THE EFFECTS OF ARTIFICIAL WATERING POINTS ON THE DISTRIBUTION AND ABUNDANCE OF AVIFAUNA IN AN ARID AND SEMI-ARID MALLEE ENVIRONMENT

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ABSTRACT

The role of artificial watering points in the avifaunal dynamics of the semi-arid mallee woodlands of southeast Australia was examined. Species richness and abundance were monitored throughout the year at different distances from water to determine how birds were distributed around water points and how this changed in relation to environmental factors such as climate. Vegetation attributes were also measured to determine which factors explained patterns in the avifauna with distance from water, and also to allow a description of the vegetation in relation to the water points. Water points were monitored throughout the year to determine which species were utilising them, under which environmental circumstances and for what purposes. Knowledge of the water utilisation behaviour of individual bird species allowed some explanation of their distribution patterns, as well as an ability to predict the likely effects of water point closure on those bird species. The closure of two water points during the study allowed an assessment of the immediate effects of water point closure on avifauna.

The two broad vegetation associations on swales and dunes within the study area are described. Both species richness and abundance of birds proved to be significantly higher in the swale vegetation, and this was attributed to the greater structural and floristic diversity of the shrub layer within this vegetation type. Vegetation around the water points was strongly influenced by distance from water, with structural diversity and palatable plant species decreasing closer to water.

A total of 42 (37%) out of 113 bird species were observed drinking, although only 28 (25%) seemed to require drinking water for their survival. Despite this, water-dependent species accounted for 75% of the individuals observed. Granivorous species such as parrots and pigeons appeared to be the most water-dependent, while some honeyeater species required drinking water during the summer months. The presence of water had a major controlling influence on the abundance and distribution of numerous bird species in this semi-arid mallee environment. Generally, water-dependent species were more abundant closer to water; these were all common species of little conservation concern. The abundance of water-dependent species decreased at distances beyond 12 km from water, although most species were detected up to 20 km from water. Species richness was higher closer to water and this was due to the abundance of water-dependent species there. A number of water-independent bird species were more abundant closer to water, and these were small insectivorous species; their increased abundance is attributed to significantly higher shrub height and cover closer to water. The majority of bird species that decreased in abundance closer to water were ground-foraging species, and were positively associated with particular low, dense shrub species that declined in abundance closer to water. Many of these bird species such as the striated grasswren, southern scrub-robin and shy heathwren are of conservation concern. Water point closure did not result in a significant change in bird abundances.

It was found that water points promote a loss of biodiversity, to the detriment of conservation objectives, common water-dependent bird species benefiting at the expense of rarer water-independent species. Vegetation and soil has been negatively impacted around water points, and this in turn has negatively impacted a number of ground-foraging bird species. The management of artificial water points within the arid zones of Australia is a critical issue, and unless practical solutions are found avian biodiversity will continue to decline.

DECLARATION

This is to certify that

(i) the thesis comprises only my original work towards the PhD,

(ii) due acknowledgement has been made in the text to all other material used,

(iii) the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

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1. INTRODUCTION AND OVERVIEW

Water points such as waterholes, water troughs and dams can have a major controlling influence on animal distribution in arid and semi-arid regions. By drawing large herbivores to new water sources, artificial water points often increase habitat degradation by concentrating grazing pressure, and the resulting changes impact both positively and negatively on different species in the affected areas (Osborn *et al*., 1932; Valentine, 1947; Lange, 1969; Andrew and Lange, 1986a, b; Andrew, 1988; James *et al*., 1995; James *et al*., 1999; Landsberg *et al*., 1999). Recent studies by CSIRO (Landsberg *et al*., 1997) in Australia's arid and semi-arid rangelands have demonstrated that effects of grazing are discernible up to 10 km from water in the acacia and bluebush-dominated habitats they studied. Most studies to date have concentrated on the changes in vegetation and mammal distributions associated with artificial water points, while little work has been conducted on the relationship between native avifauna and those water points. For example, apart from one study by Williams & Wells (1986), very little research has been conducted on the effects of water points on the avifauna in the Australian ecosystems dominated by the shrub-form eucalypts known as 'mallees'.

The provision of supplementary water points is a contentious subject in wildlife ecology. Artificial water points often simply increase the extent of habitat degradation, with an associated loss of bio-diversity. Nevertheless, water points have clear benefits for wildlife viewing by tourists. The economic benefits of ecotourism have therefore to be weighed against the ecological costs. At present there are many strong opinions, but little factual information, to guide wildlife managers in arid and semi-arid regions. The consequences of providing water will depend on where the water points are located, how the water is supplied, and how individual species respond to the provision of water (Collinson, 1983). Owen-Smith (1996) listed six possible adverse effects that water points may have: (1) favouring water-dependent species at the expense of rarer species; (2) promoting increased predator impacts on prey species; (3) inducing more widespread vegetation impacts; (4) worsening animal mortalities during droughts; (5) decreasing ecosystem stability; and (6) leading to a loss of biodiversity.

1.1 CHANGES TO WILDLIFE AROUND ARTIFICIAL WATERING POINTS

1.1.1 The Piosphere Effect

The impacts on vegetation and soils resulting from the concentration of animals in close proximity to water points is known as a "piosphere" effect (Lange, 1969; Andrews, 1988). A piosphere is the roughly circular zone of attenuating stocking pressure radiating outwards from a watering place. A number of general patterns have been identified. The area within a few hundred metres is often denuded of vegetation because of trampling and overgrazing and is referred to as the 'sacrifice zone' (Valentine, 1947). Beyond the sacrifice zone there is often a zone of dense unpalatable perennial woody shrubs and, beyond this, palatable perennial plants progressively become more abundant with increasing distance (Zumer-Linder, 1976; Graetz, 1978; Barker, 1979; Andrew & Lange, 1986b; Barker *et al.*, 1989; Adamoli *et al.*, 1990; Van Rooyen *et al.*, 1990; Wilson, 1990; Perkins & Thomas, 1993a,b; Fusco *et al.*, 1995; Thrash, 1998). The relationship between the distance from water and the response of many vegetation and soil measures is often sigmoid (Graetz & Ludwig, 1978). Plants may also respond to indirect effects of grazing such as erosion, changed nutrient levels and competition by other plants. Examples of piosphere patterns include: a radiating pattern of livestock trails (Lange, 1969; Andrew, 1988), the accumulation of livestock faeces near the water (Lange, 1969, 1985; Weir, 1971; Lange & Willcocks, 1978; Andrew & Lange, 1986a; Tolsma *et al.*, 1987; Fusco *et al.*, 1995; Gibson, 1995; Thrash *et al.*, 1995), an increase in soil nutrients near the water and their depletion further away (Weir, 1971; Georgiadis & McNaughton, 1990; Perkins & Thomas, 1993a), soil compaction (Lee, 1977; Eldridge, 1996), loss of the soil cryptogram crust (Charley & Cowling, 1968; Andrew and Lange, 1986a; Eldridge, 1996) and an increase in the amount of bare soil near the water and defoliation and other changes to the biomass of herbage (Lange, 1969; Andrew & Lange, 1986a,b). Piosphere formation has been likened to desertification (Andrew, 1988; Hanan *et al.*, 1991).

A piosphere's size and shape is determined by the distances and directions over which animals can travel between foraging areas and the water point. Animal movements will be affected by vegetation type, terrain, relief and the tendency for animals to follow established trails (Graetz, 1978; Fatchen & Lange, 1979; Lange, 1985; Pickup & Chewings, 1988; Van Rooyen *et al.*, 1994). Utilisation of *Astrebla* grasslands by sheep in western Queensland, Australia, has also been attributed to wind direction and shade availability, as well as to the position of the water point (Orr, 1980; Bosch & Gauch, 1991). Larger water resources generally have larger piospheres (Hellden, 1984).

1.1.2 Vegetation

Studies within Australia

Most artificial water points around the world have been introduced as a water source for domestic stock or wildlife, and hence the most obvious effects are those associated with grazing and trampling by large herbivorous mammals. The literature on these grazing and trampling effects is extensive, and has been recently reviewed by James *et al.* (1995), James *et al.* (1999) and Landsberg *et al.* (1999). Very little research has been conducted on the impacts to vegetation in mallee systems, but considerable literature exists for other arid and semi-arid plant communities in Australia (especially chenopod and *Acacia*-dominated shrublands) and these will be discussed here.

James *et al.* (1999) highlighted two general trends which emerge from research on the effects of grazing intensity on rangeland plant communities: grazing at moderate intensity leads to higher within-habitat species richness compared with grazing at low or high densities (Wilcox *et al.*, 1987; Andresen *et al.*, 1990; Chaneton & Facelli, 1991; Oba *et al.*, 2001); while very heavy grazing results in a decline in the number of species, a reduction in abundance of the remaining species and dominance by a few species (O'Connor, 1991; Pandey & Singh, 1991; Fusco *et al.*, 1995; Oba *et al.*, 2001). Such responses by plant communities to grazing are often collectively referred to as the intermediate disturbance hypothesis (Miller, 1982; Crawley, 1983; Sousa, 1984; Collins & Barber, 1985; Shmida & Wilson, 1985; Facelli, 1988). However a number of authors believe that this idea requires refinement because a bell-shaped response to a gradient of grazing intensity is not necessarily expected in regions with different evolutionary histories of grazing use or climate (Milchunas *et al.*, 1988; Milchunas & Lauenroth, 1993).

Andrew & Lange (1986a,b) monitored the initial development of a piosphere created by stocking a new water point with about 200 sheep at a near-pristine site in arid chenopod shrubland in South Australia. Although they found a piosphere pattern evident in grass biomass after three months, only after eight years of stocking and a drought was there a substantial mortality of the main shrub species foraged. However there was by then a linear increase in biomass with increasing distance from water and this trend became more pronounced with time. Short-lived species were more susceptible. Piosphere patterns in shrubs and grasses took longer to appear than changes to the soil surface; this was attributed to the fact that some vegetation variables not only register the direct effects of defoliation but also the subsequent plant growth in response to that defoliation (Andrew, 1988). Other studies in chenopod shrublands have determined that the dominant perennial shrubs (*Atriplex* and *Maireana* spp.) are replaced by annual chenopod shrubs, forbs or annual grasses within 400 m from water (Osborn *et al.*, 1932; Fatchen, 1978; Graetz, 1978; Graetz & Ludwig, 1978; Barker, 1979; Wilson, 1990). Species richness did not change consistently with distance from water in these studies.

Grazing within semi-arid *Acacia*-dominated shrublands has resulted in palatable perennial grasses being replaced by unpalatable grass species (Harrington *et al.*, 1979; Hodgkinson, 1991, 1992), and unpalatable shrubs such as *Eremophila*, *Senna*, *Dodonaea* and *Acacia* species becoming dominant (Harrington *et al.*, 1979; Friedel, 1981; Friedel *et al.*, 1990). The abundance of shrubs in this plant community limits grass growth, reducing the fuel load and frequency of fires, which in turn promotes further shrub establishment (Moore, 1973; Harrington, 1979; Harrington *et al.*, 1979; Hodgkinson & Harrington, 1985; Friedel, 1991). Unpalatable shrub species are more abundant close to water and bare ground cover increases at greater distances from water (Foran, 1980; Cowley, 1994; Cowley & Rogers, 1995). Species richness generally did not show a trend with distance from water in central Australia, although it was significantly higher at some sites distant from water (Friedel, 1997).

Heavy trampling by domestic stock and native herbivores around water points results in the break-up of the soil's cryptogamic crust and also in soil compaction (Eldridge, 1996). The cryptogamic crust is important as it contains nitrogen-fixing algae (Mayland & MacIntosh, 1996), particularly in Australia where the soils tend to exhibit lower nitrogen levels than in other countries (Charley & Cowling, 1968; Stafford Smith & Morton, 1990). The breakdown of this crust disrupts its nitrogen-fixing capabilities and loosens the soil surface allowing greatly increased wind and water erosion to take place. Soil compaction along sheep tracks reduces water infiltration of the soil (Tunstall & Webb, 1981; Noble & Tongway, 1983), although there is little evidence that soil compaction is widespread in arid rangelands (Lee, 1977). Numerous studies, both in Australia and overseas, have demonstrated that the accumulation of dung and urine from grazing animals is higher in the vicinity of water points in a number of different systems (Lange, 1969, 1985; Lange & Willcocks, 1978; Andrew & Lange, 1986a; Gibson, 1995; Fusco *et al*., 1995; Weir, 1971; Tolsma *et al*., 1987; Thrash *et al*., 1995). As a result, the surrounding area over which the animals forage has its phosphorus content diminished.

Studies outside Australia

The general trends detected in Australian plant communities are mirrored overseas. The development of a sacrifice zone dominated by unpalatable increaser species is well documented within arid rangelands in Africa (Zumer-Linder, 1976; Barker *et al*., 1989; Van Rooyen *et al*., 1990; Perkins & Thomas, 1993a,b; Thrash, 1998), in North America (Fusco *et al*., 1995) and in South America (Adamoli *et al*., 1990). Overgrazing by livestock in an arid savannah in Botswana led to bush encroachment (Van Vegten, 1983; Tolsma *et al*., 1987; Skarpe, 1990). However, Van Rooyen *et al.* (1994) were unable to find any relationship between distance from water and plant composition in six different habitats in the Kalahari Gemsbok National Park. While monitoring vegetation around water points in the Kalahari Gemsbok National Park, Van Rooyen *et al.* (1990) found that, although both rainfall and grazing influenced the vegetation, rainfall was the more significant factor. Likewise, Hanan *et al.* (1991) were unable to find a relationship between primary production and distance from water at a resolution of 1.1 km using satellite imagery, finding most of the variance was explained by gradients in rainfall.

In southern Africa, gradients in herbaceous plant composition were found around water supplied to livestock (Friedel, 1988; Tolsma *et al*., 1987), but not around water points for indigenous large herbivores in the Kalahari Gemsbok National Park (Child *et al*., 1971; Van Rooyen *et al*., 1990; Van Rooyen *et al.,* 1994). Despite this, Thrash *et al.* (1993) documented a shift from disturbance-related species to perennial grass species with increasing distance from water in Kruger National Park. Kalikawa (1990) measured vegetation variables around two water points of equal age in two separate habitat types in Central Kalahari Game Reserve; she found that there were significant differences between the two sites. However, relating changes at one water point to those at another in widely-separated geographical locations is unwise, as the plant associations may differ and thus affect interactions between the species (Barker, 1973).

1.1.3 Large herbivores

Artificial water points are a focus for water-dependent livestock and native animals in arid rangelands all over the world. Before the introduction of artificial water points, species that were water-dependent could only inhabit arid areas around permanent natural water, or over larger areas following heavy rainfall. Water-dependent herbivores are most abundant close to water points, a phenomenon well-documented with kangaroos in Australia (Newsome, 1965; Norbury & Norbury, 1993; Gibson, 1995) and large herbivores in Africa (Western, 1975; Mills *et al.*, 1995; Thrash *et al.*, 1995; Owen-Smith, 1996; Thrash, 1998). The distance from water that these species travel tends to decrease during dry summer periods and times of drought. The introduction of artificial water points in Australia helps maintain larger populations of kangaroos than was possible before European settlement (Ealey, 1967; Newsome, 1971, 1975; Cunningham, 1981; Norbury, 1992). In contrast, Van Der Walt (1986) found that the provision of water had little effect on the distribution of most large mammalian herbivores in Kalahari Gemsbok National Park, and Knight (1991) found that the provision of drinking water for game in Kalahari Gemsbok National Park did not influence the recruitment rate amongst wildebeest, which suggests that there are other limiting factors such as habitat and food quality and quantity. Additionally, de Leeuw *et al.* (2001) found that livestock and human activities associated with water points negatively affected the distribution of large herbivores. According to Stafford Smith & Morton (1990), food supply is the critical determinant of persistence and reproduction for animals in arid parts of Australia, and water is rarely an independent limiting resource. Weir (1971) was able to predict some animal species distributions in relation to vegetation type and soil chemistry in Africa.

1.1.4 Avifauna

The establishment of permanent water sources is likely to cause changes in the abundance and distribution of some bird species. In Australia, the increase in numbers and ranges of some species of parrot and cockatoo, the zebra finch (*Peophila guttata*), the emu, and some species of pigeons have been linked to the increased accessibility of permanent water (Ford, 1961; Fisher *et al.*, 1972; Dawson *et al.*, 1983; Reid and Fleming, 1992). Conversely, other species such as thornbills (*Acanthiza* spp.) and quail-thrushes (*Cinclosoma* spp.) appear to have either retained unchanged abundances and ranges, or decreased in abundance (Reid and Fleming, 1992). James *et al.* (1999) lists 99 bird species whose changes in abundance or range in Australia's arid rangelands have been attributed to the provision of artificial water or pastoralism. Bird species that appear to have benefited from additional water supplies seem to be those which depend on a daily supply of water for at least part of the year (Davies, 1972; Fisher *et al.*, 1972). Birds that do not depend on free-standing water seem less likely to show increases in range or numbers (Reid and Fleming, 1992).

Most authors attribute the decline in abundance or range of birds to habitat change due to grazing. Overgrazing was identified as a likely cause because canopy-dwelling species have been less affected than ground dwellers (Reid & Fleming, 1992). In mallee vegetation, Williams & Wells (1986) found that birds were less abundant in grazed areas (with water) than in ungrazed areas where water was also present. As mentioned earlier, overgrazing has been shown to lead to a decrease in the structural diversity of vegetation and this is particularly evident immediately around artificial water points (Lange, 1969; Harrington *et al.*, 1979; Reid & Fleming, 1992; Williams, 1994; Landsberg *et al.*, 1997). It is widely accepted that the diversity of avifauna increases with increased structural diversity of the vegetation (MacArthur & MacArthur, 1961; Recher, 1969; James and Wamer, 1982) and several studies, both in Australia and overseas, have linked grazing-induced vegetation changes to decreases in the species richness and population numbers of birds (Bock and Webb, 1984; Taylor, 1986; Knopf *et al.*, 1988; Reid & Fleming, 1992; Smith *et al.*, 1994). However, studies in North American arid regions have also shown that species richness can remain unchanged between grazed and ungrazed plots (Medin, 1986), and also that species richness and bird abundance can increase at grazed plots (Bock *et al.*, 1984; Knopf *et al.*, 1988; Medin & Clary, 1990). Most of these differences can be explained by the habitat preferences of the species and the particular changes in vegetation structure that grazing causes (Ryder, 1980; Taylor, 1986).

Williams & Wells (1986) found that the presence of water facilitated larger populations and higher species richness of birds in mallee-dominated communities in South Australia. The distribution and abundance of birds in the Mitchell grasslands of the Northern Territory was also affected by artificial water points, five species being more abundant within 5 km of water.

Some of the bird species that have become abundant due to water point introduction may cause competitive or aggressive displacement of other species that do not require water. The yellow-throated miner (*Manorina flavigula*) may be responsible for the local displacement of some small bird species through its aggressive behaviour toward them (Grey, 1996). Similar interactions may be occurring between other bird species, however there is no research on this subject. Another water-related interaction between bird species that has been documented is the introgressive hybidisation or “genetic swamping” by the conspecific yellow-throated miner of the endangered black-eared miner (*M. melanotis*) around water points in the mallee vegetation of south-east Australia (Schodde, 1981; Starks, 1987; McLaughlin, 1990, 1993). Yellow-throated miners have invaded the mallee vegetation at cleared sites around artificial water points and are now interbreeding with black-eared miners, producing fertile hybrid offspring (Ford, 1981; McLaughlin, 1990, 1993; Clarke & Clarke, 1999a). Recent research shows that the lowest quality black-eared miner colonies (most genetically-swamped) occur at distances less than 2 km from water, while the genetically most pure colonies are at distances greater than 5 km from water (Clarke and Clarke, 1999b).

Although a number of studies have been undertaken in Australia to determine the effects of artificial sources of water on avifauna, most notably the study by Landsberg *et al.* (1997) of *Acacia*-dominated land systems and chenopod shrublands, only one published investigation has been conducted within mallee vegetation (Williams & Wells, 1986).

1.1.5 Predation risks

Permanent water points can benefit predators to the detriment of prey populations (Berry, 1982). In fact, water points are frequented by predators largely because of the greater chances of successful hunting which they offer (Bourliere, 1963; Elliott *et al.*, 1977). The problems that predators cause to large herbivores around water points in Africa has been well documented, and increased predation due to water point introduction has even been attributed to the near extinction of a rare herbivore species (the roan antelope) in Kruger National Park (Harrington *et al.*, 1999). This example demonstrates that water points can pose a threat to biodiversity, the more common water-dependent species tending to increase in abundance at the expense of rarer species.

The mammalian predators most commonly seen at water points in Australia are cats, dingoes and foxes, but no information exists on what prey items are captured around water points by these species. Birds are their most likely prey (Jones & Coman, 1981) but, no research has been conducted on the effects such predation may be having on bird populations. Avian predators that frequent water points in the arid regions of Australia include sparrowhawks, goshawks and falcons, and these are known to be major predators of birds. Although there are no quantitative data on avian predators and their prey it is likely that, like their mammalian counterparts, they are also having a negative impact on some bird species around artificial water points.

1.2 WATER POINT PLACEMENT

Collinson (1983) proposed that artificial water points in Africa should either be well spaced (not closer than 30 km apart) and in an irregular pattern, or not introduced at all. This agrees with the view of Owen-Smith (1996) who also suggested a minimum distance of 30 km between water points. Martens (1971) suggested that bore holes as far as 15-20 km apart still contributed to veld degradation by livestock in eastern Botswana. The consequence of uniformly spacing artificial water points is likely to be an increase in non-mobile water-dependent herbivore species exercising a heavy and uniform utilisation pressure (Collinson, 1983). This would then lead to bush encroachment, an increase in competition between species, and a decrease in habitat diversity. Ultimately, such water point placement could lead to a reduction in the number of those water-dependent herbivore species which require open habitat and those which require large stands of tall grass. This prediction is supported by Harrington *et al.* (1999) who found that roan antelope numbers also declined in Kruger National Park because suitable habitat (long grass) disappeared (although the main cause for their decline appeared to be increased predation), caused by increased grazing by zebra and wildebeest around artificial water points.

Owen-Smith (1996) suggested that the marked difference in mortalities of large herbivores between two adjacent reserves in South Africa after drought were due to different distances between water points in the two reserves. At the reserve which had relatively low mortalities and pre-drought population numbers, the average distance between water points was over 10 km, while water points in the neighbouring reserve were so close together that no reserve grazing remained, and animals starved to death (Walker *et al.*, 1987). It appears that abundant water in a good season supports high ungulate populations in the short term, but in drought years, there is severe mortality. Water-dependent grazers are most vulnerable to drought-related mortality, while browsers such as giraffe and kudu are relatively little affected (Owen-Smith, 1996).

1.3 WATER POINT UTILISATION BY WILDLIFE

A number of studies have demonstrated that the utilisation of waterholes by wildlife is influenced by the total dissolved solids (TDS) in the water. Fresh drinking water is that considered to have less than 0.6% TDS (Winter, 1985), while 1.3-1.7% TDS is recommended for domestic livestock (Church, 1979). Knight *et al.* (1988) noted that significantly more animals used fresher waterholes in the Kalahari Gemsbok National Park, but that water-independent species visited the waterholes to utilise lick sites, as opposed to drinking. Sodium was the mineral in demand from these lick sites. Knight (1989) found that significantly more doves and sandgrouse drank at fresher water holes in the Kalahari Gemsbok NP. However, Child *et al.* (1971) were unable to find a significant correlation between the number of three water-dependent large herbivores and the concentration of the dissolved ions at water points in the Kalahari NP, Botswana.

During the dry season the number of water points is reduced, suggesting that there may be interspecific competition for water at such times. However, it has been suggested that different species don't compete for the water itself, but instead compete for access to the water at different times of the day (du Preez & Grobler, 1977). Interspecific confrontations are avoided by different species visiting water points at different times of the day; less aggressive species are then able to utilise the water even while sharing it with more aggressive species. Smaller herbivore species are particularly vulnerable to predation while at a water point, and this predation risk heavily influences when these herbivores drink (du Preez & Grobler, 1977; Ayeni, 1975; Weir & Davison, 1965). The most efficient time for an animal to drink is at night, but this time is less suitable for smaller herbivores as it is the period when predators commonly visit water points. Large herbivores such as elephants and rhino drink predominately during the night. Intermediate-sized herbivores such as giraffe and buffalo tend to utilise the water points throughout the whole 24-hour period and appear to be more heavily hunted as a result. Ayeni (1975) found predation of a species reflected its coincidence at water points with carnivores rather than the frequency it visited water points.

Arid regions around the world are often characterized by high air temperatures, intense solar radiation and a scarcity of surface water for all or part of the year. These environmental extremes impose difficult ecophysiological constraints on wildlife, particularly diurnal birds which, unlike most desert mammals, are not able to take advantage of the physiological benefits of underground burrows. In hot dry weather, birds must rely on evaporative cooling which places extra demands on their water balance. Despite this, Fisher *et al*. (1972) determined that 60% of the bird species in the arid and semi-arid zones of Australia were either independent of water or drank less than 50% of the time. They also determined that the majority of individuals inhabiting areas where water is present were dependent on free water, and that water availability was a critical factor in the distribution of those species.

1.4 ADAPTATIONS BY AVIFAUNA TO ARID ENVIRONMENTS

To understand fully how individual bird species interact with artificial water points, some understanding is needed of the various physiological and behavioural adaptations to arid conditions that those species possess. It may then be possible to determine whether a species requires free water continually, or requires water only infrequently, or not at all, and under what set of environmental circumstances it is required to drink.

Much of what seems to be adaptive to arid environments in birds may well be intrinsic to the avian condition. The following characteristics of birds have operated to refine the water economy of birds (Bartholomew, 1972):

1. **Energy metabolism**. Birds have high rates of energy metabolism. The rate for a small passerine in flight may go up to 10-25 times its resting metabolic rate.
2. **Body temperature**. The characteristically high body temperature (T_B) of birds allows them to lose heat to the environment by convection at most ambient temperatures (T_A), removing a primary dependence on evaporative cooling.
3. **Evaporative water loss (EWL)**. Birds have high rates of pulmocutaneous evaporative water loss, a consequence of their high metabolic rates and high T_B.
4. **Excretion**. Nitrogenous wastes are excreted in the form of uric acid, and many species excrete excess electrolytes via nasal salt glands.
5. **Diurnality**. Unlike most mammals, birds are largely diurnal, which can pose problems of water balance and thermoregulation.
6. **Mobility**. Birds are among the most mobile of terrestrial animals, allowing them to escape from environmental problems in ways not open to walking animals; however, this may also exacerbate problems of water balance, especially during migration or longer nomadic movements.

1.4.1 Drinking patterns and diet

Studies of water utilisation by birds in the Namib Desert (Willoughby and Cade, 1967) and Australia (Fisher *et al*., 1972) have identified three categories of water usage by birds: (1) *regular*, (2) *occasional* and (3) *seldom*. Regular drinkers drink daily and are water-dependent. Occasional drinkers may drink when water is available, but appear not to be water-dependent. Seldom drinkers rarely or never drink, even when water is available. Fisher *et al*. (1972) differentiated regular drinkers into *yearly drinkers*, those that follow the above pattern, and *summer drinkers* that are dependent on free water only during the hotter, drier months of the year.

The most notable bird species that fall into the 'regular drinkers' category are pigeons. Both the common bronzewing (*Phaps chalcoptera*) and the crested pigeon (*Ocyphaps lophotes*) have been observed drinking at all times of the year in arid Australia (Davies, 1972). In addition, parrots, cockatoos, finches and some honeyeaters have been observed drinking throughout the year in Australia and are classed as regular drinkers (Cameron, 1938; Ford, 1961; Davies, 1972; Fisher *et al*., 1972). Why the Meliphagidae (honeyeaters) are water-dependent is not understood, but it may be related to their high levels of activity and reliance on moisture-poor food sources such as lerp. Nectar-feeders in Africa (sunbirds) and North America (hummingbirds) drink infrequently, if at all (Maclean, 1996).

The water requirements of birds are strongly associated with diet. The water content of grass seeds is insufficient to meet the water requirements of most birds, particularly at high temperatures, and therefore most granivorous species require water (Smyth & Coulombe, 1971). However, species such as the budgerigar and zebra finch have been reported to survive on air-dried grain without drinking (Willoughby, 1968; Bartholomew, 1972). Bird species that feed on succulent vegetation or insects receive enough moisture from their diet and generally do not drink (Maclean, 1996), although the honeyeaters are an exception. As mentioned earlier, birds are mostly diurnal which restricts the behavioural responses available to them when compared with small mammals. However, they are able to reduce water requirements through evasive tactics such as seeking favourable microclimates and remaining inactive during the hottest periods of the day. However, if a bird requires drinking water there are only two options open to it: 1) it must either live near surface water, or 2) have good powers of flight so it can travel long distances between foraging areas and water (Dawson & Bartholomew, 1968).

1.5 AIMS OF THE PRESENT STUDY

Birds Australia purchased Gluepot Station (a sheep station) in the arid Murray mallee of South Australia in 1997. The mallee region of southeast Australia is characterised by low annual rainfall (± 215 mm) and, like much of the arid zone in Australia, has been well supplied with artificial water points for livestock. The above review of the literature highlights numerous negative impacts to wildlife from the introduction of water points in arid and semi-arid lands and, for these reasons, Birds Australia has been considering closing the existing water points on the property. However, due to the limited information on associations between avifauna and water points, the likely results of this management action are uncertain. The overall aims of this study were to determine which bird species utilise the water points in mallee communities and under what circumstances, how the avifauna is distributed around those water points and which species are likely to be affected by any water point closure.

The primary concern of this study was to elucidate the relationship between individual bird species and distance from water. By monitoring the diversity and abundance of the avifauna at different distances from water, and during different seasons of the year, it was hoped to determine how birds were distributed around water points and how this changed in relation to environmental factors such as seasonal differences in climate. Plant phenology is extremely important to birds, particularly the nomadic species which are so characteristic of Australia (Ford, 1985). For this reason the phenology of the dominant tree species was mapped through the year in each habitat to help explain changes in bird species distributions and abundances.

A second aim was to determine the changes in mallee vegetation and soil characteristics in the vicinity of water. The reasons for this were twofold: first, it elucidates the effects overgrazing causes to mallee vegetation and helps to determine what effects different management actions might have to this vegetation; and, secondly, it helps explain the differences in abundance and distribution of avifauna in relation to water. Multivariate pattern analysis was used to classify the vegetation and determine the relationship between avifauna and the floristic and physiognomic characteristics of the vegetation.

In order to fully understand the relationship between avifauna and water in this mallee environment it was necessary to determine which species were utilising the water points, under which environmental circumstances and for what purposes. Seasonal variation in drinking patterns and behaviour was also explored. By gaining a better understanding of the associations between bird species and artificial water points it was hoped to better explain individual species distributions, as well as predict species that might be negatively impacted by water point closure. The final aim of this study was to test the effect of water point closure by closing a number of water points and documenting the resultant effects on avifauna.

The results from this study not only provide a greater understanding of the effects of artificial water points on the avifauna in a semi-arid environment, they also allow educated management decisions to be made in the interests of preserving the endangered species on Gluepot Reserve and other arid-zone conservation reserves. Although it is generally accepted that artificial water points cause habitat degradation and associated loss of biodiversity, most of the research has been conducted on vegetation and mammals. This is the first study of its kind to explore intimately all the aspects that might control avifaunal distribution and abundance within a semi-arid environment.

2. CHANGES IN VEGETATION AND SOIL CHARACTERISTICS AROUND ARTIFICIAL WATER POINTS IN THE SEMI-ARID MALLEE OF SOUTHEAST AUSTRALIA.

2.1 INTRODUCTION

Over much of Australia artificial water points have caused negative effects on the surrounding environment, usually attributed to overgrazing and trampling caused by large herbivores attracted to the water. As outlined above, animal impacts on vegetation and soils in close proximity to water points produce a piosphere effect (Lange, 1969), where a piosphere is a zone of attenuating stocking pressure radiating outwards from the watering place. The area within a few hundred metres is often denuded of vegetation because of trampling and overgrazing and is referred to as the 'sacrifice zone' (Valentine, 1947). Beyond the sacrifice zone there is often a zone of dense unpalatable perennial woody shrubs and, beyond this, palatable perennial plants progressively become more abundant with increasing distance (Zumer-Linder, 1976; Graetz, 1978; Barker, 1979; Andrew & Lange, 1986b; Barker *et al.*, 1989; Adamoli *et al.*, 1990; Van Rooyen *et al.*, 1990; Wilson, 1990; Perkins & Thomas, 1993a,b; Fusco *et al.*, 1995; Thrash, 1998). The relationship between the distance from water and the response of many vegetation and soil measures is often sigmoid (Graetz & Ludwig, 1978). Plants may also respond to indirect effects of grazing such as erosion, changed nutrient levels and competition by other plants. Examples of piosphere patterns include: a radiating pattern of livestock trails (Lange, 1969; Andrew, 1988), the accumulation of livestock faeces near the water (Lange, 1969, 1985; Weir, 1971; Lange & Willcocks, 1978; Andrew & Lange, 1986a; Tolsma *et al.*, 1987; Fusco *et al.*, 1995; Gibson, 1995; Thrash *et al.*, 1995), an increase in soil nutrients near the water and their depletion further away (Weir, 1971; Georgiadis & McNaughton, 1990; Perkins & Thomas, 1993a), soil compaction (Lee, 1977; Eldridge, 1996), loss of the soil cryptogram crust (Charley & Cowling, 1968; Andrew and Lange, 1986a; Eldridge, 1996) and an increase in the amount of bare soil near the water and defoliation and other changes to the biomass of herbage (Lange, 1969; Andrew & Lange, 1986a,b). Piosphere formation has been likened to desertification (Andrew, 1988; Hanan *et al.*, 1991).

A piosphere's size and shape is determined by the distances and directions over which animals can travel between foraging areas and the water point. Animal movements will be affected by vegetation type, terrain, relief and the tendency for animals to follow established trails (Pickup & Chewings, 1988). Utilisation of *Astrebla* grasslands by sheep in western Queensland, Australia, has also been attributed to wind direction and shade availability, as well as to the position of the water point (Orr, 1980). Larger water resources generally have larger piospheres (Hellden, 1984).

The work in this chapter examines the piosphere patterns around artificial water points in a study area within the arid mallee vegetation in the Murraylands of south-eastern Australia. The term 'mallee' refers to a multitude of plant communities, most of which are dominated by mallee eucalypts, but have quite different understories such as *Triodia* and chenopod shrubs (e.g. *Atriplex* and *Maireana* species)

(Noble, 1984). Mallee eucalypts are characterised by multiple aerial stems emanating from a lignotuberous rootstock. Although these species are found in a wide range of habitats including coastal, tropical, sub-alpine and arid, the mallee vegetation type in this chapter refers to that found in the semi-arid rangelands of southern New South Wales, South Australia and north-western Victoria.

While very little research has been conducted on piosphere effects in mallee vegetation, changes with distance from water have been demonstrated in a number of studies in other arid shrub woodlands in Australia. Andrew & Lange (1986a,b) monitored the initial development of a piosphere created by stocking a new water point with about 200 sheep at a near pristine site in arid chenopod shrubland in South Australia. Although they found a piosphere pattern evident in grass biomass after three months, only after eight years of stocking and a drought was there a substantial mortality of the main shrub species foraged. However there was a linear increase in biomass with increasing distance from water and this trend became more pronounced with time. Short-lived species were more susceptible. Piosphere patterns in shrubs and grasses took longer to appear than changes to the soil surface and this can be attributed to the fact that some vegetation variables not only register the direct effects of defoliation, but also the subsequent plant growth in response to that defoliation (Andrew, 1988).

Barker (1973) found that three years of livestock grazing was insufficient for any plant species to have invaded or to have been removed from around a watering point in her study, although the density of one shrub species increased 200 m from the water trough. The growth of some shrub species are stimulated at intermediate distances from water, and it appears that this stimulation occurs at greater distances from older water points.

If the herbivore species utilising a water point are known and their food preferences are also known, it should be possible to predict which unpalatable plant species will increase in abundance and which unpalatable ones will decrease with distance from water. Using the dietary preferences of sheep in South Australia, Barker & Lange (1969) were able to predict changes in abundance of most species around a water point, although some species behaved contrary to prediction. In the Murray Mallee site examined during this study, the main herbivores that might be responsible for piosphere formation are goats (*Capra hircus*), sheep (*Ovis aries*), and to a lesser degree, western grey kangaroos (*Macropus fuliginosus*) and red kangaroos (*M. rufus*). The distance from water that mammalian herbivores will travel to feed results from a balance between water demands driven by temperature, water salinity, physiology and body condition, and the availability of forage (Wilson, 1978; James *et al.*, 1999). For sheep in southern Australian rangelands, wet conditions and low temperatures in winter allow sheep to forage away from permanent water for long periods, when they rely instead on ephemeral water and the moisture content of the forage (Osborn *et al.*, 1932; Wilson, 1978). In contrast, high temperatures during summer necessitate frequent drinking, and the foraging range from water of sheep is reduced from 7 km during winter to 3 km during summer (Squires, 1976). Goats are similar to sheep in their water requirements (Dawson *et al.*, 1975) and therefore are probably similar to sheep in their ability to travel away from water to graze. Chenopod shrubs, such as those found in mallee vegetation, are high in minerals and therefore herbivores browsing on these species will require larger volumes of water to flush these mineral ions from their bodies (Squires, 1970; Squires, 1976; Wilson & Graetz, 1980).

Red kangaroos have much lower water requirements than sheep or goats (Dawson *et al.*, 1975), and therefore may travel further and stay away longer from water (Ealey, 1967). However, in a study on grazing within mallee vegetation, Ballentine (1998) demonstrated that, although red kangaroos were not observed drinking, they were not recorded beyond 4 km from water. It is likely that this pattern is related to habitat because western grey kangaroos, which are more dependent on water, occurred up to 8 km from water, the maximum distance sampled during Ballentine's study. It appears that heavy grazing, and therefore its most notable effects occur less than 3 km from water, although some effects might be noted up to 8 or more km from water. This is supported by a number of studies that demonstrated the effects caused by overgrazing decreased significantly at distances over 2 km from water (Foran, 1980; Graetz & Ludwig, 1978).

The principal objective of this chapter is to explore the changes to vegetation and soil characteristics with increasing distance from artificial watering points in an arid mallee environment. Most studies on this subject have examined the more dramatic piosphere effects which occur within two kilometres of a water point, while this study attempts to measure the more subtle effects of a piosphere by sampling up to 10 kilometres from water. Additionally, changes in the cover of individual plant species with distance from water are explained by examination of the herbivore diets of that region.

Mallee vegetation is now regarded as a threatened vegetation type within Australia and, because considerable areas are within conservation reserves, the biggest threats to mallee ecosystems appear to be fire and overgrazing. Both these issues can be managed, fire with fire restrictions and fire-breaks, and overgrazing through water point closure or fencing to prohibit herbivores' entry to water points. In fact, the managers of many reserves within mallee vegetation are closing water points to reduce herbivore numbers, however they have little information to guide them on the precise effects that overgrazing is having in this vegetation type. This chapter seeks to elucidate the effects overgrazing might cause in mallee vegetation and therefore help managers to determine what management action, if any, would be most beneficial and what effects those actions might have.

2.2 METHODS

2.2.1 Study Site

Location and pastoral history

The study area comprised parts of two neighboring South Australian conservation reserves which were once pastoral properties in which artificial water points were introduced for livestock; they are the Birds

Australia Gluepot Reserve and the north-western parts of Calperum Station that borders Gluepot. The following description of Gluepot is relevant to Calperum also, which lies within the same land system. Gluepot Reserve is located in the northern Murray Mallee region of South Australia where it is a component of the Bookmark Biosphere Reserve (Figure 2.1a). The Reserve is approximately 80 km northwest from South Australia's border with New South Wales and Victoria. Gluepot Reserve is 51,300 ha in area and measures approximately 37 by 14 km. It is bounded on the east and south by two de-stocked pastoral leases, Calperum (in which 20% of this study's sites were located) and Taylorville Stations. To the north and west of Gluepot are sheep-stocked pastoral leases, Parcoola and Belah Stations.

The Gluepot Station lease was first taken up in 1910. However its major development as a pastoral property was not started until the late 1930's, when most of Gluepot's 18 dams (ground tanks) were constructed (Gobbett, *pers. comm.*). Stocking rates between this period and 1976 are not documented, but it is known that, during certain periods, there were up to 115 sheep per km^2 on the property. Stocking rates between 1976 and 1997 were moderate, averaging approximately 37 sheep per km^2 (N. Taylor, *pers. comm.*). However, when Gluepot was purchased by Birds Australia in 1997, and the sheep were removed, 6000 feral goats were removed as well. This suggests that the density of non-native herbivores probably reached 150 animals per km^2 between 1976 and 1997. Since 1997, a constant culling program to control feral animals has been maintained, keeping the numbers of non-native herbivores relatively low (D. McKenzie, *pers. comm.*). A census in Calperum estimated the density of goats to be 1.5 per km^2 in 1998 (Dominelli, 2001). In addition to sheep and goats, native macropods (the western grey kangaroo and red kangaroo) were together present in moderately high numbers (approximately 2-4 per km^2) (Dominelli, 2001). The European rabbit (*Oryctolagus cuniculus*) was present in very low numbers.

Climate

The region encompassing Gluepot is the southern-most extension of the arid zone in South Australia (Laut *et al*, 1977). It experiences low and irregular rainfall, ranging between 35 and 560 mm, with an average of 225 mm per annum (Shaw and Forward, 1996). Gluepot's mean annual rainfall is 215 mm, which falls mostly in winter, although summer thunderstorms may contribute substantially. Winds are mostly from the south-east during summer and south-west to north during winter.

Topography, soils and vegetation

The landscape of the study area is principally limestone plains with varying proportions of overlying sand dunes. The region tends to denser mallee shrublands in the east giving way to more open plains with false sandalwood (*Myoporum platycarpum*), blackoak (*Casuarina pauper*) and chenopods (e.g.

the bluebush *Maireana sedifolia* and the saltbush *Atriplex stipitata*) in the west (Forward, 1996). Gluepot (including the western parts of Calperum) follows the regional pattern, the eastern half of the property being mallee shrubland with porcupine grass (*Triodia scariosa*) on sand dunes, and the western end tending toward open bluebush and myoporum woodland, and mallee shrublands with little sand (Hyde, 2001). A series of depressions and small flood plains are scattered throughout the property. These are dominated by discrete stands of *Casuarina pauper*, have heavy soils and may contain water for some months after rain. It should be noted that there are no rivers or creeks within this landscape and that most of the larger depressions contain in-ground tanks (referred to as dams throughout this thesis), which are filled via shallow channels cut into the surrounding area.

Gluepot has a series of low east-west orientated sand dunes. On these dunes and in the swales lying between them are two distinct vegetation associations. For a full description of these vegetation associations refer to Hyde (2001). The dune vegetation is a low mallee shrubland, dominated by horned oil mallee (*Eucalyptus socialis*), the canopy of which is usually less than five metres high. Shrubs are sparse or absent and the ground layer dominated by hummocks of porcupine grass (*Triodia scariosa*), with bare sand inter-hummock spaces. The swale vegetation is dominated by oil mallee (*E. oleosa*) and shrubs are generally sparse, but include *Senna* and *Acacia* species. The ground is mostly bare, except for sparse chenopods, a cryptogamic crust and some leaf litter under the mallees. In the west of Gluepot, the swale association intergrades with a *Myoporum*-mallee woodland association. Photographs of the two main vegetation types are shown in Plates 2.1 & 2.2. Hyde (2001) described a total of 12 vegetation associations at Gluepot, but the remaining nine associations were too scarce to enable adequate replication for this study (see Appendix 6 for a map of these vegetation associations on Gluepot Reserve).

2.2.2 Sampling Design

Because the two main vegetation types (swales and dunes) had a distinct plant species composition and soil type, sampling sites were stratified into the two main vegetation associations described above. Six replicates of sites were located at 0.25 km, 2.25 km, 4.25 km, 6.25 km and 8.25 km from water in each of the two main vegetation types (dunes and swales), while two additional "remote" sites were placed at 10.5 km from water in both vegetation types. Permanent dams had usually been constructed in the larger depressions, and great care was taken to ensure that the swale sites away from water had similar properties to those close to water but, due to the high density of water points, swale sites could not always meet those requirements fully. This problem was not encountered on dune sites because dams had not been placed in this vegetation type. The map co-ordinates of these study sites as well as a list of the plant species and their percentage cover scores are set out in Appendix 1. Site locations were selected with the aid of a Garmin GPS. Once suitable habitat was located at the required distance from water, the GPS was used to pinpoint a sites location. The distances from sites to water are not precise (within 200 m) due to the inaccuracies imposed on GPS's by the U.S. military at the time of this study.

Sites were not placed on straight transect lines radiating out from water points, but instead at points scattered throughout the landscape, which met the necessary pre-requisites of distance to water and vegetation type (see Figure 2.1b). Thus a full set of sites was not necessarily located in relation to the same water point. Sites were placed in relation to permanent water points only. Sites were placed around 10 water points, nine of these being dams and one being a stock trough (Plates 2.3 and 2.4). Water points that held water for all except the worst droughts were considered permanent. The status of water points within the study area were determined by consultation with local graziers. Where possible, sites were chosen so that their distance to permanent water was closer than to any temporary water source, such as a natural depression or temporary dam which often held water after rain, but due to the density of these this was not always possible.

At each site the vertical cover of every plant species detected, and the amounts of bare ground, cryptogamic crust and leaf litter were measured using the line intercept method. Five 90-metre transects were measured at each site. The average percentage cover value of these variables was then calculated from the intercept data and used during analysis. The starting point of transects was selected randomly within 60 metres of the sampling point, but it was necessary that all transects ran parallel to the nearest dune to prevent them from entering a different vegetation type. Additionally, the diversity and vertical cover of the following variables was calculated: upper canopy (tree layer), mid canopy (cover values for this layer were measured for both shrubs less than and greater than two metres), the herbaceous layer (including perennial and annual forbs), grasses and parasites (e.g. mistletoe). The heights of the upper canopy, mid canopy and lower canopy were estimated with the aid of a three-metre rule. All measurements were taken during September 2000. It should be noted that there was below-average rainfall in the months prior to this study, which resulted in reduced growth and seedling abundance than might otherwise have been expected.

