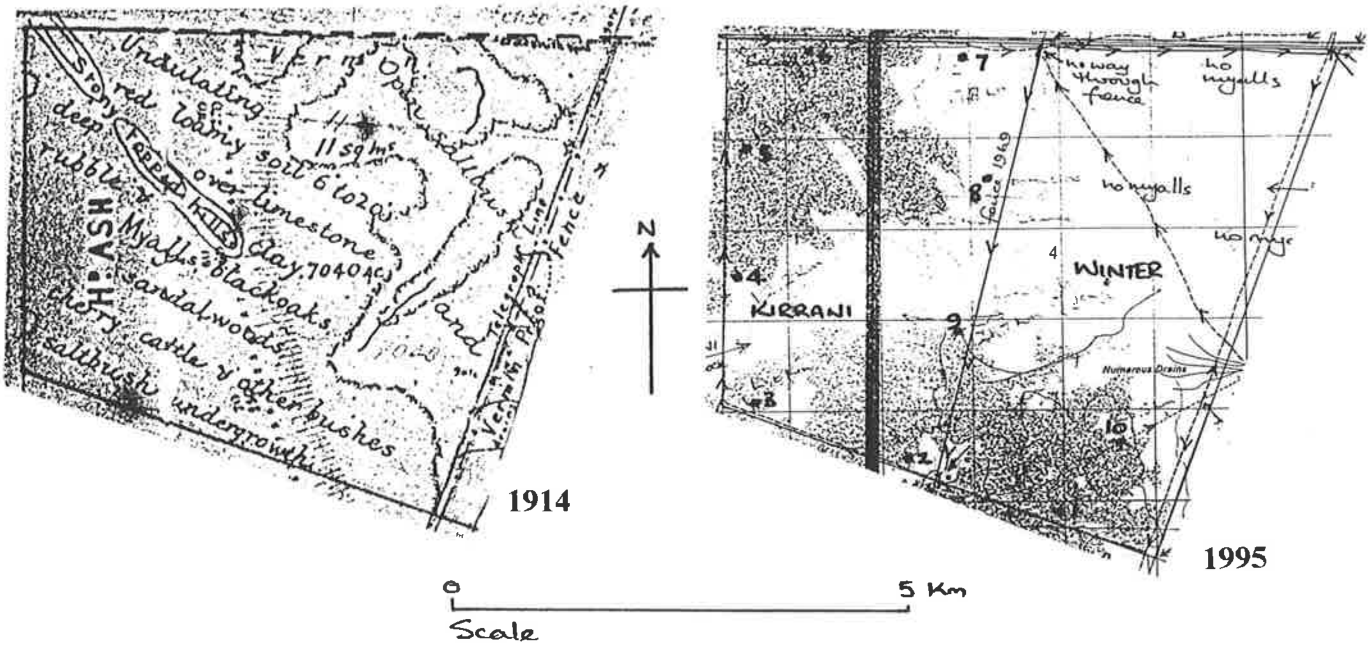
WHITE CLIFFS FOSSIL PADDOCK - TREGALANA STATION GAWLER RANGES SOIL CONSERVATION DISTRICT



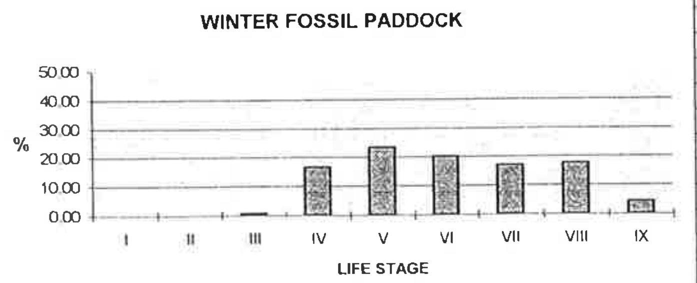
WHITE CLIFFS FP															% OF
LIFE STAGE	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10			TOTAL	LS	TOTAL
I	0	0	0	0	0	0	0	0	0	0			0	I	0.00
II	0	2	0	0	0	0	0	0	0	0			2	II	0.19
III	2	2	0	0	0	0	2	0	1	0			7	III	0.66
IV	26	33	38	19	18	38	32	27	17	32			280	IV	26.47
V	25	19	32	23	37	33	33	37	33	26			298	V	28.17
VI	16	16	14	24	39	15	16	17	31	29			217	VI	20.51
VII	23	21	8	17	11	9	14	14	18	18			153	VII	14.46
VIII	13	8	7	14	3	4	8	6	8	7			78	VIII	7.37
IX	4	4	2	4	0	1	2	3	2	1			23	IX	2.17
TOTAL	109	105	101	101	108	100	107	104	110	113			1058	1058	100.00
I Expected	no	no	no	no	no	no	no	no	no	no		yes = sheep absent, cohort expected			
II Expected	yes	yes	yes	yes	yes	no	yes	yes	no	no		no = sheep present, cohort not expected			
III Expected	yes	yes	yes	yes	yes	no	yes	yes	no	no					
													Dung Counts		
Sheep	1	0	0	1	2	2	0	2	2	2	**12**	med	0=none		
Rabbits	1	0	0	3	1	1	1	1	2	2	**12**	med	1=occasional		
Roos	2	1	1	1	1	1	2	2	2	1	**14**	med	2=common		
Lichen	1	3	3	2	1	1	1	1	1	1	**15**	med	3=abundant		
Fire	no	no	no	no	no	no	no	no	no	no					



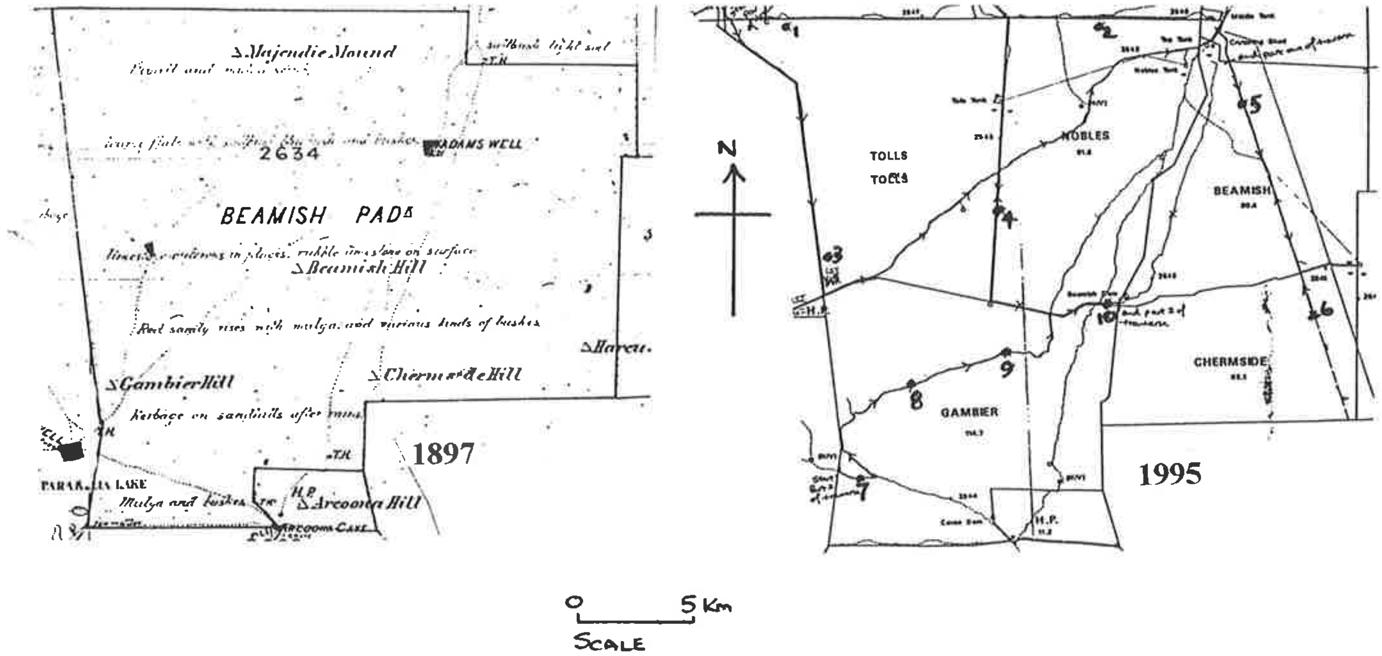
WINTER FOSSIL PADDOCK - NONOWIE STATION
GAWLER RANGES SOIL CONSERVATION DISTRICT