2.2.3 Analytical Methods

Most of the data relating to individual species cover scores did not meet the requirements for parametric analysis. For this reason, data relating to individual species were analysed using a non-parametric Spearman correlation test to determine whether there was any effect with distance from water. Lange (1969) and Fatchen (1978) found that piosphere patterns were adequately described by a linear model within the limitations of the data. Where data were normally-distributed, evidence of piosphere patterns were examined with a series of linear and second-order polynomial regressions, with distance from water as the independent variable and each of the major categories of height, cover and diversity as dependent variables. Both the above analyses were conducted separately for data from swales and dunes, and for the averages from the two vegetation types combined. A number of variables required transformation before a normal range of values was attained. The analyses were performed on the computer software package SPSS 10.1, using the procedure Regression: Curve estimation. Graetz and Ludwig (1978) proposed that a logistic equation was a better fit for describing

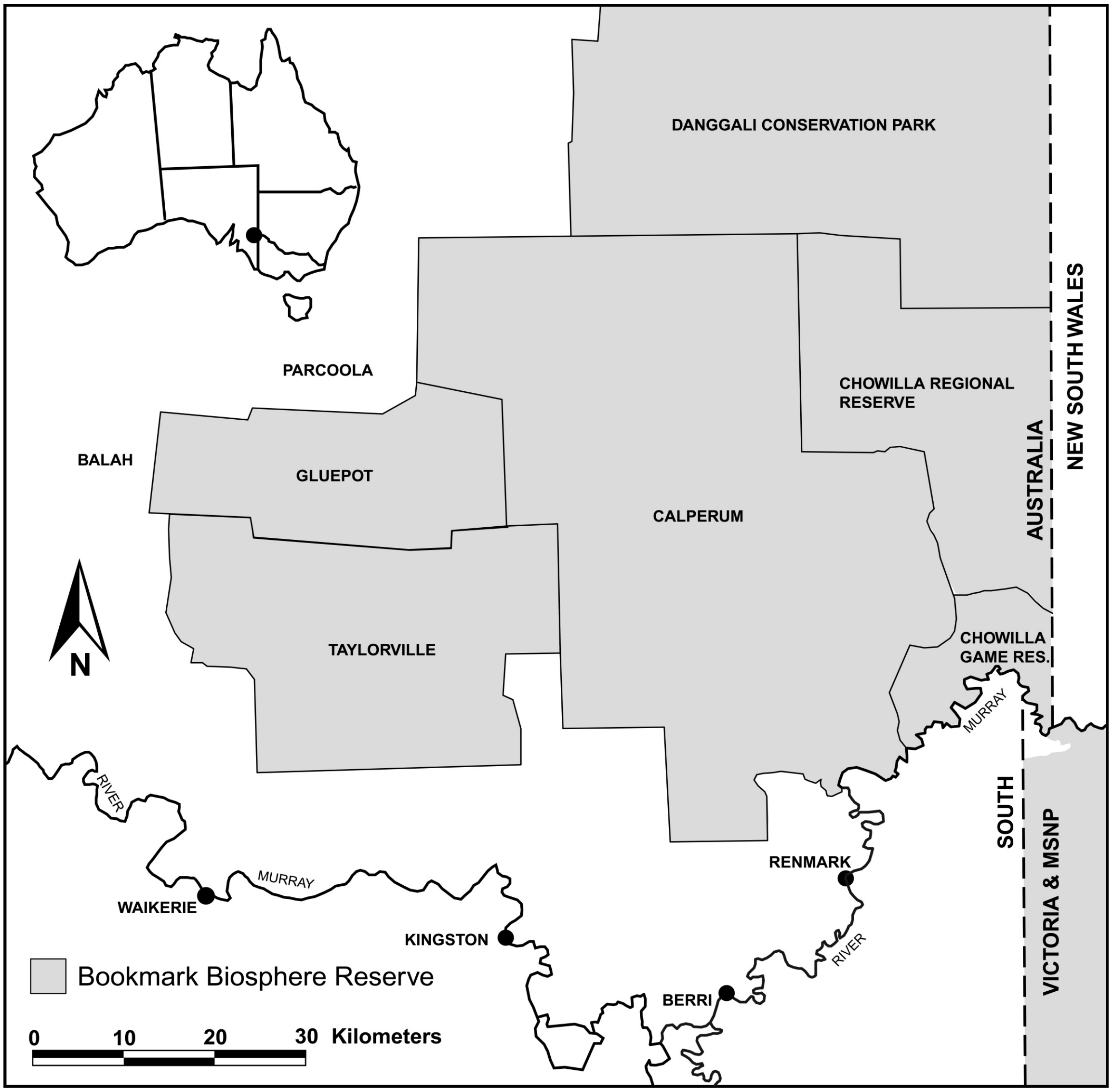
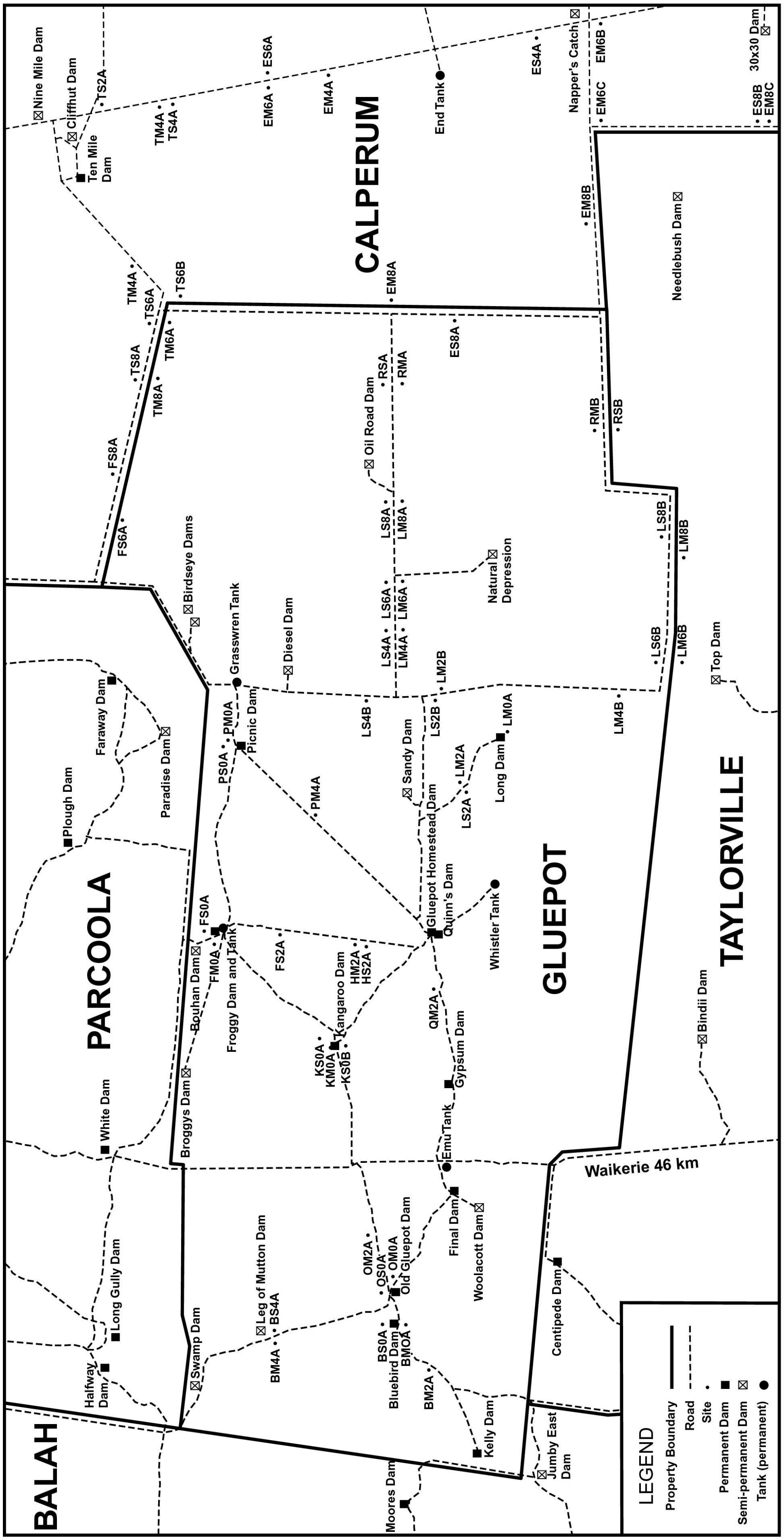


Figure 2.1a: Gluepot Reserve and Calperum Pastoral Lease in relation to Bookmark Biosphere and southeast Australia. Murray Sunset National Park is represented by the shaded area within Victoria.

Figure 2.1b (facing page): Location map showing study sites in Gluepot and Calperum. Study site names have a four-digit code (e.g. BM4A). The first letter represents the first letter of the dam name that site has been measured from (i.e. nearest permanent water point); the second letter signifies the vegetation type (M = Mallee Woodland (swale) and S = Spinifex Mallee (dune crest)); the number represents the distance to water; and the last letter is a sequential record of sites in the same habitat at the same distance from the same water point with A being the first. See Appendix 6 for a map of the water points and sampling sites in relation to the vegetation association on Gluepot Reserve.



BALAH
PARCOOLA
CALPERUM
GLUEPOT
TAYLORVILLE
Waikerie 46 km
Nine Mile Dam
Cliffhut Dam
TS2A
Ten Mile Dam
TM4A
TS4A
EM6A
ES6A
EM4A
End Tank
ES4A
Napper's Catch
EM6C
EM6B
30x30 Dam
ES8B
EM8C
EM8B
Needlebush Dam
TM4A
TS6A
TS6B
EM8A
TS8A
TM6A
TM8A
ES8A
RSA
RMA
Oil Road Dam
RMB
RSB
FS8A
FS6A
LS8A
LM8A
LS8B
LM8B
Birdseye Dams
Natural Depression
Grasswren Tank
Diesel Dam
LS4A
LM4A
LS6A
LM6A
LM2B
LS6B
LM6B
Top Dam
Faraway Dam
Paradise Dam
PS0A
PM0A
Picnic Dam
LS4B
Sandy Dam
LS2B
LM0A
LM4B
Plough Dam
PM4A
LM2A
Long Dam
LS2A
Gluepot Homestead Dam
Quinn's Dam
Whistler Tank
FS0A
Bouhan Dam
FM0A
Froggy Dam and Tank
FS2A
Kangaroo Dam
HM2A
HS2A
QM2A
KS0A
KM0A
KS0B
Gypsum Dam
Bindii Dam
White Dam
Broggys Dam
Emu Tank
Long Gully Dam
Leg of Mutton Dam
OM2A
QS0A
OM0A
Old Gluepot Dam
Final Dam
Woolacott Dam
Centipede Dam
Halfway Dam
Swamp Dam
BM4A
BS4A
BS0A
Bluebird Dam
BM0A
BM2A
Kelly Dam
Jumby East Dam
Moores Dam
LEGEND
Property Boundary
Road
Site
Permanent Dam
Semi-permanent Dam
Tank (permanent)

Plate 2.1: The sand dune vegetation is characterised by an upper canopy dominated by *Eucalyptus socialis* (horned oil mallee), a scarcity of shrubs and a ground cover dominated by *Triodia scariosa* (porcupine grass).

Plate 2.2: The swale vegetation is characterised by an upper canopy dominated by *Eucalyptus oleosa* (oil mallee), a sparse shrub layer dominated by *Senna* species and *Acacia colletioides* (veined wait-a-while) and a ground layer which is mostly bare of vegetation, except for sparse chenopods, a cryptogamic crust and leaf litter under the trees.

Plate 2.3: Quinn's Dam, Gluepot Reserve. The dams or in-ground tanks in the study area are characteristically placed in natural depressions which may collect water after rain, and have four walls constructed from soil excavated from within the dam. Water enters the dam through one or more drainage channels which are dug into the surrounding area (pictured on far side of dam). Note the surrounding *Casuarina pauper*.

Plate 2.4: A typical stock trough of the study area. Although these are usually placed within swales, water is usually piped to the trough from a water source several kilometres away. They do not normally lie in natural depressions in which *Casuarina pauper* is the dominant plant species.

piosphere data (particularly ground cover) up to 2-3 km, past which shrub cover appears to reach a stable maximum. Because this study examines piosphere patterns up to 10 km, logistic regressions were not fitted to these data.

Correlations involving data which contain high frequencies of zeros are prone to inaccuracies (Kent and Coker, 1992), and therefore the plant species cover data were re-analysed using a point-biserial correlation of the presence/absence of individual plant species with distance from water. Associations between individual species cover and topography (dune or swale) were examined using independent sample t-tests. The above calculations were also performed using SPSS version 10.1.

To ensure that sites within each of the two chosen vegetation types had the expected similar plant species associations, all sites were classified using cluster analysis. A dissimilarity matrix was first created using the cover values of the 63 most common perennial plant species using the SPSS 10.1 procedure Proximities, then a dendrogram using agglomerative clustering (Ward's Method) in the SPSS 10.1 procedure Cluster.

Note: Throughout this chapter the following symbols are used to indicate levels of statistical significance: NS = $P>0.05$; * = $P<0.05$; ** = $P<0.01$; *** = $P< 0.001$.

2.3 RESULTS

Four different types of general relationships were found for changes in vegetation variables with distance from water. These were: positive linear, negative linear, quadratic u-shaped (i.e. intermediate distances from water had low values) and quadratic n-shaped (i.e. intermediate distances from water had high values). Table 2.1 lists the results for all the vegetation variables examined first for dune crests and swales combined, then for the two vegetation types separately.

In general, less than half of the variation (7-42%) in these variables could be explained by distance from permanent water. Variables that decreased significantly and linearly with distance from permanent water were bare ground cover (Figure 2.2), perennial forb diversity (Figure 2.3) and mean shrub height (Figure 2.4). When data from the two main vegetation types were analysed separately, these variables all showed significant decreaser trends within swale vegetation but, in dunes sites, only perennial forb diversity showed a significant linear decrease with distance from water. Total herbaceous cover showed a significant negative response in swale vegetation only, while tree cover has a significant negative response within dune vegetation only.

Variables that demonstrated a significant positive linear relationship to distance from permanent water included mean shrub cover (< 2m) and leaf litter cover (Figure 2.2). When data from the two vegetation types were analysed separately, mean shrub cover (< 2m) showed a significant increase in

Table 2.1: Regression response (r), r^2 values and p-values from regressions of vegetation variables against distance from water point (in km). Linear and quadratic functions were tested and the values shown are for the function returning the higher r^2. + = positive linear response, - = negative linear response, u = u-shaped quadratic response, n = n-shaped quadratic response and NT = no trend (values for NT relate to linear function). Graphs of the statistically significant relationships are shown in Figures 2.2, 2.3 and 2.4.

Habitat type:	**Dune and Swale**			**Swale Only**			**Dune Only**		
	r	**r^2**	**p**	**r**	**r^2**	**p**	**r**	**r^2**	**p**
Upper Canopy									
Tree diversity	u	0.055	NS	u	0.095	NS	pos.	0.057	NS
Tree height	neg.	0.018	NS	neg.	0.076	NS	u	0.031	NS
Cover	pos.	0.054	NS	pos.	0.354	***	neg.	0.122	*
Parasitic diversity	neg.	0.021	NS	neg.	0.048	NS	NT	0.002	NS
Mid Canopy									
Diversity	NT	0.025	NS	neg.	0.080	NS	pos.	0.131	*
Height	neg.	0.074	*	neg.	0.169	*	neg.	0.047	NS
Cover (>2m)	n	0.002	NS	neg.	0.060	NS	neg.	0.006	NS
Cover (<2m)	pos.	0.224	***	n	0.177	*	pos.	0.426	***
Ground Cover									
Total herbaceous diversity	u	0.161	**	pos.	0.134	NS	u	0.138	NS
Annual forb diversity	neg.	0.012	NS	neg.	0.039	NS	neg.	0.002	NS
Perennial forb diversity	neg.	0.219	***	neg.	0.156	*	neg.	0.223	**
Grass diversity	u	0.210	***	pos.	0.222	**	pos.	0.019	NS
Total herbaceous cover	neg.	0.035	NS	neg.	0.128	*	u	0.178	NS
% Grass	n	0.005	NS	pos.	0.054	NS	neg.	0.023	NS
% Leaf	pos.	0.177	**	pos.	0.353	***	n	0.005	NS
% Bare ground	neg.	0.120	**	neg.	0.371	***	u	0.083	NS
% Cryptogamic crust	pos.	0.018	NS	pos.	0.034	NS	n	0.135	NS
Crust/Bare ground	pos.	0.046	NS	pos.	0.137	*	n	0.127	NS
Total plant diversity	u	0.005	NS	u	0.095	NS	pos.	0.114	NS

both swale and dune vegetation, whereas leaf litter cover showed a significant increase only in swale vegetation. Variables that increased within swale vegetation included tree cover, grass diversity and crust cover (as a proportion of bare ground). Shrub diversity increased significantly only within dune vegetation (Figure 2.3). Statistically significant u-shaped relationships were detected for herbaceous diversity and grass diversity (Figure 2.3). In both cases high values at zero distance from water led to the u-shaped response.

The results from the cluster analysis indicated that, although the two vegetation types separated clearly, a number of sites were not grouped as might be expected (Figure 2.5). Three dune sites at 0 km from water were grouped with the swale sites, while one swale site (HM2A) at 2 km from water was grouped with dune sites, and one remote (10 km) dune crest site was not similar to any other sites. The 10 km site contained heath-like vegetation which would explain its disassociation from the other sites in the dissimilarity matrix. For this reason, correlations were repeated with the 10 km sites removed. This resulted in a number of different species demonstrating a significant trend when previously they had not. These species included *Dodonaea viscosa* (r=0.383, P=0.019, crest only) and *Rhagodia*

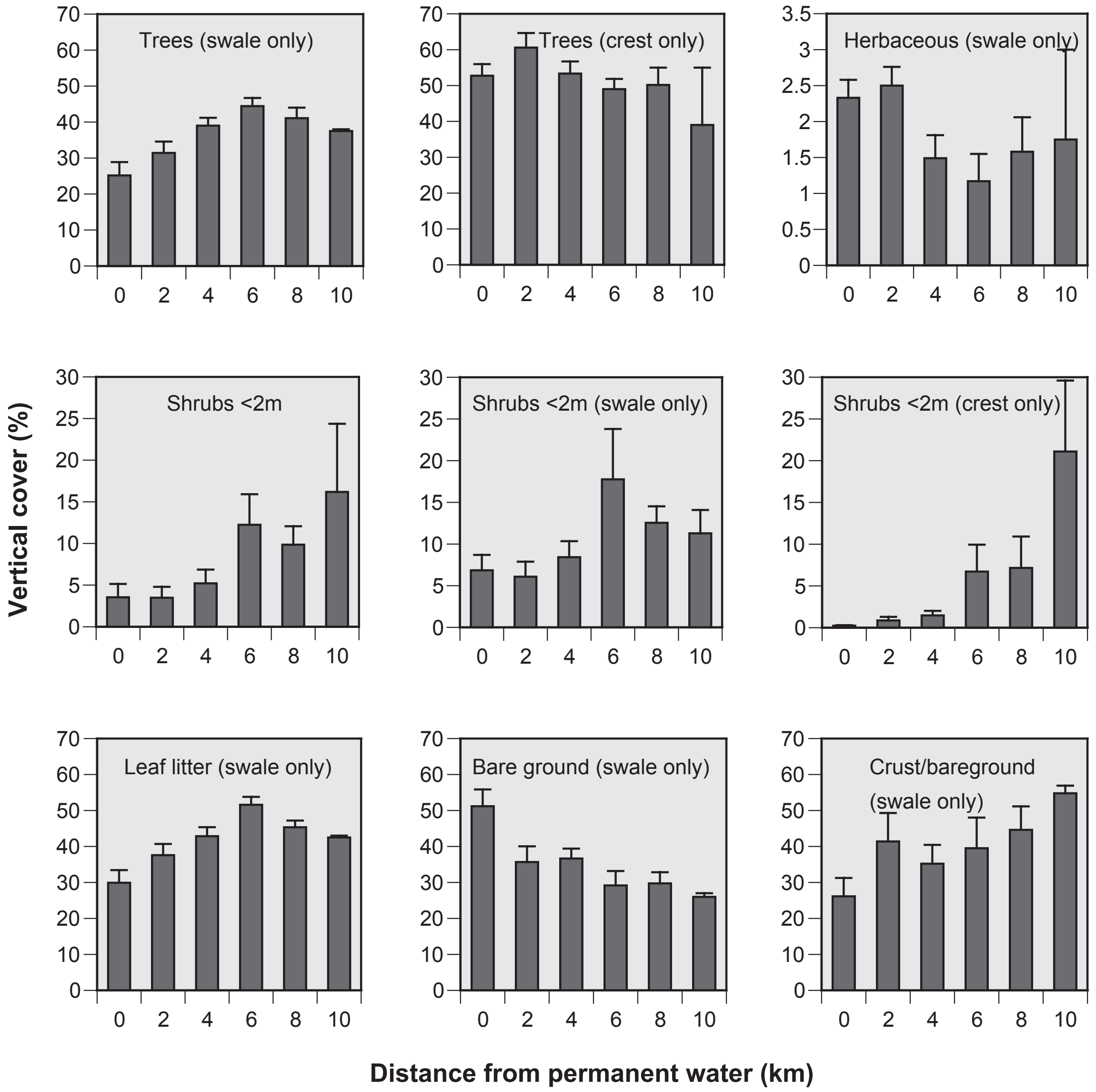


Figure 2.2: Changes in the vertical cover of trees, herbaceous vegetation, shrubs (<2m), leaf litter, bare ground and cryptogamic crust (as a proportion of bare ground) with distance from permanent water. Unless marked otherwise, figures relate to combined data from dune and swale vegetation. Additionally, bare ground had a similar significant trend when data from both vegetation types were combined, but not in dune crest vegetation alone. The remaining variables did not show statistically significant trends.

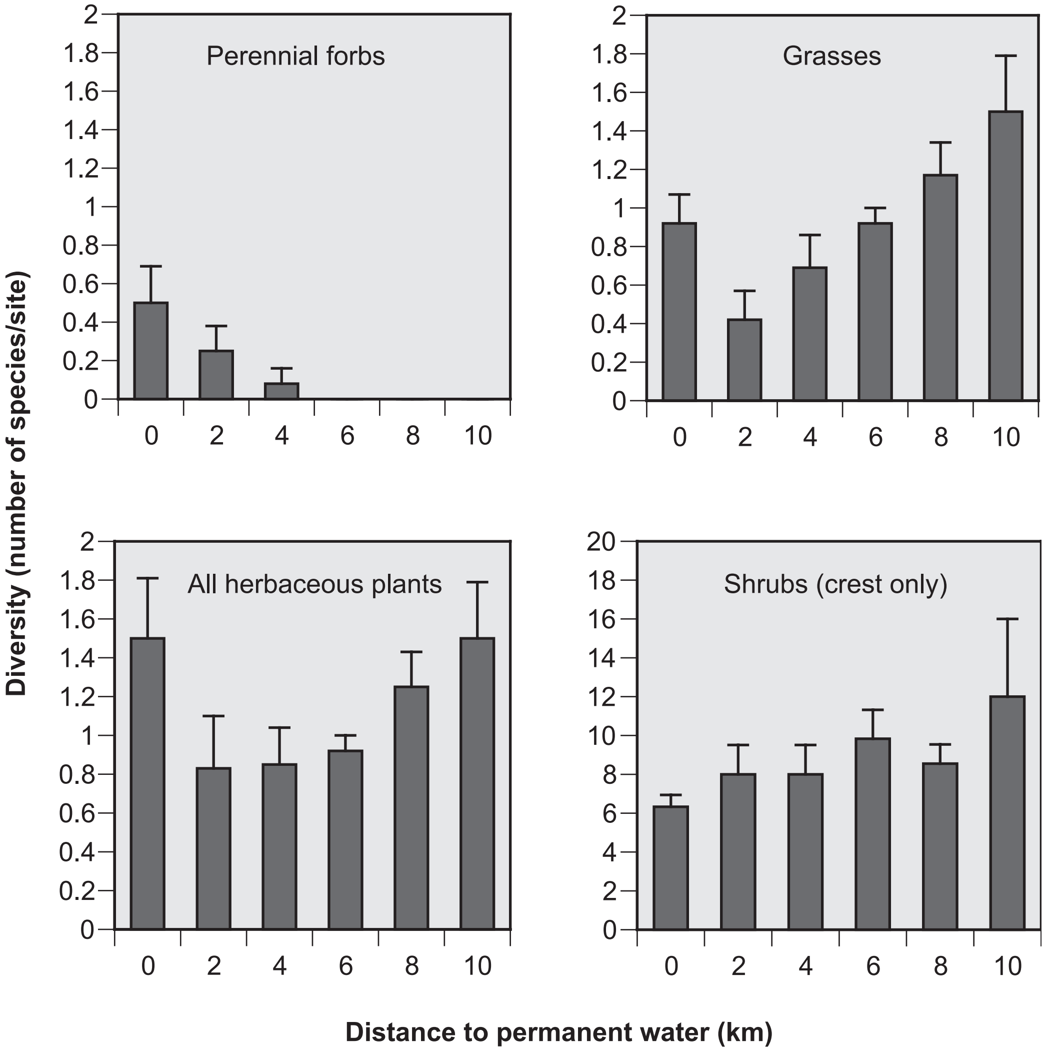


Figure 2.3: Changes in the mean diversity of perennial forbs, grasses, all herbaceous plants combined and shrubs (crest only) with distance from permanent water. Unless marked otherwise, graphs are based on combined data from dune and swale vegetation. Additionally, perennial forbs demonstrated a similar significant negative response when data from swale and dune vegetation types were analysed separately, and grasses a similar significant positive response when swale vegetation data were analysed separately.

Table 2.2: Spearman correlation coefficient (r) and significance values of significant correlations of individual plant species cover with distance from permanent water. Correlations were based on swale and dune data combined and swale and dune crest data separately. When **NS** is bold, 0.05<p<0.10. [1] indicates that the species only demonstrated a significant trend when 10 km sites were removed and a '-' indicates that there was no data for that species in that particular vegetation type.

Species	**Swale & Dune**		**Swale only**		**Dune only**	
	r	**p**	**r**	**p**	**r**	**p**
Upper Canopy						
Callitris verrucosa	+0.286	**	-	-	+0.466	***
Casuarina pauper	-0.289	**	-0.400	**	-	-
Eucalyptus oleosa	-0.032	NS	+0.331	**	-0.408	**
Myoporum platycarpum	+0.023	NS	-0.138	NS	+0.291	*
Parasites						
Amyema preissii	-0.188	**NS**	-0.382	**	+0.218	NS
Mid & Lower Canopy						
Acacia brachybotrya	+0.357	***	-	-	+0.480	***
Acacia colletiodes	-0.244	**	-0.220	**NS**	-0.416	**
Acacia nysophylla	-0.443	***	-0.617	***	-0.089	NS
Acacia schlerophylla	+0.338	***	+0.461	***	+0.105	NS
Acacia wilhelmiana	+0.256	*	+0.214	NS	+0.301	*
Atriplex stipitata	+0.242	*	+0.389	**	-	-
Baeckia crassifolia	+0.266	*	-	-	+0.396	**
Beyeria opaca	+0.317	**	+0.408	**	+0.198	NS
Cryptandra propinqua	+0.218	*	-0.290	*	-0.047	NS
Daviesia benthamii	-0.266	*	-0.350	*	-	-
[1]*Dodonea viscosa*	+0.188	**NS**	+0.074	NS	+0.383	*
Eremophila scoparia	-0.244	*	-0.278	*	-0.167	NS
Grevillea huegelii	+0.353	***	+0.181	NS	+0.578	***
Lycium australe	-0.398	***	-0.569	***	-	-
Maireana schistocarpa	-0.230	*	-0.500	***	-0.178	NS
Maireana sedifolia	-0.220	*	-0.312	*	-	-
Olearia muelleri	+0.042	NS	-0.139	NS	+0.382	**
[1]*Rhagodia spinescens*	-0.214	*	-0.061	NS	-0.223	NS
Sclerolaena obliquicuspis	-0.357	***	-0.502	***	-0.047	NS
Senna artemisoides ssp. *filifolia*	-0.012	NS	+0.200	NS	-0.285	*
Templetonia egena	+0.425	***	+0.419	**	+0.462	***
Westringia rigida	+0.413	***	+0.222	NS	+0.546	***
Zygophyllum auriantiacum	-0.175	NS	-0.410	***	-0.213	NS
Ground Cover						
Austrostipa sp.	+0.289	**	+0.316	*	+0.251	**NS**
Lomandra effusa	-0.258	*	-0.062	NS	-0.379	**
Triodia scariosa	+0.085	NS	+0.447	**	-0.108	NS

spinescens (r=-0.313, P=0.026, swale only). *Baeckia crassifolia* no longer maintained a significant decreaser response when the 10 km sites were removed from the correlation.

Because the frequency distributions of individual species cover scores were highly skewed, with a very high proportion of zero values, it was only possible to determine linear associations with distance from water using a non-parametric Spearman's correlation test. Table 2.2 sets out the plant species that demonstrated a significant change in cover with distance to water, while a list of the correlation coefficients and significance values from both the Spearman and point-biserial correlations for all the plant species sampled can be seen in Appendix 1. There were 15 species of plants which increased significantly in cover closer to water—these are known as "increasers" and have a negative correlation coefficient—and 16 species which decreased in cover closer to water - known as "decreasers", with a positive correlation coefficient.

Increaser species were represented within the upper canopy by *Casuarina pauper*, *Eucalyptus oleosa* and *Amyema preissii*, within the mid canopy by *Acacia colletioides*, *A. nysophylla, Daviesia benthamii*, *Eremophila scoparia*, *Lycium australe*, *Maireana schistocarpa*, *M. sedifolia*, *M. trichoptera*, *Olearia muelleri*, *Sclerolaena obliquicuspis*, *Senna artemisoides* ssp. *filifolia* and *Zygophyllum aurantiacum*, and within the ground layer by *Lomandra effusa* (see Figure 2.6). Decreaser species were represented within the upper canopy by *Callitris verrucosa*, *Eucalyptus oleosa* and *Myoporum platycarpum*, within the mid canopy by *Acacia brachybotrya*, *A. sclerophylla*, *A. wilhelmiana*, *Atriplex stipitata*, *Baeckia crassifolia*, *Beyeria opaca*, *Grevillea huegelii*, *Cryptandra propinqua*, *Olearia muelleri*, *Templetonia egena* and *Westringia rigida*, and within the ground layer by *Austrostipa* sp. and *Triodia scariosa* (see Figure 2.7). Some species are mentioned as both increasers and decreasers because they had opposite associations in each of the two different vegetation types (see Table 2.2).

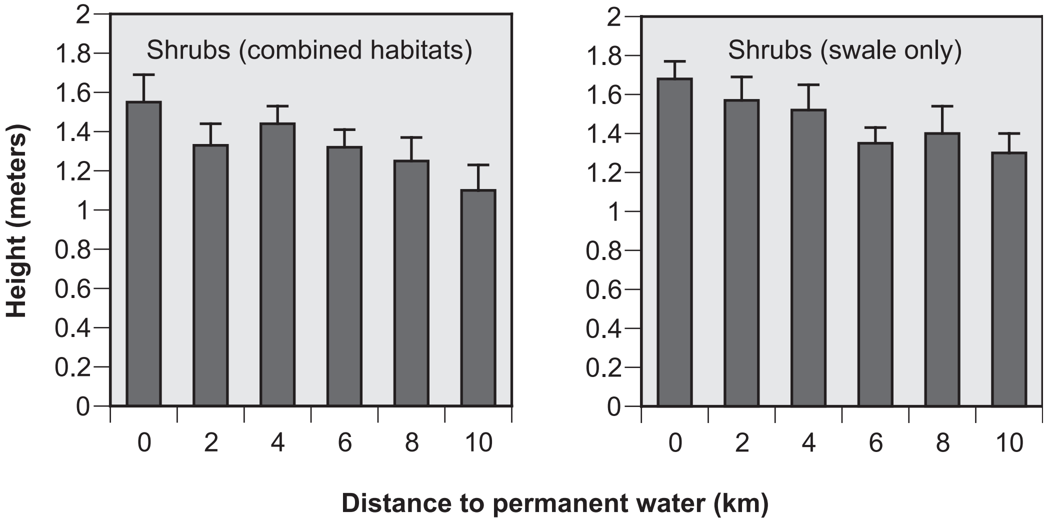


Figure 2.4: Changes in mean shrub height with distance from permanent water in swale vegetation and swale and dune vegetation combined. This trend was not statistically significant in dune vegetation.

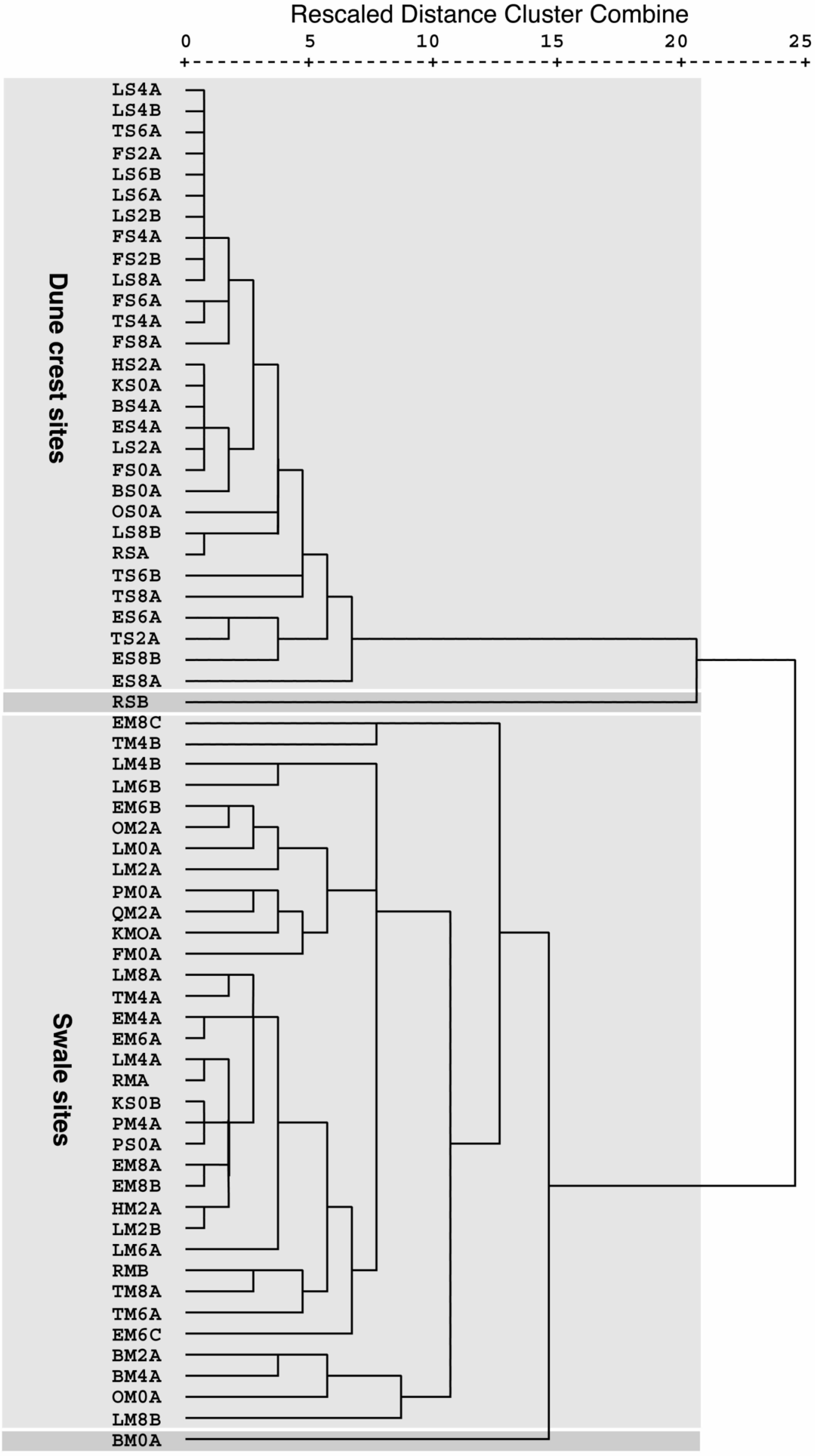


Figure 2.5: The dendrogram of sites as shown by cluster analysis of cover data on the more abundant plant species. The species codes are explained in the caption to Figure 2.1b. The two main vegetation types group separately, although two dune sites at 0 km from water are grouped with the swale sites, and one of the 10 km dune sites (RSB) and one of the 0 km swale sites are grouped separately from all the other sites. Sites grouped closely together indicate similar plant species associations.

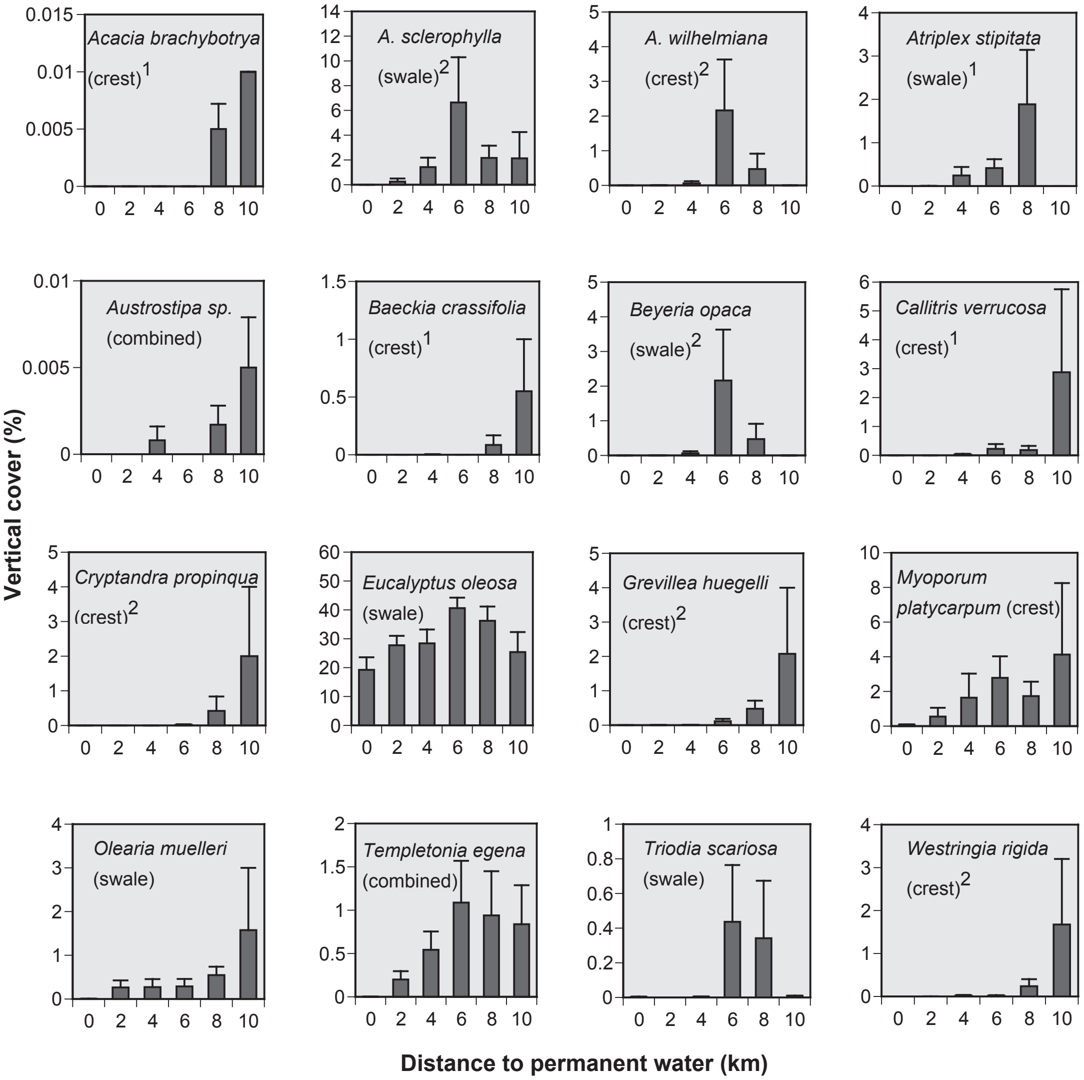


Figure 2.6: Changes in the vertical cover of decreaser plant species with distance from permanent water. Unless marked otherwise, graphs relate to data from dune and swale vegetation types combined. Combined data were used when the trends in both the separate vegetation types were the same and statistically significant. If combined data demonstrated a significant trend, but that trend was caused by data from one vegetation type only, then only data from the significant vegetation type are displayed. These species are indicated with a [1] if not present in the other vegetation type, or [2] if the species is present in both vegetation types. For more details on trends and significance values in each vegetation type refer to Appendix 1.

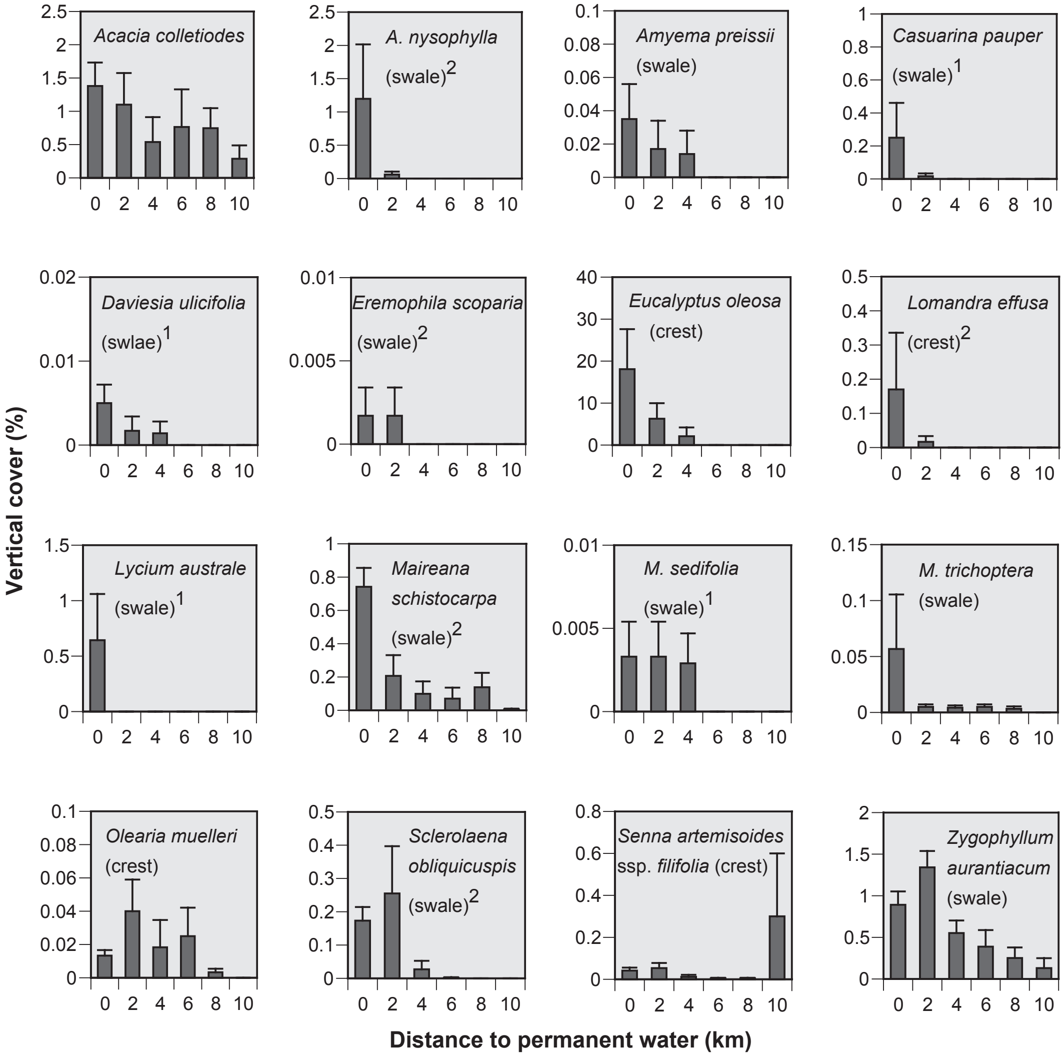


Figure 2.7: Changes in the vertical cover of increaser plant species with distance from permanent water. Unless marked otherwise, graphs relate to data from dune and swale vegetation types combined. Explanations for these graphs follow the same rules as in Figure 2.5.

When the presence or absence of plant species was analysed for trends with distance from water using the point-biserial correlation, additional significant correlations to those already detected using the Spearman correlation on cover values were detected. The additional species that were determined to be increasers (lower average distance at sites where the species was present, compared to sites where it was absent) included *Eremophila deserti*, *Exocarpus aphyllus* and *Rhagodia spinescens*. The additional species that were determined to be decreasers (higher average distance at sites where the species was present, compared to sites where it was absent) included *Eucalyptus leptophylla* and *Acacia rigens*. Results for the point-biserial correlation analysis are set out in Appendix 1.

In some cases plant species were detected either only close to or only distant from water, but were not abundant enough to show a significant trend when either correlation measure was applied to these data. Plant species which occurred only close to water included *Einadia nutans*, *Marrubium vulgare* and *Nicotiana* sp. Plant species which occurred only far from water included *Boronia coerulescens*, *Codonocarpus cotinifolius*, *Cratystylis conocephala*, *Dodonaea bursarifolia*, *Geijera linearifolia*, *Hakea leucoptera*, *Prostanthera aspalathoides* and *Waitzia accuminata*.

Table 2.3 list the vegetation variables that differed significantly between vegetation types. Table 2.4 lists those species with an average foliage cover that is significantly different between the two vegetation types according to an independent sample t-test. Species that were present in only one vegetation type and whose cover scores were not significantly different are also displayed.

Table 2.3: Vegetation variables which vary significantly between swale and dune vegetation. Mean values for each vegetation association were compared using independent samples t-tests. All measures of diversity refer to the mean number of species per site.

Variable	**Mean Value**		**t-value**	**p**
	Swale	**Dune**		
Upper Canopy				
Tree diversity	2.844	3.400	11.36	***
Tree height (m)	6.672	4.500	11.05	***
Tree cover (%)	35.92	52.28	-7.18	***
Mid Canopy				
Shrub diversity	19.53	8.375	11.36	***
Shrub height (m)	1.502	1.225	2.76	**
Shrub cover (<2m) (%)	10.47	4.405	2.71	*
Shrub cover (>2m) (%)	0.978	0.102	3.39	**
Ground Layer				
Grass cover (%)	0.151	15.94	-15.14	***
Herbaceous cover (%)	1.780	0.116	9.67	***
Crust cover (%)	22.52	6.406	8.52	***

Table 2.4: Species with cover scores which vary significantly between swale and dune vegetation. Mean cover scores for each vegetation association were compared using independent samples t-tests. If a species was present in only one vegetation type, it is included, even if it is not significantly different. Species that were found only at one site are not included because comparisons were not possible.

Species	**Mean Cover (%)**		**t-value**	**p**
	Swale	**Dune**		
Upper Canopy				
Callitris verrucosa	0	0.263	-1.44	NS
Casuarina pauper	0.050	0	1.23	NS
Eucalyptus gracilis	2.300	0	2.84	**
Eucalyptus oleosa	29.49	4.959	7.44	***
Eucalyptus socialis	1.157	37.97	-12.27	***
Mid Canopy				
Acacia brachybotrya	0	0.002	-2.4	*
Acacia colletioides	1.606	0.145	4.91	***
Acacia ligulata	0	0.050	-1.23	NS
Acacia rigens	0	0.139	-1.11	NS
Acacia sclerophylla	2.141	0.065	2.59	*
Amyema preissii	0.013	0.001	2.10	*
Atriplex stipitata	0.481	0	1.87	**NS**
Baekea crassifolia	0	0.051	-1.48	NS
Chenopodium curvispicatum	0.087	0	1.60	NS
Cratystylis conocephala	0.066	0	1.34	NS
Cryptandra propinqua	0	0.193	-1.00	NS
Daviesia benthamii	0.002	0	2.40	*
Dodonaea viscosa	0.429	0.014	2.09	*
Enchylaena tomentosa	0.044	0	2.04	**NS**
Eremophila glabra	0.763	0.016	3.38	**
Eremophila scoparia	0.873	0.034	2.84	**
Eriochiton sclerolaenoides	0.001	0	1.44	NS
Lycium australe	0.121	0	1.41	NS
Maireana appressa	0.018	0	1.87	**NS**
Maireana erioclada	0.001	0	1.79	**NS**
Maireana georgei	0.220	0.001	3.82	***
Maireana pentatropis	0.005	0.001	5.23	***
Maireana sclerolaenoides	0.223	0.001	3.82	***
Maireana sedifolia	0.002	0	2.67	*
Maireana triptera	0.021	0	1.12	NS
Maireana turbinata	0.001	0	1.44	NS
Olearia muelleri	0.326	0.019	2.89	**
Olearia subspicata	0	0.003	-1.12	NS
Phebalium glandulosum	0	0.003	-1.10	NS
Santalum accuminatum	0	0.009	-1.79	NS
Sclerolaena diacantha	0.059	0.001	3.45	**
Scaevola spinescens	0.037	0.001	2.15	*
Senna artemisioides coriacea	0.705	0.003	3.07	**
Senna artemisioides filifolia	2.588	0.041	10.03	***
Templetonia egena	0.238	0.923	-2.33	*
Thryptomene micrantha	0	0.014	-1.02	NS
Zygophyllum apiculatum	0.054	0.001	2.07	*
Zygophyllum aurantiacum	0.644	0.001	6.47	***
Ground Layer				
Dissocarpus paradoxus	0.001	0	1.79	NS
Eragrostis dielsii	0.002	0	2.40	*
Triodia scariosa	0.1478	14.59	-10.97	***

2.4 DISCUSSION

In this study the vegetation of a piosphere at sampling points up to 10 km from permanent water has been described. Past studies have described the more dramatic piosphere effects which occur within two kilometres of a water point, and which can be described by a logarithmic equation (Graetz & Ludwig, 1978; Thrash *et al*., 1993). This study has attempted to measure the more subtle effects of piospheres by sampling at a much larger scale. This strategy has been rewarding, in that some decreaser plant species were not detected until distances greater than eight kilometres from water, while some increaser species were no longer detected at all beyond two kilometres from water.

It should be noted that because most water points occur in the larger depressions it is possible that the observed trends in vegetation with distance from water may reflect subtle landscape gradients, and not the effects of the presence of water. For example, at increasing distances from water the dunes tended to get larger (and therefore drier) while the intervening swales became smaller. Because one water point (End Tank) was a trough not located in a large depression, it was possible to compare the trend around this water point with the overall trend to determine whether a landscape gradient may have been responsible for the observed pattern. Analyses of the vegetation data around End Tank revealed that a number of vegetation trends were different from the overall trend, suggesting that these may have been influenced by landscape gradients and not the presence of permanent water. The following variables responded differently to the overall trend: leaf litter cover, tree cover and the cover of *A. colletioides, T. egena* and *M. schistocarpa*. The significance of this to these variables will be discussed below.

2.4.1 Mallee vegetation

Habitat differences

A description of the two main plant species associations (dune crests and swales) within the study area can provide a better understanding of the observed trends in the vegetation data. The dunes consist of sandy soils which are considerably drier and poorer in nutrients than the red calcareous to loamy soils of the swales. Swales tend to be more protected, have a greater structural diversity and contain larger shrubs and trees. Although shrub cover and diversity was greater within swales, tree cover and diversity was greater within dunes. Approximately 20% of ground cover within swales consisted of cryptogamic crust which was mostly absent from the dunes. Swales contained a significantly greater cover of herbaceous vegetation, although dunes had more grass cover, due to the high cover of *T. scariosa* on dune sites.

The three 0 km dune sites that were grouped with swale sites in the dissimilarity matrix had low cover values for *T. scariosa*, high shrub cover and high cover values for *Eucalyptus oleosa*. The low cover values for *T. scariosa* may be due to trampling by large mammals, while the high shrub cover may be disturbance related, particularly as the dominant shrubs at these sites were unpalatable species such as *Acacia colletioides* and *Senna* species. It is unclear why the 2 km swale site (HM2A) was grouped with dune sites.

Vegetation changes

The effects of trampling were apparent in the increase in bare ground cover and decrease in cryptogamic crust cover closer to water. The regression of cryptogamic crust cover alone did not produce a significant trend, but when crust was analysed as a proportion of bare ground, a significant association with distance from water was found. Cryptogamic crust cover (as a proportion of bare ground) showed a significant positive trend within swales, but did not produce a significant trend within dunes or when the two vegetation types were combined. The absence of a trend on dune crests may be related to the very low cover scores within that vegetation type, making changes in percentage cover hard to detect because only small quantities ever exist (therefore low statistical power). Likewise, leaf litter cover increased with distance from water in swales only, possibly demonstrating the effects of trampling. However, the pattern for leaf litter cover is correlated with that of tree cover within swales ($r^2=0.368$, $p<0.01$; see Figure 2.2), suggesting that leaf litter cover may simply be a function of tree cover.

The increase in upper canopy cover with distance from water in swale vegetation may be due in part to past clearing practices, although the deeper depressions were often naturally sparsely vegetated. Pastoralists often cleared trees from around dams to increase run-off and, because dams are always in swales, tree cover tends to be sparser close to dams. Additionally, large flat areas were often cleared to increase forage, and this was often done in close proximity to water points so that stock could utilise them. The fact that the decreaser trend in tree and leaf litter cover was not observed around the above-ground trough when analysed separately supports this hypothesis. Although eucalypts form a major component of goats' diets (Ballentine, 1998) and the dominant tree species in swales, *E. oleosa* demonstrated a decreaser response, it seems unlikely that browsing pressure is responsible for the decrease in tree cover closer to water. If the observed decreaser trend in tree cover within swale vegetation was due to browsing pressure, as opposed to past clearing practices and the natural state of the vegetation, then you might expect the same trend to be displayed within dune vegetation. However, tree cover and *E. oleosa* cover had an opposite significant increaser trend on dune crests, even though goat densities on swales and dunes were not significantly different (Ballentine, 1998).

Shrub cover less than two metres tall showed a significant positive response to distance from water in dune vegetation and a significant n-shaped (and also positive) response in swale vegetation. Within dune vegetation this was caused by an increase of species such as *Acacia rigens, A. wilhelmiana*, *Baeckia crassifolia*, *Beyeria opaca*, *Dodonaea bursifolia*, *D. viscosa*, *Grevillia hugelii*, *Micromyrtus ciliata*, *Templetonia egena* and *Westringia rigida* further from water. The response within swale vegetation was brought about by species such as *Acacia sclerophylla*, *Atriplex stipitata*, *Beyeria opaca*, *Eremophila glabra*, *E. scoparia*, *Olearia muelleri*, *Senna artemisoides* ssp. *coriacea* and *Templetonia egena*.

Herbaceous vegetation was not abundant enough for individual species to demonstrate any significant patterns in cover, though overall herbaceous cover did show a negative response to distance from water within swale vegetation only. This was due to species such as *Dissocarpus paradoxus*, *Marrubium vulgare* and *Nicotiana* sp. only occurring at sites close to water.

It has been reported that browsing and grazing at moderate densities can lead to higher species richness compared with grazing at low or high densities (Wilcox *et al.*, 1987; Chaneton & Facelli, 1991), while very heavy grazing may bring about a decline in the number of species, a reduction in abundance of the remaining species and a dominance by a few species (Fusco *et al.*, 1995; James *et al.*, 1999). In the present study no clear pattern emerged for species richness with distance from water. Shrub diversity increased significantly with distance from water, but on dune crests only. Herbaceous diversity demonstrated a significant u-shaped response to distance from water and not an n-shaped response as might be expected from the literature. Herbaceous diversity was high close to water due to an abundance of annual weed species such as *Nicotiana* sp. and unpalatable perennial species such as *Dissocarpus paradoxus*, *Lomandra effusa* and *Marrubium vulgare*. At greater distances from water, more palatable herbaceous species, such as *Austrostipa* spp., became more abundant. The results relating to herbaceous vegetation should be interpreted with caution due to their low abundance, an apparent result of unseasonably low rainfall in the period preceding the vegetation sampling.

Shrub height demonstrated a statistically significant negative response to distance from water in swale vegetation. This may be due to the fact that swales appeared to become larger, and drier, with increasing distance from water.

2.4.2 Individual species responses

Responses in relation to herbivore diets

Serendipitously, Ballentine (1998) conducted a study on the diets and densities of herbivores in Calperum, using a very similar sampling design, and in some cases the same sites, as this study. This enabled a direct comparison of decreaser plant species with herbivore diets, providing an empirical basis for explanations of plant species cover trends with distance from water (decreaser plant species which were not detected in herbivore diets and increaser plants species are discussed after this section).

Analysis of faecal samples from kangaroos, goats, sheep and rabbits within Calperum showed that *Maireana* and *Sclerolaena* species were important components of the diets of these herbivores

(Ballentine, 1998). However, none of the *Maireana* or *Sclerolaena* species concerned changed in cover with distance from water as might be expected, while *M. schistocarpa*, *M. sedifolia*, *M. trichoptera* and *S. obliquicuspis* proved to be increaser species. This result may be explained by the fact that the vegetation data were collected during the 'growing' season, while many herbivores have been noted to feed on chenopods predominantly during the drier months (Ballentine, 1998; Coulson *et al.*, 1990; Doensen, 1995; Edwards *et al.*, 1996). The *Maireana* and *Sclerolaena* species above are not highly palatable, and herbivores tend to browse more palatable annual grasses and forbs before utilising these species (Cunningham *et al.*, 1981). However, *M. schistocarpa* showed an opposite trend when data from the above-ground trough were analysed separately. This species, like many *Maireana's*, prefers brown soils (Cunningham *et al.*, 1981) and the trend observed may simply be a response to soil gradients and not grazing pressure. Additionally, the numerous, large burrs on *S. obliquicuspis* may partly protect it from herbivory and explain its increaser status. Short-lived plant species often have a competitive advantage at heavily grazed sites because they are fast growing and so able to grow more quickly than other species in locations where there is reduced vegetation cover. Wilson *et al.* (1976) showed that the dominant grasses within the 'sacrifice zone' tend to be short-lived species because their survivorship is less effected by grazing. *Sclerolaena* species are generally short-lived (Andrew and Lange, 1986b) and therefore fast-growing, and so may benefit from reduced competition at sites closer to water.

Ballentine (1998) demonstrated that within Calperum a decline of *Atriplex vesicaria* (another chenopod) closer to water was explained by overgrazing. This result has also been documented in other locations (Graetz, 1978; Edwards *et al.*, 1996). *Atriplex vesicaria* was not abundant enough to provide meaningful analysis in this study though *Atriplex stipitata*, another saltbush, showed a decreaser response.

Feral goat and sheep faecal samples from Calperum contained a high proportion of *Acacia* species (Ballentine, 1998), which may explain the decrease in cover of *A. brachybotrya*, *A. rigens*, *A. sclerophylla* and *A. wilhelmiana* close to water. It is not known whether these species are browsed (Cunningham *et al.*, 1981), though feral goats and sheep have often been implicated in decreases in wattle numbers and suppression of their regeneration (Auld, 1990). Also, *A. rigens, A. sclerophylla* and *A. wilhelmiana* prefer sandy soils, so the observed trend in these species may be due to increased dune size at sites further from water. There was no direct evidence that the observed trends in these *Acacia* species were caused by grazing.

Austrostipa species are highly palatable and a major component of the diet of herbivores within Calperum (Ballentine, 1998) which probably explains the decrease in the cover of *Austrostipa* spp. closer to water. *Triodia scariosa* is another grass species which decreases in cover closer to water, and this may be due to its utilisation by kangaroos. However, this trend was only noted within the swale vegetation, while *T. scariosa* and kangaroos were significantly more abundant on crests (Ballentine, 1998). Also, swales seemed to get smaller and sandier with increasing distance from water, suggesting that this trend may simply be an artifact of swale attributes.

Westringia rigida was found to be a decreaser species, a finding supported by Ballentine (1998) who noted that it appeared to be browsed. She did not detect it in goat faecal samples, although it is known to be heavily utilised by sheep (Cunningham *et al.*, 1981). Because the decreaser response of *W. rigida* was only significant within dune vegetation and, as it is thought to prefer sandy calcareous soils, the observed trend may be partly due to the increase in dune size with increasing distance from water, as well as to the effects of grazing.

Because *Grevillea huegelii* was found in the faecal samples of herbivores from within Calperum (Ballentine, 1998) and it decreased in foliage cover closer to water, its decreaser trend can probably be attributed to the increased grazing pressure closer to water points. Despite this, Chippendale & Jephcott (1963) suggest that it is of low nutritive value and palatability.

Feral goats within the study area tended to eat eucalypt species predominantly (Ballentine, 1998). *E. leptophylla* and *E. oleosa* were the only eucalypt species that responded as decreasers. As mentioned earlier, it is likely that this association is due to past clearing practices, rather than to browsing effects, because eucalypts are considered to be extremely unpalatable; the high proportion of eucalypt species in the faeces of goats (Ballentine, 1998) may be due to the goats' inability to digest their leaves, and not because they are a dominant food source. However, the grazing of the rather more palatable eucalypt and other seedlings over extended periods may influence their abundance and distribution around water points.

Myoporum platycarpum (sugarwood) proved to be the most abundant species in the faecal samples of sheep from within Calperum (Ballentine, 1998), a finding which may explain why its foliage cover decreases closer to water. However, young individuals of *M. platycarpum* are considered unpalatable to sheep (Chesterfield and Parsons, 1985) and other studies suggest that sheep prefer grasses and forbs (Caughley *et al.*, 1987; Edwards *et al.*, 1996). Cunningham *et al.* (1981) state that younger plants of *M. platycarpum* are less palatable than the shoots of older plants. The evidence above suggest that sheep probably browse older plants and that browsing may be partially responsible for the decreaser trend displayed by this species.

Other decreasers

Several plant species demonstrated a decreaser response but have not been detected in the faeces of herbivores within the study area. This could be due to the inaccuracies associated with microscopic analyses of faecal samples caused by the differential digestion of different plant species (Barker, 1986a,b; Norbury *et al.*, 1993; Doensen, 1995); it may also be because these species are relatively uncommon, or they have been inflicted with such heavy grazing pressure for so long that they are no longer present in areas close to water. It must therefore be considered that environmental factors other than grazing pressure might be responsible for the observed trends.

Callitris verrucosa was found to be a decreaser and was also noted to be heavily browsed. However, the decreaser response of *C. verrucosa* was only significant within dune vegetation and, as it appears to be associated with gypsaceous sand dunes (M. Hyde, *pers. comm.*), the observed trend may be partly due to the gypsum deposits in the east of the property, which are distant from water, as well as to the effects of browsing.

Little can be said of *Olearia muelleri* as it responded as decreaser within swale vegetation and an increaser within dune vegetation. It is not known to be grazed, so these trends may be caused by changes in soil or vegetation associations. It is thought to prefer sandy to sandy loam calcareous red soils and so may be decreasing closer to water in swales because the soils there are less sandy, and decreasing further from water in dunes because the soils there are becoming very sandy, losing most loam components. *Cryptandra propinqua* and *Baeckia crassifolia* displayed a significant decreaser response in dune vegetation, yet they are not known to be browsed. Both are also thought to prefer sandy soils (Cunningham *et al.*, 1981), which may explain the observed response within dune vegetation.

Beyeria opaca decreased closer to water in swale vegetation, and is thought to prefer calcareous red earth soils (Cunningham *et al.*, 1981). Soils tend to become more suitable for this species closer to water, so it might be assumed that the observed response is due to grazing, although there is little evidence that this species is browsed and it was not noted in the faeces of herbivores within Calperum.

Although *Templetonia egena* appears to be relatively unpalatable to herbivores, it showed a strong decreaser response in both swale and dune vegetation. It appears likely that the observed trend in this species is a direct result of grazing pressure, or a related factor such as trampling or increased soil erosion. *Dodonaea viscosa* (hopbush) was determined to be a decreaser when correlations were re-analysed with the 10 km sites excluded. Hopbushes are unpalatable and so the above arguments could apply to this species also.

These results suggest that in some cases it is possible to explain a plant species' changes in abundance with distance from water as due mainly to grazing pressure but that, with many species, other factors may also be influencing their distributions.

Increasers

Because the closest sample site to permanent water was in fact 250 m away from it, it is possible that some increaser species were not detected. For example, exotic species such as *Marrubium vulgare* (horehound) and *Nicotiana* species were seen to be very abundant in highly disturbed areas directly around water, but rarely spread as far as 250 metres away at this study site.

Casuarina pauper is not known to be palatable, so the increaser response noted in this species is probably not related to herbivory, but instead because dams tended to be placed in the largest depressions which contain the preferred soil type for this species.

The increase in *Acacia colletioides* (spine-bush) and *A. nysophylla* close to water is not surprising because both have rigid, spiny leaves which make them unpalatable. It is often only within the impenetrable foliage of these two species that other palatable species manage to survive, such as *Rhagodia spinescens* (thorny saltbush) and *Chenopodium curvispicatum* (cottony saltbush). The increaser trend noted in *R. spinescens*, which is moderately palatable and heavily grazed during food shortages (Cunningham *et al.*, 1981) may be explained by the fact that it is only able to survive within the impenetrable foliage of increaser species such as *A. colletioides* and *A. nysophylla.* Although *Daviesia benthamii* was detected in western grey kangaroo faeces (Ballentine, 1998), it was determined to be an increaser, probably due to the sharp spike on the ends of its leaves which also make it relatively unpalatable. *Senna artemisoides* ssp. *filifolia* is rarely browsed by any form of livestock (Cunningham *et al.*, 1981) and demonstrated a decreaser response in dune vegetation, despite very high cover values at one of the two 10 km sites. *Eremophila scoparia* was present in kangaroo faeces, but responded as an increaser species. This may reflect habitat adaptation and/or life history patterns: evidence exists that woody plants can establish in areas depleted of grasses by grazing, due to reduced competition by seedlings (Fox, 1990). Thus the increase in some woody species such as *Acacia colletioides*, *A. nysophylla*, *Senna artemisoides* and *Eremophila scoparia* may be a result of their being able to out-compete the herbaceous species for water and nutrients, and become increasingly dominant. *Eremophila deserti*, which is poisonous, and *Exocarpus aphyllus*, which is of little value to stock, were both found to be increasers using the point-biserial correlation technique; both are woody species.

Lycium australe is considered unpalatable (Cunningham *et al*, 1981) and demonstrated a significant increaser response in swale vegetation. This result may well be due to a requirement for saline or very low-lying areas as well as to the effects of grazing. *Zygophyllum aurantiacum* is only rarely browsed by stock, so it may increase closer to water because it has a small growth form (not investing resources in woody material) and is relatively fast-growing which would give it a competitive advantage closer to water.

2.4.3 Conclusion

The results from this study showed clearly that the cover of some plant species either increased or decreased with distance from permanent artificial water points, while that of others remained unchanged. However, this is unsurprising as one would predict that unpalatable species would increase in abundance closer to water and that palatable species would decrease. Palatable species are likely to decrease in abundance closer to water primarily through direct browsing, and unpalatable species to increase because they are given a competitive advantage when the palatable species are removed. Of particular concern is that the cover of some species was still increasing at the maximum distance sampled during this study (10 km), suggesting that herbivory is having a negative impact on vegetation at distances greater than 10 km from water. The maximum distance from water attainable at Gluepot was approximately 12 km, and this is probably comparable to other arid rangelands throughout Australia (Landsberg *et al.*, 1997), suggesting that a very small percentage of land area in Australia's arid and semi-arid rangelands is not being influenced by grazing.

It was noted that in some instances the same plant species responded oppositely in different habitats. This was also demonstrated by Landsberg *et al.* (1997) for different habitats which were geographically isolated, but this study demonstrated that it can occur in different habitats which are in close proximity to each other. This suggests that a plant species' response to distance from water cannot always be accurately predicted simply through knowledge of the diet of the resident herbivores, but that other factors are involved, which agrees closely with the findings of Barker and Lange (1969). These other factors may include slope variation, and the fact that different soil types have different erosion, runoff and infiltration rates. Grazing intensity does not always change in an even radial pattern with distance from water either as demonstrated by Orr (1980) who noted that sheep tend to walk into prevailing winds. Others have argued that food supply, rather than water, is more influential in affecting animal abundance (Newsome, 1971; Noble and Tongway, 1986; Caughley *et al.,* 1987; Stafford-Smith and Morton, 1990). And, finally, within different habitats, plant associations will differ and thus affect interactions between species (Barker, 1973).

The findings from this chapter will allow a more informed evaluation of the distribution and abundance of avifauna around water points in the following chapters. For water-dependent bird species, distance from water will not necessarily be the most important factor in determining their distribution and abundance, the floristics and physiognomy of the vegetation will probably have an important influence as well. Likewise, patterns in non water-dependent bird species may be explained by changes in vegetation rather than the distance from water.

3. THE DISTRIBUTION AND ABUNDANCE OF AVIFAUNA AROUND ARTIFICIAL WATERING POINTS IN A SEMI-ARID MALLEE ENVIRONMENT

3.1. INTRODUCTION

The establishment of permanent water sources is likely to cause changes in the abundance and distribution of some bird species. In Australia, the increase in numbers and ranges of some species of parrot and cockatoo, the zebra finch (*Peophila guttata*), the emu, and some species of pigeons have been linked to the increased accessibility of permanent water (Ford, 1961; Fisher *et al.*, 1972; Dawson *et al.*, 1983; Reid and Fleming, 1992). Conversely, other species such as thornbills (*Acanthiza* spp.) and quail-thrushes (*Cinclosoma* spp.) appear to have either retained unchanged abundances and ranges, or decreased in abundance (Reid and Fleming, 1992). James *et al.* (1999) lists 99 bird species whose change in abundance or range in Australia's arid rangelands has been attributed to the provision of artificial water or pastoralism. Bird species that appear to have benefited from additional water supplies seem to be those which depend on a daily supply of water for at least part of the year (Davies, 1972; Fisher *et al.*, 1972). Birds that do not depend on free-standing water seem less likely to show increases in range or numbers (Reid and Fleming, 1992). Prior to the provision of artificial water points, species that are water-dependent could only inhabit arid areas around permanent natural water, and over larger areas when temporary water points were filled following high rainfall (Fisher *et al.*, 1972; Davies, 1977). Examples of species whose increase in abundance or range within mallee can be attributed to the provision of artificial water include the Australian magpie, Australian magpie-lark, common bronzewing, crested pigeon, Australian ringneck, pied butcherbird, southern whiteface, spiny-cheeked honeyeater, striated pardolate, white-plumed honeyeater and yellow-throated miner (Reid & Fleming, 1992). Conversely, the reduction in abundance and/or range of a number of bird species within mallee has been attributed to the provision of artificial water points and the associated effects of overgrazing. These species include the chestnut quail-thrush, chiming wedgebill, grey currawong, pied honeyeater, pink cockatoo (Reid & Fleming, 1992), striated grasswren and tawny-crowned honeyeater (Smith *et al.*, 1994; Smith & Smith, 1994).

Most authors attribute the decline in abundance or range of birds to habitat change due to grazing. Overgrazing was identified as a likely cause because canopy-dwelling species have been less affected than ground-dwellers (Reid & Fleming, 1992). In mallee, William & Wells (1986) found that birds were negatively impacted by grazing, being less abundant in grazed areas (with water) than in ungrazed areas where water was present.

Overgrazing has been shown to lead to a decrease in the structural diversity of vegetation (Harrington *et al.*, 1979). This is particularly evident immediately around artificial water points (Lange, 1969; Reid & Fleming, 1992; Williams, 1994; Landsberg *et al.*, 1997). It is widely accepted that the diversity of avifauna increases with increased structural diversity of the vegetation (MacArthur &

MacArthur, 1961; Recher, 1969; James & Wamer, 1982). Several studies, both in Australia and overseas, have linked grazing-induced vegetation changes with decreases in the species richness and population numbers of birds (Bock & Webb, 1984; Taylor, 1986; Knopf *et al.*, 1988; Reid & Fleming, 1992; Smith *et al.*, 1994). However, studies in North American arid regions have also shown that species richness can remain unchanged between grazed and ungrazed plots (Medin, 1986) and also that species richness and bird abundance can increase at grazed plots (Bock *et al.*, 1984; Knopf *et al.*, 1988; Medin & Clary, 1990). Most of these differences can be explained by the habitat preferences of the species and the particular change in vegetation structure that grazing causes (Ryder, 1980; Taylor, 1986). Increased diversity is not necessarily indicative of improved conditions however, what is important is whether any species are lost through the vegetation changes caused by overgrazing.

Williams & Wells (1986) found that the presence of water facilitated larger populations and higher species richness of birds in mallee in South Australia. The distribution and abundance of birds in the Mitchell grasslands (*Astrebla* sp.) of Queensland were also affected by artificial water points, five species being more abundant within 5 km of water (Fisher, 1996).

Some of the bird species that have become abundant due to water point introduction may cause competitive or aggressive displacement of other species that do not require water. The yellow-throated miner (*Manorina flavigula*) may be responsible for the local displacement of some small bird species through aggressive behaviour (Grey, 1996). Similar interactions may also be occurring between other bird species, but there is no research on this subject. Another water-related interaction between bird species that has been documented is the introgressive hybridisation or “genetic swamping” by the conspecific yellow-throated miner of the endangered black-eared miner (*M. melanotis*) around water points in the mallee vegetation of south-east Australia (Schodde, 1981; Starks, 1987; McLaughlin, 1990, 1993). Yellow-throated miners have invaded the mallee vegetation at cleared sites around artificial water points, and are now interbreeding with black-eared miners, producing fertile hybrid offspring (Ford, 1981; McLaughlin, 1990, 1993; Clarke & Clarke, 1999a). Recent research shows that the worst black-eared miner colonies (most genetically swamped) occur at distances less than two km from water, while the genetically most pure colonies are at distances greater than five km from water (Clarke and Clarke, 1999b; Muir *et al.*, 1999).

The principal objective of the work described in this chapter was to determine what changes in abundance and distribution of avifauna took place around artificial watering points in an arid mallee environment. Now that the negative effects of water points and overgrazing on biodiversity have been highlighted, the managers of many reserves within Australia’s arid rangelands are closing their water points; however they have little information to guide them on the precise effects that water point closure might have on the avifauna. This chapter seeks to elucidate the effects that water points and overgrazing might have on avifauna in mallee vegetation. Because a number of bird species within the Murray mallee of South Australia are considered to be of some conservation concern (black-eared miner, malleefowl, red-lored whistler, regent parrot, Major Mitchell’s cockatoo and striated grasswren)

(Garnett & Crowley, 2000), care may have to be taken to ensure that management actions don't negatively impact on those species. Although some studies have been undertaken in Australia to determine the effects of artificial sources of water on avifauna, most notably the study by Landsberg *et al.* (1997) of *Acacia*-dominated land systems and chenopod shrublands, only one published investigation has been conducted within mallee vegetation (Williams & Wells, 1986).

3.2 METHODS

Bird abundance and species richness were monitored throughout the year at different distances from water to determine how birds were distributed around water points and how this changed in relation to environmental factors such as climate.

3.2.1 Sampling Design

The sites used for determining bird abundance were placed at 0.25, 2.25, 4.25, 6.25 and 8.25 km from permanent water and were the same as those used for the vegetation sampling. For the methods used for their selection and placement, as well as the methods used for vegetation sampling refer to Chapter 2. These sites were sampled three times a year, over two years, during the months October, January and June. The sampling took place between October 1998 and June 2000. This allowed any seasonal changes to be identified and enabled comparisons of the hottest (January) and coldest (June) periods of the year, and the growing season (October). The order in which sites were sampled was rotated each field trip and special care taken to ensure that sites were not sampled in a repeated pattern (i.e. with increasing distance from water with time of day). Both crests and swales were sampled because there was known to be variations in bird numbers and species composition between these two vegetation types (Mules, 1998). There were thus sites at five different distances from water in two vegetation types (swale and dune) and each site was sampled six times over two years, resulting in 384 sampling units in all.

Additional sites were sampled at Murray Sunset National Park (MSNP) to enable the maximum distance from water to be extended to 20.25 km, and also to broaden the geographic scope of the study. MSNP is located in north-western Victoria (Figure 3.1) and its north-west corner is approximately 100 km south-east of Gluepot (see Chapter 2, Figure 2.1). Although the vegetation types and the species compositions of those vegetation types were comparable to those at Gluepot, the MSNP sites were in a much more degraded state due to a considerably higher grazing pressure there over a longer time period. Stock grazing has been taking place within MSNP since the 1860's, compared with the 1930's at Gluepot. Additionally, there are extended areas of grassland dispersed amongst the mallee which are absent from Gluepot. Sampling at MSNP was conducted once only, during February and March 2001. The sampling design and procedure was similar to that used at Gluepot, except that the distances from water and the number of replicates were different. Three replicates of sites were located at 0.25 km, 4.25 km, 8.25 km, 12.25 km, 16.25 km and 20.25 km from water in each of the two main vegetation associations (36 sampling units in all). The grid locations of all 36 sampling sites are listed in Appendix 2.

As with sites at Gluepot, sites at MSNP were not placed on straight transect lines radiating out from water points, but instead at points scattered through out the landscape which met the necessary pre-requisites of distance from water and vegetation type. Thus, a full set of sites was not necessarily located in relation to the same water point. Sites were placed in relation to permanent water points only. Water points that held water for all except the worst droughts were considered permanent. The status of the water points within the study area was determined by consultation with park rangers. Where possible, sites were chosen so that their distance class (distance to permanent water) was closer than any other temporary water source or the park boundary.

3.2.2 Sampling Procedure

Bird abundance measures were based on a simplified version of the fixed-point sampling procedure of Morgan (1986) (see Appendix 5), in which the number of sightings of a bird species from a fixed point in a given habitat depends on the movement pattern and rate of the species concerned, and on the time spent, as well as on its density in the area. At each site a one hour fixed point census was conducted. During each census the observer rotated slowly and recorded the following information about each individual or group of birds detected: the number of birds, the vertical angle from the observers eyes to the detection point using an inclinometer and the horizontal distance to the detection point using a range finder. Individuals that were detected during a fixed-point census, but then left the area and were seen later in the same 1-hour period were recorded as two separate sightings. Sightings were the only detection method used to record birds during a census. Birds detected by their calls were noted, but not counted due to the biases associated with this method (Recher, 1983). Because the number of sightings should then be a linear function of the time spent at a point, the number of sightings per hour should give a measure of relative abundance between sampling sites, provided that detectability doesn't vary greatly. Because movement rates differ between species, the abundances of different species cannot be compared directly without allowing for those different rates; this was not attempted in this study.

Sampling was only conducted before midday. The first census of a day was started approximately one hour after sunrise, while the last census of a day was completed by midday, or once temperatures reached over 30°C. If weather conditions became inappropriate, sampling was ceased and continued the following day. The following variables were recorded at the beginning of each census: time, temperature (°C), wind speed (Beaufort scale), wind direction and cloud cover (eighths). The occurrence of rainfall during the census was noted, and if the rainfall noticeably reduced visibility, then the census was terminated and a new census started after the rainfall event finished. The number of

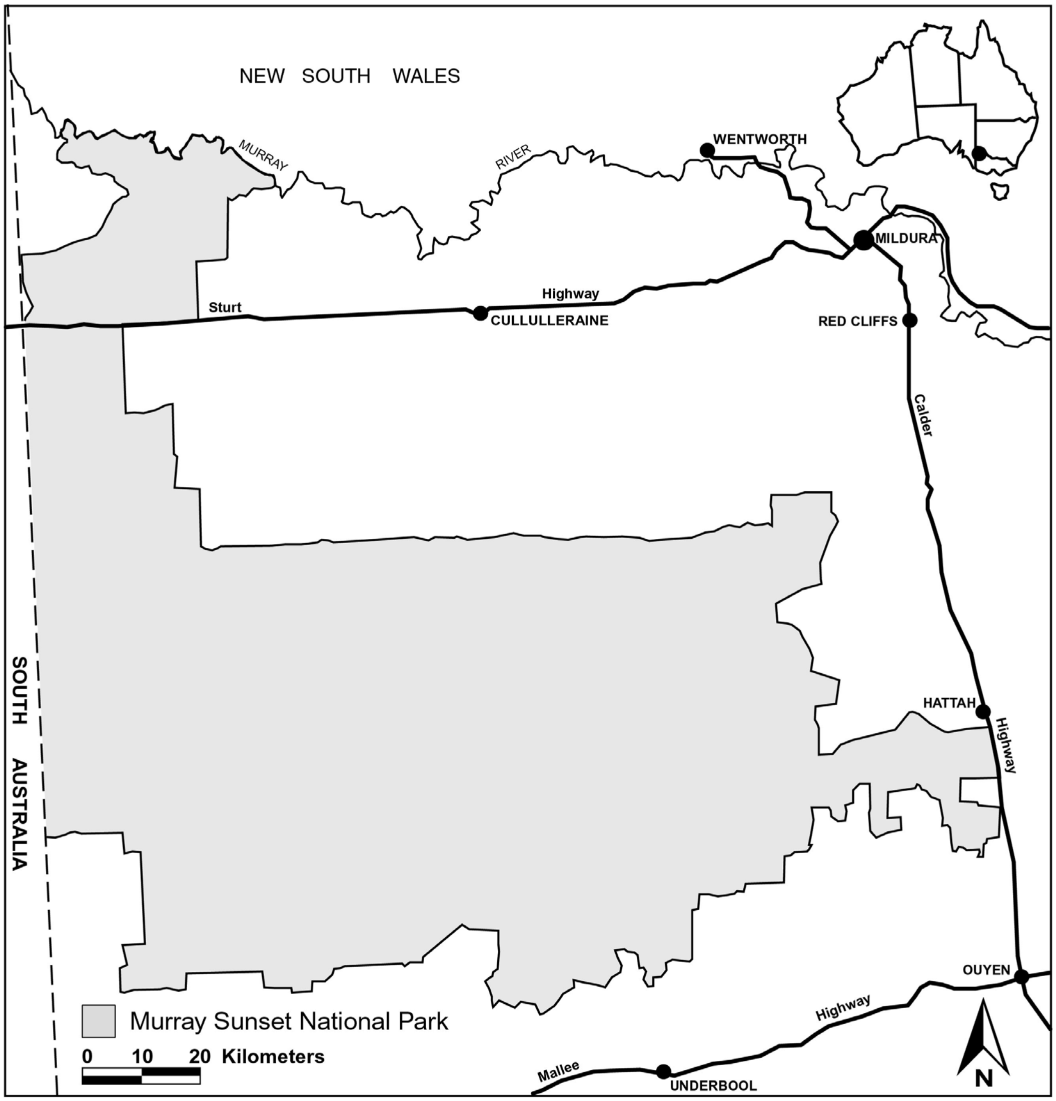


Figure 3.1: The location of Murray Sunset National Park in north-west Victoria.

flowering eucalypts visible from the sampling point was also recorded because this could strongly influence the abundance of certain bird species.

Abundance measures within a single species using this fixed-point method are comparable between sites and times, provided that habitat characteristics such as vegetation cover and structure are similar. Inter-species comparisons are invalid, and have been largely avoided in this study. The vegetation structure at sites in this mallee habitat were very similar, even between the two major vegetation types (see Chapter 2). Frequency histograms of direct-line sighting distances for each bird species indicated that detectability was similar at all sites, probably because vegetation structure was similar between sites. The main principle of the above model is that detectability of a particular species will vary depending on habitat characteristics such as vegetation cover, and that a detectability function can be used to calculate its density provided that movement rate data are available (see Appendix 5). Because detection distances for each species were similar at different sites, standardised counts were used as an index of abundance.

5.2.3 Analytical Methods

Gluepot

Power analysis (G•Power) determined that only 42 of the 113 species detected during this study occurred sufficiently frequently to provide the statistical power for meaningful statistical analyses. Also, because the frequency distributions of bird abundances were almost all highly skewed, with a very high proportion of zero values, abundance data for each of the 42 species were analysed for changes with distance from water using non-parametric correlation methods, utilising Spearman's correlation coefficient for ranked data. These analyses were conducted using the average abundance per site from the two vegetation types combined, except where a species was significantly more abundant in one vegetation type, when the data were also analysed using the separate data from its preferred habitat type. Of the 42 species, 29 of these met the assumptions to enable some parametric statistical analysis. For each species, a General Linear Model (GLM) was fitted using the computer software package SPSS 10.1 (GLM: Univariate procedure). The main factors used in the model were distance to water, habitat and season, while number of flowering eucalypts and period of the day were covariates. Polynomial contrasts were used to decide whether each significant change was due to a systematic trend with distance from water. Changes in species richness, as well as the total number of individuals of all species, with distance from water were also analysed using a GLM, using the factors distance to water, habitat and season, while number of flowering eucalypts was a covariate. Polynomial contrasts were again used to decide whether a significant change was due to a systematic trend with distance to water.

It should be noted that two water points were closed after one year of sampling to test the effects of water point closure on avifauna distribution and abundance (see Chapter 6). All the analyses conducted on the effects of distance from water on avifauna used only the data from open water points.

MSNP

Methods of analysis of MSNP data were very similar to those used with Gluepot data, except that only 21 bird species at MSNP were sufficiently abundant to enable their relative densities to be calculated and further analyses performed. Because the frequency distributions of the abundance estimates for these species were not normally-distributed, changes in abundance with distance from water were examined using non-parametric Spearman correlations. These analyses were conducted using the average abundance estimates from the two vegetation types combined only. Of the 21 species, eight had frequency distributions that enabled parametric statistical analysis. For each of these species, a GLM was again fitted using distance from water and habitat as main factors, and number of flowering eucalypts and period of day as covariates. Polynomial contrasts were used to determine whether each significant change was due to a systematic trend with distance from water. To determine changes in species richness and total number of individuals of all species combined with distance from water, data were also analysed using a GLM with the factors distance from water and habitat as factors, while number of flowering eucalypts was a covariate. Polynomial contrasts were again used to determine that a significant change was due to a systematic trend with distance to water.

3.3 RESULTS

3.3.1 Changes in abundance

Gluepot

A total of 113 species were detected in the fixed-point samples at Gluepot during the course of this study (see Appendix 2 for a complete list of species). To determine whether there were any associations between abundance and distance from water, non-parametric correlation coefficients were computed (Table 3.1). There were 12 species that significantly increased in abundance with proximity to water (they are termed "increasers", and have a negative correlation coefficient). There are four species that decreased closer to water (termed "decreasers", with a positive correlation coefficient). Increaser species were the Australian magpie, Australian raven, Australian ringneck, brown-headed honeyeater, brown treecreeper, chestnut-rumped thornbill, jacky winter, red-capped robin, red wattlebird, spiny-cheeked honeyeater, weebill and willie wagtail (Figure 3.2). Decreaser species were the shy heathwren, southern scrub-robin, white-fronted honeyeater and yellow-plumed honeyeater (Figure 3.3).

The abundances of 16 species proved to be significantly different between swale and dune vegetation (see Figure 5.7, Chapter 5 for a list of each bird species vegetation type preference). The correlation coefficients for these species were re-analysed using data from their preferred vegetation type only. The Gilbert's whistler (r=0.168, p=0.022) showed a significant negative trend within swale vegetation only, while the striated grasswren (r=0.174, p=0.019) showed a significant positive association in dune vegetation only (Figure 3.3).

The results of fitting a GLM to the data from 29 bird species are given in Table 3.2. 13 of the 29 species analysed showed a significant change in abundance with distance from water. Seven of these showed significant differences in abundance between seasons as well. However, none of these seven species displayed a different response type between seasons, except for the Australian ringneck which had an increaser response in all seasons except summer, where it had a decreaser response (Figure 3.4). Additionally, seven species showed significant changes in abundance between habitats. To determine the effect of water points on population numbers of birds the number of individuals from all species combined were examined for changes with distance from water with a GLM. A non-significant n-shaped pattern was found (F=0.641, p=0.634), although bird numbers were significantly affected by season (F=10.058, p<0.001), habitat (F=5.345, p=0.022) and the number of flowering eucalypts (3.045, p=0.011). The numbers of birds observed were higher in winter than spring or summer, and higher in

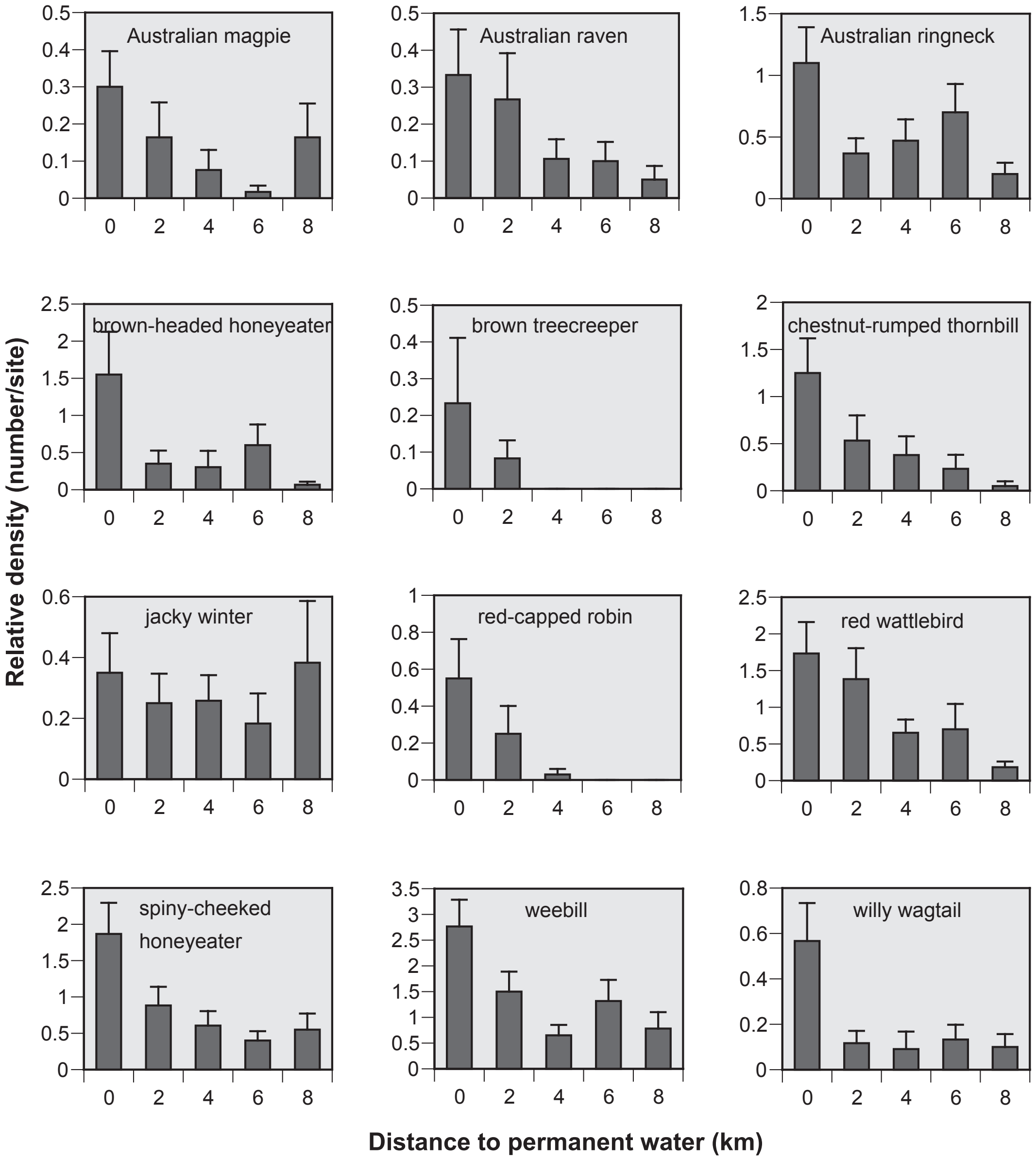


Figure 3.2: Changes in abundance of increaser bird species with distance from permanent water at Gluepot Reserve. Figures relate to combined data from swale and dune crest sites. Error bars indicate standard error.

Table 3.1: Associations between bird species' abundances and distance from water at Gluepot. Spearman's non-parametric correlation was used on data from the dune and swale sites combined. When **ns** is bold, $0.05<p<0.10$. [1] Denotes known water-dependent species.