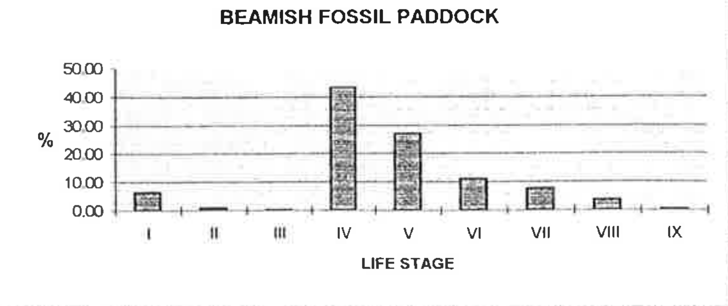
WINTER FP													% OF
LIFE STAGE	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	TOTAL	LS	TOTAL
I	0	0	0	0	0	0	0	0	0	0	0	I	0.00
II	0	0	0	0	0	0	0	0	0	0	0	II	0.00
III	0	1	2	1	0	1	1	0	0	0	6	III	0.66
IV	37	12	15	23	18	16	1	1	22	7	152	IV	16.65
V	30	43	21	26	16	23	3	6	28	17	213	V	23.33
VI	15	30	23	21	17	18	3	8	22	28	185	VI	20.26
VII	8	10	12	15	23	17	10	14	19	27	155	VII	16.98
VIII	9	5	14	15	27	24	12	13	20	23	162	VIII	17.74
IX	4	0	2	0	7	2	16	3	1	5	40	IX	4.38
TOTAL	103	101	89	101	108	101	46	45	112	107	913	913	100.00
I Expected	no	no	no	no	no	no	no	no	no	no	yes = sheep absent, cohort expected		
II Expected	no	no	no	no	no	no	no	no	no	no	no = sheep present, cohort not expected		
III Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	Dung Counts		
Sheep	Data not collected at this site										0=none		
Rabbits	Data not collected at this site										1=occasional		
Roos	Data not collected at this site										2=common		
Lichen	Data not collected at this site										3=abundant		
Fire	no	no	no	no	no	no	no	no	no	no			



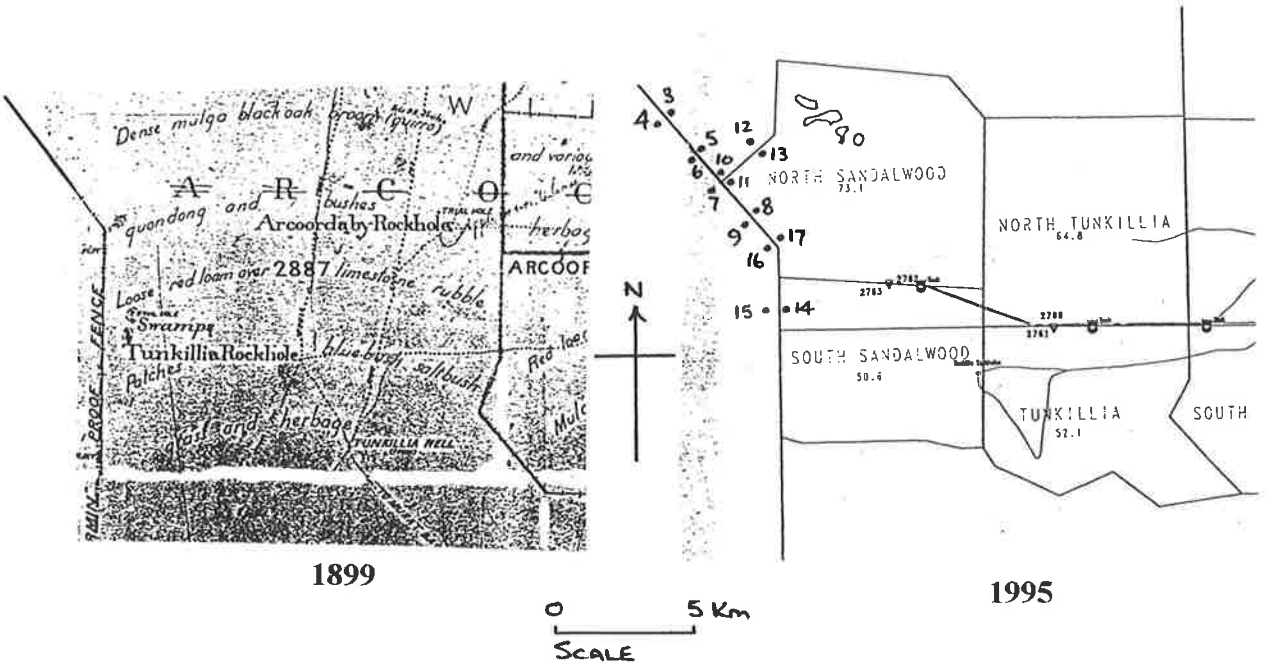
BEAMISH FOSSIL PADDOCK - PARAKYLIA STATION
KINGOONYA SOIL CONSERVATION DISTRICT



BEAMISH FP																% OF
LIFE STAGE	NB1	NB2	NB3	NB4	NB5	NB6	NB7	NB8	NB9	NB10				TOTAL	LS	TOTAL
I	0	1	39	28	0	0	0	0	0	0				68	I	6.31
II	0	1	1	7	1	0	0	0	0	0				10	II	0.93
III	0	1	0	0	0	0	0	0	0	0				1	III	0.09
IV	53	54	34	37	56	53	44	42	43	49				465	IV	43.14
V	27	30	22	23	30	25	31	35	33	35				291	V	26.99
VI	13	7	9	9	8	17	13	12	18	13				119	VI	11.04
VII	4	5	7	6	4	12	11	12	14	8				83	VII	7.70
VIII	2	3	4	4	2	5	5	3	8	2				38	VIII	3.53
IX	1	0	0	0	0	1	1	0	0	0				3	IX	0.28
TOTAL	100	102	116	114	101	113	105	104	116	107				1078	1078	100.00
I Expected	yes	yes	yes	no	no	yes	yes	yes	yes	no			yes = sheep absent, cohort expected			
II Expected	yes	yes	yes	yes	no	yes	yes	yes	yes	yes			no = sheep present, cohort not expected			
III Expected	yes	yes	yes	yes	no	yes	yes	yes	yes	yes						
														Dung Counts		
Sheep	1	2	2	2	2	1	0	0	0	2	**12**	med		0=none		
Rabbits	2	1	0	0	1	2	2	2	1	1	**12**	med		1=occasional		
Roos	1	1	1	1	2	2	1	2	2	2	**15**	med		2=common		
Lichen	2	2	1	2	1	2	2	2	1	1	**16**	med		3=abundant		
Fire	no	no	no	no	no	no	no	no	no	no						