Species	r	p	Species	r	p
Negative correlation ("increasers")					
Australian magpie[1]	-0.148	**	Australian raven[1]	-0.129	*
Australian ringneck[1]	-0.158	**	brown-headed honeyeater[1]	-0.171	**
brown-treecreeper	-0.120	*	chestnut-rumped thornbill	-0.263	***
jacky winter	-0.134	*	red-capped robin	-0.219	***
red wattlebird[1]	-0.239	***	spiny-cheeked honeyeater[1]	-0.142	*
weebill	-0.259	***	willie wagtail	-0.160	**
Positive correlation ("decreasers")					
Gilbert's whistler	0.110	**ns**	shy heathwren	0.125	*
southern scrub-robin	0.163	**	striated grasswren	0.174	**ns**
white-fronted honeyeater	0.138	*	yellow-plumed honeyeater[1]	0.332	***
No correlation					
black-eared miner	0.018	ns	black-faced cuckoo-shrike	-0.028	ns
common bronzewing[1]	-0.013	ns	chestnut-crowned babbler	-0.068	ns
chestnut quail-thrush	0.088	ns	crested bellbird	-0.004	ns
grey butcherbird	-0.071	ns	grey currawong[1]	-0.019	ns
grey shrike-thrush	0.035	ns	hooded robin	-0.078	ns
masked woodswallow[1]	-0.037	ns	mulga parrot[1]	-0.058	ns
purple-crowned lorikeet[1]	0.076	ns	rainbow bee-eater[1]	-0.026	ns
restless flycatcher	-0.077	ns	spotted pardalote	-0.042	ns
striated pardalote	0.063	ns	striped honeyeater	0.052	ns
varied sitella	-0.046	ns	variegated fairywren	0.046	ns
white-browed babbler	0.040	ns	white-browed woodswallow	0.024	ns
white-eared honeyeater[1]	0.183	ns			

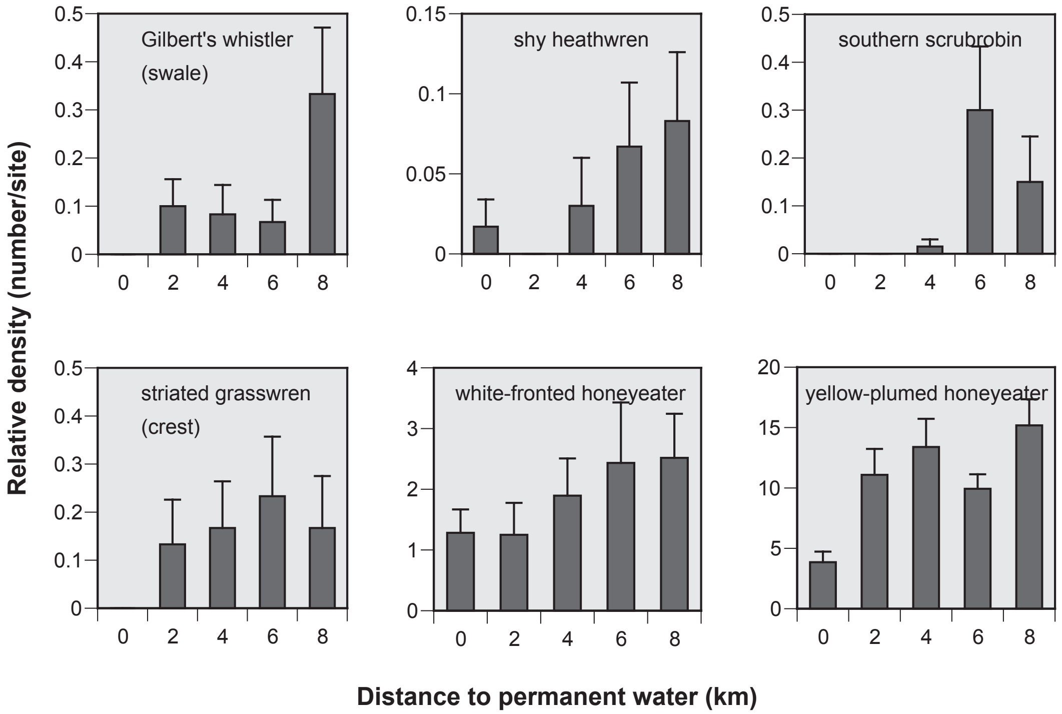


Figure 3.3: Changes in abundance of decreaser bird species with distance from permanent water at Gluepot Reserve. Unless otherwise marked, graphs relate to combined data from swale and dune crest sites. Error bars indicate standard error.

swale sites compared to dune sites; they also increased as the number of flowering eucalypts increased. None of the interactions between these factors were statistically significant. In some cases bird species were detected either only close to or only distant from water, but were not abundant enough to show a significant trend when either analysis was applied to these data. Bird species that occurred only close to water included the crested pigeon, emu, galah and southern whiteface. Bird species that occurred only far from water included the regent parrot and red-lored whistler, even though the regent parrot is water-dependent.

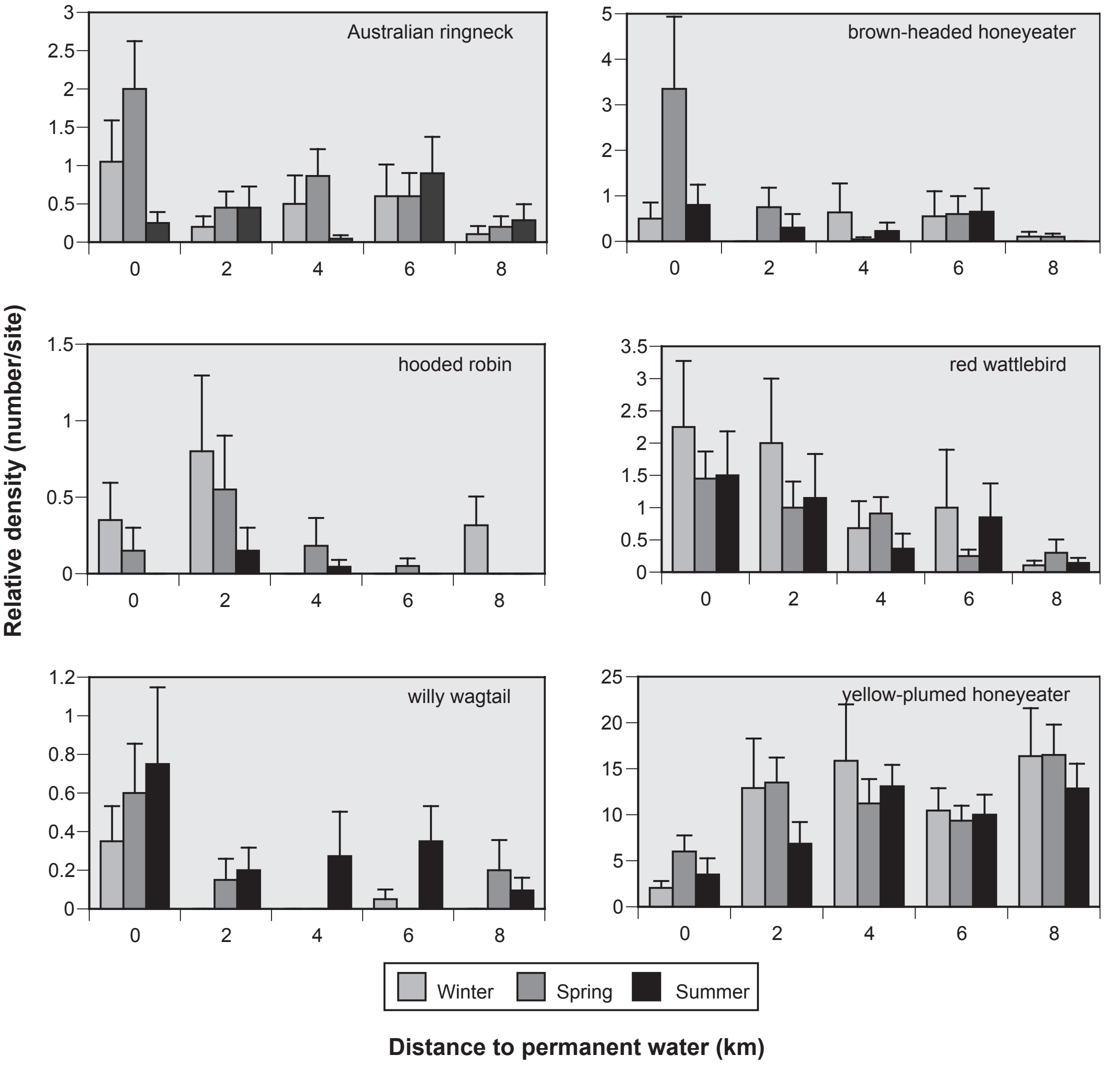


Figure 3.4: Changes in the abundance with distance from water of bird species that demonstrated statistically significant differences in abundance between seasons. Error bars indicate standard error.

Table 3.2: Analysis of covariance results on the abundance of bird species with distance from water at Gluepot. Main factors used in the model are distance to water, habitat and season, while number of flowering eucalypts and period of the day are covariates. Only species with significant associations with distance to water have been displayed and only the significant factors and interaction terms from those species are displayed. Polynomial contrasts were used to confirm that significant differences with distance to water were due to a systematic trend. See Appendix 4 for full ANCOVA results.

Species	SS	df	MS	F	p	r^2
Australian magpie						
distance to water	3.57	4	0.92	2.53	0.040	
period of day	2.30	1	2.30	6.35	0.012	
error	121.52	336	0.36			
total	143.00	368				0.102
polynomial contrasts (quadratic) P=0.024						
Australian raven						
distance to water	6.96	4	1.74	2.40	0.049	
error	241.92	334	0.724			
total	297.00	366				0.130
polynomial contrasts (linear)	P=0.003					
Australian ringneck						
distance to water	36.21	4	9.05	3.67	0.006	
flowering eucalypts 29.64	1	29.64	12.02	0.001		
period of day	20.64	1	20.64	8.37	0.004	
habitat type	20.30	1	20.30	8.23	0.004	
season	20.53	2	10.26	4.16	0.016	
error	823.70	334	247			
total	1153.0	365				0.194
polynomial contrasts (quadratic) P=0.096						
brown-headed honeyeater						
distance to water	100.75	4	25.19	4.90	0.001	
season	33.39	2	16.70	3.25	0.04	
distance * season	102.40	8	12.80	2.49	0.012	
error	1716.3	334	5.14			
total	2207.0	366				0.172
polynomial contrasts (linear)	P=0.014					
chestnut-rumped thornbill						
distance to water	47.40	4	11.85	4.36	0.002	
habitat	14.14	1	14.14	5.20	0.023	
error	908.52	334	2.72			
total	1118.0	366				0.139
polynomial contrasts (linear)	P<0.001					
hooded robin						
distance to water	7.61	4	1.90	3.20	0.013	
flowering eucalypts	2.82	1	2.82	4.75	0.30	
season	4.56	2	2.28	3.84	0.022	
error	198.37	334	0.594			
total	234.00	366				0.125
polynomial contrasts (linear)	P=0.093					
red-capped robin						
distance to water	12.69	4	3.17	4.81	0.001	
habitat	6.67	1	6.67	10.11	0.002	
distance * habitat	8.60	4	2.15	3.26	0.012	
error	220.28	334	0.66			
total	270.00	366				0.161
polynomial contrasts (linear)	P=0.001					
red wattlebird						
distance to water	134.31	4	33.58	5.78	<0.001	
flowering eucalypts	75.87	1	75.87	13.06	<0.001	
period of day	38.67	1	38.67	6.65	0.010	
habitat	37.30	1	37.30	6.42	0.012	
season	63.56	2	31.78	5.47	0.005	
error	1941.0	334	5.81			
total	2893.0	366				0.229
polynomial contrasts (linear)	P<0.001					

Table 3.2 continued

Species	SS	df	MS	F	p	r^2
spiny-cheeked honeyeater						
distance to water	76.75	4	19.19	5.27	<0.001	
flowering eucalypts	40.12	1	40.12	11.03	0.001	
habitat	51.19	1	51.19	14.07	0.000	
error	1215.5	334	3.64			
total	1784.0	366				0.197
polynomial contrasts (linear)	P<0.001					
southern scrub-robin						
distance to water	2.77	4	0.69	2.47	0.045	
habitat	3.64	1	3.64	12.98	<0.001	
error	93.57	334	0.280			
total	110.00	366				0.124
polynomial contrasts (linear)	P=0.006					
weebill						
distance to water	348.80	4	87.20	6.32	<0.001	
error	4605.7	334	13.79			
total	6165.0	366				0.145
polynomial contrasts (linear)	P=0.001					
willie wagtail						
distance to water	9.56	4	2.39	4.80	0.001	
season	4.26	2	2.13	4.28	0.015	
error	166.09	334	0.497			
total	205.00	366				0.128
polynomial contrasts (linear)	P=0.003					
yellow-plumed honeyeater						
distance to water	4384.2	4	1096.1	6.14	<0.001	
flowering eucalypts	3606.4	1	3606.4	20.20	<0.001	
habitat	1000.9	1	1000.9	5.61	0.018	
season	1257.4	2	628.70	3.52	0.031	
error	59645	334	178.58			
total	115612	366				0.188
polynomial contrasts (linear)	P<0.001					

MSNP

A total of 60 species was detected in the fixed-point samples at MSNP during the course of this study (see Appendix 2 for a complete list of species). To determine whether the data on the 21 species with sufficient power for statistical analysis had any associations between abundance and distance from water, non-parametric correlations were calculated. Table 3.3 lists the correlation coefficients and significance levels for these species. There were five species that increased significantly closer to water and two species that decreased closer to water. Increaser species were the Australian magpie, Australian raven, Australian ringneck, red wattlebird and spiny-cheeked honeyeater (Figure 3.5). The decreaser species were the chestnut quail-thrush and grey shrike-thrush (Figure 3.6). The mean abundance was not significantly different between the two vegetation types for any of these 21 species, as tested by independent-samples t-tests. For this reason, correlation coefficients were not calculated using data from swale and dune sites separately.

The results of fitting a GLM to the data for eight bird species from MSNP are given in Table 3.4. Two species showed a significant change in abundance with distance from water: both the mulga parrot and the yellow-plumed honeyeater increased in abundance closer to water (Figure 3.5). When the mean numbers of individuals of all species combined were examined for changes with distance from water with a GLM, no pattern was found and neither of the factors (habitat or number of flowering eucalypts) had an effect.

A number of bird species at MSNP were only detected close to water, but were not abundant enough to show a significant trend when statistical analysis was applied. These were the brown treecreeper, crested pigeon, emu, galah, grey currawong, little crow and white-winged chough. There were no bird species which only occurred at high distances from water at MSNP.

Table 3.3: Associations between bird species' relative densities and distance from water at MSNP. Spearman's non-parametric correlation was used on data from the dune crest and swale sites combined. When **ns** is bold, 0.05<p<0.10. [1] Denotes species that were observed drinking.

Species	r	p	Species	r	p
Negative					
Australian magpie[1]	-0.393	*	Australian raven[1]	-0.496	**
Australian ringneck[1]	-0.457	**	brown treecreeper	-0.296	**ns**
mulga parrot	-0.305	**ns**	red wattlebird	-0.414	*
spiny-cheeked honeyeater	-0.347	*	yellow-plumed honeyeater	-0.300	**ns**
Positive					
chestnut quail-thrush	0.429	**	grey shrike-thrush	0.329	*
shy heathwren	0.315	**ns**			
No correlation					
chestnut-rumped thornbill	0.010	ns	grey butcherbird	-0.271	ns
grey currawong	-0.236	ns	jacky winter	-0.028	ns
spotted pardalote	-0.111	ns	striated pardalote	-0.219	ns
weebill	0.149	ns	white-eared honeyeater	0.109	ns
white-fronted honeyeater	-0.145	ns	willie wagtail	-0.225	ns

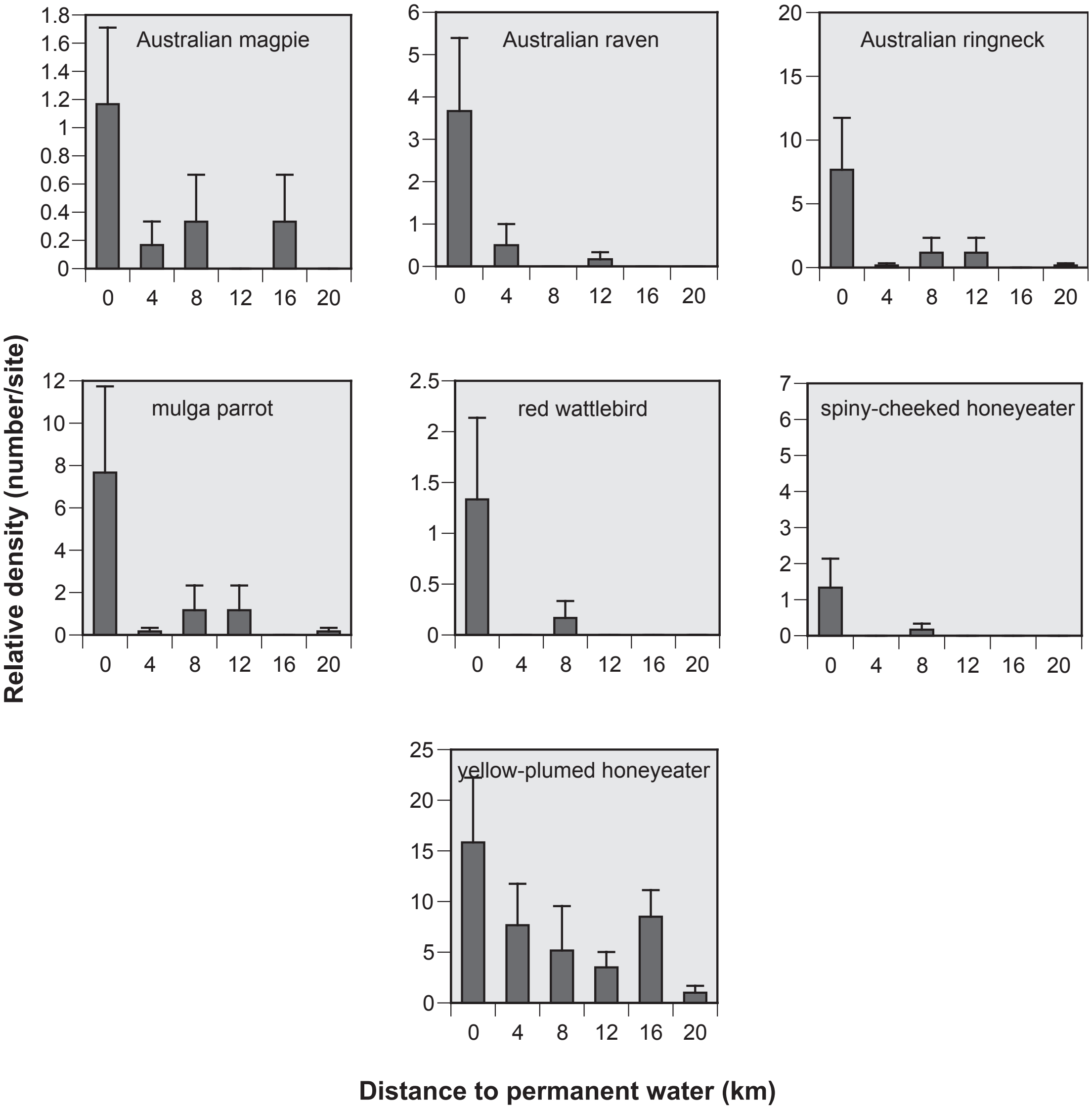


Figure 3.5: Changes in abundance of increaser bird species with distance from permanent water at MSNP. Figures relate to combined data from swale and dune crest sites. Error bars indicate standard error.

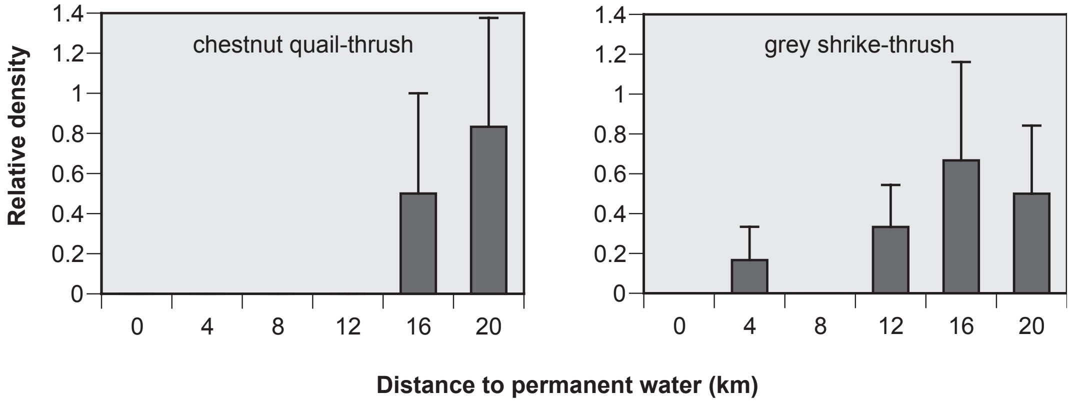


Figure 3.6: Changes in abundance of decreaser bird species with distance from permanent water at MSNP. Graphs are based on combined data from swale and dune crest sites. Error bars indicate standard error.

Table 3.4: Analysis of covariance results on the abundance of bird species with distance from water at MSNP. Main factors are distance to water, habitat and season, while number of flowering eucalypts is a covariate. Only species with significant associations with distance to water have been displayed and only the significant factors and interaction terms from those species are displayed. Polynomial contrasts were used to confirm that significant differences with distance to water were due to a systematic trend. See Appendix 4 for full ANCOVA results.

Species	SS	df	MS	F	p	r^2
mulga parrot						
distance	241.141	5	48.228	2.828	.042	
error	358.08	21	17.052			
total	950.00	35				0.574
yellow-plumed honeyeater						
flowering eucalypts	425.144	1	425.14	6.639	.018	
distance	943.616	5	188.72	2.947	.036	
error	1344.7	21	64.034			
total	5075.0	35				0.603

3.3.2 Changes in species richness

The last part of this analysis looks at the relationship between bird species richness and distance from water at the two study sites.

Gluepot

The results of a GLM indicated that the species richness of birds at Gluepot changed significantly with distance from water, and the use of polynomial contrasts showed that this trend was systematic with distance from water (Table 3.5, Figure 3.7). There was a statistically significant difference in species richness between habitats: swale vegetation had greater bird diversity than dune crest vegetation. There was also an interaction effect between the factors distance to water and habitat type, the trend in species richness with distance to water only being statistically significant in the swale vegetation type (Figure 3.8).

MSNP

The results of a GLM indicated that the species richness of birds at MSNP changed significantly with distance from water, and the use of polynomial contrasts showed that this trend was systematic with distance from water (Table 3.5, Figure 3.7). There was not a statistically significant difference in species richness between habitats and it was not possible to test for between-season variation because sampling was only conducted during one season at MSNP.

Table 3.5: Analysis of covariance results on the diversity of bird species with distance from water at Gluepot. Main factors are distance to water, habitat and season, while number of flowering eucalypts is a covariate. Only species with significant associations with distance to water have been displayed and only the significant factors and interaction terms from those species are displayed. Polynomial contrasts were used to confirm that significant differences with distance to water were due to a systematic trend. Full ANCOVA results can be seen in Appendix 4.

Source	SS	df	MS	F	p	r^2
Gluepot						
distance to water	341.732	4	85.433	4.596	.001	
habitat	726.396	1	726.396	39.079	.000	
distance * habitat	172.200	4	43.050	2.316	.057	
error	6226.92	335	18.588			
total	61826.0	366				0.257
polynomial contrasts (linear)	P=0.008					
MSNP						
distance to water	341.48	5	68.296	3.553	.017	
error	422.83	22	19.219			
total	6349.0	35				0.738
polynomial contrasts (linear)	P<0.001					

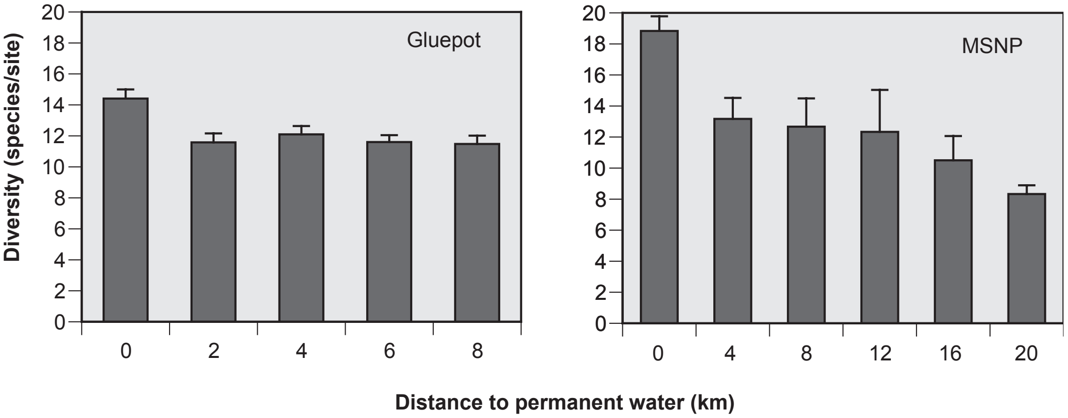


Figure 3.7: Changes in mean diversity of bird species with distance from permanent water at Gluepot and MSNP. Graphs are based on combined data from swale and dune crest sites. Error bars indicate standard error.

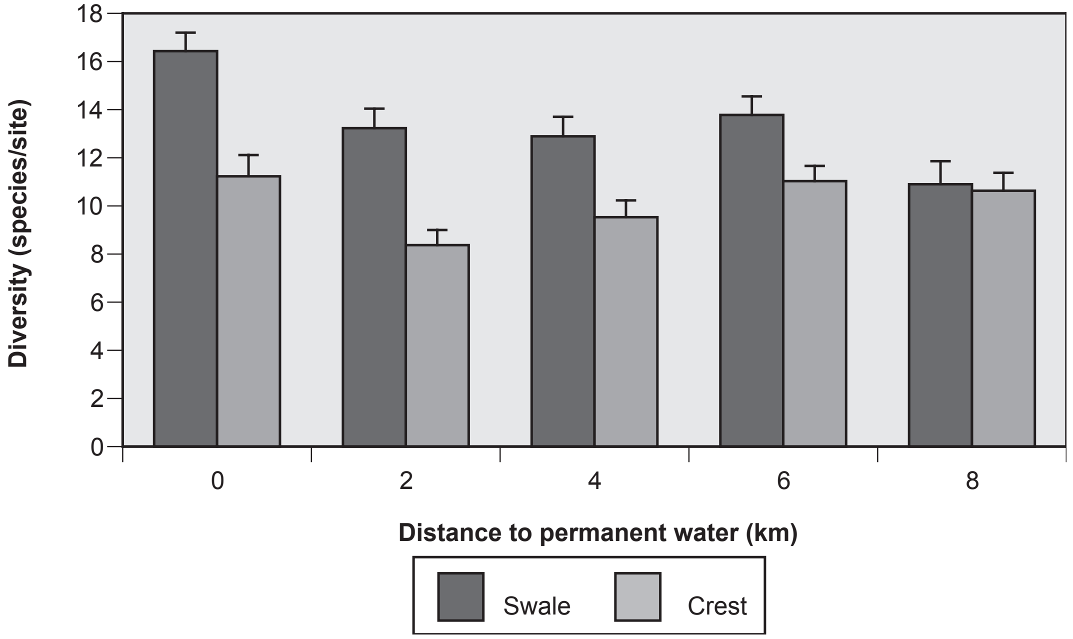


Figure 3.8: Changes in mean diversity of bird species with distance from permanent water in swale and dune crest vegetation at Gluepot. Error bars indicate standard error.

3.4 DISCUSSION

Many of the bird species identified as having changed in abundance or range in the arid zone since European settlement (see Table 1 in James *et al.*, 1999) were recorded during this study. A list of these species and their responses to the presence of water found during this study can be seen in Table 3.6.

Species such as parrots, corvids and a number of honeyeaters have been identified as increaser species in both this and other studies (Curry & Hacker, 1990; Saunders & Curry, 1990; Landsberg *et al.*, 1997). A number of these species were very abundant only close to water (0.25 km); at greater distances from water their numbers were either much lower and stable, or they continued to decrease slowly with increasing distance from water. Many of these species are probably very abundant close to water due to a dependence on the water for drinking (Fisher *et al.*, 1972; Reid & Fleming, 1992), rather than other factors related to water availability, such as local vegetation, food resources or competition with other bird species. Increaser species in this category include the Australian magpie, Australian raven, Australian ringneck, brown-headed honeyeater, mulga parrot, red wattlebird, spiny-cheeked honeyeater and willie wagtail. Other species that probably fall into this category but did not produce significant increaser trends due to insufficient data are the crested pigeon, emu, galah, grey currawong, little crow and white-winged chough. A list of all bird species seen during this study that have been identified as

Table 3.6: Birds seen during this study that have increased or decreased in range or abundance since European settlement of the arid zone. Species have been extracted from Table 1 in James *et al*. (1999). EX = excluded from analysis; INC = increaser; DEC = decreaser; NT = no trend; OC = only close to water; OD = only distant from water. GR = Gluepot Reserve and MSNP = Murray Sunset National Park.

Species	Response type	Habitat reported from
Increased in range or abundance		
Australian kestrel	EX	grassland, heath, spinifex, *Acacia* scrub
Australian magpie	INC at GR; INC at MSNP	*Acacia* scrub, mallee
Australian magpie-lark	EX	grassland, chenopod, *Acacia* scrub, mallee
Australian raven	INC at GR; INC at MSNP	grassland, heath, spinifex, *Acacia* scrub
Australian ringneck	INC at GR; INC at MSNP	*Acacia* scrub, mallee
black kite	EX	grassland, spinifex
black-faced woodswallow	EX	spinifex, chenopod, *Acacia* scrub
black-shouldered kite	EX	grassland
common bronzewing	NT	heath, chenopod, spinifex, *Acacia* scrub
crested pigeon	OC at GR; OC at MSNP	grassland, chenopod, mallee
fairy martin	EX	grassland
galah	OC at GR; OC at MSNP	grassland, heath, spinifex, *Acacia* scrub
grey butcherbird	NT	grassland
little crow	NT at GR; OC at MSNP	grassland, spinifex, *Acacia* scrub, chenopod
southern whiteface	OC at GR; EX at MSNP	spinifex, *Acacia* scrub, mallee
spiny-cheeked honeyeater	INC at GR; INC at MSNP	spinifex, *Acacia* scrub, mallee
striated pardolate	NT	mallee
willie wagtail	INC at GR; NT at MSNP	grassland, heath, chenopod, *Acacia* scrub
yellow-rumped thornbill	EX	grassland, spinifex, chenopod, *Acacia* scrub
yellow-throated miner	EX	heath, mallee
Decreased in range or abundance		
malleefowl	EX	mallee
scarlet-chested parrot	EX	spinifex, *Acacia* scrub, mallee
chestnut quail-thrush	NT at GR; DEC at MSNP	spinifex, *Acacia* scrub, chenopod
grey currawong	NT at GR; OC at MSNP	heath, mallee
peregrine falcon	EX	heath, spinifex
pied honeyeater	EX	spinifex, *Acacia* scrub, mallee
pink cockatoo	EX	grassland, *Acacia* scrub, mallee
purple-crowned lorikeet	NT at GR; EX at MSNP	mallee
striated grasswren	DEC at GR; EX at MSNP	spinifex, mallee
white-fronted chat	EX	grassland, heath, chenopod

having increased in range or abundance since European settlement of the arid zone – and consequent multiplication of water points - can be seen in Table 3.5.

Interestingly, not all drinking birds were found to be increasers: the yellow-plumed honeyeater was a decreaser at Gluepot and an increaser at MSNP. Yellow-plumed honeyeaters were only detected drinking in summer which may help explain this anomaly: sampling at MSNP only occurred during summer, while at Gluepot sampling was conducted throughout the whole year. The data from seasons other than summer at Gluepot may be masking a similar trend to that found at MSNP. Although there was an increaser trend at Gluepot in summer, this was not statistically significant. Another possible reason is that *E. oleosa*, which is a major food source at Gluepot for nectar-feeding honeyeaters, was a decreaser species and correlated with yellow-plumed honeyeater abundance (r=0.247, p=0.048).

Water-dependent species might be expected to show stronger increaser trends during the hotter months because an increased requirement for water could reduce the distances they could forage from water. This proved not to be the case; in fact the Australian ringneck, which was an increaser species during winter and spring, showed a decreaser trend during summer. A possible explanation for this is that food resources can differ between seasons, thus influencing a particular species' water requirements. *E. oleosa*, which is a known food source of the Australian ringneck at Gluepot, flowers predominantly in spring and summer in this environment, and was correlated with Australian ringneck abundance (r=0.342, p=0.005).

Like the individual species data, the increaser trend in species richness data at Gluepot was due to a high number of species very close to water; at distances beyond 0.25 km, species richness was lower, and relatively stable (Figure 3.7). A similar pattern was evident at MSNP, but there species richness began to decline again at distances greater than 12.25 km because water dependent species became less abundant at these distances. The overall pattern is that, as the distance from water increases, the number of water-dependent species decreases, being replaced by non water-dependent decreaser species; thus species richness remains constant with increasing distance from water.

A number of increaser bird species were not observed drinking water during this study: the brown treecreeper, chestnut-rumped thornbill, red-capped robin and weebill. The factors influencing the distribution and abundance of non water-dependent species are more complex than those for water-dependent species. Landsberg *et al.* (1997) mentions four factors that may influence the distribution and abundance of bird species in relation to a piosphere: (1) the presence of aggressively-dominant bird species near a water point; (2) disturbance and opening-up of the habitat under heavy grazing; (3) changes to vegetation composition and structure; and (4) changes to food resources. Another major factor that may influence the distribution and abundance of avifauna is predation. The problems that predators such as lions and crocodiles cause for large herbivores around water points in Africa has been well documented, and increased predation due to artificial water point proliferation has even been implicated in the near-extinction of the roan antelope (*Hippotragus equinus*) in Kruger National Park (Harrington *et al.*, 1999). Mammalian predators commonly seen at water points in Australia are cats, dingoes and foxes, but no information exists on prey items captured around water points by these species. Birds are their most likely prey (Jones & Coman, 1981), but no research has been conducted on the effects predation may be having on the populations of those species. Avian predators that frequented water points at Gluepot were the collared sparrowhawk, brown goshawk and peregrine falcon, and these are major predators of birds. Although there is no quantitative data on avian predators and their prey, it is likely that they are having a negative impact on some bird species, particularly around artificial water points.

The distribution of some of the water-independent increaser species can be explained by some obvious aspects of their habitat requirements. The brown treecreeper may be found only close to water because of its requirement for old, large trees with hollows. During the 1950's a massive wild-fire went through the region and the only areas that were not burnt were near dams where overgrazing had reduced the fuel load. For this reason, the oldest and largest trees occur only close to dams. The pattern observed in the red-capped robin and chestnut-rumped thornbill can be explained by their preference for vegetation containing *Casuarina* species. *Casuarina pauper* is only located in the larger depressions at Gluepot, in the same location as many of the dams (see Chapter 2)s. The relationship between bird species distributions and vegetation and soil variables is discussed in more detail in Chapter 5.

With the exception of the yellow-plumed honeyeater, all the identified decreaser species were not dependent on water at any period of the year. The remaining decreaser species were all to some degree ground-foragers: the chestnut quail-thrush, Gilbert's whistler, grey shrike-thrush, shy heathwren, southern scrub-robin and striated grasswren. It has been suggested that ground-dwellers are at high risk from grazing because of modification to their habitat (Reid & Fleming, 1992); this conclusion is strongly supported by the results of the current study. A strong positive association between leaf litter cover and distance from water (see Chapter 2) may partly explain the predominance of ground-dwellers among the decreaser species. In contrast, a large proportion of the increaser species are canopy and shrub foragers. It is worth noting that, with a number of decreaser species, there is no evidence that their abundance has begun to stabilise even at the most distant sites (8.25 km at Gluepot and 20.25 km at MSNP). This suggests that, for these species, their optimal habitat may lie even further away from water than 20 km.

A number of threatened or endangered bird species occur at Gluepot (black-eared miner, malleefowl, red-lored whistler, regent parrot, Major Mitchell's cockatoo and striated grasswren) and the impact of water provision on these and other rare species is of great interest to wildlife managers. Unfortunately, rare species are often not encountered frequently enough to conduct statistical analysis. This was true for the malleefowl, red-lored whistler, regent parrot and scarlet-chested parrot in this study. It should be noted, though, that the red-lored whistler and regent parrot (a water-dependent species) were only seen at sites distant from water. There was no evidence that the numbers of canopy-dwelling black-eared miners were influenced by distance from water, but other studies have shown that the degree of genetic introgression between yellow-throated and black-eared miners is greater closer to water (Clarke & Clarke, 1999). The degree of hybridisation was not determined during this study as it requires very careful examination of individuals, which was not possible during a fixed-point census. The ground-dwelling striated grasswren was identified as a decreaser species. Unfortunately, there was insufficient evidence to suggest whether most of these endangered species are negatively impacted by the presence of water points. However, most of the increaser species were common canopy-dwelling species, while many of the decreaser species were uncommon ground-foraging species.

Summary

This chapter has demonstrated that artificial water points are influencing the distribution and abundance of avifauna in mallee vegetation up to 20 km from water and that common water-dependent species are benefiting, while rarer non water-dependent species are being impacted negatively. Water points have become so abundant in Australia's rangelands that most rangelands now lie within 10 km of artificial water, and as little as 3-8% of pastoral rangelands are remote from water (Landsberg & Gillieson, 1996); this situation is found at Gluepot. It means that Australian decreaser bird species, many of which are of conservation concern, may have few if any refuges from the negative effects of grazing.

4. PATTERNS OF WATER UTILISATION BY AVIFUANA IN AN ARID MALLEE ENVIRONMENT

4.1 INTRODUCTION

In Australia, 70% of arid and semi-arid lands have been developed for pastoralism (James *et al.*, 1999). This has resulted in artificial water points being placed at close intervals in an otherwise relatively waterless environment. Before the development of artificial water points for pastoralism, water in Australia was only available in the major waterways and their tributaries, of which there are only 18 (Condon, 1983). Artificial sources of water are now found at such high densities over the arid and semi-arid zones of Australia that only the desert regions have substantial areas that are more than 10 km from a water point (Landsberg & Gillieson, 1996). The provision of this water has allowed a number of species to expand their geographic range and/or increase in abundance, either through the presence of the water or the indirect effects of grazing. Examples of species whose increase in abundance or range within the mallee environment can be attributed to the provision of artificial water are the Australian magpie, Australian magpie-lark, common bronzewing, crested pigeon, Australian ringneck, pied butcherbird, southern whiteface, spiny-cheeked honeyeater, striated pardolate, white-plumed honeyeater and yellow-throated miner (Reid & Fleming, 1992). Conversely, the reduction in abundance and/or range of a number of bird species within the mallee habitat has been attributed to the provision of artificial water points. These species include the chestnut quail-thrush, chiming wedgebill, grey currawong, pied honeyeater, pink cockatoo (Reid & Fleming, 1992), striated grasswren and tawny-crowned honeyeater (Smith *et al.*, 1994; Smith & Smith, 1994).

The arid lands of Australia are characterized by high air temperatures, intense solar radiation and a scarcity of surface water for much of the year. These environmental extremes impose difficult ecophysiological constraints on wildlife, particularly diurnal birds which, unlike most desert mammals, are not able to take advantage of the physiological benefits of underground burrows. In hot dry weather, birds must therefore rely heavily on evaporative cooling which places extra demands on their water balance. Despite this, Fisher *et al.* (1972) determined that 60% of bird species in the arid and semi-arid zones of Australia were either independent of surface water or drank less than 50% of the time. They also discovered, however, that the majority of individuals inhabiting areas where water is present were dependent on free water, and its availability was a critical factor in the distribution of those species. Prior to the introduction of artificial water points, these water-dependent species could only inhabit arid areas where there was permanent natural water, and could only occur in other areas following good falls of rain (Fisher *et al.*, 1972; Davies, 1977). It should be noted however, that although weather conditions in Australia are unpredictable with extended periods of drought, the reverse is true where la Nina periods result in the presence of abundant surface water for years at a time.

The water requirements of birds are strongly associated with diet. The water content of grass seeds is insufficient to meet the water requirements of most birds, particularly at high temperatures, and most granivorous species require water (Smyth & Coulombe, 1971). However, species such as the budgerigar and zebra finch have been reported to survive on air-dried grain without drinking (Willoughby, 1968; Bartholomew, 1972). Bird species that feed on succulent vegetation or insects receive enough moisture from their diet and usually do not drink (Maclean, 1996), although the honeyeaters are an exception. As mentioned earlier, most birds are diurnal which restricts the behavioural responses available to them when compared with small mammals. However, they are able to reduce water requirements through evasive tactics such as seeking favourable microclimates and remaining inactive during the hottest periods of the day. However, if a bird requires drinking water, there are only two options available to it: 1) it must either live near surface water, or 2) have good powers of flight so it can travel long distances between foraging areas and water (Dawson & Bartholomew, 1968).

There are several ways in which birds might utilise artificial water points in the mallee. The primary way is drinking, but birds may also bathe or hunt for insects that are attracted to water. As described earlier, different species of birds have different water requirements: some need a daily supply of water at all times of year, some only during hotter months, and some have no physiological need to drink. Studies of water utilisation by birds in the Namib Desert (Willoughby and Cade, 1967) and in Australia (Fisher *et al.*, 1972) have identified three categories of water usage by birds; (1) regular, (2) occasional and (3) seldom. Regular drinkers drink daily and are water-dependent. Occasional drinkers may drink when water is available, but appear not to be water-dependent. Seldom drinkers rarely or never drink, even when water is available. Fisher *et al.* (1972) differentiated regular drinkers into yearly drinkers that follow the above pattern, and summer drinkers that are dependent on free water only during the hotter, drier months of the year.

The principal objective of the work described in this chapter was to examine which species are utilising water points in the semi-arid mallee vegetation and, under which environmental conditions. Seasonal variation in drinking patterns and behaviour is also explored. By gaining a better understanding of the associations between bird species and artificial water points in this environment, it should be possible to better explain individual species' distributions, as well as predict which species might be negatively impacted by water point closures.

4.2 METHODS

4.2.1 Sampling Design

The five water points used for this study were Homestead Dam, Bluebird Dam, Picnic Dam, Whistler Tank and Grasswren Tank (see Figure 2.2 for locations). During this study five water points (three dams and two concrete tanks) were watched during spring, summer and winter over a two-year period, beginning in October 1998 and continuing until June 2000. Observations were conducted using a time-lapse video recorder attached to a small colour digital camera (Faunatech Series 2000 Wildlife Surveillance Recording System). The video recorder was programmed to automatically turn itself on at first light (dawn) and then automatically turn itself off at last light (dusk), thus reducing disturbance potentially caused by an observer at the site. Preliminary observations determined that only spotted nightjars visited the water points after dark. The camera was fitted with a light sensor and this triggered infra-red illumination when light conditions were low (ie. the twilight periods before sunrise and after sunset).

Because the camera's field of view was restricted, an attempt was made to restrict birds' access points to the water. There appeared to be a definite preference by most bird species to drink from a perching point such as a log semi-submerged in the dam or tank, rather than from the edges of these structures. All but one of the potential perching points within the dam or tank were removed so that birds were therefore encouraged to drink in one location. This worked well in the concrete tanks because birds were forced to drink from the log, except when they drank on the wing. The water level in the concrete tanks was kept low to try to prevent birds from drinking from the tank wall. However, during dam observations, some birds did drink from other points around the dam wall, outside the camera's field of view. Species which consistently drank from the dam wall included common bronzewings, corvids and raptors. This problem was partially overcome by conducting observations of bird drinking behaviour at each dam prior to the initial placement of the camera. There was a particular location on each of the dam walls that appeared to be preferred by most species, usually close to vegetation which afforded them some form of cover or protection. By placing a log in the water at this point and focusing the camera on it, it was possible to detect a majority of the birds that visited the dam. A total of 125 days of observations were conducted, an equivalent of approximately 1500 hours. Not all days were recorded from dawn until dusk due to technical difficulties, and data from those days was excluded from analysis.

Following Fisher *et al.* (1972), species that were observed drinking regularly (at more than 25% of the observed water points) during the winter months, as well as during summer and spring were classed as 'yearly drinkers' (Y). If a species regularly drank in summer and spring, but was not observed drinking during winter, it was classed as a 'summer drinker' (S). Bird species that were observed drinking at less than 25% of the water points during the summer months were classed as 'occasional (non water-dependent) drinkers' (O). Bird species that were observed in the habitat surrounding the water points, but were not observed drinking were classed as seldom drinkers or 'non-drinkers' (N). The densities of bird species in the habitat surrounding the water points were recorded using a fixed-point census method (see Chapter 3 for a detailed description of the procedure) to allow comparison with the numbers observed drinking.

4.2.2 Sampling Procedure

During each watch, the following were recorded: the species, the number of individuals in any group, the type of behaviour/s exhibited, and the time the visit started and ended. It was usually impossible to tell whether an individual was on its first or a repeat visit, so every visit was treated as though a different individual was visiting the water point. Unlike all other studies conducted on the drinking behaviours of birds, during this study it was possible to record the time spent drinking by each individual. Because it was not possible to determine whether an individual bird visited the water point on more than one occasion, it was felt that the average total time per day spent drinking by each species, rather than number of individuals drinking, was a better indicator of drinking behaviour. Time spent is therefore used as the measure of drinking behaviour for all analyses and figures throughout this chapter.

4.2.3 Analytical Methods

Times recorded during the watches required correction so that midday for each watch was equal to the time when the sun was at its zenith at the longitude of Gluepot Homestead. This required a correction of minus 8 minutes from South Australian Time in September/October and June, and minus 68 minutes from South Australian Summer Time in January/February.

All species seen during the water point observations were classified as either yearly, summer, occasional, or non-drinking species, as outlined above. Of the 43 species seen drinking during the observations, 23 species visited the water points more than 20 times. The mean total time spent drinking per day for each of these 23 species in different seasons was examined specifically. To determine the patterns of daily water-use for each species and overcome the problem of varying day length through the year, data from all the observations were combined and displayed as total time drinking in each of seven equal time periods between first and last light. Chambers (2000) has demonstrated that time of day is effectively categorised this way, rather than using arbitrary half-hour intervals (e.g. Fisher *et al*., 1972). To ensure that variations in the number of individuals of a particular species seen drinking between seasons were not caused by seasonal variation in population numbers, the relative proportion of individuals from each species in each season is displayed graphically. The relative proportion of individuals drinking in each season was calculated by dividing the mean total time spent drinking per day by a species by the relative abundance for that species in each season. Relative abundance was calculated from the census data (see Chapter 3). The census data were also used to compare the number of individuals of water-dependent species with water-independent species using a t-test.

The relationship between temperature and time spent drinking for each species was examined using regression analysis, with appropriate curves being fitted to the models. Temperature measurements were based on the daily maximum temperature recorded at the Australian Bureau of Meteorology station based at Gluepot Homestead. Due to the high variation in numbers of individuals of each species visiting the different water points, analysis was restricted to the water point at which a species was most abundant. Sufficient data were available to analyse the data from 12 species.

4.3 RESULTS

Table 4.1 lists all the bird species identified at the five water points during this study, the total number of individuals that visited in each season, their water-use category and their behaviour. (For a list of all species observed at Gluepot Reserve refer to Appendix 3).

Drinking bird species have been divided into four main groups to display their daily drinking patterns graphically: a general group of larger carnivore/insectivores (see Figure 4.1), parrots, cockatoos and pigeons (Figure 4.2), honeyeaters (Figure 4.3) and mainly smaller insectivorous species (Figure 4.4). Fisher *et al*. (1972) had observed that the daily drinking patterns of birds fell into three categories: a) species that drank at dawn and dusk only; b) species that drank at dawn only; and c) species that drank throughout the day without a peak period of drinking. In addition to these three patterns, a fourth pattern was observed during this study: drinking which peaked at dawn and steadily declined as the day progressed. This pattern was observed especially in summer-drinking species such as honeyeaters (Figure 4.3).

Daily and seasonal drinking patterns within the larger carnivore/insectivore group did not show a consistent pattern across species (Figure 4.1). The Australian magpie drank throughout the day but predominantly at dawn, and this pattern and the number of individuals involved did not vary significantly between seasons. The Australian raven drank throughout the day but with peaks at midday and mid-afternoon, and only in summer and spring. The apostlebird drank almost exclusively during summer, predominantly in the late afternoon. The collared sparrowhawk was observed drinking at midday during summer only. The grey currawong drank throughout the day with a peak in the late afternoon, and this pattern was consistent in all seasons. The white-winged chough was observed drinking predominantly in summer with no specific daily pattern. Other species that were observed drinking were the grey butcherbird and spotted nightjar, the spotted nightjar appearing to utilise the water point predominantly to hunt insects in the early evening. These species were both occasional drinkers.