DOG FENCE FOSSIL PADDOCK - NORTH WELL AND WILGENA STATIONS KINGOONYA SOIL CONSERVATION DISTRICT



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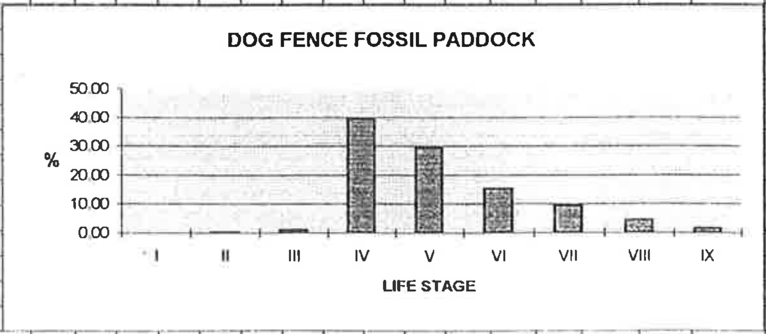
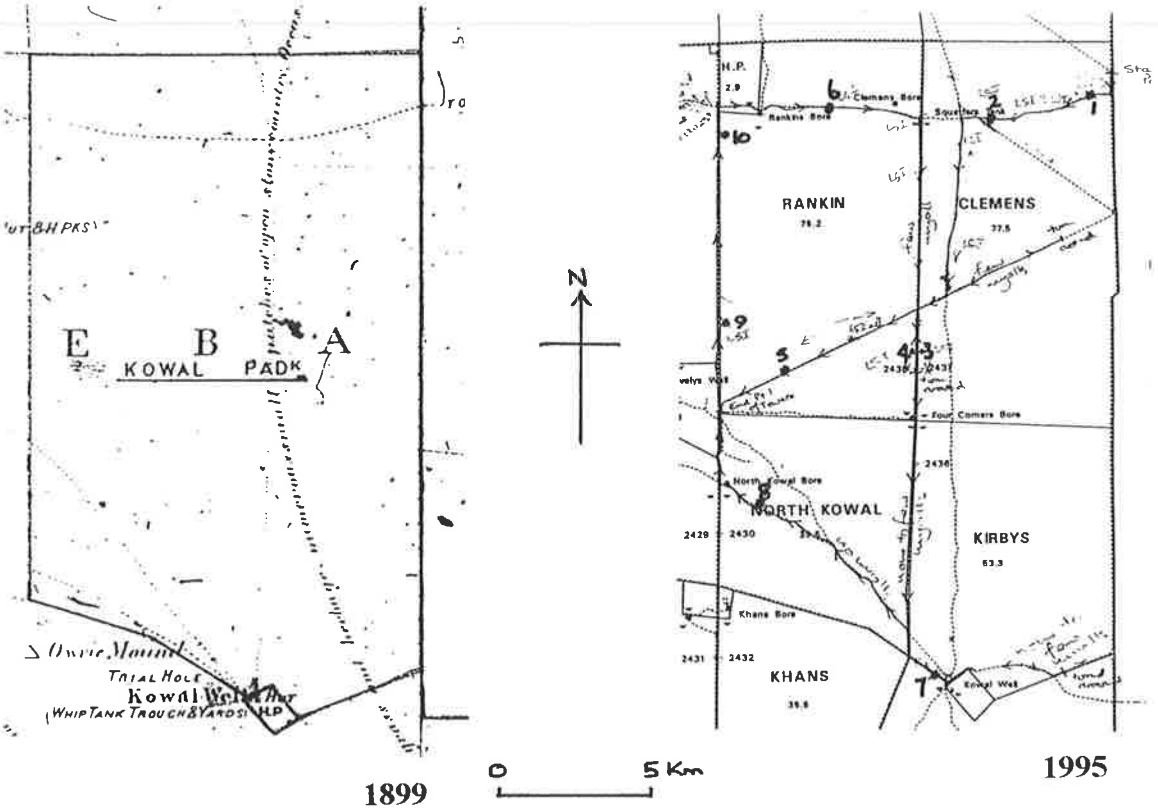
DOG FENCE FP																		% OF
LIFE STAGE	NW3	NW4	NW5	NW6	NW7	NW8	NW9	NW10	NW11	NW12	NW13	NW14	NW15	NW16	NW17	TOTAL	LS	TOTAL
I	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	I	0.07
II	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	II	0.13
III	0	0	0	0	0	5	3	4	0	0	0	0	2	0	0	14	III	0.92
IV	18	28	31	33	20	51	52	65	58	37	33	43	50	37	39	595	IV	39.22
V	12	21	39	35	12	34	30	25	28	48	37	24	32	31	34	442	V	29.14
VI	9	17	20	16	8	7	8	7	15	26	22	16	18	25	18	232	VI	15.29
VII	7	16	10	13	9	7	8	2	6	14	10	18	7	9	7	143	VII	9.43
VIII	3	13	6	6	3	2	1	1	3	4	7	6	4	4	3	66	VIII	4.35
IX	1	8	5	4	0	0	0	0	0	1	2	1	0	0	0	22	IX	1.45
TOTAL	50	103	111	107	52	106	102	104	113	130	111	108	113	106	101	1517	1517	100.00
I Expected	yes	yes	yes	yes	yes	no	yes	yes	no	yes	no	no	yes	yes	no	yes = sheep absent,		
II Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	cohort expected		
III Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no = sheep present,		
																cohort not expected		
Sheep	1	0	0	0	0	0	0	0	1	0	1	0	1	0	1	**5**	low	
Rabbits	1	1	1	1	1	1	1	2	2	1	1	2	1	1	1	**18**	med	
Roos	3	0	3	0	0	2	0	2	2	1	2	0	2	1	3	**21**	med	
Lichen	2	2	3	2	1	2	2	1	1	2	2	2	1	3	1	**27**	med	
Fire	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no			

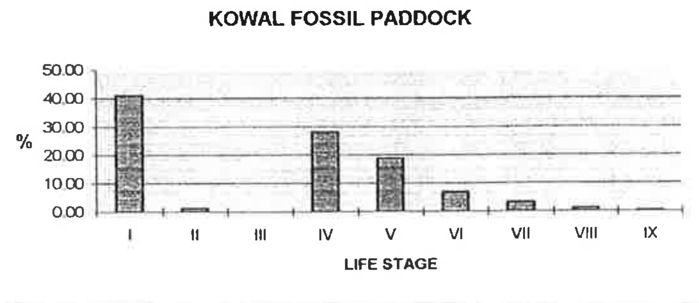


Dung Counts
0=none
1=occasional
2=common
3=abundant

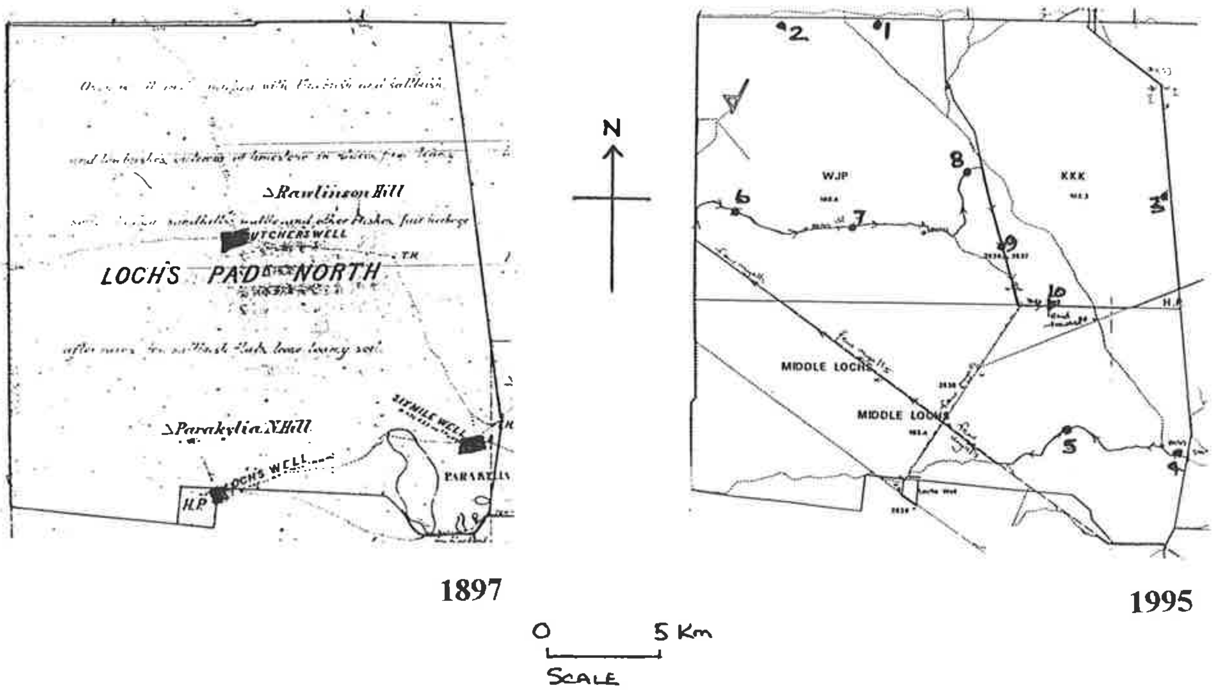
KOWAL FOSSIL PADDOCK - MOUNT VIVIAN STATION KINGOONYA SOIL CONSERVATION DISTRICT



KOWAL FP															% OF
LIFE STAGE	NK1	NK2	NK3	NK4	NK5	NK6	NK7	NK8	NK9	NK10			TOTAL	LS	TOTAL
I	90	70	39	38	0	47	52	12	18	68			434	I	40.94
II	5	4	2	1	0	0	0	0	0	0			12	II	1.13
III	0	0	0	0	0	0	0	0	0	0			0	III	0.00
IV	1	21	31	28	67	31	20	42	41	15			297	IV	28.02
V	4	16	22	21	33	20	22	22	28	11			199	V	18.77
VI	1	5	8	11	3	10	11	9	9	6			73	VI	6.89
VII	0	3	5	7	0	4	3	2	6	4			34	VII	3.21
VIII	1	0	1	2	0	1	1	1	1	2			10	VIII	0.94
IX	0	0	1	0	0	0	0	0	0	0			1	IX	0.09
TOTAL	102	119	109	108	103	113	109	88	103	106			1060	1060	100.00
I Expected	yes	no	yes	yes	no	no	no	no	no	no		yes = sheep absent, cohort expected			
II Expected	yes	yes	yes	yes	no	yes	no	no	no	yes		no = sheep present, cohort not expected			
III Expected	yes	yes	yes	yes	yes	yes	no	yes	yes	yes					
													Dung Counts		
Sheep	2	2	3	3	1	3	3	2	2	3	24	high	0=none		
Rabbits	0	0	0	0	2	0	0	0	0	0	2	low	1=occasional		
Roos	1	1	1	1	1	1	1	1	1	2	11	med	2=common		
Lichen	1	1	1	1	1	1	1	1	1	1	10	low	3=abundant		
Fire	yes	no	no	yes	no	no	no	no	no	no					



LOCHS NORTH FOSSIL PADDOCK - PARAKYLIA STATION
KINGOONYA SOIL CONSERVATION DISTRICT



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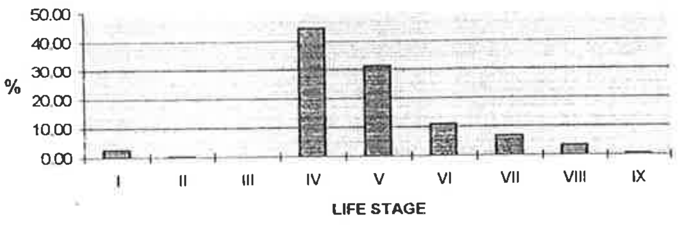
LOCHS NORTH FP

LIFE STAGE	NNL1	NNL2	NNL3	NNL4	NNL5	NNL6	NNL7	NNL8	NNL9	NNL10			TOTAL	LS	% OF TOTAL
I	9	1	1	0	0	0	4	0	0	12			27	I	2.51
II	1	0	1	0	0	0	0	0	0	0			2	II	0.19
III	0	0	0	0	0	0	0	0	0	0			0	III	0.00
IV	62	52	53	46	43	47	43	46	45	41			478	IV	44.42
V	26	31	36	34	38	35	36	32	38	32			338	V	31.41
VI	8	9	12	16	10	12	13	12	9	17			118	VI	10.97
VII	3	6	5	8	7	7	11	6	6	14			73	VII	6.78
VIII	1	5	4	2	2	3	6	4	2	7			36	VIII	3.35
IX	0	1	0	0	0	0	1	1	0	1			4	IX	0.37
TOTAL	110	105	112	106	100	104	114	101	100	124			1076	1076	100.00
I Expected	no	yes	yes	no	no	yes	no	no	no	no					
II Expected	yes	yes	yes	no	no	yes	no	no	no	yes					
III Expected	yes	yes	yes	no	no	yes	no	no	no	yes					
Sheep	1	1	2	2	0	0	0	0	1	2	**9**	low			
Rabbits	0	3	1	2	2	2	0	1	1	0	**12**	med			
Roos	2	2	1	2	1	1	2	2	2	1	**16**	med			
Lichen	1	1	2	2	2	3	2	2	1	1	**17**	med			
Fire	no	no	no	yes	no	no	no	no	no	no					

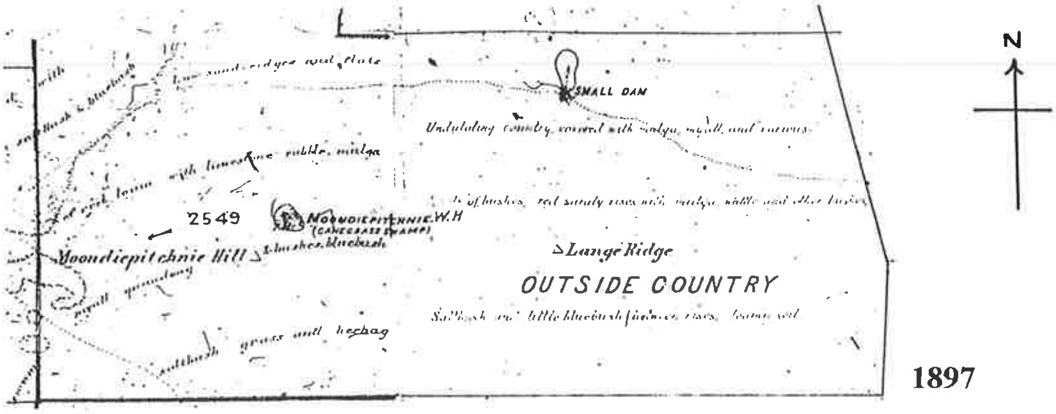
yes = sheep absent, cohort expected
no = sheep present, cohort not expected

Dung Counts
0=none
1=occasional
2=common
3=abundant

LOCHS NORTH FOSSIL PADDOCK



OUTSIDE COUNTRY FOSSIL PADDOCK - PARAKYLIA STATION
KINGOONYA SOIL CONSERVATION DISTRICT



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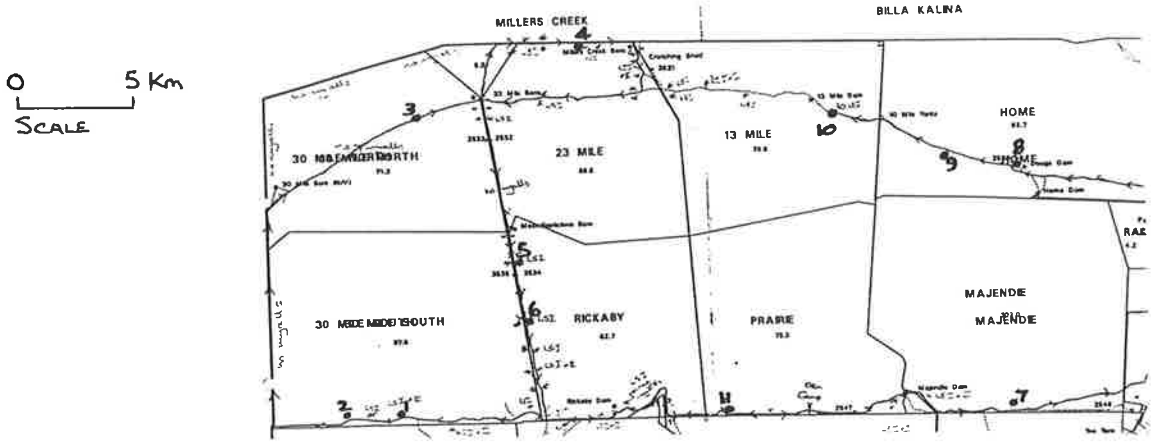

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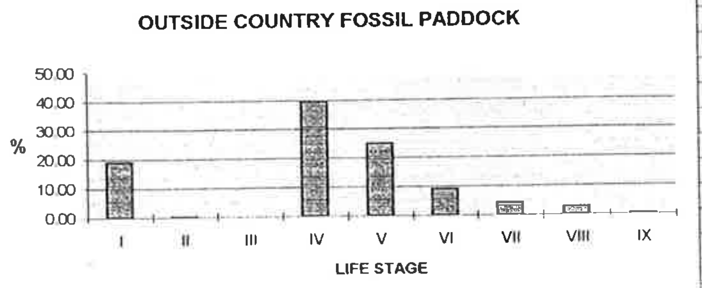
OUTSIDE COUNTRY FP													
LIFE STAGE	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8	NO9	NO10	NO11	TOTAL	LS	% OF TOTAL
I	10	0	0	67	74	50	1	0	0	28	2	232	I	19.08
II	1	0	0	0	0	0	0	0	0	0	1	2	II	0.16
III	0	0	0	0	0	0	0	0	0	0	0	0	III	0.00
IV	50	53	59	26	27	34	46	48	49	38	52	482	IV	39.64
V	33	30	32	8	9	18	34	36	35	25	42	302	V	24.84
VI	13	13	4	6	2	5	17	16	13	8	12	109	VI	8.96
VII	5	7	2	4	0	1	7	8	4	7	7	52	VII	4.28
VIII	4	5	2	4	0	1	3	6	3	3	2	33	VIII	2.71
IX	0	2	1	0	0	0	1	0	0	0	0	4	IX	0.33
TOTAL	116	110	100	115	112	109	109	114	104	109	118	1216	1216	100.00