With the parrots and cockatoos (Figure 4.2), the daily drinking patterns of the two parrot species were very similar, both the Australian ringneck and mulga parrot drinking predominantly at dawn. However, the Australian ringneck proved to be a yearly drinker, while the mulga parrot was a summer drinker. The two cockatoo species had similar daily and seasonal patterns, both the galah and Major

Table 4.1: Bird species recorded at or close to water points in three different seasons. Water-use categories are after Fisher *et al.* (1972): Y is a yearly drinker, S is a summer drinker, O is an occasional drinker, N is a non-drinker. Water behaviour categories are: D = drinking, B = bathing, F = hawking for insects, N = no behaviour. * indicates that the species was observed at a water point, but was not seen drinking.

Species	**Total number drinking**			**Min**	**Water-use**	**Water-use**
	Summer	Spring	Winter	temp.	**Category**	**Behaviour**
emu	1	1	9	15.7	Y	D B
collared sparrowhawk	12	2		36.8	O	D
Australian hobby	2	*		38.0	O	D
nankeen kestrel		*		-	N	N
brown falcon		*		-	N	N
wedge-tailed eagle		*		-	N	F
common bronzewing	287	448	208	12.6	Y	D
crested pigeon	*	19		26.3	Y	D
purple-crowned lorikeet		3		36.8	O	D
galah		44	23	16.5	Y	D
Major Mitchell's cockatoo	5	13	3	17.8	Y	D
regent parrot	*	6		31.3	Y	D
Australian ringneck	173	95	194	12.6	Y	D B
mulga parrot	773	155	34	17.4	S	D B
scarlet-chested parrot		2		38.2	S	D
Horsfield's bronze-cuckoo	2			34.1	O	D
southern boobook	1			42.0	O	D
spotted nightjar		9		36.8	O	F
rainbow bee-eater	11	31		28.8	S	D B
fairy martin		39		38.2	Y	D
tree martin		199		36.8	Y	D F
black-faced cuckoo-shrike			3	17.7	O	D
yellow-throated miner	16	1	4	15.2	Y	D
red wattlebird	735	204	424	16.5	Y	D B
spiny-cheeked honeyeater	1427	204	64	16.5	S	D B
striped honeyeater		1		36.8	N	D
brown-headed honeyeater	540	40	1	19.6	S	D
white-fronted honeyeater	6			24.9	O	D F
white-eared honeyeater	1	*		-	N	D
pied honeyeater	223			27.7	S	D
singing honeyeater	26			35.1	S	D
yellow-plumed honeyeater	1432	308	38	16.5	S	D B
spotted pardalote		*		-	N	N
hooded robin		3	1	19.4	O	D F
grey shrike-thrush	1	5	2	18.5	O	D B
crested bellbird			3	15.2	N	D
magpie-lark	*		2	15.7	O	D F
willie wagtail	80	96	27	12.6	Y	D B F
jacky winter	*	*	1	15.2	N	D
restless flycatcher	6	5	4	12.6	O	D F
Richard's pipit		*		-	N	F
variegated fairywren			*	-	N	B
weebill		*		-	N	N
white-browed woodswallow	4	26		38.2	S	D
dusky woodswallow			1	42.0	O	D
Australian magpie	43	7	34	16.5	Y	D B F
white-winged chough	116	5		24.6	S	D B
grey currawong	70	26	116	16.5	Y	D B
grey butcherbird	6		2	12.6	0	D
Australian raven	116	376	10	15.7	S	D B F
little crow	1			24.6	O	D
apostlebird	147	34	2	17.7	S	D B
common starling	1	2	1	15.7	Y	D F

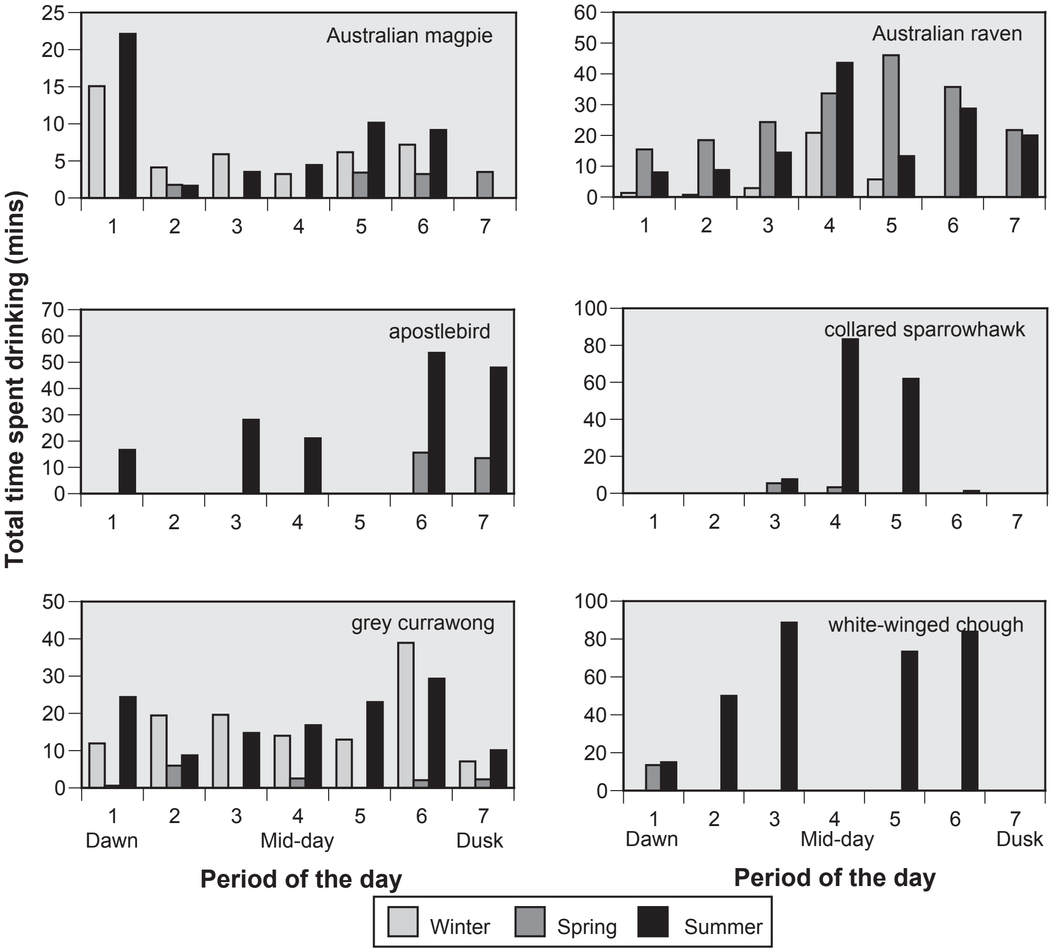


Figure 4.1: Daily patterns of drinking of the larger carnivore/insectivore bird species at Gluepot Reserve in three separate seasons. Values represent the mean total time spent drinking per day based on data from the five water points sampled.

Mitchell's cockatoo being yearly drinkers that drank throughout the day without a peak drinking period.

Most of the honeyeater species (Figure 4.3) displayed a broadly similar daily drinking pattern, in which drinking peaked at dawn and steadily declined as the day progressed. Exceptions to this were observed in the singing honeyeater and yellow-throated miner, which were both observed in very low numbers. All the honeyeater species were predominantly summer drinkers, although the red wattlebird and yellow-throated miner were observed drinking for small time periods during winter.

With the exception of the willie wagtail, all the insectivorous species (Figure 4.4) drank predominantly while in flight. Data collected on these species should therefore be viewed with some caution because drinking by many individuals is likely to have been missed due to a brief appearance in the camera's field of view during surveillance. It should be noted that the initial observations in the spring of 1998 were conducted using an observer in a hide (rather than the video surveillance equipment) and this may explain the predominance of these species drinking in spring. The presence of an observer allowed accurate recording of species that drank on the wing compared to the video surveillance equipment which was used at all other times. Observations of the flight-drinking insectivorous species (fairy martin, tree martin, rainbow bee-eater and white-browed woodswallow) suggest they are mainly summer drinkers which drink predominantly during the mid-afternoon; these species are spring and summer migrants who were mostly absent during winter. The willie wagtail was found to be a yearly drinker with the main drinking times in the early morning and late afternoon, except in winter when drinking mostly took place in the afternoons.

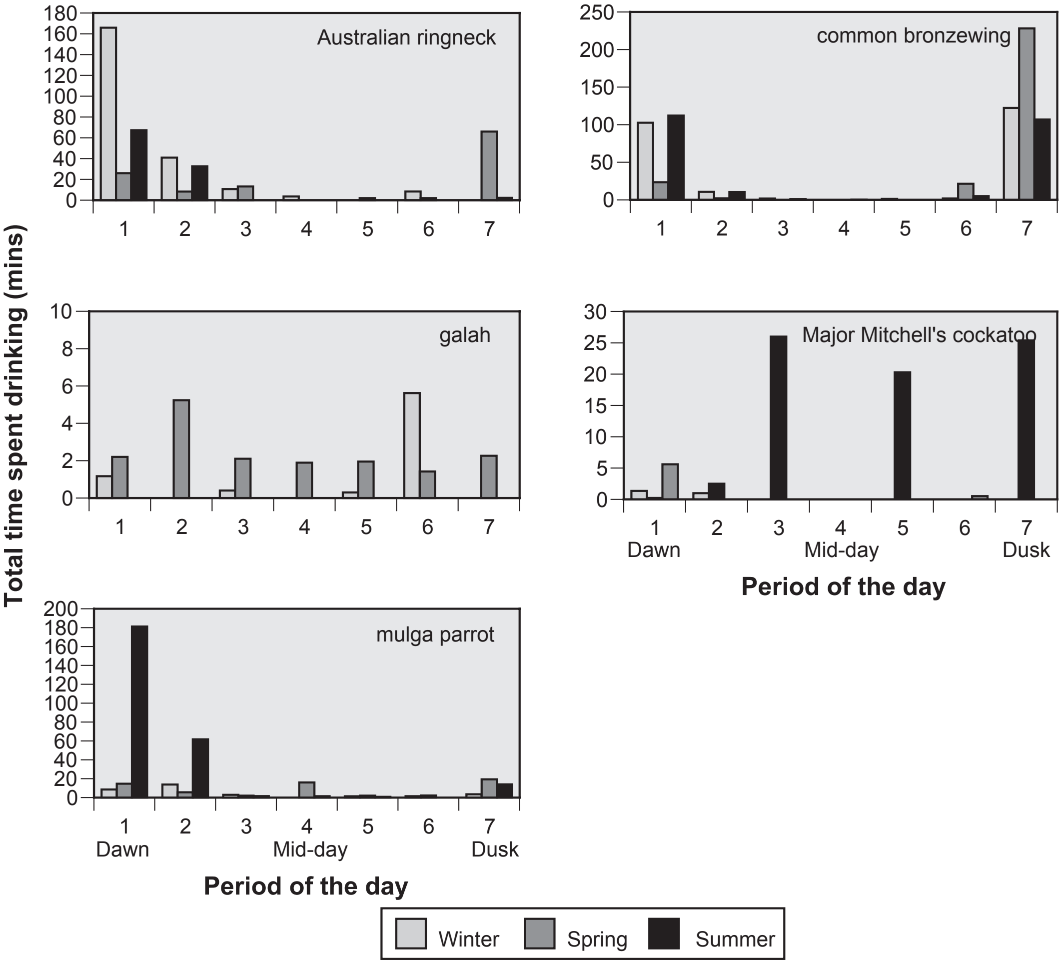


Figure 4.2: Daily patterns of drinking of parrots, cockatoos and pigeons at Gluepot Reserve in the three seasons. Values represent the mean total time spent drinking per day based on data from the five water points sampled.

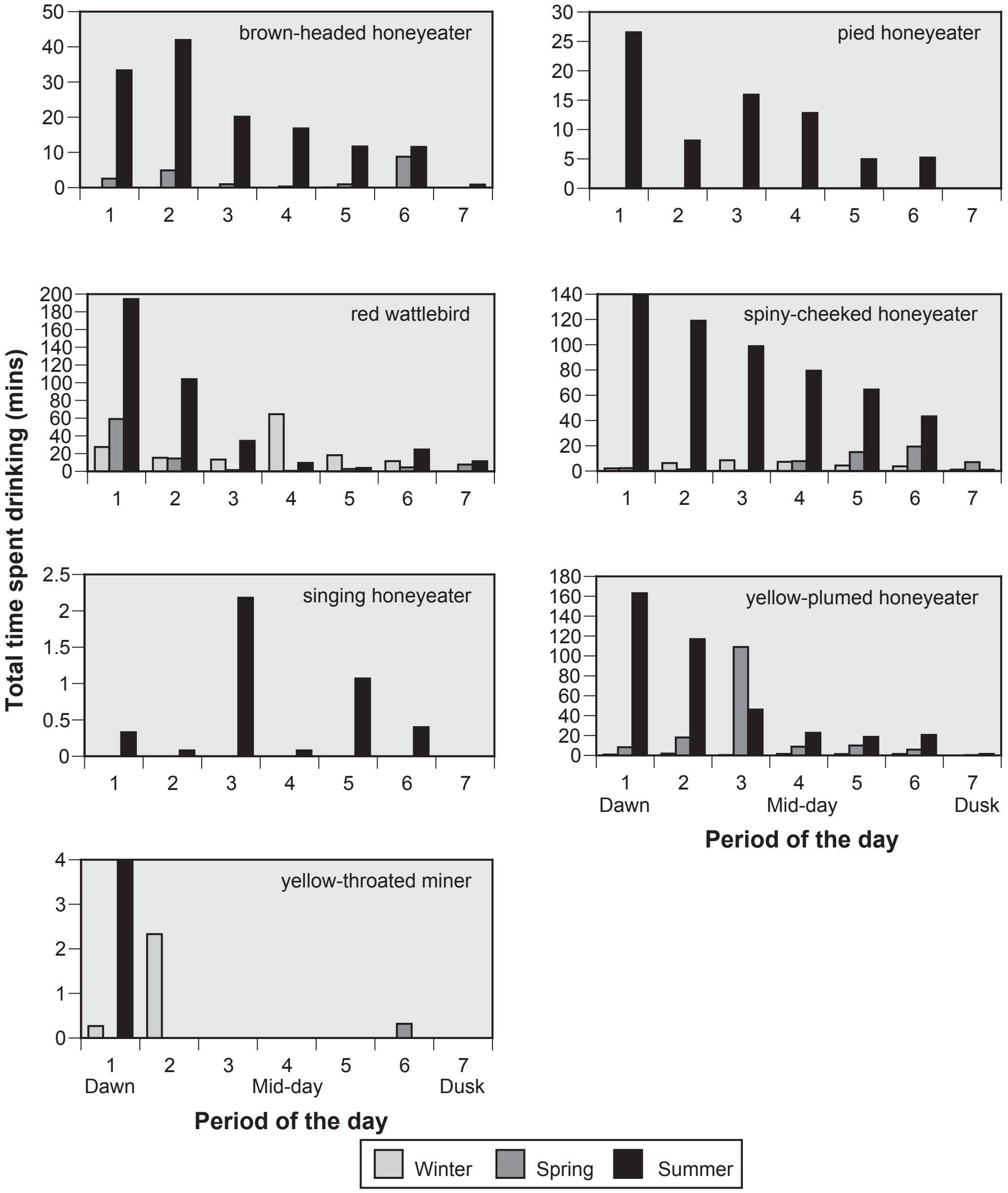


Figure 4.3: Daily patterns of drinking of honeyeaters at Gluepot Reserve in three seasons. Values represent the mean total time spent drinking per day based on data from the five water points sampled.

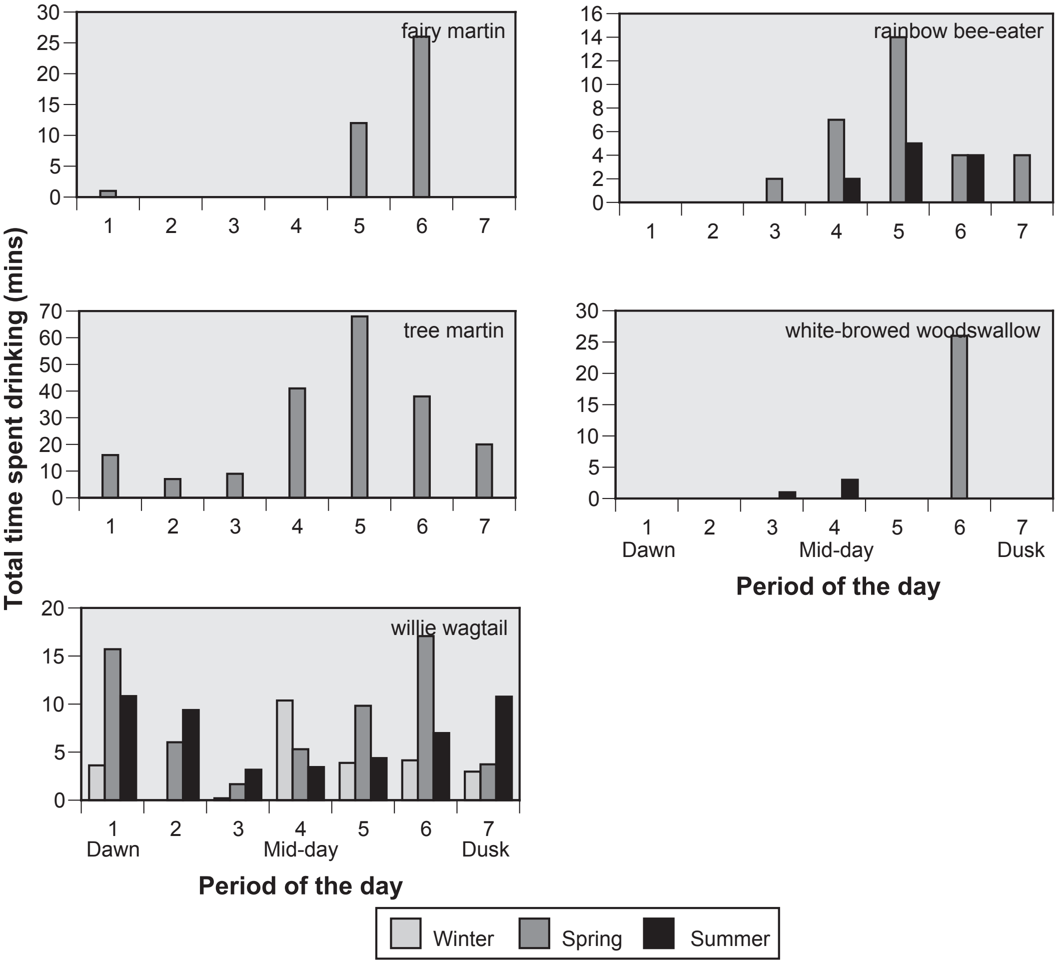


Figure 4.4: Daily patterns of drinking of miscellaneous insectivorous species at Gluepot Reserve over three seasons. Values represent the mean total time spent drinking per day based on data from the five water points sampled.

Figure 4.5 shows the relative proportions of individual bird species drinking in each season. It was not possible to calculate these proportions for all drinking species because, although they may have been relatively numerous at the water points observed, they were rare in the surrounding habitat and not detected in all seasons. Species that fell into this category include the apostlebird, collared sparrowhawk, white-winged chough, galah, Major Mitchell's cockatoo, pied honeyeater, singing honeyeater, yellow-throated miner, fairy martin, tree martin and white-browed woodswallow. The results supported the views that the following species were yearly drinkers, drinking in similar proportions during all seasons: Australian magpie, Australian ringneck, common bronzewing, grey currawong and willie wagtail. Species that drank during winter, but at a considerably lower proportion of their time than during summer, included the mulga parrot, red wattlebird and spiny-cheeked honeyeater. Species that drank during summer, but were almost never observed to drink during winter included the Australian raven, brown-headed honeyeater and yellow-plumed honeyeater.

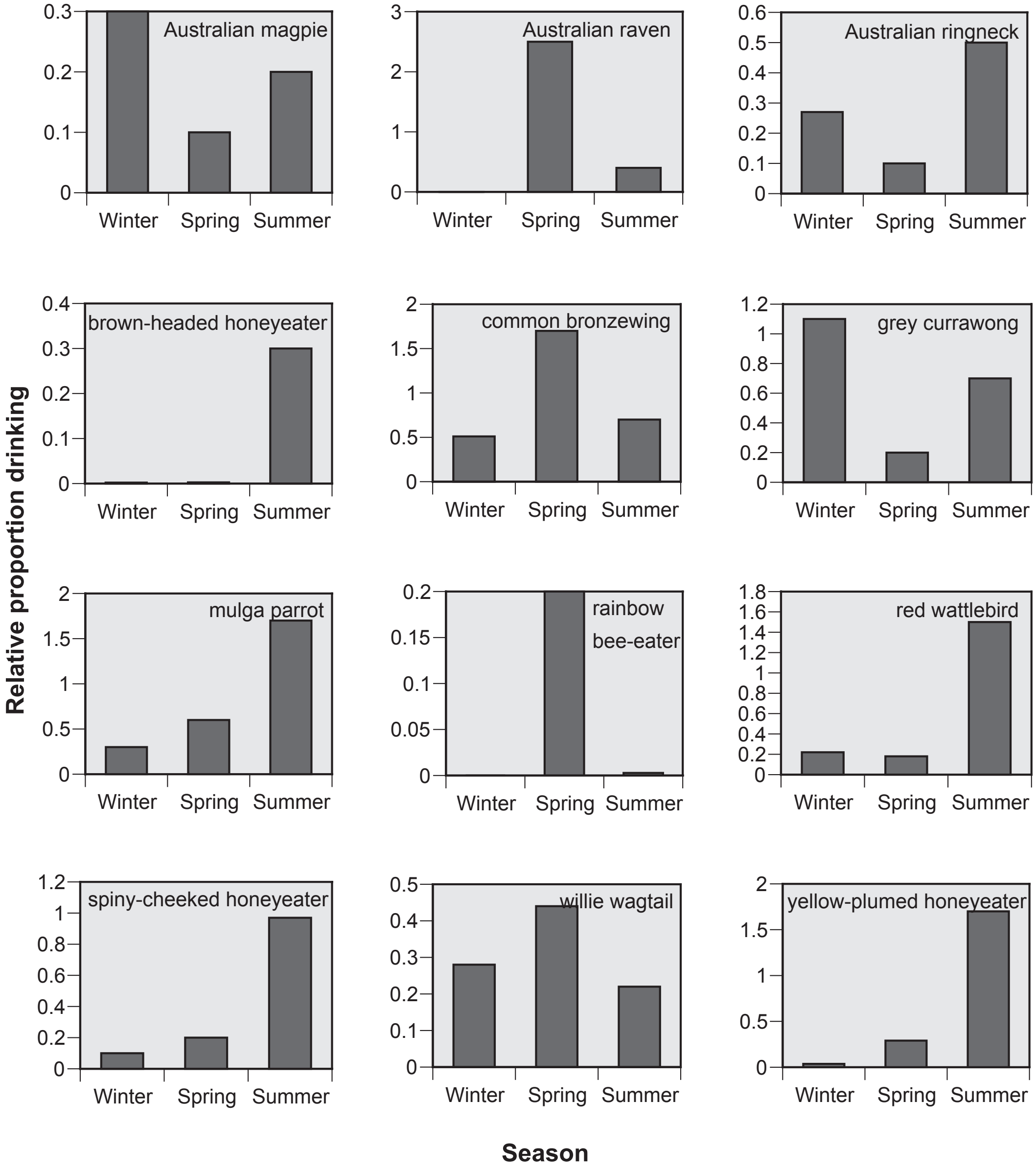


Figure 4.5: The relative proportions of individuals drinking in each season. This was calculated by dividing the total time spent drinking by a species by the relative abundance of that species, expressed as minutes per number per day.

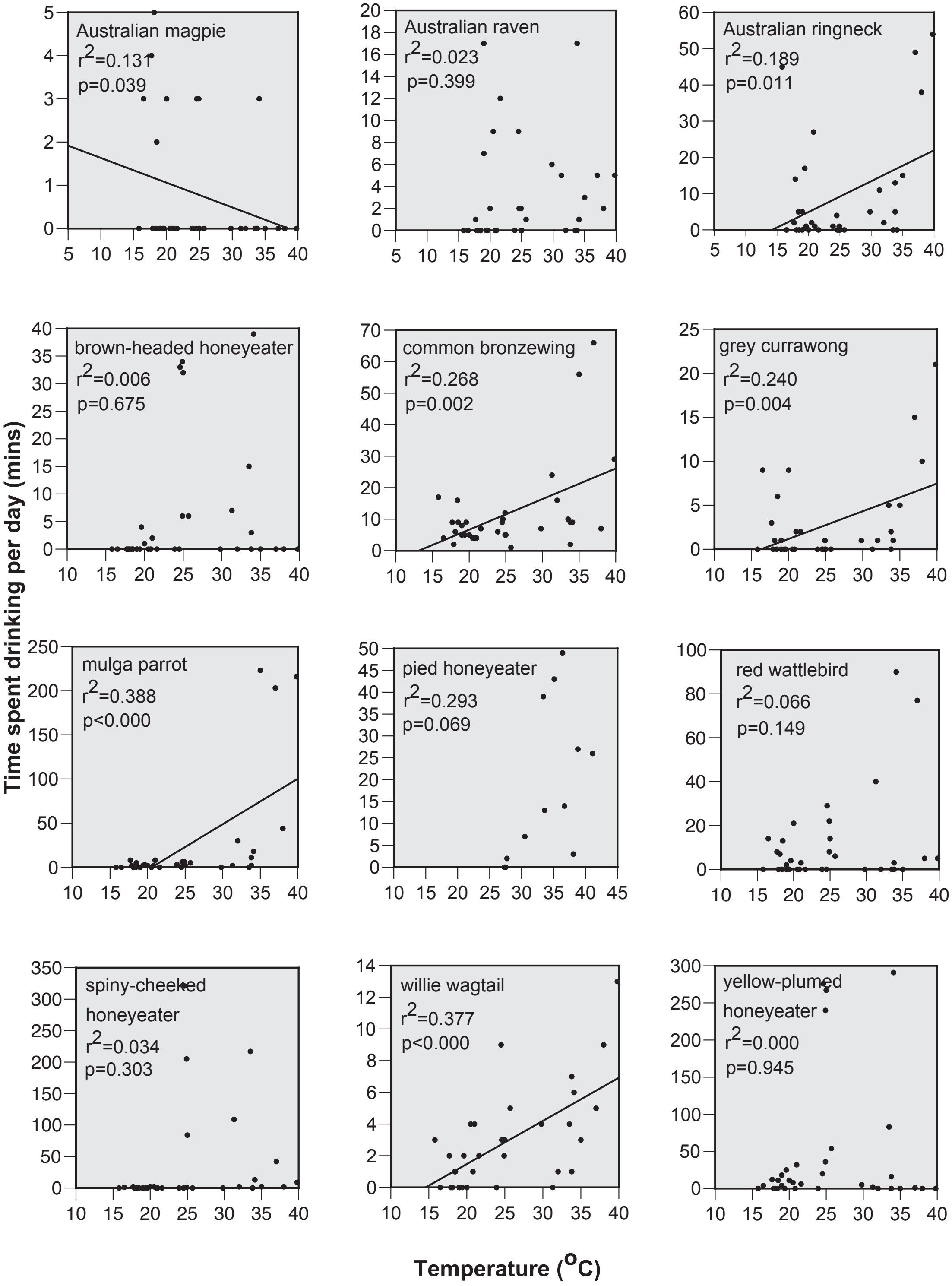


Figure 4.6: Linear regressions of total time spent drinking per day and mean daily maximum temperature for 11 bird species. Data from days where the total rainfall in the seven preceding days exceeded 10 mm have been excluded from the analyses. The data for all species is from observations at Whistler Tank, except for the pied honeyeater, which is from Homestead Dam.

Associations between the time spent drinking by individual bird species and the daily maximum temperatures are displayed in Figure 4.6 with a linear regression line fitted where the relationship was statistically significant. It should be noted though that these species did not display a significant trend until data from days on which there had been more than 10 mm of rainfall in the preceding seven days had been removed. Species which demonstrated a statistically significant increase in time spent drinking with increases in temperature included the Australian ringneck, common bronzewing, grey currawong, mulga parrot and willie wagtail; the Australian magpie data suggested the opposite trend, although the results are not conclusive (p=0.039).

Comparisons of the mean number per site of water-dependent and non water-dependent species suggest that water-dependent species made up a vast majority of individuals at Gluepot Reserve (Figure 4.7).

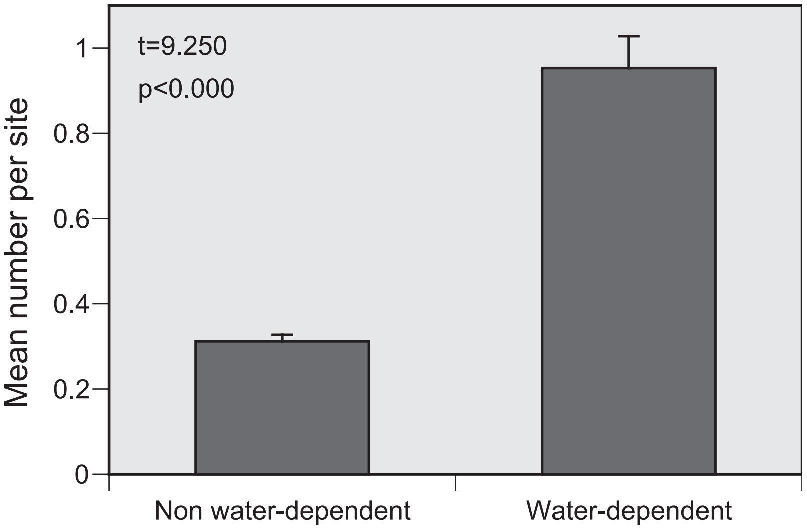


Figure 4.7: Comparison of the mean number of individuals of water-dependent and non water-dependent bird species at Gluepot Reserve.

4.4 DISCUSSION

In the mallee vegetation of Gluepot Reserve 42 (37%) of 113 species were observed drinking, although only 28 (25%) could be classed as either yearly or summer drinkers. Despite this, water-dependent species accounted for 75% of the individuals counted. Because permanent water is not an original component of this environment, the presence of such a large number of water-dependent birds probably represents a change following European settlement which may have had a profound effect on non water-dependent species through competition for food and other resources, aggressive exclusion and predation.

Species with an insectivorous, carnivorous or omnivorous diet can usually gain sufficient water from their diets, and from metabolic water, to survive without drinking (Fisher *et al.*, 1972; Maclean, 1996). All the species that showed no apparent need to drink in this study (the occasional and non-drinkers) were either insectivorous or carnivorous. An exception to this was the purple-crowned lorikeet, which is a nectar-feeder. Although nectar-feeders in Africa (the sunbirds) and North America (the hummingbirds) drink infrequently if at all (Maclean, 1996), most nectar feeders in this study (the meliphagids) were occasional drinkers. A number of physiological and behavioural adaptations such as tolerance to prolonged high ambient temperatures, hypothermia and dehydration, higher conductance and a lower resting metabolic rate have lessened the need for drinking in arid-zone bird species when compared with their wet-zone counterparts (Calder, 1964; Dawson *et al.*, 1983; Schleucher *et al.*, 1991; Maclean, 1996; Casotti & Richardson, 1992, 1993; Casotti *et al.*, 1993; Williams *et al.*, 1993). These adaptations, combined with their diet, may explain why these species do not require drinking water. The purple-crowned lorikeet was not observed drinking using the video surveillance equipment but were observed drinking incidentally while perched to the side of concrete tanks on a number of occasions, a method which would have excluded them from the video surveillance. It may be that this species does require drinking water but that the surveillance methods used were unable to capture them drinking.

All the granivorous species recorded during this study were regular (yearly or summer) drinkers. Studies in Africa (Cade, 1965; Siegfried, 1984), North America (Smyth & Coulombe, 1971) and Australia (Fisher *et al.*, 1972) have shown that all granivorous bird species drink regularly. The common bronzewing, crested pigeon, galah, Major Mitchell's cockatoo, regent parrot, Australian ringneck and mulga parrot are all granivorous, with a diet consisting predominantly of seeds and plant matter (Barker & Vestjens, 1989). These species probably need to drink regularly because, like other granivorous bird species, their diet provides insufficient moisture for body requirements (Williams *et al.*, 1993) and they cannot survive on metabolic water alone (MacMillen, 1990). Unlike granivorous mammals of similar size, birds are diurnal and unable to take advantage of the physiological benefits of underground burrows. The absence of galahs during summer and the scarcity of drinking visits by the Major Mitchell's cockatoo during winter and summer may be due to the small number of individuals present, rather than represent real patterns, especially in that Fisher *et al.* (1972) identified both these species as yearly drinkers. The common bronzewing is a yearly drinker, drinking predominantly at dawn and dusk.

During this study, seven of the 12 honeyeater species that were relatively abundant required water at some period of the year. Why many of the Meliphagidae (the honeyeaters) are water-dependent is not understood, but may be related to their high levels of activity (Davies, 1984; Maclean, 1996). It is unlikely that honeyeaters were only observed drinking because of changes in food resources during this season, because one of the major food sources for these species is nectar from flowering eucalypts, and this was most abundant in spring and summer. However, another major food source of these species is lerp, the dry sugary (carbohydrate) exudate of psyllid insects, and while it is very high in energy it has a very low moisture content. Lerp can be very abundant at times in mallee vegetation, and its predominance in the honeyeaters' diets at these times may increase their requirements for drinking water.

There were two other groups of water-dependent birds that did not conform to the general dietary rules suggested earlier: 1) insectivorous airborne feeders such as martins and woodswallows, and also the willie wagtail and rainbow bee-eater; and 2) an insectivorous/carnivorous group including the Australian magpie, white-winged chough, grey currawong, Australian raven, little crow and apostlebird. The water-dependence seen in the first group, the insectivorous species that feed from the air, might be related to their high levels of activity (Maclean, 1996). All these species, including the willie wagtail and rainbow bee-eater, spend a high proportion of the time hawking insects from the air. However, it is also possible that the insects that these species feed on are more abundant near water and they are simply opportunistically drinking because the water is close to their food source. The second group, the larger insectivores/carnivores, are well documented in the literature as drinking species, though no work has been done on their need to drink. All these species are relatively large and unable to utilise refuges and micro-climates or evaporative heat loss to the same extent as smaller birds.

The mallee bird species displayed several characteristic daily patterns of drinking. The heavily water-dependent species such as the parrots and pigeons tend to drink either early in the morning or in the late afternoon. If they were travelling large distances between water and their foraging sites then these times of day would allow them to avoid high daytime temperatures and intense solar radiation, and provide an uninterrupted period of feeding during the daylight hours. Because the larger carnivorous/insectivorous species such as the Australian raven, Australian magpie and collared sparrowhawk tended to visit water points to drink during the middle periods of the day, the drinking times of heavily water-dependent species may have evolved to avoid predation. However, sparrowhawks hunt at dawn near water and then drink or bathe after they have eaten their prey. Studies on the drinking behaviour of mammals in Africa have demonstrated that many species have specific drinking times which lessen the likelihood of encountering predators and other larger or more numerous herbivores (Ayeni, 1975; du Preez & Grobler, 1977). The pattern observed in the meliphagids, where drinking peaked in the morning and then declined slowly as the day progressed, may be caused by a combination of the factors mentioned above and the honeyeaters' foraging techniques. Honeyeaters are not heavily water-dependent and, because most are nomadic, they would cover large distances while foraging; they may simply drink fortuitously as they encounter water, a relatively abundant resource at Gluepot. The water-dependent insectivorous species which feed predominantly in the mid to late afternoon may simply be responding to insect activity rather than any of the factors mentioned above.

Summary

Granivorous species are the most dependent on water in this mallee environment. Meliphagid species required drinking water during the summer months only, and their requirement for water may in part be due to their high levels of activity. A number of the larger insectivorous/carnivorous species also appeared to be water-dependent despite their food type. While airborne insectivorous feeders were partially dependent on drinking water, most small insectivorous species were never observed to drink. There appears to be a direct association between temperature and time spent drinking in the heavily water-dependent granivorous species, but this was not the case with summer drinkers such as honeyeaters and the larger insectivores/carnivores.

Water-dependent species accounted for the great majority of individuals observed and, with the exception of the Major Mitchell's cockatoo and regent parrot, belonged to species of little conservation concern. The presence of water points in the arid and semi-arid mallee of south-eastern Australia is benefiting common water-dependent species, whose numbers are vastly greater than the non water-dependent species. It is likely that competition for food and other resources such as nest sites is high, and that, if water was not present in this environment, then the number of rarer, non water-dependent species would be considerably higher. The endangered species most likely to be negatively affected by elevated numbers of water-dependent honeyeaters is the black-eared miner. Indirect competition for resources such as lerp and nectar is likely, and to a lesser extent, direct competition from large aggressive species such as the red wattlebird. Elevated numbers of nest-predators and predators of young such as ravens, currawongs, magpies and sparrowhawks may together act together to reduce breeding success, with a disproportionate impact on endangered species such as the black-eared miner. Nest predation on black-eared miners has been reported to be very high (Baker-Gabb, 2001).

5. THE RELATIONSHIP BETWEEN VEGETATION STRUCTURE AND FLORISTICS, DISTANCE TO WATER AND AVIFAUNA IN A MALLEE SYSTEM

5.1 INTRODUCTION

It has become widely accepted that the diversity of avifauna in terrestrial communities increases with increased diversity in the vegetation, and that the structural diversity of the vegetation is the major determinant of bird diversity (MacArthur and MacArthur, 1961; Recher, 1969; James and Wamer, 1982). However, Rotenberry (1985) and Weins (1989) have argued that, at a regional scale, it is the floristic composition of habitats rather than physiognomy which explains their patterns of distribution. In Australia MacNally (1991) demonstrated that structural features were also important at a regional scale, and that it may be difficult to generalise about which characteristics of habitats best account for distributions of avifauna. Studies in North America suggest that structural diversity, particularly the presence of an understorey, explains higher diversities of bird species (England *et al*, 1981; Knopf, 1985). It appears then that both floristic and physiognomic variables are important in determining the distribution and diversity patterns of birds in different habitat types.

This chapter investigates the relationship between avifauna of mallee systems, and the floristics and structure of the vegetation. The results are then discussed in terms of vegetation type and the effects of distance from water. Additionally, the role of seasonal factors (phenology) is examined, providing a better understanding of the role of floristics in determining avifaunal abundance and distributions.

5.2 METHODS

5.2.1 Analytical Methods

Ordination of sites in plant species and vegetation structure space

Multivariate analyses were used to investigate the structure of the vegetation and to formulate predictive hypotheses about the relationship between the species composition and structure of the vegetation and the relative abundances of individual bird species. The analysis of vegetation data re-scaled the field data to an ordinal scale of one to five for both plant species cover values and vegetation structure data. Analyses were then conducted using the Categorical Principal Components Analysis (CatPCA) procedure in SPSS 10.1. PCA is an extremely effective method for summarising variation in environmental data, provided that the variables are standardised and the assumption of linearity of correlations between species is met (Kent and Coker, 1992). To ensure that these assumptions were met all data were subjected to a zero mean/unit variance standardisation and a scatter plot was conducted using the species cover data to ensure that it met the assumption of linearity and did not have a 'horseshoe' distribution.

The mean cover value of plant species and vegetation attributes at each site were ordinated separately to classify habitats into groups based on their vegetation. Only the 60 most common plant species were used for the final analysis to reduce "noise" caused by very rare species. Nineteen vegetation attributes from all 64 sites were used to ordinate sites (see Chapter 2). The ordinations grouped sites that supported similar plant species or vegetation attributes along several axes according to the component scores on that axis. Correlations between both vegetation and individual bird species abundances for each site and the component scores for these axes allowed the habitat requirements for each bird species to be investigated. Weins and Rotenberry (1981) have pointed out that bird species respond individually to environmental factors, and these methods allow the attributes of soil and vegetation that are controlling individual bird species to be investigated.

5.3 RESULTS

Results of the plant species ordinations are set out first, followed by ordinations of the vegetation structure data.

5.3.1 Associations between plant species and avifauna

The results of a three-dimensional ordination using the plant species data are shown in Figures 5.1a and 5.1b. The ordination of sites by plant species formed very clear associations, with the swale (M) and dune crest (S) sites grouping separately. Ordination around these three axes accounted for 35.9% of the variation (Table 5.1). Correlations between plant species cover scores and the first three axes of this ordination are shown in Table 5.2. The first axis (Dimension 1) accounted for 22.0% of the total variation and separated the swale sites (positively correlated) from the dune crest sites (negatively correlated). Axis 2 accounted for 7.8% of the variation and separated sites according to distance from water, sites close to water being positively correlated while sites far from water were negatively correlated (Figure 5.1a). The association between Axis 2 and the distance from water was strong in the swale sites, but less obvious in the dune crest sites. Axis 3 accounted for 6.1% of the variance and separated dune crest sites according to distance from water, sites close to water being negatively correlated while sites far from water being positively correlated (Figure 5.1b). Axis 3 also separated swale sites according to distance from water, although in an opposite direction to the dune sites, sites close to water being positively correlated with it while sites far from water being negatively correlated.

Correlations between bird species abundance and Axes 1-3 from the ordination of plant species data are shown in Table 5.3. Axis 1 was positively correlated with the abundance of the Australian ringneck,

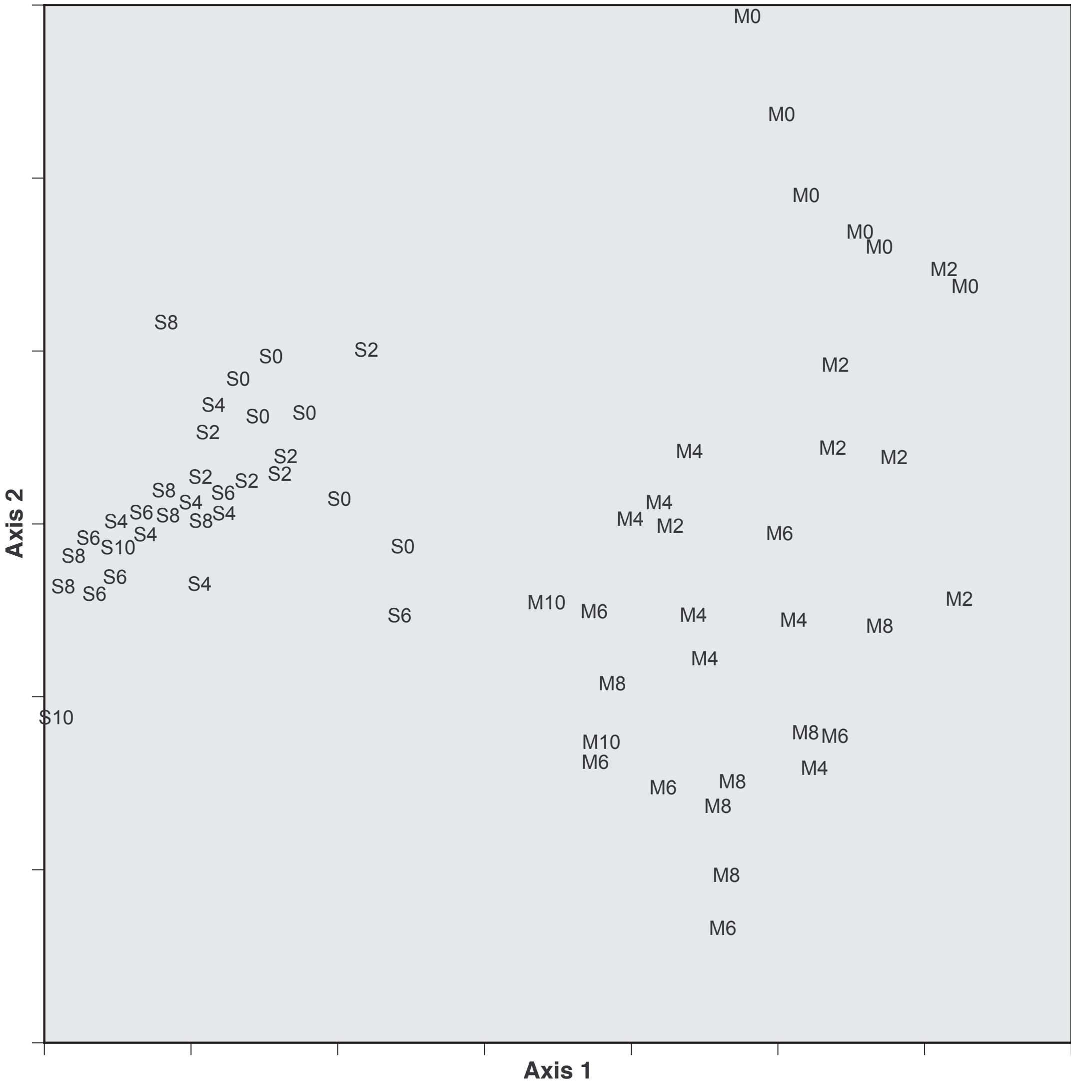


Figure 5.1a: Ordination diagram (PCA) of sites in plant species space in which Axis 1 is plotted against Axis 2. The diagram was created using the component scores for each axis. The percentage of variance extracted by each axis is displayed in Table 5.1. Each site is labelled with a two-digit code (eg. M8). The letter refers to the vegetation type (M = mallee in swales; S = spinifex mallee on dune crests) and the number refers to distance from water in kilometres.

Table 5.1: Percentage variance extracted by first three axes of the ordination of sites in plant species space.

Axis	% of variance	Cum. % of variance
1	21.97	21.97
2	7.80	29.77
3	6.14	35.91

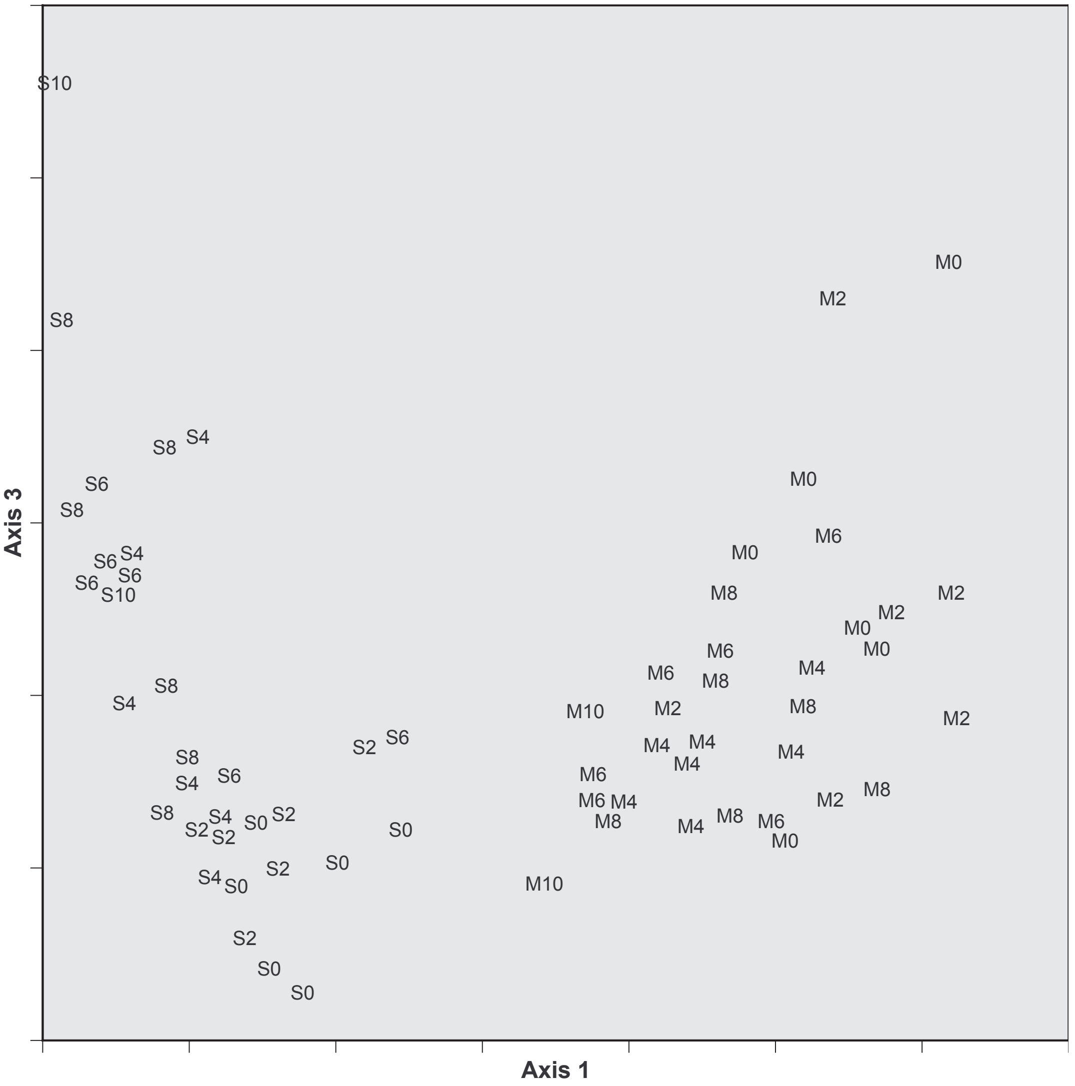


Figure 5.1b: Ordination diagram (PCA) of sites in plant species space with Axis 1 plotted against Axis 3. The diagram was again created using the component scores for each axis. The percentage of variance extracted by each axis is displayed in Table 5.1. See Figure 5.1a for a description of the labels.

Table 5.2: Spearman correlations of plant species cover with the component scores of the first three ordination axes of sites in plant species space.

	Axis 1		**Axis 2**		**Axis 3**	
	r	**p**	**r**	**p**	**r**	**p**
Upper Canopy						
Alectryon oleifolius	+0.379	**	-0.062	NS	+0.272	*
Casuarina pauper	+0.315	*	+0.378	**	+0.373	**
Callitris verrucosa	-0.594	***	-0.128	NS	+0.553	***
Eucalyptus gracilis	+0.295	*	+0.047	NS	-0.080	NS
Eucalyptus incrassata	-0.223	**NS**	+0.010	NS	-0.042	NS
Eucalyptus leptophylla	-0.312	*	+0.083	NS	-0.133	NS
Eucalyptus oleosa	+0.724	***	-0.345	**	-0.068	NS
Eucalyptus socialis	-0.819	***	+0.165	NS	-0.080	NS
Myoporum platycarpum	-0.227	**NS**	+0.128	NS	+0.056	NS
Parasites						
Amyema preissii	+0.232	NS	+0.444	***	+0.139	NS
Cassytha melantha	+0.113	NS	-0.337	**	+0.041	NS
Mid Canopy						
Acacia acanthoclada	-0.236	**NS**	+0.311	*	-0.330	**
Acacia brachybotrya	-0.422	***	-0.132	NS	+0.302	*
Acacia colletiodes	+0.679	***	+0.254	*	-0.098	NS
Acacia ligulata	-0.232	**NS**	-0.174	NS	+0.268	*
Acacia nysophylla	+0.512	***	+0.492	***	+0.295	*
Acacia oswaldii	+0.197	NS	+0.144	NS	-0.329	**
Acacia rigens	-0.359	**	-0.022	NS	+0.337	**
Acacia sclerophylla	+0.137	NS	-0.607	***	-0.134	NS
Acacia wilhemiana	-0.449	***	-0.157	NS	+0.302	*
Atriplex stipitata	+0.417	**	-0.532	***	+0.043	NS
Baekia crassifolia	-0.426	***	-0.080	NS	+0.437	***
Beyeria opaca	-0.169	NS	-0.540	***	+0.250	*
Chenopodium curvispicatum	+0.625	***	-0.001	NS	+0.128	NS
Cryptandra propinqua	-0.358	**	+0.043	NS	+0.356	**
Daviesia ulicifolia	+0.339	**	+0.308	*	+0.083	NS
Dissocarpus paradoxus	+0.277	*	+0.238	**NS**	-0.066	NS
Dodonaea bursarifolia	-0.219	**NS**	+0.085	NS	-0.001	NS
Dodonaea viscosa	+0.285	*	-0.127	NS	+0.050	NS
Enchylaena tomentosa	+0.755	***	-0.060	NS	+0.215	**NS**
Eremophila deserti	+0.418	**	+0.273	*	-0.202	NS
Eremophila glabra	+0.681	***	-0.287	*	+0.097	NS
Eremophila scoparia	-0.140	NS	+0.338	**	+0.087	NS
Exocarpus aphyllus	+0.206	NS	+0.149	NS	+0.376	**
Grevillea huegelii	+0.118	NS	-0.522	***	+0.529	***
Heterodendrum oleofolium	+0.379	**	-0.062	NS	+0.272	*
Lycium australe	+0.388	**	+0.501	***	+0.229	**NS**
Maireana appressa	+0.565	***	-0.103	NS	+0.150	NS
Maireana erioclada	+0.219	**NS**	-0.039	NS	-0.008	NS
Maireana georgei	+0.723	***	-0.160	NS	+0.138	NS
Maireana pentatropis	+0.522	***	+0.082	NS	+0.282	*
Maireana schistocarpa	+0.791	***	+0.094	NS	+0.152	NS
Maireana sedifolia	+0.419	**	+0.235	**NS**	+0.221	**NS**
Maireana trichoptera	+0.547	***	+0.067	NS	+0.265	*
Maireana triptera	+0.377	**	-0.046	NS	+0.052	**NS**
Olearia magniflora	+0.082	NS	-0.074	NS	+0.336	**
Olearia muelleri	+0.497	***	-0.356	**	-0.377	**
Olearia pimeleoides	+0.440	***	-0.432	***	-0.050	NS
Prostanthera aspalathoides	-0.133	NS	+0.004	NS	+0.328	**

Table 5.2 continued

	Axis 1		**Axis 2**		**Axis 3**	
	r	**p**	**r**	**p**	**r**	**p**
Rhagodia spiniscens	+0.589	***	+0.067	NS	+0.013	NS
Santalum acuminatum	-0.250	*	-0.059	NS	+0.160	NS
Scaevolia spinescens	+0.468	***	-0.245	**NS**	+0.057	NS
Sclerolaena diacantha	+0.707	***	-0.285	*	+0.042	NS
Sclerolaena obliquicuspis	+0.506	***	+0.433	***	+0.337	**
Senna artemisoides ssp. *coriacea*	+0.720	***	-0.243	**NS**	+0.178	NS
Senna artemisoides ssp. *filifolia*	+0.774	***	-0.345	**	+0.066	NS
Templetonia egena	-0.630	***	-0.325	**	+0.244	NS
Westringia rigida	-0.390	**	-0.443	***	+0.446	***
Zygophyllum apiculatum	+0.517	***	-0.282	*	-0.085	NS
Zygophyllum auriantiacum	+0.873	***	-0.042	NS	+0.112	NS
Ground Layer						
Austrostipa sp.	+0.077	NS	-0.394	**	+0.200	NS
Eragrostis dielsii	+0.397	**	+0.129	NS	+0.255	*
Lomandra effusa	-0.068	NS	+0.264	*	-0.355	**
Triodia scariosa	-0.715	***	+0.037	NS	-0.257	*

brown treecreeper, chestnut-crowned babbler, jacky winter, mulga parrot, red-capped robin, crested bellbird, red wattlebird, southern scrub-robin and spiny-cheeked honeyeater. This suggests that these bird species may be associated with the plant species that occur within swales. Only the striated grasswren was negatively correlated with Axis 1 (dune crest sites). Axis 2 showed positive correlations with the abundance of the Australian magpie, Australian raven, chestnut-rumped thornbill, red-capped robin, red wattlebird and willie wagtail. These bird species are therefore strongly associated with plant species that are more abundant close to water within swales. Bird species with abundances that were negatively correlated with Axis 2 were the chestnut quail-thrush, Gilbert's whistler, purple-crowned lorikeet, shy heathwren, southern scrub-robin, striped honeyeater, white-eared honeyeater and yellow-plumed honeyeater. This suggests that these bird species are associated with plant species that are more abundant further from water within swales. Axis 3 was positively correlated with the white-fronted honeyeater (sites distant from water on dunes) and negatively correlated with the restless flycatcher (sites distant from water in swales).

Table 5.3: Spearman correlations of bird species abundance with the component scores of the first three ordination axes of sites in plant species space. Only species with statistically significant correlations are displayed.

Axis:	**One**		**Two**		**Three**	
	r	**p**	**r**	**p**	**r**	**p**
Australian magpie	-0.052	NS	+0.328	**	-0.089	NS
Australian raven	+0.262	*	+0.275	*	+0.096	NS
Australian ringneck	+0.486	***	+0.055	NS	+0.051	NS
brown treecreeper	+0.427	***	+0.244	**NS**	+0.127	NS
brown-headed honeyeater	+0.234	**NS**	+0.181	NS	+0.100	NS
chestnut-crowned babbler	+0.357	**	+0.108	NS	+0.066	NS
chestnut quail-thrush	+0.231	**NS**	-0.345	**	-0.010	NS
chestnut-rumped thornbill	+0.317	*	+0.379	**	-0.101	NS
common bronzewing	+0.057	NS	+0.053	NS	+0.235	**NS**
crested bellbird	+0.283	*	+0.102	NS	+0.127	NS
Gilbert’s whistler	+0.194	NS	-0.278	*	+0.013	NS
grey butcherbird	+0.228	**NS**	+0.017	NS	-0.065	NS
jacky winter	+0.327	**	+0.010	NS	-0.048	NS
mulga parrot	+0.321	**	-0.036	NS	-0.041	NS
purple-crowned lorikeet	+0.191	NS	-0.381	**	+0.061	NS
rainbow bee-eater	+0.048	NS	+0.231	**NS**	+0.166	NS
red wattlebird	+0.414	***	+0.313	*	+0.051	NS
red-capped robin	+0.393	**	+0.406	**	+0.115	NS
restless flycatcher	+0.149	NS	-0.055	NS	-0.312	*
shy heathwren	-0.049	NS	-0.322	**	+0.123	NS
southern scrub-robin	+0.311	*	-0.375	**	+0.020	NS
spiny-cheeked honeyeater	+0.580	***	+0.161	NS	-0.050	NS
striated grasswren	-0.482	***	+0.122	NS	+0.136	NS
striated pardolate	+0.208	**NS**	-0.021	NS	+0.191	NS
striped honeyeater	+0.104	NS	-0.290	*	+0.055	NS
white-browed babbler	+0.184	NS	-0.260	*	+0.081	NS
white-browed woodswallow	+0.300	*	-0.111	NS	-0.009	NS
white-eared honeyeater	-0.140	NS	-0.299	*	+0.204	NS
white-fronted honeyeater	+0.175	NS	-0.167	NS	+0.286	*
willie wagtail	+0.083	NS	+0.294	*	-0.185	NS
yellow-plumed honeyeater	+0.239	**NS**	-0.404	**	+0.128	NS

5.3.2 Associations between vegetation structure and avifauna

Ordination of sites by vegetation structure also showed very clear associations, with the swale and dune crest sites again grouping separately (Figures 5.2a & 5.2b). The three axes in a three-dimensional PCA together accounted for 64.0% of the total variation in vegetation structure (Table 5.4). Correlations between vegetation attributes and the first three axes are shown in Table 5.5. Axis 1 accounted for 37.8% of the total variation and is positively correlated with tree height, shrub diversity, total plant diversity, shrub height, shrub cover, herbaceous ground cover and cryptogamic crust cover, while tree cover and grass cover are negatively correlated with this axis. Axis 1 separated the swale sites (positively correlated) from the dune crest sites (negatively correlated), indicating that dune crests have

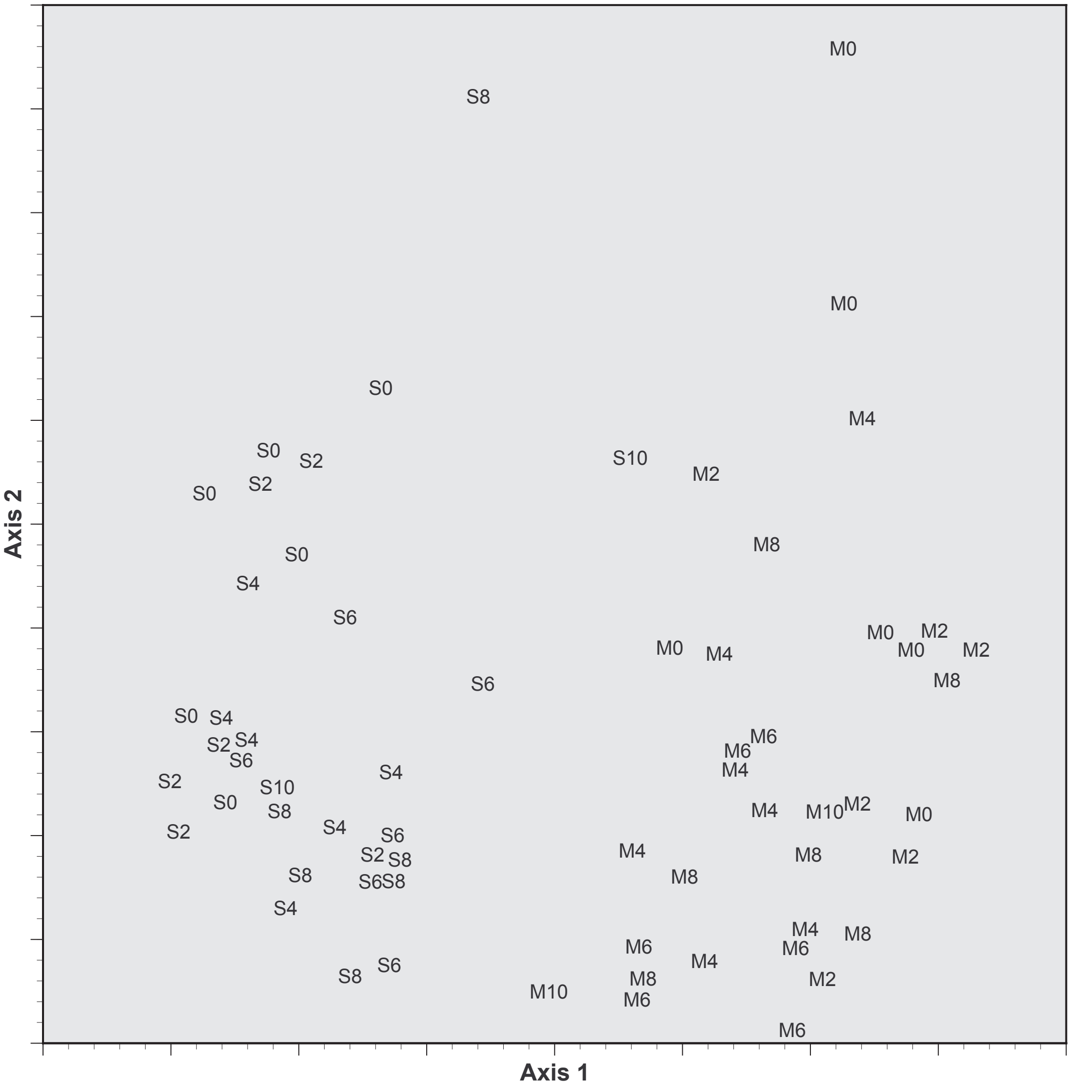


Figure 5.2a: Ordination diagram (PCA) of sites in vegetation attribute space with Axis 1 plotted against Axis 2. The diagram was created using the component scores for each axis. The percentage of variance extracted by each axis is displayed in Table 5.4. See Figure 5.1a for a description of the labels.

Table 5.4: Percentage variance extracted by first three axes of the ordination of sites by vegetation attributes.

Axis	% of variance	Cum. % of variance
1	37.80	37.80
2	14.96	52.76
3	11.20	63.96

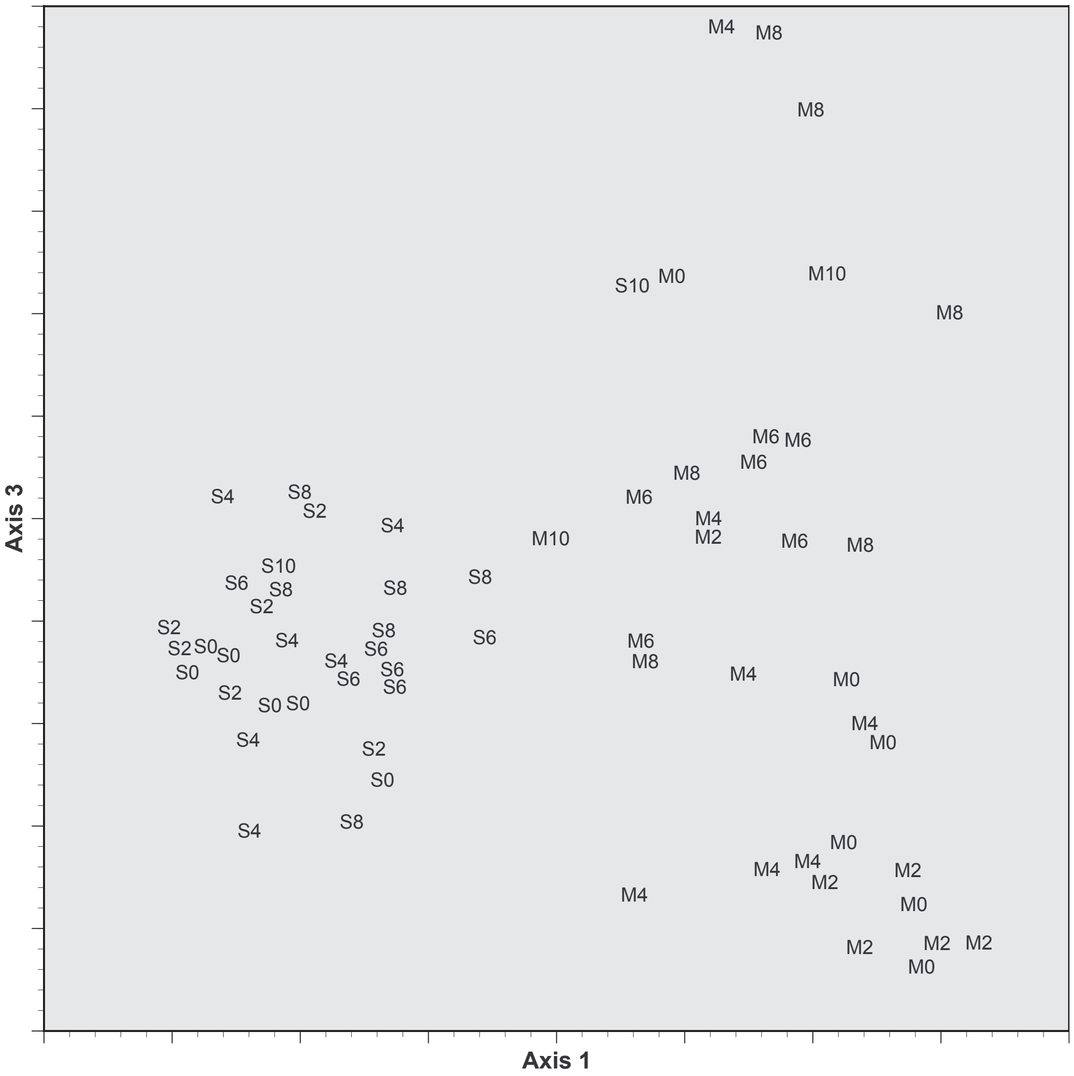


Figure 5.2b: Ordination diagram (PCA) of sites in vegetation attribute space showing Axes 1 and 3. The diagram was created using the component scores for each axis. The percentage of variance extracted by each axis is displayed in Table 5.4. See Figure 5.1a for a description of the labels. Only one S10 site is remote from the remainder of the crest sites (S).

significantly greater tree and grass cover. Axis 2 accounted for 15.0% of the variation and shows positive correlations with tree diversity, parasite diversity, herbaceous ground cover diversity and bare ground cover, while shrub cover (>2m) and leaf litter cover are negatively correlated with this axis. Axis 2 tended to separate sites according to distance to water, sites close to water being positively correlated while sites far from water were negatively correlated (Figure 5.2a). The association between Axis 2 and distance from water was stronger in swale sites than in dune crest sites. Axis 3 accounted for 11.20% of the variance and is positively correlated with herbaceous ground plant diversity, grass diversity and leaf litter cover. Shrub height is negatively correlated with Axis 3. This axis also separated swale sites according to distance from water, with sites close to water being negatively correlated while sites far from water were positively correlated (Figure 5.2b). There was no clear separation of dune crest sites on Axis 3.

Correlations between bird species abundance and the first three axes from the ordination of vegetation structure are shown in Table 5.6. Axis 1 was positively correlated with abundances of the Australian ringneck, brown treecreeper, brown-headed honeyeater, chestnut-crowned babbler, chestnut quail-thrush, crested bellbird, Gilbert's whistler, jacky winter, mulga parrot, red wattlebird, red-capped robin, southern scrub-robin, spiny-cheeked honeyeater, white-browed babbler, white-fronted honeyeater and yellow-plumed honeyeater. All these species are associated with the vegetation structures that are represented in swales. Both the spotted pardolate and striated grasswren are negatively correlated with Axis 1, suggesting they are associated with the vegetation structure common on dunes. Axis 2 shows positive correlations with the abundances of the Australian magpie, Australian raven, red wattlebird, spiny-cheeked honeyeater and weebill; these species are therefore associated with the vegetation structure found predominantly near water. Bird species that were negatively correlated with Axis 2 include the purple-crowned lorikeet, shy heathwren and yellow-plumed honeyeater. This suggests that these species are associated with the vegetation structure found at sites distant from water. There are only negative correlations between bird species abundance and Axis 3, these species including the Australian raven, brown treecreeper, brown-headed honeyeater, red wattlebird and red-capped robin. These species are associated with the vegetation structure characteristic of swale sites close to water.

Because the black-eared miner is an endangered species (Garnett & Crowley, 2000), its situation was explored further by increasing the number of dimensions in the ordination. It was discovered that this species was negatively correlated with the axis of Dimension 6 of the ordination, and that this dimension accounted for 5.24% of the variation. Both grass diversity and cryptogamic crust cover are negatively correlated with this axis, while bare ground cover is positively correlated. This combination of factors is characteristic of sites that are distant from water (see Chapter 2), and suggests black-eared miners are associated with sites containing low bare ground cover, but high cryptogamic crust cover and high grass diversity. However, direct correlations of black-eared miner abundance with these variables did not produce any statistically significant results. There were no plant species that were specifically associated with the abundance of black-eared miners.

Table 5.5: Spearman correlations of vegetation structure with the component scores of the first three ordination axes of sites in vegetation structure space.

Axis:	**One**		**Two**		**Three**	
	r	**p**	**r**	**p**	**r**	**p**
Upper Canopy						
tree diversity	-0.116	NS	+0.446	***	+0.249	*
tree height	+0.801	***	0.017	NS	-0.209	**NS**
cover	-0.751	***	-0.163	NS	+0.286	*
parasitic diversity	+0.274	*	+0.474	***	-0.118	NS
Mid Canopy						
diversity	+0.909	***	-0.009	NS	+0.095	NS
height	+0.490	***	+0.045	NS	-0.450	***
cover (>2m)	+0.650	***	-0.427	***	+0.232	**NS**
cover (<2m)	+0.666	***	+0.174	NS	-0.404	**
Ground Cover						
total herbaceous diversity	-0.107	NS	+0.580	***	+0.488	***
annual forb diversity	+0.018	NS	+0.428	***	-0.009	NS
perennial forb diversity	+0.082	NS	+0.557	***	-0.192	NS
grass diversity	-0.212	**NS**	+0.205	NS	+0.685	***
total herbaceous cover	+0.842	***	+0.134	NS	-0.007	NS
% grass	-0.894	***	+0.090	NS	+0.144	NS
% leaf litter	+0.074	NS	-0.435	***	+0.593	***
% bare ground	-0.087	NS	+0.649	***	-0.219	**NS**
% cryptogamic crust	+0.718	***	-0.465	***	-0.136	NS
crust as a proportion of bare ground	+0.620	***	-0.567	***	-0.062	NS
Total plant diversity	+0.882	***	+0.178	NS	+0.158	NS

Both vegetation types (swale and dune crests) had distinct floristics and structure. To enable a better understanding of the association between bird abundance and the attributes of these two vegetation types, each bird species' preference for vegetation type was explored further. This was done by comparing the mean abundances per site of each bird species in the two vegetation types using an independent-samples t-test (Table 5.7). The purple-crowned lorikeet, Australian ringneck, mulga parrot, brown treecreeper, chestnut-crowned babbler, chestnut-rumped thornbill, Gilbert's whistler, jacky winter, red-capped robin, southern scrub-robin, grey butcherbird, red wattlebird, spiny-cheeked honeyeater, white-fronted honeyeater, yellow-plumed honeyeater and white-browed babbler were all significantly more abundant in swales. Only the striated grasswren was significantly more abundant on dune crests.

Table 5.6: Spearman correlations of bird species abundance with the component scores of the first three ordination axes of sites in vegetation structure space. Only species with statistically significant correlations are displayed. When **NS** is bold, $0.05<p<0.10$.

	Axis 1		**Axis 2**		**Axis 3**	
	r	**p**	**r**	**p**	**r**	**p**
Australian magpie	-0.157	NS	+0.314	*	+0.047	NS
Australian raven	+0.138	NS	+0.313	*	-0.267	*
Australian ringneck	+0.414	**	+0.007	NS	-0.185	NS
brown treecreeper	+0.457	***	-0.028	NS	-0.378	**
brown-headed honeyeater	+0.297	*	+0.239	**NS**	-0.329	**
chestnut-crowned babbler	+0.443	***	+0.068	NS	-0.128	NS
chestnut quail-thrush	+0.295	*	-0.129	NS	+0.024	NS
chestnut-rumped thornbill	+0.197	NS	+0.228	**NS**	-0.144	NS
common bronzewing	+0.238	**NS**	+0.188	NS	+0.020	NS
crested bellbird	+0.400	**	-0.012	NS	-0.189	NS
Gilbert's whistler	+0.275	*	-0.167	NS	-0.027	NS
jacky winter	+0.278	*	+0.015	NS	-0.180	NS
mulga parrot	+0.312	*	+0.018	NS	-0.065	NS
purple-crowned lorikeet	+0.201	NS	-0.286	*	-0.011	NS
rainbow bee-eater	+0.081	NS	+0.209	**NS**	-0.220	**NS**
red wattlebird	+0.346	**	+0.247	*	-0.388	**
red-capped robin	+0.410	**	+0.034	NS	-0.449	***
shy heathwren	+0.121	NS	-0.245	*	+0.150	NS
southern scrub-robin	+0.341	**	-0.192	NS	+0.108	NS
spiny-cheeked honeyeater	+0.541	***	+0.274	*	-0.180	NS
spotted pardolate	-0.275	*	+0.184	NS	+0.055	NS
striated grasswren	-0.358	**	-0.113	NS	+0.019	NS
weebill	+0.063	NS	+0.260	*	-0.044	NS
white-browed babbler	+0.272	*	+0.124	NS	+0.158	NS
white-browed woodswallow	+0.084	NS	-0.227	**NS**	-0.087	NS
white-eared honeyeater	+0.087	NS	-0.173	NS	+0.213	**NS**
white-fronted honeyeater	+0.497	***	-0.066	NS	-0.029	NS
willie wagtail	+0.006	NS	+0.242	**NS**	-0.162	NS
yellow-plumed honeyeater	+0.359	**	-0.275	*	-0.019	NS

Table 5.7: Bird species preference for vegetation type as determined using an independent-samples t-test of mean abundance per site (number per site). When **NS** is bold, 0.05<p<0.10.

Species	**Mean abundance per site**		**t**	**p**
	Swales	Crests		
Australian magpie	0.13	0.15	-0.327	NS
Australian raven	0.24	0.19	0.639	NS
Australian ringneck	0.89	0.26	3.872	***
black-eared miner	0.68	0.71	-0.092	NS
black-faced cuckoo-shrike	0.14	0.20	-0.731	NS
brown treecreeper	0.15	0.00	2.307	*
brown-headed honeyeater	0.75	0.47	1.142	NS
chestnut quail-thrush	0.14	0.07	1.519	NS
chestnut-crowned babbler	0.53	0.041	2.827	**
chestnut-rumped thornbill	0.63	0.23	2.280	*
common bronzewing	0.056	0.021	1.513	NS
crested bellbird	0.29	0.20	1.540	NS
galah	5.06	1.94	0.903	NS
Gilbert's whistler	0.11	0.02	2.726	**
grey butcherbird	0.37	0.18	2.207	*
grey currawong	0.11	0.13	-0.455	NS
grey shrike-thrush	0.25	0.21	0.551	NS
hooded robin	0.21	0.10	1.295	NS
jacky winter	0.42	0.09	3.489	***
magpie lark	0.00	0.02	-1.016	NS
masked woodswallow	0.98	0.92	0.116	NS
mulga parrot	0.39	0.10	2.618	**
purple-crowned lorikeet	0.87	0.35	2.129	*
rainbow bee-eater	0.11	0.17	-0.517	NS
red wattlebird	1.41	0.56	3.253	**
red-capped robin	0.26	0.02	2.850	**
restless flycatcher	0.11	0.05	1.413	NS
shy heathwren	0.06	0.02	1.440	NS
southern scrub-robin	0.17	0	3.323	**
spiny-cheeked honeyeater	1.23	0.38	4.404	***
spotted pardalote	0.98	1.17	-0.518	NS
striated grasswren	0.00	0.16	-4.098	***
striated pardalote	0.89	0.79	0.326	NS
striped honeyeater	0.14	0.06	1.179	NS
variegated fairywren	0.22	0.11	1.044	NS
varied sitella	0.16	0.08	0.940	NS
weebill	1.65	1.59	0.144	NS
white-browed babbler	0.70	0.16	3.057	***
white-browed woodswallow	9.44	3.47	1.737	**NS**
white-eared honeyeater	0.14	0.18	-0.667	NS
white-fronted honeyeater	2.73	1.29	2.495	*
willie wagtail	0.18	0.20	-0.296	NS
yellow-plumed honeyeater	12.88	8.14	3.413	**

5.4 DISCUSSION

5.4.1 Differences between vegetation types

The two major vegetation types had distinct floristics and structure, with the greater abundance and diversity of birds in the swale vegetation (see Chapter 3). This can be attributed to the vegetation attributes that differ most significantly from those of the dune crests. By using values for plant species cover and vegetation structure from Chapter 2 it was possible to compare how significantly-correlated variables from the ordination differed between vegetation types. Swale vegetation had a significantly greater tree height, shrub diversity, shrub height, shrub cover and herbaceous diversity when compared with dune crest vegetation. Interestingly, tree diversity and tree cover were greater in the dune crest vegetation, suggesting that structural diversity of the lower strata (shrub and herbaceous layer) is perhaps more important to the abundance and diversity of bird species in mallee. However, the most statistically significant vegetation difference was the shrub diversity of the swales, suggesting that floristics of the shrub layer may also be very important. Swale vegetation is characterised by a distinct plant species composition. Species that were responsible for this included *Eucalyptus oleosa*, *Alectryon oleifolius* and *Casuarina pauper* in the upper canopy, and an abundance of shrubs such as species of *Acacia*, *Eremophila*, *Enchylaena*, *Maireana*, *Olearia*, *Senna* and *Zygophyllum*. On the other hand, dune crest vegetation was characterised by *E. socialis* in the upper canopy, a sparse shrub layer including species of *Acacia* and *Senna*, and frequent hummocks of *Triodia scariosa*.

Most bird species that show a preference for a particular vegetation type are associated with the swale sites, as opposed to the dune sites. The increased abundance and diversity of avifauna in swales probably relates to the structural and floristic differences described above. In addition, swales are depressions and more mesic than dunes, and probably more productive. By examining the factors (floristic and physiognomic) that are most significantly correlated with individual bird species, and the diets of those bird species, it is possible to get a better understanding of the vegetation attributes that may influence their abundances and distributions.

The only species that were significantly associated with dune crest vegetation were the striated grasswren and spotted pardalote. The striated grasswren was considerably more abundant in the dune vegetation and highly correlated with both floristic and structural components of that vegetation, a major factor probably being the high cover of *Triodia scariosa* in this vegetation type which provides foraging sites and shelter for this species. The abundance of the spotted pardalote, a species of the eucalypt canopy, was correlated with structural attributes of the crests only, suggesting that the structurally more diverse tree layer within the dune crest vegetation is important to this species. It is worth noting that the very similar striated pardalote seems more closely associated with floristics of the swale vegetation (although that was not statistically significant in this study), and this may be demonstrating an ecological resource partitioning between these two species within this region.

Honeyeaters

Most of the more widespread abundant honeyeater species showed an apparent preference for swale vegetation, though the factors within this vegetation group that influenced individual species varied. Species that appeared to select swale vegetation for physiognomic reasons included the brown-headed honeyeater, white-fronted honeyeater and yellow-plumed honeyeater. These species all have very similar food requirements, feeding predominantly on the nectar of eucalypts and shrubs such as emu-bushes (*Eremophila*), as well as on small insects (Barker and Vestjens, 1989). Because the structure of the upper canopy within swale and dune vegetation does not vary greatly, both being dominated predominantly by multi-stemmed eucalypt species, it seems likely that the increased structural diversity of the shrub layer within swale vegetation is probably responsible for their higher abundance there. The high structural diversity of swale vegetation may also increase food resources such as nectar and insect abundance (Knopf, 1985; Recher, 1985; Gilmore, 1985).

Both the red wattlebird and spiny-cheeked honeyeater were highly associated with floristic and structural attributes of the vegetation. These species have very similar feeding habits to the above species, and their correlation with structural components of the vegetation is probably related to the shrub layer also. Floristically, these species are probably more abundant in swales because production by eucalypt species may be greater due to the more mesic conditions there and, perhaps more importantly, by the high abundances of certain shrub species (e.g. *Eremophila glabra* and *Enchylaena tomentosa*). The nectar of eremophila flowers and the seeds of *Enchylaena tomentosa* are important food sources for these two bird species (Barker & Vestjens, 1989), and they were observed utilising them heavily during this study.

Bird species that feed predominantly in the upper canopy may not be affected by vegetation type in this region because, although the eucalypt species differ between vegetation types, they have similar structure and phenology. However, the amounts of nectar produced and the level of insect attack is likely to vary between eucalypt species (Paton, pers. comm.) and this may influence some of the avifaunal patterns observed. Honeyeater species that use this part of the vegetation include the black-eared miner, striped honeyeater and white-eared honeyeater.

Parrots

Both the Australian ringneck and mulga parrot were significantly more abundant in swale vegetation, associated with both structural and floristic components of the vegetation. These species have similar food requirements, feeding on the seeds and fruit of small shrubs such as species of the chenopods *Atriplex*, *Chenopodium*, *Enchylaena* and *Maireana* (Barker & Vestjens, 1989). These parrot species are also known to feed on the nectar of some mallee eucalypts and their parasitic mistletoe (pers. obs.). Both parrots are probably more abundant within the swale vegetation because of the high shrub and herbaceous cover and the high shrub diversity in this vegetation type. The major shrub species responsible for this increased diversity were *Atriplex stipitata*, *Enchylaena tomentosa*, *Lycium australe*, seven *Maireana* species and two *Sclerolaena* species: all known to be food for these parrot species.

Insectivores

The remaining bird species that were more abundant in swale vegetation were all insectivores, divisible into species that feed either mainly on the ground or mainly in the canopy. The chestnut-rumped thornbill, red-capped robin, jacky winter and brown treecreeper are all sub canopy-foraging insectivores that are more abundant in swale vegetation, and associated with both floristic and structural components of the vegetation. Brown treecreepers require large trees with hollows and, because the swale sites had significantly larger trees, this may explain their preference for this vegetation type. The floristic and structurally more diverse shrub layer in swales probably results in greater insect abundance, and this may explain the increased abundance of the other sub canopy-foraging species in this vegetation type. The higher abundance of the red-capped robin and chestnut-rumped thornbill can be further explained by their preference for *Casuarina* species in this district; these are mainly in the swale vegetation.

Ground-foraging insectivorous bird species that were significantly more abundant in swale vegetation included the chestnut-crowned babbler, white-browed babbler, Gilbert's whistler and southern scrub-robin. These species' abundances were all strongly correlated with vegetation structure and, to a much lesser degree, with floristics. Structural diversity, particularly the presence of an understorey, best explains the higher abundance of these ground-dwelling species in swale vegetation. This result agrees with their foraging habits, which involves gleaning insects from the lower branches of shrubs and foraging amongst leaf litter beneath shrubs. It would seem unlikely that individual plant species might influence the distribution and abundance of these bird species because they are predominantly insectivores, foraging on a variety of insects not necessarily associated with particular plant species. It should be noted that the abundance of both the chestnut quail-thrush and crested bellbird (ground-feeders) were highly correlated with mid-canopy vegetation structure, although they did not show significant differences in abundance between vegetation types.

5.4.2 Differences with distance from water

Vegetation at different distances from water had distinct floristics and structure (Chapter 2). Sites close to water had significantly less shrub cover, tree cover and associated leaf litter cover, less cryptogamic crust cover and more bare ground cover when compared with sites distant from water. Perennial forb diversity was greater close to water while grass diversity was greater at sites distant from water. The number of vegetation layers and the cover values within those vegetation layers (structural diversity) appears to increase with distance from water, although not as markedly as between vegetation types.

Sites at different distances from water also have distinct plant species. Sites close to water were characterised by *Casuarina pauper* and the mistletoe *Amyema preissii* in the upper canopy and shrubs such as *Acacia colletioides*, *A. nysophylla*, three *Maireana* species, *Sclerolaena obliquicuspis* and *Zygophyllum aurantiacum* in the shrub layer. The increased cover of shrubs at sites distant from water was caused by species such as *Acacia sclerophylla*, *Atriplex stipitata*, *Beyeria opaca*, *Eremophila glabra*, *Grevillea huegelii*, two *Olearia* species, *Senna artemisioides* and *Westringia rigida*.

Increaser bird species

Interestingly, very few of the water-dependent bird species that displayed increaser responses were correlated with vegetation attributes close to water, suggesting that their presence close to water may be due to drinking requirements and not to food or shelter requirements. Other factors that were not measured during this study but may influence these species distributions include landscape position and competition with other bird species. Bird species that fall under this category include the brown-headed honeyeater, mulga parrot, Australian ringneck, red wattlebird, spiny-cheeked honeyeater and willie wagtail. Both the Australian magpie and Australian raven are water-dependent but show correlations with both structural and floristic components of the vegetation. Structurally, these species appear to select open vegetation located close to water. The Australian magpie is almost entirely insectivorous so any interpretation of floristic data is probably meaningless. However, the Australian raven has a proportion of plant seeds and fruit in its diet, but the only plant species it was correlated with and it is known to feed from were three *Maireana* species.

Increaser bird species that are not water-dependent generally did show highly significant correlations with vegetation attributes. These bird species are all insectivores and include the brown treecreeper, chestnut-rumped thornbill, red-capped robin, jacky winter and weebill. The brown treecreeper abundance was highly correlated with structural attributes of the vegetation, perhaps due to its previously-mentioned requirement for large trees with hollows. However, other correlated structural attributes included shrub height and cover. Both the chestnut-rumped thornbill and red-capped robin were highly correlated with floristics and, as discussed earlier, are associated with *Casuarina pauper*, which occurs only at sites close to water. The jacky winter and weebill are not correlated with either structural or floristic components of the vegetation, suggesting that the abundance of their prey might be more strongly influenced by the presence of water than by the vegetation.

Decreaser bird species

Decreaser bird species fall into two categories: ground-foraging insectivores (Gilbert's whistler, shy heathwren, southern scrub-robin, striated grasswren and chestnut quail-thrush) and canopy-dwelling honeyeaters (yellow-plumed and white-fronted honeyeaters) (see Chapter 3). The abundance of the white-fronted honeyeater was not correlated with either floristic or structural attributes of the vegetation, although yellow-plumed honeyeater abundance was correlated with floristic components, and this may be related to the increase in nectar-producing plant species such as *Eucalyptus oleosa*, *Amyema preissii* (a mistletoe), *Eremophila glabra* and *Grevillea huegelii* with distance from water. Both the white-eared honeyeater and striped honeyeater were correlated with the same vegetation attributes as the yellow-plumed honeyeater in the ordination, although they did not display a significant decreaser response. This suggests that these species may feed on similar plant species to the yellow-plumed honeyeater and, had they been more abundant, they may also have displayed a decreaser response.

All the remaining ground-foraging decreaser bird species except the striated grasswren displayed high correlations only with floristic components of the vegetation. The high correlation with shrub species such as *Acacia sclerophylla*, *Atriplex stipitata*, *Grevillea huegelii* and *Beyeria opaca* probably account for the high abundance of these bird species at sites distant from water. All these shrub species have a low, dense canopy that traps leaf litter, thus providing an excellent foraging environment for ground-feeding bird species.

5.4.3 Conclusion

Ordination of sites in vegetation space has strengthened the knowledge gained in Chapter 2 about vegetation attributes associated with each vegetation type, as well as how these attributes change in relation to water. Swale sites were both structurally and floristically more diverse than dune sites. Furthermore, the greater structural and floristic diversity of the shrub layer in swales seems to be responsible for the increased abundance and diversity of avifauna in this vegetation type. By analysing changes in vegetation structure and floristics, it becomes possible to explain the distribution and abundance of individual bird species in relation to vegetation type and distance from water. The abundances of many ground-foraging species are correlated with structural and floristic diversity of the shrub layer, preferring dense, low-spreading shrub species. Honeyeater numbers are also correlated with structural diversity of the shrub layer, together with the abundance of nectar-producing species such as *Eremophila glabra* and *Grevillea huegelii*. Parrots are influenced by the abundance of smaller shrubs such as chenopods. Water-dependent increaser bird species tended not to show strong associations with vegetation, suggesting that their higher abundances close to water is due to water requirements rather than those for food or shelter. Honeyeater species that display a decreaser response are correlated with nectar producing shrubs, while ground-dwelling decreaser bird species were correlated with low, dense shrubs. Finally, the endangered black-eared miner was found to be associated with greater grass diversity and cryptogamic crust cover, and lower bare ground cover, factors that are characteristic of sites distant from water.

6. THE IMMEDIATE EFFECTS OF WATER POINT CLOSURE ON AVIFAUNA IN A MALLEE ENVIRONMENT

6.1 INTRODUCTION

Water points have a major controlling influence on animal distribution in arid and semi-arid regions all over the world. In Australia, a number of bird species have expanded their geographic range or increased in abundance because of the provision of artificial water points (James *et al.*, 1999). Conversely, other species appear to have decreased in abundance and range, and it is widely accepted this is due to the provision of artificial water points and the associated effects of overgrazing (Reid and Fleming, 1992). Prior to the introduction of artificial water points, water-dependent bird species could only inhabit arid areas around permanent natural water, and over other areas following heavy rains (Fisher et al., 1972; Davies, 1977). The bird species that appear to have benefited most from the additional water supplies seem to be those which depend on a daily supply of water for at least part of the year (Davies, 1972; Fisher *et al.*, 1972). Birds that do not depend on free-standing water seem less likely to show increases in range or numbers where water has been introduced (Reid and Fleming, 1992). Only 35% of bird species in Australia's arid rangelands are water dependent, but they represent 75% of the individuals (Fisher et al., 1972; Chapter 4).

Water points are beneficial to common water-dependent bird species, but are negatively impacting rarer ground-dwelling species through the indirect actions of overgrazing (Reid & Fleming, 1992; Chapter 3). Water-independent bird species may also be negatively effected by competitive or aggressive displacement by more numerous water-dependent species. For example, yellow-throated miners may be aggressively displacing some small birds (Grey, 1996). Another water-related interaction between bird species that has been documented is the introgressive hybidisation or "genetic swamping" by the yellow-throated miner of the endangered black-eared miner (*M. melanotis*) around water points in the mallee vegetation of south-east Australia (Schodde, 1981; Starks, 1987; McLaughlin, 1990, 1993). James *et al.* (1999) highlight that similar competitive or aggressive displacement interactions may well be occurring between other species of birds, although there has been no research on this topic.

The negative effects of artificial water points and overgrazing on biodiversity have been highlighted, and managers of many reserves within Australia's arid rangelands have been closing water points as a consequence (e.g. Murray Sunset National Park (Manning, pers. comm.); Sturt National Park (Velez, 2001)). Although it is known that large herbivores such as kangaroos are negatively affected when water points are closed (Gibson, 1995), there is no information to guide managers on the precise effects that water point closure might have on avifauna. It might be expected that numbers of water-dependent bird species and the overall diversity of the avifauna would decline, while non water-dependent species remained unchanged, or increased, after water point closure.

This chapter seeks to elucidate the effect that water point closure might cause to avifauna in mallee vegetation and therefore help managers to determine what management action, if any, would be most appropriate. A number of bird species within the mallee of South Australia are of conservation concern (black-eared miner, malleefowl, red-lored whistler, regent parrot, Major Mitchell's cockatoo and striated grasswren) (Garnett & Crowley, 2000), and so it is important that management actions don't negatively impact on these species. By closing two water points at Gluepot Reserve it was possible to assess the short-term effects of water point closure on the avifauna in the immediate vicinity of those points.