	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8	NO9	NO10	NO11
I Expected	yes	yes	no	no	no	no	no	no	no	no	no
II Expected	yes	yes	no	no	no	no	no	no	no	no	no
III Expected	yes	yes	yes	yes	no	no	yes	yes	yes	no	yes

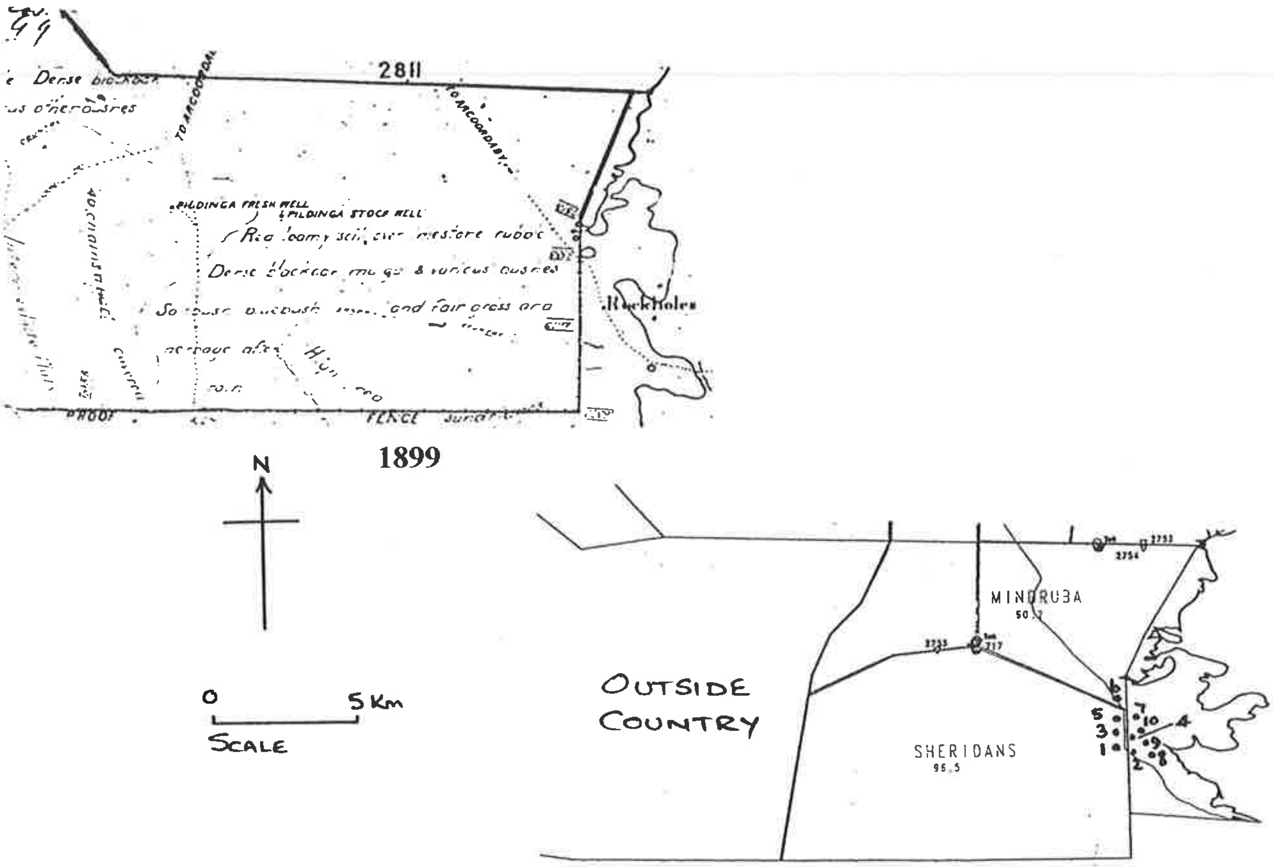
yes = sheep absent, cohort expected
no = sheep present, cohort not expected

	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8	NO9	NO10	NO11		
Sheep	2	1	1	2	3	3	2	3	2	2	1	**22**	med
Rabbits	0	3	3	0	0	0	1	1	3	0	0	**11**	low
Roos	1	2	1	2	1	1	1	1	1	1	1	**13**	med
Lichen	1	1	2	1	1	1	1	1	1	1	1	**12**	med
Fire	no	no	no	no	no	no	no	no	no	no	no		

Dung Counts
0=none
1=occasional
2=common
3=abundant



SHERIDANS FOSSIL PADDOCK - NORTH WELL STATION KINGOONYA SOIL CONSERVATION DISTRICT



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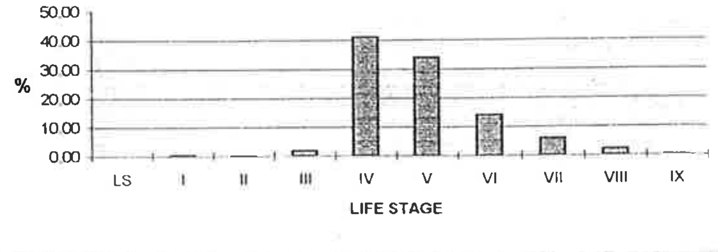
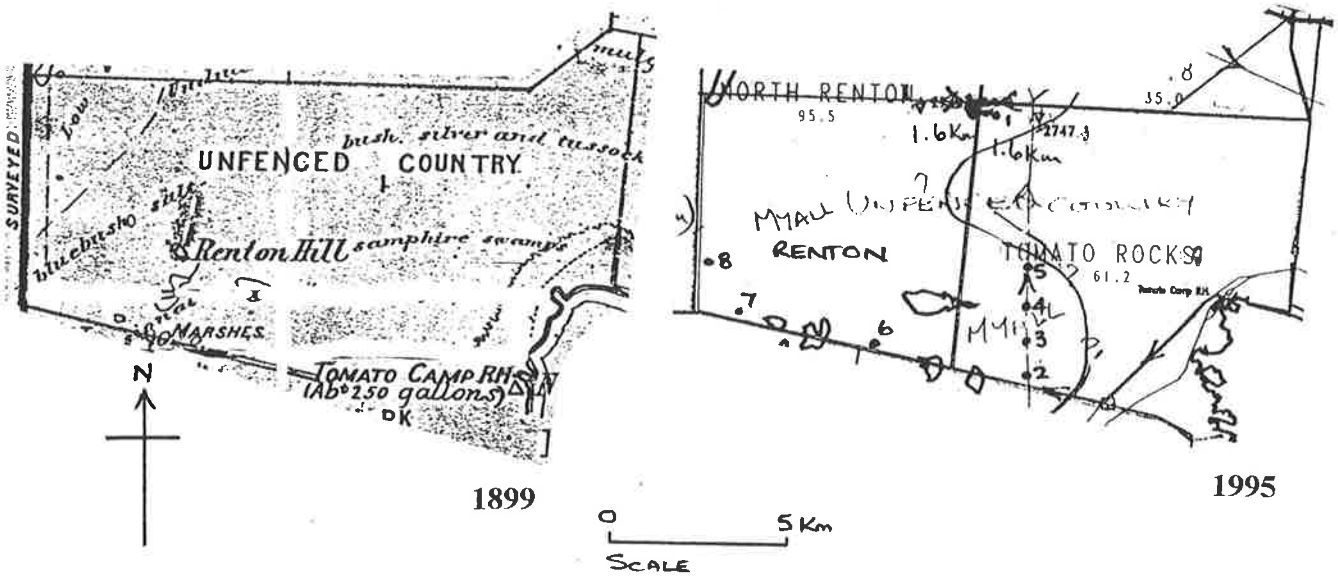
SHERIDANS FP															
LIFE STAGE	NWS1	NWS2	NWS3	NWS4	NWS5	NWS6	NWS7	NWS8	NWS9	NWS10			TOTAL	LS	% OF TOTAL
I	0	0	0	0	3	0	1	0	0	0			4	I	0.39
II	0	0	1	1	0	0	0	0	0	0			2	II	0.20
III	0	2	6	0	0	2	2	3	0	4			19	III	1.85
IV	35	31	42	35	45	23	51	56	59	43			420	IV	40.98
V	51	43	31	34	30	16	37	31	33	43			349	V	34.05
VI	13	11	17	22	19	7	13	16	12	16			146	VI	14.24
VII	9	11	7	5	4	4	5	6	3	7			61	VII	5.95
VIII	2	3	3	6	4	2	1	1	1	0			23	VIII	2.24
IX	0	0	0	0	0	1	0	0	0	0			1	IX	0.10
TOTAL	110	101	107	103	105	55	110	113	108	113			1025	1025	100.00
I Expected	no	yes	no	yes	no	no	yes	yes	yes	yes		yes = sheep absent, cohort expected			
II Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		no = sheep present, cohort not expected			
III Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes					
													Dung Counts		
Sheep	3	0	2	0	1	3	0	0	0	0	9	low	0=none		
Rabbits	1	1	1	1	1	2	1	1	2	1	12	med	1=occasional		
Roos	1	2	2	1	1	1	1	1	2	1	13	med	2=common		
Lichen	1	2	2	1	1	1	1	1	2	1	13	med	3=abundant		
Fire	no	no	no	no	no	no	no	no	no	no					