6.2 METHODS

As described in Chapter 2, the avifauna at six replicate sites at each of five distances from water in each of the two principal mallee vegetation types had been sampled, with each site sampled three times a year (in February, June and October) for a period of two years, beginning in October 1998. Bird species and their abundances were mapped through the year in each habitat type using a fixed-point census technique (Chapter 3). Once sites had been sampled for a period of one year (three seasons), two water points (Long Dam and Kangaroo Dam) were closed in September, 1999, and then sampling continued there for a further year. The closure of the water points affected the distances from water of one third of the sites (Table 6.1). The data for water-dependent and non water-dependent species were then compared between the 'closed' and 'open' water point sites to determine if water point closure had influenced their abundances. *A priori* predictions were that the abundance of water-dependent species would decline, while non water-dependent species would be unchanged or increase at 'closed' sites. Also, avifaunal diversity was expected to decline at 'closed' sites as water-dependent species decreased at those sites.

Before-and-after closure abundance data were compared using Multiple Before-After Control-Impact (MBACI) analysis (Keough & Mapstone, 1995, 1997). The MBACI design allows changes due to environmental differences before and after the impact (water point closure) to be accounted for when analysing the effect of the impact. Rainfall in the year before water point closure was approximately half that in the year after closure, and this resulted in increased numbers of birds in the year after closure. The model for the ANOVA is as follows:

$$F_{3,10} = \frac{\mathbf{MS(BA * CI)}}{\mathbf{MS(Site(CI) * BA)}}$$

where: BA = Before-After

CI = Control-Impact

The model in this study used data from Sites 1-6, from Field Trips 1-6, before and after water point closure. Field Trips 1 to 3 sampled the sites before water point closure, while Trips 4 to 6 sampled after closure. Sites 1 and 2 were the impact (closure) sites, while Sites 3 to 6 were the control sites (remaining open). The same MBACI design was used separately on data from 0.25 km and 2.25 km sites and, at these distances, separately on data for water-dependent, non water-dependent, yearly water-dependent and non-yearly water-dependent species (see Chapter 4 for definitions and bird species that fall into each category). Data on individual bird species were not analysed because the data did not meet the assumptions of the analysis. The effects of water point closure at sites more distant from water than this (ie. 4.25 km, 6.25 km and 8.25 km) were not considered because the differences between the before and after distances were not large enough (see Table 6.1).

Table 6.1: Changes to distance from permanent water at sites affected by water point closure. The water points closed were Kangaroo and Long Dam. The location of these water points, as well as the sites affected by their closure, can be seen in Figure 2.2.

Site	Distance to water (km)		Water point closed	New nearest water point
	Before closure	After closure		
KM0A	0.22	5.07	Kangaroo Dam	Homestead Dam
LM0A	0.31	5.40	Long Dam	Whistler Tank
KS0A	0.15	5.04	Kangaroo Dam	Homestead Dam
KS0B	0.38	4.88	Kangaroo Dam	Homestead Dam
LM2A	2.20	3.79	Long Dam	Whistler Tank
LM2B	2.05	6.90	Long Dam	Whistler Tank
LS2A	2.28	3.39	Long Dam	Whistler Tank
LS2B	2.41	6.84	Long Dam	Grasswren Tank
LM4A	4.35	5.17	Long Dam	Grasswren Tank
LM4B	4.44	7.93	Long Dam	Sandalwood Dam
LS4A	4.25	5.41	Long Dam	Grasswren Tank
LS4B	4.29	4.38	Long Dam	Grasswren Tank
LM6A	5.91	6.08	Long Dam	Grasswren Tank
LM6B	6.19	8.04	Long Dam	Sandalwood Dam
LS6A	5.88	6.02	Long Dam	Grasswren Tank
LS6B	5.92	7.88	Long Dam	Sandalwood Dam
LM8A	8.25	8.54	Long Dam	Grasswren Tank
LM8B	8.27	11.2	Long Dam	Sandalwood Dam
LS8A	8.30	8.61	Long Dam	Grasswren Tank
LS8B	8.61	11.8	Long Dam	Sandalwood Dam

6.4 RESULTS

Results of the MBACI analysis of variance (Table 62) indicated that the abundances of drinking, non-drinking, yearly drinking and non-yearly drinking bird species were not influenced significantly by the closure of water points at sites 0.25 km and 2.25 km from water. Although not statistically significant, the total numbers of birds observed within all these categories increased at nearly all sites after water point closure (Figure 6.1). In contrast, the ANOVA results indicated that the diversity of bird species was significantly higher at sites 0.25 km from water *after* water point closure, although this was not significant at sites 2.25 km from water (Figure 6.2).

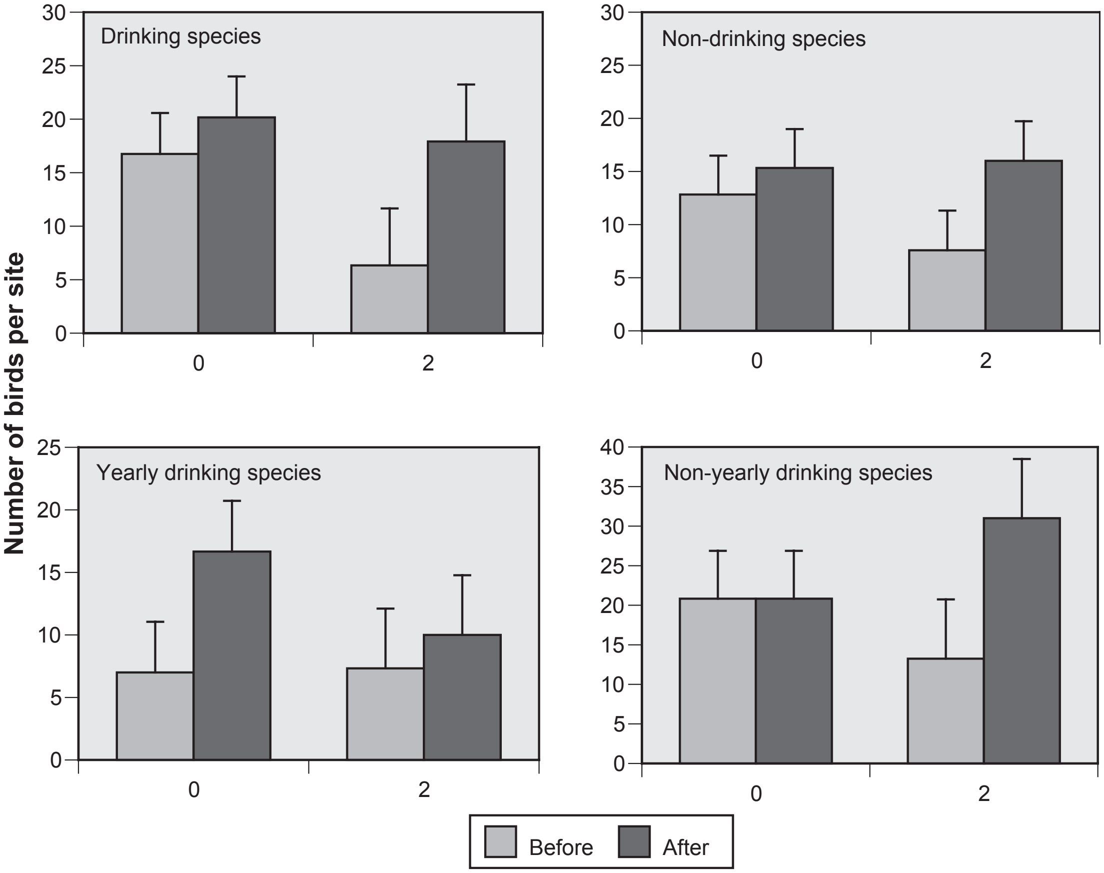


Figure 6.1: The changes in the observed abundances of drinking, non-drinking, yearly drinking and non-yearly drinking bird species at study sites before and after water point closure. Graphs represent the results from sites at 0.25 km (0) and 2.25 km (2) from water. Values represent the mean number of birds detected in each category per site.

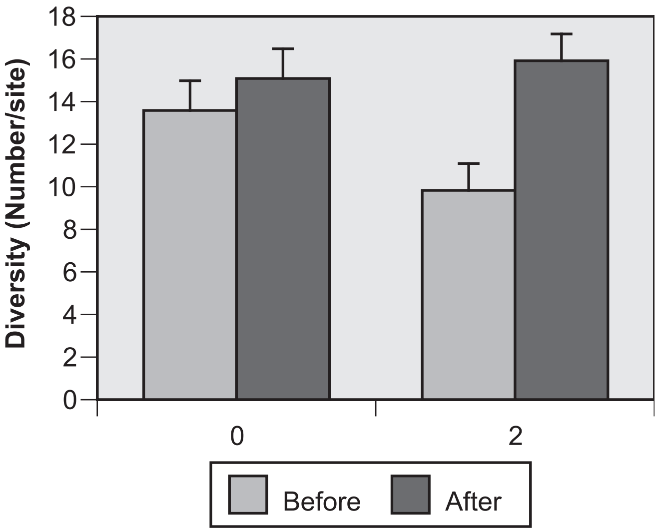


Figure 6.2: The change in diversity (species/site) of bird species at impact sites before and after water point closure. The results from sites at both 0.25 km and 2.25 km are again displayed.

Table 6.2: Table of MBACI (ANOVA) results on the effect of water point closure on the abundance and species richness of avifauna. Bird abundance data were analysed in four different categories (drinking, non-drinking, yearly-drinking, non yearly-drinking) at two distances from water (0.25 km and 2.25 km). The full ANOVA design and details are given in Appendix 3, and the full ANOVA results displayed in Appendix 4. Power was calculated on G•Power using the methods described in Keough & Mapstone (1995, 1997).

Species Category	**Source**	**df**	**MS**	**F**	**p**	**Power**
Abundance						
Drinkers (0 km)	MBACI model	1	61.36	0.776	NS	0.874
Non-drinkers (0 km)	MBACI model	1	237.6	2.60	NS	0.977
Yearly Drinkers (0km)	MBACI model	1	119.17	1.63	NS	0.915
Non-yearly drinkers (0km)	MBACI model	1	370.5	1.02	NS	0.911
Drinkers (2 km)	MBACI model	1	14.06	0.03	NS	0.874
Non-drinkers (2 km)	MBACI model	1	171.1	1.21	NS	0.977
Yearly drinkers (2 km)	MBACI model	1	9.00	0.03	NS	0.915
Non-yearly drinkers (2 km)	MBACI model	1	98.34	0.15	NS	0.911
Diversity						
All species (0 km)	MBACI model	1	55.01	6.86	*	0.842
All species (2 km)	MBACI model	1	7.11	1.59	NS	0.842

6.5 DISCUSSION

Although water points are thought to have a major controlling influence on drinking bird species in arid and semi-arid environments, it was not possible to detect any short-term effect of water point closure on the overall abundances of these bird species. Although the results indicate that the number of both water-dependent and water-independent bird species actually increased after water points were closed, this was an artefact of variation in rainfall between the before-and-after water point closure periods of the study. By using the MBACI design (Keough & Mapstone, 1995, 1997) these variations between the 'before' and 'after' periods were accounted for, yet a significant effect was still not detected.

In contrast to abundance, the overall species richness of birds increased significantly at sites after water points were closed, contrary to expectation. The diversity of birds might well be expected to drop immediately after water point closure when water-dependent species were forced to leave the area due to the absence of water. Water-independent bird species were not responsible for the increase in diversity at closed water points, but instead summer drinkers such as some of the honeyeaters and the Australian raven were. Water-independent species would not be expected to increase immediately after water point closure as they are generally associated with vegetation attributes that change in relation to distance from water, and not the presence of water itself (Chapter 5). In the long-term, vegetation regeneration due to decreased grazing pressure may result in the increase of these water-independent species at sites previously close to water, but this may take many years, if not decades.

Contrary to expectation, the results set out in this chapter fail to conclude that water-dependent bird species are affected by water point closure. Instead they suggest that the changes in distance from water at sites after water point closure (averaging about 5 km, see Table 6.1) were insufficient to influence water-dependent bird species distribution or abundance. The density of water points at Gluepot Reserve is high and, after the closure of water points, birds there were almost certainly able to utilise other water points without changing the areas in which they forage. In the work described in Chapter 3 it was found that water-dependent bird species in this habitat did not start to decline in abundance until distances of greater than 12.25 km from water were reached. If water point closure involved water points at least 12 km apart, then the abundance of water-dependent species might well be noticeably affected. Unfortunately, at Gluepot Reserve and Calperum Station, it was not possible to close the water points that would have created appropriate distances from water because these water points were required for fire fighting. At a regional scale, this research suggests that, for water point closure to have significant benefit for avifauna, water points must be closed over large areas so that distances to permanent water are increased to at least 12 km, but preferably more.

7. AN EVALUATION OF THE EFFECTS OF WATER POINTS ON THE VEGETATION AND AVIFAUNA OF A SEMI-ARID MALLEE ENVIRONMENT

This examination of avifauna around artificial water points in south-east Australian mallee-dominated communities has identified a number of factors which affect bird abundance and distribution in those environments. The introduction of artificial water points has a marked effect on the abundance and distribution of a number of bird species. By studying the vegetation and avifaunal patterns around artificial water points in this set of land systems, it was possible to determine the role water plays in shaping avifauna in a semi-arid ecosystem.

Water points and mallee vegetation

The principal mallee habitat within the study area could be divided clearly into two broad vegetation associations: dune and swale vegetation. Dune vegetation consisted of a low mallee shrubland, dominated by *Eucalyptus socialis* in the upper canopy, with a sparse or absent shrub layer, and a ground layer dominated by the hummock grass *Triodia scariosa.* The swale vegetation is dominated by *E. oleosa*, shrubs were relatively sparse but included *Senna* and *Acacia* species, while the ground was mostly bare, except for scattered chenopods. As well as their floristic composition, the two vegetation types are characterised by a distinctly different vegetation structure. Swale vegetation had a significantly greater tree height, shrub diversity, shrub height, shrub cover and herbaceous plant diversity when compared with dune vegetation. The structural and floristic diversity of the shrub layer was identified as the most important component separating these two vegetation types.

The vegetation around artificial water points in these two vegetation types is strongly influenced by distance from water. Vegetation around artificial water points changes in its diversity, heterogeneity and composition with distance from water. The structural diversity of the vegetation tends to decrease closer to water, with shrub and tree cover decreasing significantly; however mean shrub height did increase closer to water (Chapter 2, 5). Perennial forb diversity is greater close to water while grass diversity is greater at sites distant from water. The ground layer is characterised by significantly lower leaf litter (which is related to tree cover) and crust cover, and greater bare ground cover close to water. Sites at different distances from water also have distinct plant species. Those close to water are characterised by *Casuarina pauper* and the mistletoe *Amyema preissii* in the upper canopy and shrubs such as *Acacia colletiodes*, *A. nysophylla*, three *Maireana* species, *Sclerolaena obliquicuspis* and *Zygophyllum aurantiacum* in the middle strata. The increased cover of shrubs at sites distant from water is caused by species such as *Acacia sclerophylla*, *Atriplex stipitata*, *Beyeria opaca*, *Eremophila glabra*, *Grevillea huegelii*, two *Olearia* species, *Senna artemisoides* and *Westringia rigida.*

Swale vegetation contains a higher diversity and abundance of avifauna than dune vegetation. This has been attributed to the greater structural diversity of this vegetation type and the consequent availability of more niches and more abundant resources (Knopf, 1985; Recher, 1985; Gilmore, 1985), and the floristics of the shrub layer when it is associated with phenology. By examining the factors (both floristic or physiognomic) that were most significantly correlated with individual bird species, and the diets of those bird species, it was possible to get a better understanding of the vegetation attributes that controlled their abundance and distribution. Only two species were primarily associated with dune vegetation: the striated grasswren and the spotted pardalote.

The greater abundance of honeyeater species in swale vegetation can be attributed to the high structural diversity of that vegetation type, as well as the abundance of certain food plants, particularly *Eremophila glabra* and *Enchylaena tomentosa*. Two parrot species (the Australian ringneck and the mulga parrot) were abundant in the swale vegetation and their preference for this habitat can be attributed both to a higher shrub and herbaceous cover in swales, and to the presence of food plants such as *Atriplex*, *Enchylaena*, *Lycium*, *Maireana* and *Sclerolaena* species in that vegetation. A number of insectivorous bird species also showed a preference for swale vegetation; they can be divided into two categories: canopy-foraging and ground-foraging species. Increased insect abundance because of the structurally and floristically more diverse shrub layer in swales can explain the higher abundance of canopy-foraging insectivorous species. Furthermore, it is possible in some instances to further explain individual species' habitat requirements. For example, the brown treecreeper appeared to require large trees which may reflect its requirement for tree hollows, while the red-capped robin and chestnut-rumped thornbill were strongly associated with the abundance of the tree *Casuarina pauper*. Ground-foraging insectivorous species that were significantly more abundant in swale vegetation were significantly associated with vegetation structure and, to a much lesser degree, with floristics. In particular, they were associated with low, dense shrubs which probably provide them with suitable foraging sites such as low branches and leaf litter.

Bird species and water

In the mallee vegetation at the study site, 42 (37%) of the 113 bird species detected were observed drinking, although only 28 (25%) appeared to require drinking water for their survival (Chapter 4). However the water-dependent species were very abundant and accounted for 75% of the individuals present. It is hypothesised that this relatively large biomass of common water-dependent bird species is likely to be having a profound and probably negative impact on the rarer non water-dependent species, although there is no quantitative data collected during this or other studies to support this. Possible negative impacts include competition for food and other resources such as nest sites, aggressive exclusion and predation. These possible negative interactions are worthwhile subjects for further investigation.

Granivorous bird species are the most dependent on water in a semi-arid environment. At the study site such species include the common bronzewing, crested pigeon, galah, Major Mitchell's cockatoo, regent parrot, Australian ringneck and mulga parrot. Meliphagid species required drinking water during the summer months only, and their requirement for water may in part be related to their relatively high levels of activity (Maclean, 1996) and their high dependence on moisture-deficient food such as lerp. A number of the larger insectivorous/carnivorous species also appeared to be water-dependent, despite their food type. These species include the Australian magpie, Australian raven, white-winged chough, grey currawong and apostlebird. While airborne insectivorous feeders such as martins and woodswallows were partially dependent on water for drinking, most small insectivorous species were never observed to drink. A direct association was found between temperature and the time spent drinking by heavily water-dependent granivorous species, while this trend was not detected in summer drinkers such as honeyeaters and the larger insectivorous/carnivorous bird species.

The presence of water proved to have a major controlling influence on the abundance and distribution of numerous bird species in this semi-arid mallee environment. Generally, most water-dependent bird species were more abundant closer to water; this was apparently due solely to their drinking requirements because their abundance was unrelated to vegetation (Chapter 5). Also, at distances beyond 0.25 km from water, the abundance of these species was relatively uniform. Bird species in this category include the brown-headed honeyeater, mulga parrot, Australian ringneck, red wattlebird, spiny-cheeked honeyeater and willie wagtail. The abundance of most of the water-dependent species began to decline at distances beyond 12 km from water, although most were still present up to 20 km from water (the maximum distance from water sampled during this study). In contrast, the Australian magpie and Australian raven, both increaser species, are water-dependent and also seem to prefer open vegetation located close to water. Like the individual species' responses, the increaser trend in species richness was brought about by the high number of species very close to water; at distances beyond 0 km, species richness was lower and relatively uniform. At distances beyond 12 km species richness began to decline again due to the lowered abundance of water-dependent species at these distances.

Unlike water-dependent increaser bird species, increaser species that were not water-dependent usually showed strong and statistically significant associations with vegetation attributes. These bird species were all insectivores and include the brown treecreeper, chestnut-rumped thornbill, red-capped robin, jacky winter and weebill. The abundances of these species were all correlated with shrub height and cover that were both greater close to water. For example, the brown treecreeper required large trees with hollows which were more abundant closer to water, while the red-capped robin and chestnut-rumped thornbill showed strong correlations with the cover of *Casuarina pauper*, which is greater closer to water.

Decreaser bird species were placed into two categories: ground-dwelling insectivores (Gilbert's whistler, shy heathwren, southern scrub-robin, striated grasswren and chestnut quail-thrush) and canopy-dwelling honeyeaters (yellow-plumed and white-fronted honeyeaters). Although the white-fronted honeyeater was not associated with any vegetation attributes, the distribution and abundance of the yellow-plumed honeyeater were highly correlated with nectar-producing plant species such as *Eucalyptus oleosa*, *Eremophila glabra* and *Grevillea huegelii* which all increased in cover at greater distances from water. Ground-foraging decreaser bird species were all strongly associated with particular low-spreading shrub species such as *Acacia sclerophylla*, *Atriplex stipitata*, *Grevillea huegelii* and *Beyeria opaca*, all of which increased in cover with distance from water. It is worth noting that, with a number of decreaser species, there was no evidence that their abundance had begun to stabilise, even at the most distant sites (20 km), which suggests that, for these species, their optimal habitat may lie even further away from water than 20 km.

Rare bird species

The abundances of a number of birds, which are of conservation concern, were examined in relation to distance from water. Most of them were encountered too infrequently to allow statistical analysis; it interesting to observe in this context that both the red-lored whistler and regent parrot (a water-dependent species) were only located at sites greater than 6 km from water. The abundance of the endangered black-eared miner did not show a significant trend with distance from water, though its abundance was correlated with high grass diversity and cryptogamic crust cover, and low bare ground cover, factors which are characteristics of sites distant from water. Although the data on rare species is not conclusive, a disturbing trend is clear. Close to water there has been an increase in the abundances of common canopy-dwelling species at the expense of uncommon ground-foraging species such as Gilbert's whistler, the shy heathwren, the southern scrub-robin and the chestnut quail-thrush.

Water point closure

The final component of this study was to determine the immediate effects of water point closure on avifauna in a mallee environment. No short-term effects of water point closure on the abundance of either water-dependent or water-independent bird species were found during this study. In contrast to abundance, the overall species richness of birds actually increased significantly at sites once water points were closed, contrary to expectation. The reason for this is unknown. The absence of a decrease in species abundance after closure of the water points in the short-term is thought to be due to the presence of alternative water sources at relatively short distances (5 km) from the closed water points; these can be reached relatively quickly by most of the species likely to be affected by the closure.

This study demonstrates that providing additional water points in a semi-arid region can reduce abundance or cause local extinction in some bird species, to the detriment of conservation objectives. Common and wide-spread water-dependent bird species benefit at the expense of rarer non water-dependent species. Vegetation and soil are negatively affected over a large area and this in turn has negatively impacted a number of ground-foraging bird species.

This study has shown which bird species are being influenced by the presence of artificial water points and has at least partly explained the changes observed in these bird species, vegetation being one factor of considerable importance. However, other mechanisms such as competition and predation are probably controlling avian distribution and abundance around artificial water points and, although beyond the scope of this study, they require further investigation. Until these mechanisms are better understood and water provision is managed in a more effective way, some dryland bird species are likely to continue to decline in the arid-zones of Australia.

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APPENDICES

APPENDIX 1

Table A1.1: Relationships between plant species abundance and distance from water for all plant species detected, arranged alphabetically under the species' position in the vegetation structure. The frequency of occurrence (of a total of 64 for combined vegetation types and 32 for individual vegetation types) and the average foliage cover, as well as details of the cover correlations and the point-biserial correlations with distance from water, are displayed for each species. For each species the first line of data refers to both vegetation types combined, the second to swale vegetation only, and the third to dune crest vegetation only. Where **NS** is bold, 0.05<p<0.10. Species that were present in all sites could not be analysed using the point-biserial correlation method as it relies on comparing the mean distance from water between sites where a species is present against the mean distance where it was absent. '-' indicates that there was no data for that species (i.e. it was absent) from that particular vegetation type.

Species correlation	**Family**	**Cover correlation**		**Freq.**	**Cover**	**Point-biserial**		
		r	p			r^2	t	p
Upper Canopy								
Alectryon oleifolius	Sapindaceae	+0.031	NS	7	0.19	0.000	0.12	NS
		-0.043	NS	6	0.38	0.005	0.40	NS
		+0.218	NS	1	<0.01	0.045	1.19	NS
Callitris verrucosa	Cupressaceae	+0.286	**	10	0.13	0.094	2.55	**
		-	-	0	0	-	-	-
		+0.466	***	10	0.26	0.231	3.00	**
Casuarina pauper	Casuarinaceae	-0.289	**	4	0.02	0.100	2.65	**
		-0.400	**	4	0.05	0.209	2.86	**
		-	-	0	0	-	-	-
Codonocarpus cotinifolius	Gyrostemonaceae	+0.135	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
		+0.218	NS	1	<0.01	-	-	-
Eucalyptus dumosa	Myrtaceae	-0.028	NS	16	0.78	0.000	0.12	NS
		+0.135	NS	5	0.42	0.033	1.03	NS
		-0.123	NS	11	1.16	0.013	0.63	NS
Eucalyptus gracilis	Myrtaceae	-0.084	NS	8	1.13	0.009	0.75	NS
		-0.116	NS	8	2.23	0.020	0.80	NS
		-	-	0	0	-	-	-
Eucalyptus incrassata	Myrtaceae	+0.100	NS	5	0.92	0.009	0.73	NS
		-	-	0	0	-	-	-
		+0.075	NS	5	1.87	0.019	0.76	NS
Eucalyptus leptophylla	Myrtaceae	+0.083	NS	24	3.06	0.021	1.17	NS
		+0.240	**NS**	9	1.80	0.113	1.99	*
		-0.060	NS	15	4.35	0.000	0.08	NS
Eucalyptus oleosa	Myrtaceae	-0.032	NS	40	17.71	0.041	1.64	**NS**
		+0.331	**	33	30.08	-	-	-
		-0.408	**	7	4.96	0.234	3.02	**
Eucalyptus socialis	Myrtaceae	+0.062	NS	38	19.26	0.011	0.83	NS
		+0.105	NS	7	1.12	0.025	0.89	NS
		+0.101	NS	31	37.97	0.06	1.39	**NS**
Geijera linearifolia	Rutaceae	+0.192	**NS**	2	0.02	0.037	1.56	**NS**
		+0.193	NS	1	<0.01	-	-	-
		+0.146	NS	1	0.03	0.030	0.97	NS
Hakea leucoptera	Proteaceae	+0.177	**NS**	2	0.03	0.050	1.82	**NS**
		+0.077	NS	1	<0.01	-	-	-
		+0.251	**NS**	1	0.06	0.131	2.13	*
Myoporum platycarpum	Myoporaceae	+0.023	NS	41	1.16	0.011	0.85	NS
		-0.138	NS	16	0.80	0.034	1.05	NS
		+0.291	*	25	1.53	0.000	0.11	NS
Parasites								
Amyema miquelii	Loranthaceae	-0.071	NS	2	<0.01	0.005	0.58	NS
		-0.077	NS	1	<0.01	-	-	-
		-0.024	NS	1	<0.01	0.000	0.10	NS

Amyema preissii	Loranthaceae	-0.188	**NS**	6	0.01	0.043	1.67	**NS**
		-0.382	**	5	0.01	0.182	2.62	**
		+0.218	NS	1	<0.01	0.045	1.19	NS
Cassytha melantha	Lauraceae	+0.052	NS	4	<0.01	0.002	0.38	NS
		+0.200	NS	3	0.01	0.048	1.24	NS
		-0.178	NS	1	<0.01	0.057	1.34	NS
Mid & Lower Canopy								
Acacia acanthoclada	Mimosaceae	-0.100	NS	10	0.01	0.010	0.79	NS
		+0.046	NS	2	0.01	-	-	-
		-0.158	NS	8	0.01	0.036	1.06	NS
Acacia brachybotrya	Mimosaceae	+0.357	***	5	<0.01	0.176	3.67	***
		-	-	0	0	-	-	-
		+0.480	***	5	<0.01	0.385	4.33	***
Acacia colletioides	Mimosaceae	-0.244	**	54	0.86	0.074	2.26	*
		-0.220	**NS**	31	1.56	0.007	0.48	NS
		-0.416	**	23	0.14	0.176	2.53	**
Acacia ligulata	Mimosaceae	+0.126	NS	5	0.03	0.026	1.29	NS
		+0.170	NS	1	<0.01	-	-	-
		+0.108	NS	4	0.05	0.024	0.85	NS
Acacia murrayana	Mimosaceae	+0.063	NS	1	<0.01	-	-	-
		+0.123	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Acacia nysophylla	Mimosaceae	-0.443	***	15	0.12	0.222	4.24	***
		-0.617	***	10	0.23	0.498	5.55	***
		-0.089	NS	1	<0.01	0.017	0.72	NS
Acacia oswaldii	Mimosaceae	-0.164	NS	6	<0.01	0.032	1.44	**NS**
		-0.128	NS	4	0.01	0.026	0.90	NS
		-0.202	NS	1	<0.01	0.059	1.37	**NS**
Acacia rigens	Mimosaceae	+0.195	**NS**	4	0.07	0.050	1.82	*
		-	-	0	0	-	-	-
		+0.279	**NS**	4	0.14	0.107	1.89	*
Acacia sclerophylla	Mimosaceae	+0.338	***	26	1.09	0.162	3.49	***
		+0.461	***	17	2.08	0.439	4.92	***
		+0.105	NS	9	0.06	0.016	0.69	NS
Acacia wilhelmiana	Mimosaceae	+0.256	*	11	0.25	0.070	2.18	*
		+0.214	NS	2	0.01	0.074	1.57	NS
		+0.301	*	9	0.50	0.088	1.70	*
Atriplex stipitata	Chenopodiaceae	+0.242	*	12	0.24	0.060	2.00	*
		+0.389	**	12	0.47	0.148	2.32	*
		-	-	0	0	-	-	-
Atriplex versicaria	Chenopodiaceae	+0.135	NS	1	<0.01	-	-	-
		+0.193	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Baeckia crassifolia	Myrtaceae	+0.266	*	6	0.03	0.103	2.69	**
		-	-	0	0	-	-	-
		+0.396	**	6	0.05	0.230	3.00	**
Bertya mitchelli	Euphorbiaceae	-0.087	NS	1	<0.01	-	-	-
		-0.139	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Beyeria opaca	Euphorbiaceae	+0.317	**	17	0.76	0.113	2.84	**
		+0.408	**	8	0.43	0.230	3.04	**
		+0.198	NS	9	1.10	0.037	1.07	NS
Boronia coerulescens	Rutaceae	+0.135	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
		+0.218	NS	1	<0.01	-	-	-
Chenopodium curvispicatum	Chenopodiaceae	-0.100	NS	16	0.04	0.018	1.08	NS
		-0.089	NS	16	0.08	0.053	1.32	NS
		-	-	0	0	-	-	-
Chenopodium sp.	Chenopodiaceae	-0.176	NS	2	<0.01	0.036	1.54	**NS**
		-0.211	NS	2	<0.01	0.073	1.57	**NS**
		-	-	0	0	-	-	
Cratystylis conocephala	Asteraceae	+0.140	NS	3	0.03	0.029	1.38	**NS**
		+0.163	NS	3	0.06	0.059	1.40	**NS**
		-	-	0	0	-	-	-
Cryptandra propinqua	Myrtaceae	+0.218	*	9	0.10	0.053	1.88	*
		-0.139	NS	1	<0.01	0.001	0.13	NS
		+0.382	**	8	0.21	0.184	2.60	**
Daviesia ulicifolia	Fabaceae	-0.266	*	5	<0.01	0.083	2.39	**
		-0.350	*	5	<0.01	0.177	2.58	**
		-	-	0	0	-	-	-
Dissocarpus paradoxus	Chenopodiaceae	-0.196	**NS**	3	<0.01	0.046	1.74	*
		-0.285	**NS**	3	<0.01	0.094	1.79	*

		-	-	0	0	-	-	-
Dodonaea bursariifolia	Sapindaceae	+0.027	NS	11	0.42	0.001	0.25	NS
		-0.118	NS	4	0.03	0.031	0.99	NS
		+0.135	NS	7	0.83	0.033	1.01	NS
Dodonaea stenozyga	Sapindaceae	+0.063	NS	1	0.10	0.003	0.43	NS
		-	-	0	0	-	-	-
		+0.088	NS	1	0.19	0.006	0.43	NS
Dodonaea viscosa	Sapindaceae	+0.131	NS	26	0.22	0.033	1.46	**NS**
		+0.044	NS	17	0.42	0.013	0.64	NS
		+0.282	**NS**	9	0.01	0.070	1.50	**NS**
Einadia nutans	Chenopodiaceae	-0.159	NS	1	<0.01	-	-	-
		-0.185	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Enchylaena tomentosa	Chenopdiaceae	-0.094	NS	24	0.02	0.012	0.89	NS
		-0.177	NS	24	0.04	0.057	1.37	**NS**
		-	-	0	0	-	-	
Eremophila deserti	Myoporaceae	-0.183	NS	14	0.03	0.051	1.84	*
		-0.108	NS	11	0.07	0.041	1.16	NS
		-0.265	**NS**	3	<0.01	0.092	1.75	*
Eremophila glabra	Myoporaceae	+0.043	NS	46	0.39	0.000	0.11	NS
		+0.198	NS	31	0.75	0.015	0.69	NS
		-0.084	NS	15	0.02	0.001	0.20	NS
Eremophila scoparia	Myoporaceae	-0.244	*	23	0.45	0.129	3.05	**
		-0.278	*	17	0.85	0.247	3.19	**
		-0.167	NS	6	0.03	0.050	1.25	NS
Eriochiton sclerolaenoides	Chenopodiaceae	–0.176	NS	2	<0.01	0.036	1.52	NS
		-0.227	NS	2	<0.01	0.072	1.55	**NS**
		-	-	0	0	-	-	
Exocarpus aphyllus	Santalaceae	-0.055	NS	10	0.02	0.007	0.65	NS
		-0.260	**NS**	6	<0.01	0.095	1.80	*
		+0.218	NS	3	0.04	0.051	1.26	NS
Grevillea huegelii	Proteaceae	+0.353	***	43	0.24	0.126	3.01	**
		+0.181	NS	28	0.23	0.038	1.10	NS
		+0.578	***	15	0.24	0.282	3.44	***
Lycium australe	Solanaceae	-0.398	***	6	0.06	0.195	3.90	***
		-0.569	***	6	0.12	0.421	4.75	***
		-	-	0	0	-	-	-
Maireana appressa	Chenopodiaceae	-0.023	NS	16	0.01	0.000	0.13	NS
		-0.040	NS	16	0.02	0.001	0.17	NS
		-	-	0	0	-	-	-
Maireana erioclada	Chenopodiaceae	-0.021	NS	3	<0.01	0.000	0.12	NS
		-0.030	NS	3	<0.01	0.001	0.13	NS
		-	-	0	0	-	-	-
Maireana georgei	Chenopodiaceae	-0.001	NS	24	0.11	0.000	0.10	NS
		-0.018	NS	23	0.21	0.003	0.32	NS
		+0.088	NS	1	<0.01	-	-	-
Maireana pentatropis	Chenopodiaceae	-0.106	NS	17	<0.01	0.011	0.85	NS
		-0.156	NS	16	<0.01	0.033	1.03	NS
		-0.178	NS	1	<0.01	0.000	0.05	NS
Maireana schistocarpa?	Chenopodiaceae	-0.230	*	29	0.12	0.033	1.45	**NS**
		-0.500	***	28	0.23	0.145	2.30	*
		-0.178	NS	1	<0.01	0.06	1.35	**NS**
Maireana sedifolia	Chenopodiaceae	-0.220	*	6	<0.01	0.058	1.97	*
		-0.312	*	6	<0.01	0.127	2.11	*
		-	-	0	0	-	-	-
Maireana trichoptera	Chenopodiaceae	-0.210	**NS**	18	0.01	0.051	1.84	*
		-0.290	*	16	0.01	0.122	2.08	*
		-0.047	NS	2	<0.01	0.010	0.55	NS
Maireana triptera	Chenopodiaceae	+0.000	NS	8	0.01	0.001	0.17	NS
		-0.012	NS	8	0.02	0.001	0.19	NS
		-	-	0	0	-	-	-
Maireana turbinata	Chenopodiaceae	+0.012	NS	2	<0.01	0.000	0.13	NS
		+0.022	NS	2	<0.01	0.001	0.13	NS
		-	-	0	0	-	-	-
Marrubium vulgare	Lamiaceae	-0.159	NS	1	<0.01	-	-	-
		-0.226	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Nicotiana sp.	Solanaceae	-0.159	NS	1	<0.01	-	-	-
		-0.226	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Olearia magniflora	Asteraceae	+0.051	NS	3	<0.01	0.008	0.70	NS
		-0.055	NS	2	<0.01	0.011	0.59	NS
		+0.251	**NS**	1	<0.01	0.131	2.13	*
Olearia muelleri	Asteraceae	+0.042	NS	50	0.19	0.068	2.14	*
		+0.444	***	32	0.35	0.122	2.07	*

		-0.409	**	18	0.02	0.396	4.44	***
Olearia pimeleoides	Asteraceae	+0.150	NS	24	0.02	0.029	1.37	**NS**
		+0.251	**NS**	18	0.03	0.069	1.51	**NS**
		+0.013	NS	4	0.02	0.007	0.44	NS
Olearia subspicata	Asteraceae	+0.090	NS	2	<0.01	0.007	0.65	NS
		-	-	0	0	-	-	-
		+0.098	NS	2	<0.01	0.014	0.65	NS
Phebalium glandulosum	Rutaceae	+0.173	NS	2	<0.01	0.050	1.81	*
		-	-	0	0	-	-	-
		+0.236	NS	2	<0.01	0.103	1.85	*
Prostanthera aspalathoides	Lamiaceae	+0.065	NS	3	<0.01	0.003	0.41	NS
		-0.139	NS	1	<0.01	-	-	-
		+0.163	NS	2	<0.01	0.037	1.07	NS
Rhagodia spinescens	Chenopodiaceae	-0.193	NS	29	0.12	0.029	1.38	**NS**
		-0.252	**NS**	23	0.22	0.088	1.73	*
		-0.071	NS	6	<0.01	0.007	0.46	NS
Santalum acuminatum	Santalaceae	+0.049	NS	3	<0.01	0.008	0.72	NS
		-	-	0	0	-	-	-
		+0.101	NS	3	0.01	0.017	0.73	NS
Santalum murrayanum	Santalaceae	-0.087	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
		-0.073	NS	1	<0.01	-	-	-
Scaevolia spinescens	Goodeniacea	+0.009	NS	14	0.02	0.002	0.31	NS
		+0.048	NS	13	0.03	0.012	0.62	NS
		-0.121	NS	1	<0.01	0.018	0.74	NS
Sclerolaena diacantha	Chenopodiaceae	-0.010	NS	31	0.03	0.001	0.18	NS
		-0.038	NS	27	0.06	0.007	0.48	NS
		-0.081	NS	2	<0.01	0.003	0.28	NS
Sclerolaena obliquicuspis	Chenopodiaceae	-0.357	***	23	0.05	0.180	3.72	***
		-0.502	***	14	0.08	0.464	5.18	***
		-0.047	NS	3	0.01	0.010	0.56	NS
Senna artemisoides ssp. *coriacea*	Caesalpiniaceae	-0.006	NS	25	0.39	0.001	0.24	NS
		+0.032	NS	23	0.76	0.002	0.27	NS
		-0.017	NS	2	<0.01	0.001	0.20	NS
Senna artemisoides ssp. *filifolia*	Caesalpiniaceae	-0.012	NS	54	1.33	0.047	1.76	*
		+0.200	NS	34	2.58	-	-	-
		-0.285	*	20	0.04	0.123	2.05	*
Templetonia egena	Fabaceae	+0.425	***	41	0.57	0.331	5.58	***
		+0.419	**	16	0.23	0.334	3.94	***
		+0.462	***	25	0.92	0.402	4.49	***
Thryptomene micrantha	Myrtaceae	+0.119	NS	2	0.01	0.028	1.34	**NS**
		-	-	0	0	-	-	-
		+0.144	NS	2	0.01	0.057	1.35	**NS**
Westringia rigida	Lamiaceae	+0.413	***	29	0.09	0.202	3.99	***
		+0.222	NS	13	0.02	0.091	1.76	*
		+0.546	***	16	0.16	0.355	4.06	***
Zygophyllum apiculatum	Zygophyllaceae	+0.074	NS	21	0.03	0.008	0.72	NS
		+0.165	NS	18	0.05	0.048	1.25	NS
		-0.93	NS	2	<0.01	0.014	0.65	NS
Zygophyllum auriantiacum	Zygophyllaceae	-0.175	**NS**	38	0.33	0.008	0.73	NS
		-0.410	***	34	0.65	-	-	-
		-0.213	NS	4	<0.01	0.079	1.60	**NS**
Ground Cover								
Austrostipa sp.	Poaceae	+0.289	**	5	<0.01	0.131	3.08	**
		+0.316	*	4	<0.01	0.152	2.35	*
		+0.251	**NS**	1	<0.01	0.131	2.13	*
Calandrinia calyptrata	Portulacaceae	-0.087	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
		-0.121	NS	1	<0.01	-	-	-
Dissocarpus paradoxus	Chenopodiaceae	-0.196	**NS**	3	<0.01	0.046	1.74	*
		-0.267	**NS**	3	<0.01	0.094	1.79	*
		-	-	0	0	-	-	-
Eragrostis dielsii	Poaceae	-0.129	NS	5	<0.01	0.019	1.11	NS
		-0.137	NS	5	<0.01	0.041	1.15	NS
		-	-	0	0	-	-	-
Goodenia sp.	Goodeniaceae	-0.087	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
		-0.073	NS	1	<0.01	-	-	-
Lepidium monoplocoides	Brassicaceae	-0.012	NS	1	<0.01	-	-	-
		-0.062	NS	1	0.01	-	-	-
		-	-	0	0	-	-	-

Lomandra effusa	Xanthorrhoeaceae	-0.258	*	5	0.03	0.085	2.43	**
		-0.062	NS	1	0.02	-	-	-
		-0.379	**	4	0.04	0.209	2.82	**
Marrubium vulgare	Lamiaceae	-0.159	NS	1	<0.01	-	-	-
		-0.239	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Nicotiana sp.	Solanaceae	-0.159	NS	1	<0.01	-	-	-
		-0.239	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
Triodia scariosa	Poaceae	+0.085	NS	46	7.26	0.101	2.65	**
		+0.447	**	18	0.14	0.337	3.97	***
		-0.108	NS	29	14.59	0.0001	0.14	NS
Waitzia acuminata	Asteraceae	+0.135	NS	1	<0.01	-	-	-
		-	-	0	0	-	-	-
		+0.218	NS	1	<0.01	-	-	-

Table A1.2: Location of sampling sites within Gluepot and Calperum. The name of the water points that sites are positioned in relation to and the property that the site is located in are also displayed. If a site is located on a boundary, both property names are mentioned, the first name referring to the property of the sites actual position. Study site names have a four-digit code (e.g. BM4A). The first digit represents the first letter of the water point name that the site has been measured from (i.e. the nearest permanent water point). The second digit signifies the vegetation type (M = mallee woodland (swale) and S = spinifex mallee (dune crest)). The number represents the distance to water in kilometres and the last digit is a sequential record of sites in the same habitat at the same distance from the same water point with A being the first. Site codes that begin with R refer to 'remote' sites and these were approximately 10 km from water. The map datum used for co-ordinates is Australian Geodetic '84.

Site code	Location	Water point name	Property
BM0A	33.75631 S, 139.98669 E	Bluebird Dam	Gluepot
BM2A	33.76628 S, 139.96735 E	Bluebird Dam	Gluepot
BM4A	33.71916 S, 139.97957 E	Bluebird Dam	Gluepot
BS0A	33.75354 S, 139.98751 E	Bluebird Dam	Gluepot
BS4A	33.71681 S, 139.98131 E	Bluebird Dam	Gluepot
EM4A	33.72293 S, 140.43663 E	End Tank	Calperum
EM4B	33.79546 S, 140.45304 E	End Tank	Calperum
EM6A	33.70616 S, 140.43315 E	End Tank	Calperum
EM6B	33.81436 S, 140.45644 E	End Tank	Calperum
EM6C	33.81204 S, 140.41580 E	End Tank	Calperum/Taylorville
EM8A	33.75027 S, 140.35055 E	End Tank	Calperum/Gluepot
EM8B	33.81023 S, 140.37053 E	End Tank	Calperum/Taylorville
EM8C	33.83263 S, 140.41576 E	End Tank	Calperum
ES4A	33.79287 S, 140.45250 E	End Tank	Calperum
ES6A	33.70783 S, 140.43475 E	End Tank	Calperum
ES8A	33.77110 S, 140.34831 E	End Tank	Gluepot/Calperum
ES8B	33.83178 S, 140.41485 E	End Tank	Calperum/Taylorville
FM0A	33.70104 S, 140.12249 E	Froggy Dam	Gluepot
FS0A	33.69872 S, 140.12461 E	Froggy Dam	Gluepot
FS2A	33.72163 S, 140.12533 E	Froggy Dam	Gluepot
FS2B	33.69989 S, 140.14926 E	Froggy Dam	Gluepot
FS4A	33.52364 S, 140.26071 E	Froggy Dam	Gluepot
FS6A	33.67071 S, 140.28243 E	Faraway Dam	Gluepot
FS8A	33.67415 S, 140.30434 E	Faraway Dam	Calperum
HM2A	33.74509 S, 140.12135 E	Homestead Dam	Gluepot
HS2A	33.74608 S, 140.12005 E	Homestead Dam	Gluepot
KM0A	33.73599 S, 140.08278 E	Kangaroo Dam	Gluepot
KS0A	33.73437 S, 140.08466 E	Kangaroo Dam	Gluepot
KS0B	33.73862 S, 140.08300 E	Kangaroo Dam	Gluepot
LM0A	33.78469 S, 140.19787 E	Long Dam	Gluepot
LM2A	33.76970 S, 140.17762 E	Long Dam	Gluepot
LM2B	33.77090 S, 140.21290 E	Long Dam	Gluepot
LM4A	33.75179 S, 140.22459 E	Long Dam	Gluepot
LM4B	33.81989 S, 140.21256 E	Long Dam	Gluepot
LM6A	33.75227 S, 140.24814 E	Long Dam	Gluepot
LM6B	33.83329 S, 140.22312 E	Long Dam	Taylorville/Gluepot
LM8A	33.75157 S, 140.27670 E	Long Dam	Gluepot
LM8B	33.83416 S, 140.25993 E	Long Dam	Taylorville/Gluepot
LS2A	33.77252 S, 140.17419 E	Long Dam	Gluepot
LS2B	33.76467 S, 140.21033 E	Long Dam	Gluepot
LS4A	33.75374 S, 140.22588 E	Long Dam	Gluepot
LS4B	33.74578 S, 140.20975 E	Long Dam	Gluepot
LS6A	33.75025 S, 140.24789 E	Long Dam	Gluepot
LS6B	33.83160 S, 140.22029 E	Long Dam	Gluepot/Taylorville
LS8A	33.74963 S, 140.27616 E	Long Dam	Gluepot
LS8B	33.83267 S, 140.26657 E	Long Dam	Gluepot/Taylorville

OM0A	33.75294 S, 140.00080 E	Old Gluepot Dam	Gluepot
OM2A	33.74594 S, 140.02001 E	Old Gluepot Dam	Gluepot
OS0A	33.75084 S, 139.99893 E	Old Gluepot Dam	Gluepot
PM0A	33.70451 S, 140.20486 E	Picnic Dam	Gluepot
PM4A	33.73459 S, 140.17557 E	Picnic Dam	Gluepot
PS0A	33.70348 S, 140.20268 E	Picnic Dam	Gluepot
QM2A	33.76510 S, 140.10281 E	Quinn’s Dam	Gluepot
RMA	33.75225 S, 140.32019 E	End Tank	Gluepot
RMB	33.81255 S, 140.30648 E	End Tank	Gluepot
RSA	33.74945 S, 140.32038 E	End Tank	Gluepot
RSB	33.81413 S, 140.30686 E	End Tank	Taylorville/Gluepot
TM4A	33.67586 S, 140.36487 E	Ten Mile Dam	Calperum
TM4B	33.68834 S, 140.42876 E	Ten Mile Dam	Calperum
TM6A	33.68333 S, 140.34694 E	Ten Mile Dam	Gluepot/Calperum
TM8A	33.67863 S, 140.32053 E	Ten Mile Dam	Gluepot/Calperum
TS2A	33.66471 S, 140.42536 E	Ten Mile Dam	Calperum
TS4A	33.68968 S, 140.42876 E	Ten Mile Dam	Calperum
TS6A	33.68106 S, 140.34806 E	Ten Mile Dam	Calperum/Gluepot
TS6B	33.69285 S, 140.35138 E	Ten Mile Dam	Calperum/Gluepot
TS8A	33.67644 S, 140.32174 E	Ten Mile Dam	Calperum/Gluepot

APPENDIX 2

Table A2.1: Location of sampling sites within Gluepot and Calperum. The name of the water points that sites are positioned in relation to and the property that the site is located in are also displayed. If a site is located on a boundary, both property names are mentioned, the first name referring to the property of the site's actual position. Study site names have a four-digit code (e.g. BM4A). The first digit represents the first letter of the water point name that the site has been measured from (i.e. the nearest permanent water point). The second digit signifies the vegetation type (M = mallee woodland (swale) and S = spinifex mallee (dune crest)). The number represents the distance to water in kilometres and the last digit is a sequential record of sites in the same habitat at the same distance from the same water point with A being the first. Site codes that begin with R refer to 'remote' sites and these were approximately 10 km from water. The map datum used for co-ordinates is Australian Geodetic '84.