SHERIDANS FOSSIL PADDOCK



TOMATO ROCKS FOSSIL PADDOCK - NORTH WELL STATION KINGOONYA SOIL CONSERVATION DISTRICT



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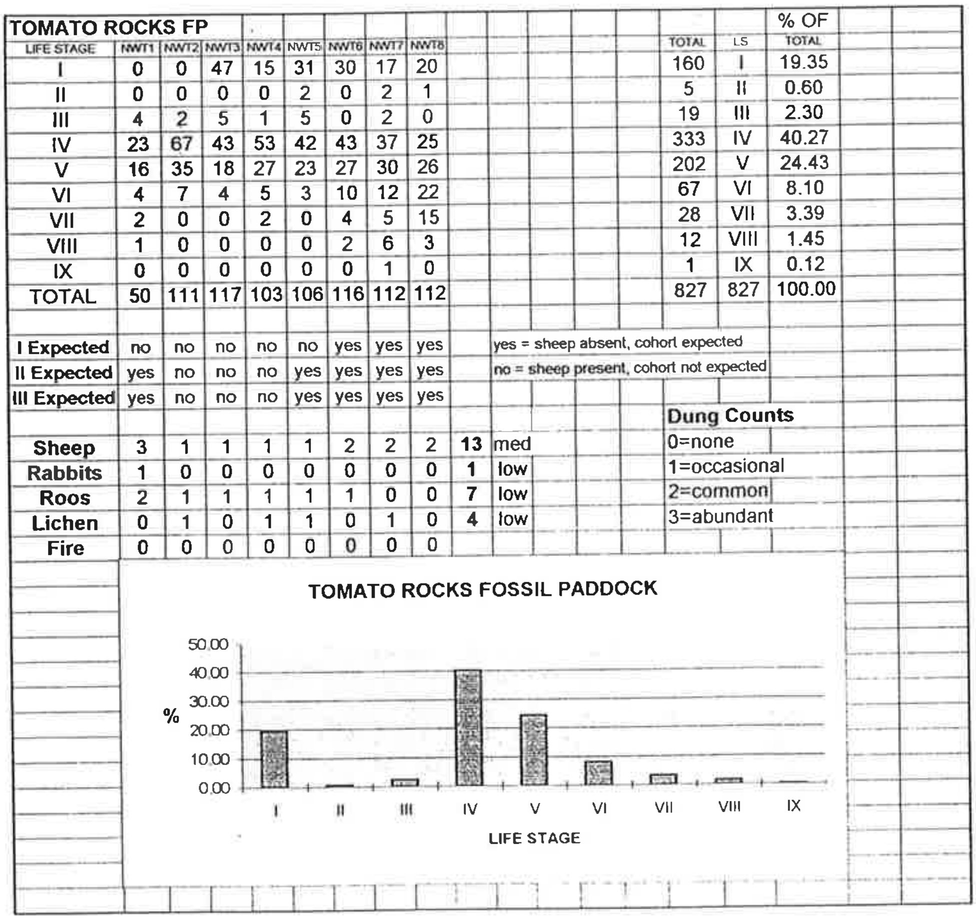
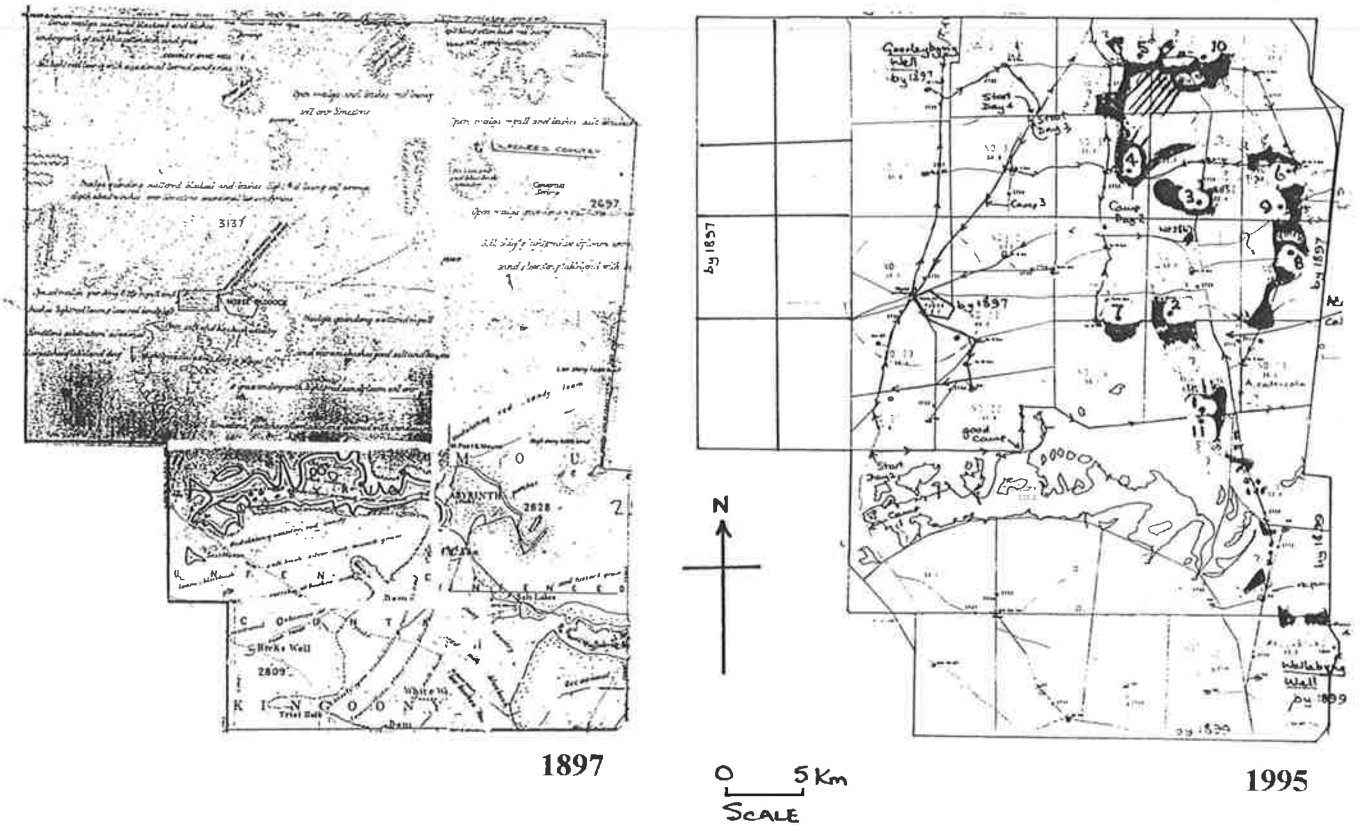


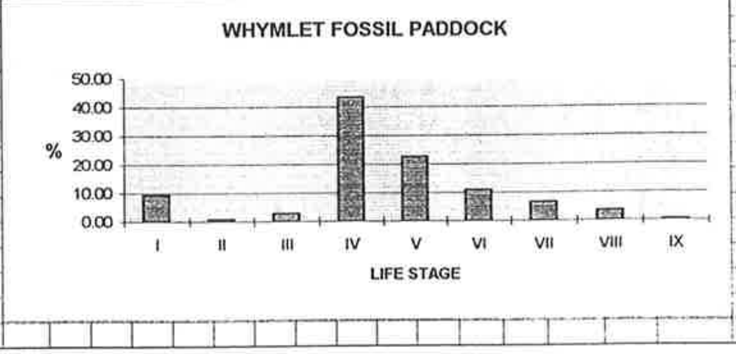
TOMATO ROCKS FP LIFE STAGE	NWT1	NWT2	NWT3	NWT4	NWT5	NWT6	NWT7	NWT8			TOTAL	LS	% OF TOTAL
I	0	0	47	15	31	30	17	20			160	I	19.35
II	0	0	0	0	2	0	2	1			5	II	0.60
III	4	2	5	1	5	0	2	0			19	III	2.30
IV	23	67	43	53	42	43	37	25			333	IV	40.27
V	16	35	18	27	23	27	30	26			202	V	24.43
VI	4	7	4	5	3	10	12	22			67	VI	8.10
VII	2	0	0	2	0	4	5	15			28	VII	3.39
VIII	1	0	0	0	0	2	6	3			12	VIII	1.45
IX	0	0	0	0	0	0	1	0			1	IX	0.12
TOTAL	50	111	117	103	106	116	112	112			827	827	100.00
I Expected	no	no	no	no	no	yes	yes	yes		yes = sheep absent, cohort expected			
II Expected	yes	no	no	no	yes	yes	yes	yes		no = sheep present, cohort not expected			
III Expected	yes	no	no	no	yes	yes	yes	yes					
											Dung Counts		
Sheep	3	1	1	1	1	2	2	2	**13**	med	0=none		
Rabbits	1	0	0	0	0	0	0	0	**1**	low	1=occasional		
Roos	2	1	1	1	1	1	0	0	**7**	low	2=common		
Lichen	0	1	0	1	1	0	1	0	**4**	low	3=abundant		
Fire	0	0	0	0	0	0	0	0					

WHYMLET FOSSIL PADDOCK - NORTH WELL STATION
KINGOONYA SOIL CONSERVATION DISTRICT



1897 1995

WHYMLET FP																% OF
LIFE STAGE	NWW1	NWW2	NWW3	NWW4	NWW5	NWW6	NWW8	NWW9	NWW10	NWW11	NWW12			TOTAL		TOTAL
I	1	2	8	0	0	54	4	1	25	0	4			99	I	9.25
II	0	0	0	0	0	0	0	0	8	0	0			8	II	0.75
III	3	4	3	0	8	0	0	3	0	3	5			29	III	2.71
IV	51	40	45	54	50	22	30	53	10	57	53			465	IV	43.46
V	27	27	29	25	24	12	12	37	4	25	20			242	V	22.62
VI	18	18	12	18	9	7	2	1	0	17	13			115	VI	10.75
VII	13	7	8	8	9	4	1	2	1	7	11			71	VII	6.64
VIII	4	4	3	6	7	3	0	5	0	3	2			37	VIII	3.46
IX	0	0	1	1	1	0	0	1	0	0	0			4	IX	0.37
TOTAL	117	102	109	112	108	102	49	103	48	112	108			1070	1070	100.00
I Expected	no	no	no	no	no	no	no	no	no	no	no		yes = sheep absent, cohort expected			
II Expected	no	no	no	no	no	no	no	no	no	no	no		no = sheep present, cohort not expected			
III Expected	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no					
															Dung Counts	
Sheep	1	1	2	2	1	3				0	2	**12**	med		0=none	
Rabbits	1	0	0	1	1	0				0	1	**4**	low		1=occasional	
Roos	1	2	1	1	1	2				1	1	**10**	med		2=common	
Lichen	1	2	1	1	0	1				1	1	**8**	low		3=abundant	
Fire	no	no	no	no	no	yes	no	no	no	no	no					



APPENDIX 8: VEGETATION DESCRIPTIONS FROM THE LATE 19th CENTURY

BEAMISH FOSSIL PADDOCK, PARAKYLIA STATION

Northern part of paddock E.A. King, Surveyor - 27/8/1897 Plan 414
- Myall and mulga scrub, loamy flats with saltbush, bluebush and bushes, limestone outcrops in places, rubble limestone on surface.

Southern part of paddock E.A. King, Surveyor - 27/8/1897 Plan 414
- Red sandy rises with mulga and various kinds of bushes, herbage on sandhills after rain.
- Mulga and bushes.

DOG FENCE FOSSIL PADDOCK, NORTH WELL AND WILGENA STATIONS

Northern part of paddock T.U.L. Rogers, Surveyor - 22/5/1899 Plan 494
- Continuous red sandridges bearing about 110. Dense mulga, mallee and various low bushes. Occasional fairly large blackoak flats of red loamy soil. Timbered with blackoak, mulga, sandalwood, quandong and bushes. Inferior country.

North central part of paddock T.U.L. Rogers, Surveyor - 22/5/1899 Plan 494
- Chiefly loose red loamy soil with patches of sandhill country. Timbered with dense blackoak, mulga, little sandalwood and myall, stunted whitewood, quandong, broom and various bushes. Fair saltbush and blue bush in places with grass and herbage after rain.

Central part of paddock T.U.L. Rogers, Surveyor - 23/3/1899 Plan 478
- Dense mulga, blackoak, broom (quirro), quandong and bushes. Loose red loam over limestone rubble. Patches bluebush, saltbush, grass and herbage.

South central part of paddock T.U.L. Rogers, Surveyor - 23/3/1899 Plan 479
- Red loamy soil over limestone rubble. Dense blackoak, mulga, quandong, broom and various other bushes.

Southern part of paddock T.U.L. Rogers, Surveyor - 23/3/1899 Plan 479
- High red sandridges bearing about 110 and from 15 to 20 chains apart covered with dense mulga and mallee. Intermediate flats of red loam over limestone rubble and clay. Blackoak, broom, silver wattle and various other bushes. Patches of saltbush and grass, geranium and other herbage after rain. Inferior country.

West of the Dog Fence T.U.L. Rogers, Surveyor - 1/7/1899 Plan 495
- Undulating red loamy country, soil 6" to 12" deep over limestone rubble timbered with mulga blackoak and occasional low sandridges.

Fair sized red loamy flats covered with myall, blackoak etc. along edge of sandhill country that lies further west, with small patches of kopi.

DURBRIDGES FOSSIL PADDOCK, CORUNNA STATION

North western part of paddock Guy M. May, Surveyor - 3/5/1892 Plan 174
- Open saltbush and bluebush plains with clumps of bushes and scattered myalls and sandalwoods.

Eastern part of paddock **Guy M. May, Surveyor - 3/5/1892 Plan 174**

- Undulating red loamy soils 6" to 20" deep over limestone rubble and clay. Myalls, blackoaks, sandalwoods, cherry, cattle and other bushes, saltbush undergrowth.

Southern part of paddock **E.C. Playford, Surveyor - 8/1/1894 Plan 258**

- Undulating country covered with saltbush and samphire, scattered myall, sandalwood and bushes. Red loamy soil and white gypsous earth. Salt lagoons and samphire swamps.

GAP FOSSIL PADDOCK, CARIEWERLOO STATION

Whole paddock **L.A. Wells, Surveyor - 1/3/1888 - Plan 43**

- Writing illegible

KOWAL FOSSIL PADDOCK, MOUNT VIVIAN STATION

Whole Paddock **J.H. McNamara, Surveyor - 18/2/1899 Plan 475**

- Undulating country, red sandy loam, limestone substratum, mulga, myall, quandong and bushes, bluebush, saltbush, silver and tussock grass and herbage, numerous small patches of open stony country, occasional canegrass swamps.

LAKE FOSSIL PADDOCK, WARTAKA STATION

Northern part of paddock **W.R. Illmay(?), Surveyor - 9/12/1889 Plan 109**

- Red sandy loam densely timbered with blackoak, myall, sandalwood and various bushes with abundant saltbush and bluebush.

Southern part of paddock **W.R. Illmay(?), Surveyor - 9/12/1889 Plan 109**

- Red granite ridges. Open saltbush and few bushes.

LOCHS NORTH FOSSIL PADDOCK, PARAKYLIA STATION

Whole Paddock **E.A. King, Surveyor - 27/8/1897 Plan 414**

- Open myall and mulga with bluebush and saltbush and low bushes, outcrops of limestone in places, firm loamy soil. Mulga sandhills with other bushes, fair herbage after rains, few saltbush flats, loose loamy soil.

LOW HILL NORTH FOSSIL PADDOCK, SIAM STATION

Northern part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**

- Rich loose sandy soil over clay and gypsum, banks of decomposed gypsum, large myall, blackoak, sandalwood and a few bushes, good saltbush, blue bush and fair grass.

Central part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**

- Stony hills clothed with mulga

South Central part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**

- Fairly open level country, deep chocolate loam clothed with myall, sandalwood, blackoak, few bushes and saltbush, bluebush and grass.

Southwest part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Firm deep chocolate loam, few scattered bushes, good saltbush, excellent grass.

Western part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Firm deep chocolate soil, large myall, sandalwood, blackoak, good saltbush and bluebush.
- Low hills with quartzite outcrops, grass and good saltbush.

Southern part of paddock (Low Hill) **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Hills of granite and sandstone clothed with mulga.

Eastern part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Loose deep chocolate sandy soil, slightly undulating, clothed with dense large myall, blackoak, sandalwood and quandong bushes, bluebush and fair saltbush, patches of grass, inferior pasture land.

LOW HILL SOUTH FOSSIL PADDOCK, SIAM STATION

Northern part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Hills of granite and sandstone clothed with mulga.
- Open myall, good saltbush
- Low sandstone ridges clothed with mulga grass and saltbush

Northeastern part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Loose deep chocolate sandy soil, slightly undulating, clothed with dense large myall, blackoak, sandalwood and quandong bushes, bluebush and fair saltbush, patches of grass, inferior pasture land.

Western part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Gently undulating firm chocolate loan over clay, scattered myall, good grass and saltbush.

Central part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Prominent granite hill

Southwestern part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Dry basin with gypsum banks.
- Deep firm chocolate loam and sandy patches, open myall, sandalwood, good saltbush and fair grass.
- Bold granite hills, good grass and saltbush.

Eastern part of paddock **L.A. Wells, Surveyor - 30/3/1893 Plan 201**
- Level deep firm chocolate loam, scattered myall, sandalwood, and bushes, saltbush, bluebush and excellent grass.

MOONLIGHT FOSSIL PADDOCK, TREGALANA STATION

Western part of paddock **L.A. Wells, Surveyor - 2/4/1887 Plan 47**
- Chocolate coloured sandy loam, rubble subsoil. Timbered with myalls, sandalwoods and various kinds of bushes. Bluebush and saltbush.

Eastern part of paddock **L.A. Wells, Surveyor - 2/4/1887 Plan 47**
- High rough range, very steep hills.

Southern part of paddock **L.A. Wells, Surveyor - 2/4/1887 Plan 47**
- Open salt and bluebush.

MOUNT LAURA FOSSIL PADDOCK, MIDDLEBACK STATION

Western part of paddock A.D. Smith, Surveyor - 9/4/1914 Plan 537

- Undulating red loamy soils 6" to 20" deep over limestone rubble and clay. Myalls, blackoaks, sandalwoods, and various bushes and saltbush and blue bush undergrowth.

North eastern part of paddock A.D. Smith, Surveyor - 9/4/1914 Plan 537

- Belts of sparse myalls, sandalwoods and blackoaks and bushes with saltbush undergrowth and open plains of salt and blue bush with scattered trees and clumps of bushes.

South eastern part of paddock A.D. Smith, Surveyor - 9/4/1914 Plan 537

- Red loamy soil 6" to 20" over limestone rubble and clay.

OUTSIDE COUNTRY FOSSIL PADDOCK, PARAKYLIA STATION

Eastern part of paddock E.A. King, Surveyor - 27/8/1897 Plan 414

- Undulating country, covered with mulga, myall and various kinds of bushes, red sandy rises with mulga, wattle and other bushes. Saltbush and little bluebush between rises, loamy soil.

Western part of paddock J.H. McNamara, Surveyor - 18/2/1899 Plan 475

- Low sand ridges and flats of rich loam with limestone rubble, mulga, myall, quandong and bushes, bluebush, salt bush, grass and herbage.

Northwestern part of paddock J.H. McNamara, Surveyor - 18/2/1899 Plan 475

- Open stony country, red loam covered with loose flint and ironstone, sparsely covered with saltbush and bluebush.

SHERIDANS FOSSIL PADDOCK, NORTH WELL STATION

Whole paddock T.U.L. Rogers, Surveyor - 23/3/1899 Plan 479

- Red loamy soil over limestone rubble. Dense blackoak, mulga and various bushes. Saltbush, bluebush and fair grass and herbage.

SOAKAGE FOSSIL PADDOCK, KATUNGA STATION

Northern part of paddock L.A. Wells, Surveyor - 4/6/1894 Plan 232

- Good red and light loam over rubble limestone and little gypseous earth, fairly open country and undulations, myall, sandalwood bushes, saltbush, bluebush and good grass.

Western part of paddock L.A. Wells, Surveyor - 4/6/1894 Plan 232

- Dense mallee, myall and bushes, loose red sandy soil.

Southern part of paddock L.A. Wells, Surveyor - 4/6/1894 Plan 232

- Good red loam over marl and few stony ridges, dense blackoak, myall, sandalwood, various bushes, saltbush, bluebush and little grass.

TOMATO ROCKS FOSSIL PADDOCK, NORTH WELL STATION

North western part of paddock J.H. McNamara, Surveyor - 12/4/1899 Plan 482

- Low scrub or bushes

Balance of paddock J.H. McNamara, Surveyor - 12/4/1899 Plan 482

- Undulating country, red loam, mulga, myall, bluebush, saltbush, silver and tussock grass, occasional samphire swamps.

WHITE CLIFFS FOSSIL PADDOCK, TREGALANA STATION

Western part of paddock L.A. Wells, Surveyor - 2/4/1887 Plan 47

- Chocolate coloured sandy loam, rubble subsoil. Timbered with myalls, sandalwoods and various kinds of bushes. Bluebush and saltbush.

Eastern part of paddock L.A. Wells, Surveyor - 2/4/1887 Plan 47

- Open salt and bluebush.

WHYMLET FOSSIL PADDOCK, NORTH WELL STATION

North western part of paddock P.M. Hunt(?), Surveyor - 7/31/1897 Plan 410

- Dense mulga scattered blackoak and bushes, undergrowth of salt, blue, cottonbush and grass. Soil light red loamy with occasional low red sand rises.
- Open mulga and bushes, red loamy soil over limestone.
- Spaced mulga, quandong, little myall and bushes, light red loam and loose red sandy soil, limestone substratum, occasional low patches of tableland stony.
- Open salt and bluebush country slightly undulating stony in places.
- Mulga, quandong, scattered myall and various bushes, good salt and bluebush, grass undergrowth, light red sandy loam soil over limestone, patches of low tableland covered with ironstone rubble.

North eastern part of paddock P.M. Hunt(?), Surveyor - 1897 Plan 411

- Open undulating covered with salt bush, cotton bush, red loamy soil over limestone.
- Open mulga, myall and bushes, salt bush and grass undergrowth.
- Open mulga, quandong, myall, few blackoak and various bushes, good salt and blue bush and grass undergrowth. Soil chiefly light and red sandy loam average depth 6 to 15 inches over limestone, occasional patches of sand and low stony tableland with broken bushes.

South eastern part of paddock J.H. McNamara, Surveyor - 20/4/1899 Plan 481

- Undulating red sandy loam with numerous small patches of stony country. Bluebush, saltbush, silver and tussock grass. Timbered with mulga, myall and low bushes. Occasional clumps of blackoak.
- Open stony country chiefly covered with bluebush, saltbush and low bushes. Red loamy soil.

Lake Labyrinth J.H. McNamara, Surveyor - 12/4/1899 Plan 482

- Chiefly loam with saline efflorescence, occasional sandridges covered with stunted pine.
- Mallee in places skirting lake.

South western part of paddock J.H. McNamara, Surveyor - 12/4/1899 Plan 482

- Undulating country, red sandy loam, bluebush, salt bush, silver and tussock grass. Low scrub of bushes with scattered clumps of mulga.

South central part of paddock **J.H. McNamara, Surveyor - 12/4/1899 Plan 482**

- Chiefly open undulating country, red loamy flats, stony rises, bluebush, silver and tussock grass.

WINTER FOSSIL PADDOCK, NONOWIE STATION

North eastern part of paddock **A.D. Smith, Surveyor - 9/4/1914 Plan 537**

- Open saltbush and bluebush plains with clumps of bushes and scattered myalls and sandalwoods.

Balance of paddock **A.D. Smith, Surveyor - 9/4/1914 Plan 537**

- Undulating red loamy soils 6" to 20" deep over limestone rubble and clay. Myalls, blackoaks, sandalwoods, cherry, cattle and other bushes, saltbush undergrowth.

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