Site code	Location	Water point name	Property
BM0A	33.75631 S, 139.98669 E	Bluebird Dam	Gluepot
BM2A	33.76628 S, 139.96735 E	Bluebird Dam	Gluepot
BM4A	33.71916 S, 139.97957 E	Bluebird Dam	Gluepot
BS0A	33.75354 S, 139.98751 E	Bluebird Dam	Gluepot
BS4A	33.71681 S, 139.98131 E	Bluebird Dam	Gluepot
EM4A	33.72293 S, 140.43663 E	End Tank	Calperum
EM4B	33.79546 S, 140.45304 E	End Tank	Calperum
EM6A	33.70616 S, 140.43315 E	End Tank	Calperum
EM6B	33.81436 S, 140.45644 E	End Tank	Calperum
EM6C	33.81204 S, 140.41580 E	End Tank	Calperum/Taylorville
EM8A	33.75027 S, 140.35055 E	End Tank	Calperum/Gluepot
EM8B	33.81023 S, 140.37053 E	End Tank	Calperum/Taylorville
EM8C	33.83263 S, 140.41576 E	End Tank	Calperum
ES4A	33.79287 S, 140.45250 E	End Tank	Calperum
ES6A	33.70783 S, 140.43475 E	End Tank	Calperum
ES8A	33.77110 S, 140.34831 E	End Tank	Gluepot/Calperum
ES8B	33.83178 S, 140.41485 E	End Tank	Calperum/Taylorville
FM0A	33.70104 S, 140.12249 E	Froggy Dam	Gluepot
FS0A	33.69872 S, 140.12461 E	Froggy Dam	Gluepot
FS2A	33.72163 S, 140.12533 E	Froggy Dam	Gluepot
FS2B	33.69989 S, 140.14926 E	Froggy Dam	Gluepot
FS4A	33.52364 S, 140.26071 E	Froggy Dam	Gluepot
FS6A	33.67071 S, 140.28243 E	Faraway Dam	Gluepot
FS8A	33.67415 S, 140.30434 E	Faraway Dam	Calperum
HM2A	33.74509 S, 140.12135 E	Homestead Dam	Gluepot
HS2A	33.74608 S, 140.12005 E	Homestead Dam	Gluepot
KM0A	33.73599 S, 140.08278 E	Kangaroo Dam	Gluepot
KS0A	33.73437 S, 140.08466 E	Kangaroo Dam	Gluepot
KS0B	33.73862 S, 140.08300 E	Kangaroo Dam	Gluepot
LM0A	33.78469 S, 140.19787 E	Long Dam	Gluepot
LM2A	33.76970 S, 140.17762 E	Long Dam	Gluepot
LM2B	33.77090 S, 140.21290 E	Long Dam	Gluepot
LM4A	33.75179 S, 140.22459 E	Long Dam	Gluepot
LM4B	33.81989 S, 140.21256 E	Long Dam	Gluepot
LM6A	33.75227 S, 140.24814 E	Long Dam	Gluepot
LM6B	33.83329 S, 140.22312 E	Long Dam	Taylorville/Gluepot
LM8A	33.75157 S, 140.27670 E	Long Dam	Gluepot
LM8B	33.83416 S, 140.25993 E	Long Dam	Taylorville/Gluepot
LS2A	33.77252 S, 140.17419 E	Long Dam	Gluepot
LS2B	33.76467 S, 140.21033 E	Long Dam	Gluepot
LS4A	33.75374 S, 140.22588 E	Long Dam	Gluepot
LS4B	33.74578 S, 140.20975 E	Long Dam	Gluepot

LS6A	33.75025 S, 140.24789 E	Long Dam	Gluepot
LS6B	33.83160 S, 140.22029 E	Long Dam	Gluepot/Taylorville
LS8A	33.74963 S, 140.27616 E	Long Dam	Gluepot
LS8B	33.83267 S, 140.26657 E	Long Dam	Gluepot/Taylorville
OM0A	33.75294 S, 140.00080 E	Old Gluepot Dam	Gluepot
OM2A	33.74594 S, 140.02001 E	Old Gluepot Dam	Gluepot
OS0A	33.75084 S, 139.99893 E	Old Gluepot Dam	Gluepot
PM0A	33.70451 S, 140.20486 E	Picnic Dam	Gluepot
PM4A	33.73459 S, 140.17557 E	Picnic Dam	Gluepot
PS0A	33.70348 S, 140.20268 E	Picnic Dam	Gluepot
QM2A	33.76510 S, 140.10281 E	Quinn’s Dam	Gluepot
RMA	33.75225 S, 140.32019 E	End Tank	Gluepot
RMB	33.81255 S, 140.30648 E	End Tank	Gluepot
RSA	33.74945 S, 140.32038 E	End Tank	Gluepot
RSB	33.81413 S, 140.30686 E	End Tank	Taylorville/Gluepot
TM4A	33.67586 S, 140.36487 E	Ten Mile Dam	Calperum
TM4B	33.68834 S, 140.42876 E	Ten Mile Dam	Calperum
TM6A	33.68333 S, 140.34694 E	Ten Mile Dam	Gluepot/Calperum
TM8A	33.67863 S, 140.32053 E	Ten Mile Dam	Gluepot/Calperum
TS2A	33.66471 S, 140.42536 E	Ten Mile Dam	Calperum
TS4A	33.68968 S, 140.42876 E	Ten Mile Dam	Calperum
TS6A	33.68106 S, 140.34806 E	Ten Mile Dam	Calperum/Gluepot
TS6B	33.69285 S, 140.35138 E	Ten Mile Dam	Calperum/Gluepot
TS8A	33.67644 S, 140.32174 E	Ten Mile Dam	Calperum/Gluepot

Table A2.2: Location of sampling sites within MSNP and the names of the closest permanent water points. Study site names follow the same format as in table 2.1.

Site	Location	Water point name
AM8A	34.61059 S, 141.09771 E	Airstrip Tank
AM8B	34.61967 S, 141.06314 E	Airstrip Tank
AM12A	34.64847 S, 141.09947 E	Airstrip Tank
AS4A	34.58183 S, 141.05386 E	Airstrip Tank
AS8A	34.61224 S, 141.09779 E	Airstrip Tank
AS8B	34.62207 S, 141.06216 E	Airstrip Tank
DM4A	34.58154 S, 141.89738 E	Dam 41
GM16A	34.69401 S, 141.49255 E	Goat Trap Trough
GM20A	34.71109 S, 141.40218 E	Goat Trap Trough
GS16A	34.69247 S, 141.49132 E	Goat Trap Trough
GS20A	34.71205 S, 141.40234 E	Goat Trap Trough
HM4A	34.63260 S, 141.93065 E	Henschke Tank
HM12A	34.65527 S, 141.82865 E	Henschke Tank
HM16A	34.70136 S, 141.82259 E	Henschke Tank
HM16B	34.71200 S, 141.83566 E	Henschke Tank
HM20A	34.73853 S, 141.80497 E	Henschke Tank
HS8A	34.64645 S, 141.87958 E	Henschke Tank
HS12A	34.65243 S, 141.82792 E	Henschke Tank
HS12B	34.66023 S, 141.83499 E	Henschke Tank
HS12C	34.64651 S, 141.82316 E	Henschke Tank
HS16A	34.70281 S, 141.82075 E	Henschke Tank
HS16B	34.71004 S, 141.83757 E	Henschke Tank
HS20A	34.73755 S, 141.80763 E	Henschke Tank
LM0A	34.89325 S, 141.62019 E	Large Tank
LM4A	34.85311 S, 141.62494 E	Large Tank
LS0A	34.89563 S, 141.61975 E	Large Tank
LS4A	34.84961 S, 141.62140 E	Large Tank
PM0A	35.05479 S, 141.75382 E	Pink Lakes Trough
PS0A	35.05397 S, 141.75214 E	Pink Lakes Trough
RM8A	34.98141 S, 141.71274 E	Red Dam
RM12A	34.93952 S, 141.71753 E	Red Dam
RS4A	35.00616 S, 141.74814 E	Red Dam
TM20A	34.70812 S, 141.28955 E	Temporary Trough
TS20A	34.70979 S, 141.29059 E	Temporary Trough
WM0A	34.91413 S, 142.03066 E	Wymlet Dam
WS0A	34.91741 S, 142.03328 E	Wymlet Dam

APPENDIX 3

Table A3.1: List of family, Latin and common names of bird species found in the mallee ecosystems of Gluepot Reserve and Murray Sunset National Park (MSNP) during this study.

Family	Species	Common name	Gluepot	MSNP
Casuariidae	*Dromaius novahollandiae*	emu	*	*
Cygninae	*Cygnus atratus*	black swan	*	
Ardeidae	*Ardea novaehollandiae*	white-faced heron	*	
Accipitridae	*Elanus notatus*	black-shouldered kite	*	*
Accipitridae	*Accipiter fasciatus*	brown goshawk	*	
Accipitridae	*Accipiter cirrrhocepalus*	collared sparrowhawk	*	
Accipitridae	*Aquila audax*	wedge-tailed eagle	*	*
Accipitridae	*Hieraaetus morphnoides*	little eagle	*	
Accipitridae	*Milvus migrans*	black kite	*	
Falconidae	*Falco berigora*	brown falcon	*	
Falconidae	*Falco cenchroides*	Australian kestrel	*	
Falconidae	*Falco peregrinus*	peregrine falcon	*	
Falconidae	*Falco longipennis*	Australian hobby	*	
Falconidae	*Falco cenchroides*	nankeen kestrel	*	
Megapodiidae	*Leipoa ocellata*	malleefowl	*	
Phasianidae	*Coturnix pectoralis*	stubble quail		*
Turnicidae	*Turnix velox*	little button-quail	*	
Charadriidae	*Vanellus miles*	masked lapwing	*	
Columbidae	*Geopelia placida*	peaceful dove		*
Columbidae	*Phaps chaloptera*	common bronzewing	*	*
Columbidae	*Geophaps lophotes*	crested pigeon	*	*
Cacatuidae	*Cacatua leadbeateri*	Major Mitchell’s cockatoo	*	*
Cacatuidae	*Cacatua roseicapilla*	galah	*	*
Loriidae	*Glossopsitta porphyrocephala*	purple-crowned lorikeet	*	
Polytelitidae	*Polytelis anthopeplus*	regent parrot	*	*
Platycercidae	*Melopsittacus undulatus*	budgerigar	*	*
Platycercidae	*Barnardius zonarius*	Australian ringneck	*	*
Platycercidae	*Psephotus haematonotus*	red-rumped parrot	*	
Platycercidae	*Psephotus varius*	mulga parrot	*	*
Platycercidae	*Northiella haematogaster*	blue bonnet	*	
Platycercidae	*Neophema chrysostoma*	blue-winged parrot	*	
Platycercidae	*Neophema splendida*	scarlet-chested parrot	*	
Cuculidae	*Chrysococcyx osculans*	black-eared cuckoo	*	
Cuculidae	*Chrysococcyx basalis*	Horsfield's bronze-cuckoo	*	
Cuculidae	*Cuculus flabelliformis*	fan-tailed cuckoo	*	
Cuculidae	*Cuculus pallidus*	pallid cuckoo	*	*
Strigidae	*Ninox novaeseelandiae*	southern boobook	*	
Aegothelidae	*Aegotheles cristatus*	Australian owlet-nightjar	*	*
Caprimulgidae	*Caprimulgus guttatus*	spotted nightjar	*	*
Alcedinidae	*Dacelo novaeguineae*	laughing kookaburra		*
Alcedinidae	*Todiramphus pyrrhopygia*	red-backed kingfisher		*
Meropidae	*Merops ornatus*	rainbow bee-eater	*	
Hirundinidae	*Hirundo ariel*	fairy martin	*	
Hirundinidae	*Hirundo nigricans*	tree martin	*	
Motacillidae	*Anthus novaeseelandiae*	Richard’s pipit	*	*
Campephagidae	*Coracina novaehollandiae*	black-faced cuckoo-shrike	*	*
Campephagidae	*Lalage tricolor*	white-winged triller	*	
Muscicapidae	*Drymodes brunneopygia*	southern scrub-robin	*	
Muscicapidae	*Petroica goodenovii*	red-capped robin	*	*
Muscicapidae	*Melanodryas cucullata*	hooded robin	*	*
Muscicapidae	*Microeca leucophaea*	jacky winter	*	*
Muscicapidae	*Pachycephala rufogularis*	red-lored whistler	*	

Muscicapidae	*Pachycephala inornata*	Gilbert's whistler	*	
Muscicapidae	*Pachycephala pectoralis*	golden whistler	*	*
Muscicapidae	*Pachycephala rufiventris*	rufous whistler	*	*
Muscicapidae	*Colluricincla harmonica*	grey shrike-thrush	*	*
Muscicapidae	*Oreoica gutturalis*	crested bellbird	*	*
Muscicapidae	*Myiagra inquieta*	restless flycatcher	*	*
Muscicapidae	*Rhipidura fuliginosa*	grey fantail	*	
Muscicapidae	*Rhipidura leucophys*	willy wagtail	*	*
Orthonychidae	*Cinclosoma castanotum*	chestnut quail-thrush	*	*
Pomatostomidae	*Pomatostomus superciliosus*	white-browed babbler	*	*
Pomatostomidae	*Pomatostomus ruficeps*	chestnut-crowned babbler	*	
Sylviidae	*Cinclorhamphus cruralis*	brown songlark	*	
Maluridae	*Malurus splendens*	splendid fairy-wren	*	*
Maluridae	*Malurus lamberti*	variegated fairy-wren	*	*
Maluridae	*Stipiturus mallee*	mallee emu-wren		*
Maluridae	*Amytornis stiatus*	striated grasswren	*	*
Acanthizidae	*Hylacola cauta*	shy heathwren	*	*
Acanthizidae	*Smicrornis brevirostris*	weebill	*	*
Acanthizidae	*Acanthiza apicalis*	inland thornbill	*	*
Acanthizidae	*Acanthiza uropygialis*	chestnut-rumped thornbill	*	*
Acanthizidae	*Acanthiza chrysorrhoa*	yellow-rumped thornbill	*	*
Acanthizidae	*Acanthiza nana*	yellow thornbill	*	
Acanthizidae	*Aphelocephala leucopsis*	southern whiteface	*	*
Neosittidae	*Daphoenositta chrysoptera*	varied sitella	*	*
Climacteridae	*Climacteris affinis*	white-browed treecreeper	*	
Climacteridae	*Climacteris picumnus*	brown treecreeper	*	*
Meliphagidae	*Anthochaera carunculata*	red wattlebird	*	*
Meliphagidae	*Acanthagenys rufogularis*	spiny-cheeked honeyeater	*	*
Meliphagidae	*Plectorhyncha lanceolata*	striped honeyeater	*	*
Meliphagidae	*Manorina melanotis*	black-eared miner	*	
Meliphagidae	*Manorina flavigula*	yellow-throated miner	*	
Meliphagidae	*Lichenostomus virescens*	singing honeyeater	*	
Meliphagidae	*Lichenostomus leucotis*	white-eared honeyeater	*	*
Meliphagidae	*Lichenostomus cratitius*	purple-gaped honeyeater	*	
Meliphagidae	*Lichenostomus ornatus*	yellow-plumed honeyeater	*	*
Meliphagidae	*Lichenostomus plumulus*	grey-fronted honeyeater	*	
Meliphagidae	*Lichenostomus penicillatus*	white-plumed honeyeater	*	
Meliphagidae	*Melithreptus brevirostris*	brown-headed honeyeater	*	*
Meliphagidae	*Phylidonyris albifrons*	white-fronted honeyeater	*	*
Meliphagidae	*Certhionyx variegatus*	pied honeyeater	*	
Ephthianuridae	*Ephthianura tricolor*	crimson chat	*	
Ephthianuridae	*Ephthianura albifrons*	white-fronted chat	*	
Dicaeidae	*Dicaeum hirundinaceum*	mistletoebird	*	
Pardalotidae	*Pardalotus punctatus*	spotted pardolate	*	*
Pardalotidae	*Pardalotus striatus*	striated pardolate	*	*
Ploceidae	*Poephila guttata*	zebra finch	*	
Sturnidae	*Sturnus vulgaris*	common starling	*	
Artamidae	*Artamus cinereus*	black-faced woodswallow	*	
Artamidae	*Artamus cyanopterus*	dusky woodswallow	*	
Artamidae	*Artamus superciliosus*	white-browed woodswallow	*	*
Artamidae	*Artamus personatus*	masked woodswallow	*	
Grallinidae	*Grallina cyanoleuca*	magpie-lark	*	*
Corcoracidae	*Corcorax melanorhamphos*	white-winged chough	*	*
Corcoracidae	*Struthidea cinerea*	apostlebird	*	
Cracticidae	*Strepera versicolor*	grey currawong	*	*
Cracticidae	*Cracticus nigrogularis*	pied butcherbird	*	
Cracticidae	*Cracticus torquatus*	grey butcherbird	*	*
Cracticidae	*Gymnorhina tibicen*	Australian magpie	*	*
Corvidae	*Corvus coronoides*	Australian raven	*	*
Corvidae	*Corvus bennetti*	little crow	*	*

APPENDIX 4

Table 4.1: Analysis of covariance results on the density of bird species with distance from water at Gluepot. Only data from sites situated in relation to open sites was used for analyses. Main factors are distance to water, habitat and season, and random factors are number of flowering eucalypts and period of the day. Polynomial contrasts were used to confirm that significant differences with distance to water were due to a systematic trend.

Species	SS	df	MS	F	p
Australian magpie					
intercept	6.003	1	6.003	16.598	.000
flowering eucalypts	1.127	1	1.127	3.115	.078
period of day	2.295	1	2.295	6.346	.012
distance to water	3.659	4	.915	2.529	.040
habitat	.0002	1	.0002	.001	.978
season	.243	2	.122	.337	.714
distance * habitat	3.180	4	.795	2.198	.069
distance * season	3.557	8	.445	1.229	.281
habitat * season	.387	2	.192	.535	.586
distance * habitat * season	.599	8	.075	.207	.990
error	121.52	334	.362		
total	143.00	366			
R Squared = .102					
Polynomial contrasts (quadratic) P=0.024					
Australian raven					
intercept	.078	1	.078	.108	.743
flowering eucalypts	2.201	1	2.201	3.038	.082
period of day	.731	1	.731	1.009	.316
distance to water	6.961	4	1.740	2.402	.050
habitat	.0912	1	.0912	.126	.723
season	1.504	2	.752	1.038	.355
distance * habitat	4.473	4	1.118	1.544	.189
distance * season	5.866	8	.733	1.012	.426
habitat * season	.545	2	.272	.376	.687
distance * habitat * season	11.690	8	1.461	2.017	.044
error	241.94	334	.724		
total	297.00	366			
R Squared = .130					
Polynomial contrasts (linear) P=0.003					
Australian ringneck					
intercept	2.232	1	2.232	2.410	.122
flowering eucalypts	29.639	1	29.639	12.018	.001
period of day	20.638	1	20.638	8.368	.004
distance to water	36.212	4	9.053	3.671	.006
habitat	20.301	1	20.301	8.232	.004
season	20.527	2	10.264	4.162	.016
distance * habitat	9.824	4	2.456	.996	.410
distance * season	29.770	8	3.721	1.509	.153
habitat * season	4.322	2	2.161	2.333	.099
distance * habitat * season	6.984	8	.873	.942	.482
error	823.70	334	2.466		
total	1153.0	366			
R Squared = .194					

Polynomial contrasts (linear) P=0.030

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black-eared miner

intercept	33.502	1	33.502	4.294	.039
flowering eucalypts	.587	1	.587	.075	.784
period of day	2.821	1	2.821	.362	.548
distance to water	16.731	4	4.183	.536	.709
habitat	.493	1	.493	.063	.802
season	73.508	2	36.754	4.711	.010
distance * habitat	18.299	4	4.575	.586	.673
distance * season	87.014	8	10.877	1.394	.198
habitat * season	17.716	2	8.858	1.135	.323
distance * habitat * season	36.906	8	4.613	.591	.785
error	2605.7	334	7.802		
total	3032.0	366			

R Squared = .089

Polynomial contrasts (quadratic) P=0.096

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brown-headed honeyaeter

intercept	39.595	1	39.595	7.705	.006
flowering eucalypts	.845	1	.845	.164	.685
period of day	7.680	1	7.680	1.495	.222
distance to water	100.75	4	25.189	4.902	.001
habitat	12.220	1	12.220	2.378	.124
season	33.391	2	16.695	3.249	.040
distance * habitat	18.349	4	4.587	.893	.468
distance * season	102.39	8	12.799	2.491	.012
habitat * season	21.470	2	10.735	2.089	.125
distance * habitat * season	53.125	8	6.641	1.292	.246
error	1716.295		334	5.139	
total	2207.000		366		

R Squared = .172

Polynomial contrasts (linear) P=0.014

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chestnut quail-thrush

intercept	.324	1	.324	.966	.326
flowering eucalypts	.318	1	.318	.948	.331
period of day	.0342	1	.0342	.102	.750
distance to water	1.134	4	.284	.846	.497
habitat	.699	1	.699	2.085	.150
season	.649	2	.325	.968	.381
distance * habitat	.755	4	.189	.563	.690
distance * season	3.273	8	.409	1.220	.286
habitat * season	1.454	2	.727	2.167	.116
distance * habitat * season	3.977	8	.497	1.482	.162
error	111.99	334	.335		
total	128.00	366			

R Squared = .097

Polynomial contrasts (linear) P=0.105

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chestnut-crowned babbler

intercept	.302	1	.302	.105	.747
flowering eucalypts	.911	1	.911	.315	.575
period of day	2.362	1	2.362	.816	.367

distance to water	25.676	4	6.419	2.219	.067
habitat	23.421	1	23.421	8.095	.005
season	2.563	2	1.281	.443	.643
distance * habitat	32.311	4	8.078	2.792	.026
distance * season	21.925	8	2.741	.947	.478
habitat * season	5.221	2	2.611	.902	.407
distance * habitat * season	24.835	8	3.104	1.073	.382
error	966.34	334	2.893		
total	1136.0	366			
R Squared = .126					
Polynomial contrasts (linear) P=0.033					
chestnut-rumped thornbill					
intercept	17.257	1	17.257	6.344	.012
flowering eucalypts	7.053	1	7.053	2.593	.108
period of day	1.562	1	1.562	.574	.449
distance to water	47.395	4	11.849	4.356	.002
habitat	14.137	1	14.137	5.197	.023
season	1.189	2	.594	.218	.804
distance * habitat	15.093	4	3.773	1.387	.238
distance * season	22.524	8	2.816	1.035	.409
habitat * season	19.998	2	9.999	3.676	.026
distance * habitat * season	25.712	8	3.214	1.182	.309
error	908.52	334	2.720		
total	1118.0	366			
R Squared = .139					
Polynomial contrasts (linear) P<0.001					
crested bellbird					
intercept	.267	1	.267	3.789	.052
flowering eucalypts	.00167	1	.00167	.024	.878
period of day	.04333	1	.04333	.615	.433
distance to water	.01656	4	.01656	.059	.994
habitat	.158	1	.158	2.242	.135
season	.01764	2	.00882	.125	.882
distance * habitat	.145	4	.03627	.515	.725
distance * season	.257	8	.03210	.456	.886
habitat * season	.087	2	.044	.621	.538
distance * habitat * season	.654	8	.082	1.162	.322
error	23.520	334	.07042		
total	26.000	366			
R Squared = .056					
Polynomial contrasts (linear) P=0.869					
Gilbert's whistler					
intercept	.525	1	.525	4.855	.028
flowering eucalypts	.363	1	.363	3.362	.068
period of day	.250	1	.250	2.315	.129
distance to water	.673	4	.168	1.556	.186
habitat	.641	1	.641	5.930	.015
season	.345	2	.173	1.597	.204
distance * habitat	.814	4	.203	1.882	.113
distance * season	.875	8	.109	1.013	.426
habitat * season	.202	2	.101	.934	.394

distance * habitat * season	1.170	8	.146	1.354	.216
error	36.090	334	.108		
total	43.000	366			

R Squared = .126

Polynomial contrasts (linear) P=0.044

grey butcherbird

intercept	13.149	1	13.149	16.467	.000
flowering eucalypts	.0978	1	.0978	.123	.727
period of day	4.164	1	4.164	5.215	.023
distance to water	4.238	4	1.060	1.327	.260
habitat	3.917	1	3.917	4.906	.027
season	1.369	2	.685	.857	.425
distance * habitat	1.818	4	.454	.569	.685
distance * season	5.922	8	.740	.927	.494
habitat * season	4.458	2	2.229	2.792	.063
distance * habitat * season	7.512	8	.939	1.176	.313
error	266.70	334	.798		
total	329.00	366			

R Squared = .108

Polynomial contrasts (linear) P=0.130

grey currawong

intercept	.948	1	.948	4.172	.042
flowering eucalypts	.04074	1	.04074	.179	.672
period of day	.09278	1	.09278	.408	.523
distance to water	1.583	4	.396	1.742	.140
habitat	.215	1	.215	.948	.331
season	1.149	2	.575	2.529	.081
distance * habitat	2.036	4	.509	2.240	.064
distance * season	4.937	8	.617	2.716	.007
habitat * season	.190	2	.095	.418	.659
distance * habitat * season	3.338	8	.417	1.837	.069
error	75.880	334	.227		
total	94.000	366			

R Squared = .153

Polynomial contrasts (quadratic) P=0.009

grey shrike-thrush

intercept	4.992	1	4.992	9.832	.002
flowering eucalypts	.782	1	.782	1.540	.215
period of day	.497	1	.497	.979	.323
distance to water	1.458	4	.365	.718	.580
habitat	.401	1	.401	.789	.375
season	1.065	2	.533	1.049	.351
distance * habitat	2.243	4	.561	1.104	.354
distance * season	5.248	8	.656	1.292	.247
habitat * season	.422	2	.211	.415	.661
distance * habitat * season	7.088	8	.886	1.745	.087
error	169.57	334	.508		
total	209.00	366			

R Squared = .100

Polynomial contrasts (linear) P=0.952

hooded robin					
intercept	3.110	1	3.110	5.236	.023
flowering eucalypts	2.822	1	2.822	4.751	.030
period of day	1.971	1	1.971	3.319	.069
distance to water	7.611	4	1.903	3.204	.013
habitat	.858	1	.858	1.445	.230
season	4.563	2	2.282	3.842	.022
distance * habitat	4.972	4	1.243	2.093	.081
distance * season	3.560	8	.445	.749	.648
habitat * season	.578	2	.289	.487	.615
distance * habitat * season	2.091	8	.261	.440	.897
error	198.37	334	.594		
total	234.00	366			
R Squared = .125					
Polynomial contrasts (linear) P=0.093					
jacky winter					
intercept	2.232	1	2.232	2.410	.122
flowering eucalypts	1.802	1	1.802	1.945	.164
period of day	.164	1	.164	.177	.674
distance to water	2.045	4	.511	.552	.698
habitat	12.372	1	12.372	13.355	.000
season	3.157	2	1.579	1.704	.184
distance * habitat	3.003	4	.751	.810	.519
distance * season	4.755	8	.594	.642	.743
habitat * season	4.322	2	2.161	2.333	.099
distance * habitat * season	6.984	8	.873	.942	.482
error	309.41	334	.926		
total	374.00	366			
R Squared = .110					
Polynomial contrasts (linear) P=0.862					
purple-crowned lorikeet					
intercept	26.662	1	26.662	5.007	.026
flowering eucalypts	134.09	1	134.094	25.182	.000
period of day	20.252	1	20.252	3.803	.052
distance to water	24.529	4	6.132	1.152	.332
habitat	2.273	1	2.273	.427	.514
season	122.91	2	61.455	11.541	.000
distance * habitat	38.984	4	9.746	1.830	.123
distance * season	51.206	8	6.401	1.202	.297
habitat * season	1.170	2	.585	.110	.896
distance * habitat * season	24.065	8	3.008	.565	.807
error	1778.5	334	5.325		
total	2371.0	366			
R Squared = .203					
Polynomial contrasts (linear) P=0.052					
red-capped robin					
intercept	.878	1	.878	1.331	.249
flowering eucalypts	1.671	1	1.671	2.534	.112
period of day	.0444	1	.0444	.067	.795
distance to water	12.687	4	3.172	4.809	.001
habitat	6.671	1	6.671	10.114	.002

season	.216	2	.108	.164	.849
distance * habitat	8.603	4	2.151	3.261	.012
distance * season	4.173	8	.522	.791	.611
habitat * season	1.522	2	.761	1.154	.317
distance * habitat * season	8.122	8	1.015	1.539	.142
error	220.28	334	.660		
total	270.00	366			
R Squared = .161					
Polynomial contrasts (linear) P=0.001					
red wattlebird					
intercept	96.156	1	96.156	16.546	.000
flowering eucalypts	75.871	1	75.871	13.055	.000
period of day	38.670	1	38.670	6.654	.010
distance to water	134.31	4	33.578	5.778	.000
habitat	37.300	1	37.300	6.418	.012
season	63.557	2	31.779	5.468	.005
distance * habitat	41.432	4	10.358	1.782	.132
distance * season	28.708	8	3.588	.617	.763
habitat * season	32.850	2	16.425	2.826	.061
distance * habitat * season	67.898	8	8.487	1.460	.171
error	1941.0	334	5.811		
total	2893.0	366			
R Squared = .229					
Polynomial contrasts (linear) P<0.001					
southern scrub-robin					
intercept	.560	1	.560	2.000	.158
flowering eucalypts	.548	1	.548	1.958	.163
period of day	.00217	1	.00217	.008	.930
distance to water	2.765	4	.691	2.467	.045
habitat	3.635	1	3.635	12.976	.000
season	.151	2	.07549	.269	.764
distance * habitat	2.536	4	.634	2.263	.062
distance * season	1.749	8	.219	.780	.620
habitat * season	.067	2	.034	.120	.887
distance * habitat * season	1.787	8	.223	.797	.605
error	93.574	334	.280		
total	110.00	366			
R Squared = .124					
Polynomial contrasts (linear) P=0.006					
spiny-cheeked honeyeater					
intercept	13.874	1	13.874	3.812	.052
flowering eucalypts	40.121	1	40.121	11.025	.001
period of day	.00298	1	.00298	.001	.977
distance to water	76.752	4	19.188	5.273	.000
habitat	51.191	1	51.191	14.067	.000
season	4.401	2	2.201	.605	.547
distance * habitat	32.873	4	8.218	2.258	.063
distance * season	38.412	8	4.802	1.319	.233
habitat * season	13.874	1	13.874	3.812	.052
distance * habitat * season	14.119	8	1.765	.485	.867
error	1215.5	334	3.639		

total	1784.0	366			
R Squared = .197					
Polynomial contrasts (linear) P<0.001					
spotted pardolate					
intercept	179.911	1	179.911	14.121	.000
flowering eucalypts	.231	1	.231	.018	.893
period of day	58.439	1	58.439	4.587	.033
distance to water	37.235	4	9.309	.731	.572
habitat	1.546	1	1.546	.121	.728
season	144.01	2	72.006	5.652	.004
distance * habitat	51.436	4	12.859	1.009	.403
distance * season	226.92	8	28.365	2.226	.025
habitat * season	8.265	2	4.132	.324	.723
distance * habitat * season	72.807	8	9.101	.714	.679
error	4255.5	334	12.741		
total	5235.0	366			
R Squared = .112					
Polynomial contrasts (linear) P=0.387					
striated grasswren					
intercept	1.016	1	1.016	7.037	.008
flowering eucalypts	.03347	1	.03347	.232	.630
period of day	.378	1	.378	2.619	.107
distance to water	.978	4	.244	1.693	.151
habitat	2.516	1	2.516	17.424	.000
season	.03317	2	.01658	.115	.892
distance * habitat	.901	4	.225	1.560	.185
distance * season	1.188	8	.148	1.028	.414
habitat * season	.136	2	6.823E-02	.473	.624
distance * habitat * season	1.085	8	.136	.939	.484
error	48.220	334	.144		
total	58.000	366			
R Squared = .132					
Polynomial contrasts (linear) P=0.099					
striated pardolate					
intercept	16.094	1	16.094	1.968	.162
flowering eucalypts	122.67	1	122.67	15.000	.000
period of day	2.725	1	2.725	.333	.564
distance to water	31.163	4	7.791	.953	.434
habitat	.00491	1	.00491	.001	.980
season	207.36	2	103.68	12.677	.000
distance * habitat	30.957	4	7.739	.946	.437
distance * season	112.94	8	14.117	1.726	.091
habitat * season	.147	2	.073	.009	.991
distance * habitat * season	33.475	8	4.184	.512	.848
error	2731.6	334	8.178		
total	3486.0	366			
R Squared = .158					
Polynomial contrasts (linear) P=0.097					
weebill					
intercept	105.902	1	105.902	7.680	.006

flowering eucalypts	3.151	1	3.151	.229	.633
period of day	1.859	1	1.859	.135	.714
distance to water	348.80	4	87.201	6.324	.000
habitat	.668	1	.668	.048	.826
season	54.434	2	27.217	1.974	.141
distance * habitat	73.734	4	18.434	1.337	.256
distance * season	107.96	8	13.495	.979	.452
habitat * season	56.151	2	28.076	2.036	.132
distance * habitat * season	132.774	8	16.597	1.204	.296
error	4605.7	334	13.789		
total	6165.0	366			

R Squared = .145

Polynomial contrasts (linear) P=0.001

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white-browed babbler

intercept	11.185	1	11.185	3.563	.060
flowering eucalypts	19.199	1	19.199	6.116	.014
period of day	3.619	1	3.619	1.153	.284
distance to water	24.521	4	6.130	1.953	.101
habitat	21.822	1	21.822	6.951	.009
season	8.508	2	4.254	1.355	.259
distance * habitat	14.827	4	3.707	1.181	.319
distance * season	40.583	8	5.073	1.616	.119
habitat * season	3.564	2	1.782	.568	.567
distance * habitat * season	9.518	8	1.190	.379	.931
error	1048.5	334	3.139		
total	1269.0	366			

R Squared = .125

Polynomial contrasts (linear) P=0.087

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white-browed woodswallow

intercept	1802.4	1	1802.4	1.595	.207
flowering eucalypts	17905	1	17905	15.85	.000
period of day	3563.8	1	3563.8	3.154	.077
distance to water	2614.5	4	653.63	.578	.678
habitat	504.16	1	504.17	.446	.505
season	26402	2	13201	11.68	.000
distance * habitat	2474.7	4	618.68	.548	.701
distance * season	3399.2	8	424.91	.376	.933
habitat * season	1802.4	1	1802.4	1.595	.207
distance * habitat * season	4022.8	8	502.84	.445	.893
error	377421	334	1130.0		
total	468012	366			

R Squared = .164

Polynomial contrasts (linear) P=0.514

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white-eared honeyeater

intercept	2.226	1	2.226	6.500	.011
flowering eucalypts	.443	1	.443	1.295	.256
period of day	.812	1	.812	2.370	.125
distance to water	1.937	4	.484	1.414	.229
habitat	.328	1	.328	.957	.329
season	.03107	2	.0155	.045	.956
distance * habitat	2.919	4	.730	2.131	.077

distance * season	3.063	8	.383	1.118	.350
habitat * season	.491	2	.245	.717	.489
distance * habitat * season	.491	2	.245	.717	.489
error	114.39	334	.342		
total	135.00	366			

R Squared = .106

Polynomial contrasts (linear) P=0.059

white-fronted honeyeater

intercept	224.427	1	224.427	7.482	.007
flowering eucalypts	841.06	1	841.06	28.039	.000
period of day	107.11	1	107.11	3.571	.060
distance to water	94.337	4	23.584	.786	.535
habitat	62.232	1	62.232	2.075	.151
season	172.97	2	86.486	2.883	.057
distance * habitat	116.33	4	29.084	.970	.424
distance * season	165.70	8	20.712	.691	.700
habitat * season	27.712	2	13.856	.462	.630
distance * habitat * season	342.185	8	42.773	1.426	.184
error	10018	334	29.996		
total	13653	366			

R Squared = .179

Polynomial contrasts (linear) P=0.046

willie wagtail

intercept	3.447	1	3.447	6.931	.009
flowering eucalypts	1.159E-02	1	1.159E-02	.023	.879
period of day	.595	1	.595	1.197	.275
distance to water	9.556	4	2.389	4.804	.001
habitat	.04954	1	.04954	.100	.752
season	4.257	2	2.129	4.281	.015
distance * habitat	.370	4	.09254	.186	.946
distance * season	1.270	8	.159	.319	.959
habitat * season	4.506	2	2.253	4.531	.011
distance * habitat * season	2.725	8	.341	.685	.705
error	166.09	334	.497		
total	205.00	366			

R Squared = .128

Polynomial contrasts (linear) P=0.003

yellow-plumed honeyeater

intercept	4082.6	1	4082.6	22.862	.000
flowering eucalypts	3606.4	1	3606.4	20.195	.000
period of day	230.67	1	230.67	1.292	.257
distance to water	4384.2	4	1096.0	6.138	.000
habitat	1000.9	1	1000.9	5.605	.018
season	1257.4	2	628.70	3.521	.031
distance * habitat	704.4	4	176.10	.986	.415
distance * season	1097.9	8	137.24	.768	.631
habitat * season	1348.0	2	674.02	3.774	.024
distance * habitat * season	388.911	8	48.614	.272	.975
error	59645	334	178.58		
total	115612	366			

R Squared = .188

Polynomial contrasts (linear) P<0.001

Table 4.2: Analysis of covariance results on the density of bird species with distance from water at MSNP. Main factors are distance to water and habitat, and random factors are number of flowering eucalypts and period of the day. Polynomial contrasts were again used to confirm that significant differences with distance to water were due to a systematic trend.

Species	SS	df	MS	F	p
Australian ringneck					
intercept	.123	1	.123	1.155	.372
flowering eucalypts	9.830	1	9.830	.140	.712
period of day	210.29	1	210.29	2.987	.099
distance	532.45	5	106.49	1.513	.228
habitat	47.182	1	47.182	.670	.422
distance * habitat	347.61	5	69.523	.988	.449
error	1478.3	21	70.397		
total	2825.0	35			
R Squared = .443					
grey shrike-thrush					
intercept	2.967	1	2.967	8.693	.008
flowering eucalypts	1.482	1	1.482	4.340	.050
period of day	.957	1	.957	2.802	.109
distance	3.425	5	.685	2.007	.119
habitat	.189	1	.189	.554	.465
distance * habitat	4.055	5	.811	2.376	.074
error	7.168	21	.341		
total	18.000	35			
R Squared = .527					
mulga parrot					
intercept	66.759	1	66.759	3.915	.061
flowering eucalypts	.417	1	.417	.024	.877
period of day	25.208	1	25.208	1.478	.238
distance	241.141	5	48.228	2.828	.042
habitat	42.624	1	42.624	2.500	.129
distance * habitat	98.294	5	19.659	1.153	.364
error	358.08	21	17.052		
total	950.00	35			
R Squared = .574					
red wattlebird					
intercept	1.921	1	1.921	3.096	.093
flowering eucalypts	.286	1	.286	.461	.505
period of day	1.503	1	1.503	2.422	.135
distance	3.710	5	.742	1.196	.345
habitat	1.408	1	1.408	2.269	.147
distance * habitat	5.318	5	1.064	1.714	.175
error	13.031	21	.621		
total	27.000	35			
R Squared = .491					

spiny-cheeked honeyeater					
intercept	4.557	1	4.557	.990	.331
flowering eucalypts	5.927	1	5.927	1.287	.269
period of day	.360	1	.360	.078	.783
distance	50.636	5	10.127	2.200	.093
habitat	29.414	1	29.414	6.389	.020
distance * habitat	64.598	5	12.920	2.806	.043
error	96.673	21	4.603		
total	316.00	35			
R Squared = .629					
shy heathwren					
intercept	.543	1	.543	4.145	.055
flowering eucalypts	.180	1	.180	1.372	.255
period of day	1.172	1	1.172	8.936	.007
distance	1.368	5	.274	2.087	.107
habitat	.132	1	.132	1.007	.327
distance * habitat	.318	5	.0636	.486	.783
error	2.753	21	.131		
total	6.000	35			
R Squared = .503					
weebill					
intercept	10.103	1	10.103	2.877	.105
flowering eucalypts	1.913	1	1.913	.545	.469
period of day	2.172	1	2.172	.618	.440
distance	23.513	5	4.703	1.339	.287
habitat	8.795	1	8.795	2.504	.128
distance * habitat	29.918	5	5.984	1.704	.178
error	73.753	21	3.512		
total	193.00	35			
R Squared = .474					
yellow-plumed honeyeater					
intercept	161.791	1	161.791	2.527	.127
flowering eucalypts	425.144	1	425.14	6.639	.018
period of day	20.953	1	20.953	.327	.573
distance	943.616	5	188.72	2.947	.036
habitat	70.404	1	70.404	1.099	.306
distance * habitat	343.34	5	68.670	1.072	.404
error	1344.7	21	64.034		
total	5075.0	35			
R Squared = .603					

Table 4.3: Full analysis of covariance results on the diversity of bird species with distance from water at Gluepot and MSNP. Main factors are distance to water, habitat, season and number of flowering eucalypts. Polynomial contrasts were used to confirm that significant differences with distance to water were due to a systematic trend.

Source	SS	df	MS	F	p	r^2
Gluepot						
intercept	35886	1	35886	1930.6	.000	
distance to water	341.73	4	85.433	4.596	.001	
habitat	726.40	1	726.40	39.079	.000	
season	41.991	2	20.996	1.130	.324	
flowering eucalypts	15.462	1	15.462	.832	.362	
distance * habitat	172.20	4	43.050	2.316	.057	
distance * season	234.19	8	29.274	1.575	.131	
distance * Season * habitat	90.851	8	11.356	.611	.769	
error	6226.9	335	18.588			
total	61826	366				0.257
polynomial contrasts (linear)	P=0.008					
MSNP						
intercept	3567.6	1	3567.6	185.63	.000	
distance to water	341.48	5	68.296	3.553	.017	
habitat	3.841	1	3.841	.200	.659	
flowering eucalypts	7.008	1	7.008	.365	.552	
distance * habitat	33.323	5	6.665	.347	.879	
error	422.83	22	19.219			
total	6349.0	35				0.738
polynomial contrasts (linear)	P<0.001					

Table 4.4: Table of MBACI (ANOVA) results on the effect of water point closure on the abundance and species richness of avifauna. Bird species abundance data was analysed in four different categories (drinking, non-drinking, yearly-drinkers and non yealy-drinkers), over two distances from water (0.25 km and 2.25 km).

Species category	**Source**	**SS**	**df**	**MS**	**F**	**p**
Abundance						
Drinkers (0 km)	BA	462.25	1	462.25	2.63	0.110
	CI	1272.1	1	1272.1	7.25	0.009
	CI*BA	61.361	1	61.36	0.35	0.557
	BA*SITE(CI)	790.79	10	79.08	0.45	0.914
	MBACI model	61.36	1	61.36	0.776	0.399
Non-drinkers (0 km)	BA	29.34	1	29.34	0.18	0.671
	CI	41.17	1	41.17	0.25	0.615
	CI*BA	237.6	1	237.6	1.47	0.229
	BA*SITE(CI)	913.8	10	91.38	0.56	0.833
	MBACI model	237.6	1	237.6	2.60	0.138
Yearly drinkers (0 km)	BA	770.0	1	770.0	3.90	0.053
	CI	16.67	1	16.67	0.08	0.772
	CI*BA	119.1	1	119.1	0.60	0.440
	BA*SITE(CI)	732.9	10	73.29	0.37	0.954
	MBACI model	119.1	1	119.1	1.62	0.231
Non-yearly drinkers(0 km)	BA	370.5	1	370.5	0.84	0.362
	CI	95.06	1	95.06	0.21	0.643
	CI*BA	370.5	1	370.5	0.84	0.362
	BA*SITE(CI)	3627.1	10	362.7	0.82	0.605
	MBACI model	370.5	1	370.5	1.02	0.336
Drinkers (2 km)	BA	2508.3	1	2508.3	7.37	0.009
	CI	451.56	1	451.56	1.32	0.254
	CI*BA	14.06	1	14.06	0.04	0.840
	BA*SITE(CI)	3651.7	10	365.17	1.07	0.397
	MBACI model	14.06	1	14.06	0.03	0.848
Non-drinkers (2 km)	BA	423.6	1	423.6	2.53	0.117
	CI	55.00	1	55.00	0.32	0.568
	CI*BA	171.1	1	171.1	1.02	0.316
	BA*SITE(CI)	1411.7	10	141.1	0.84	0.588
	MBACI model	171.17	1	171.1	1.21	0.297
Yearly drinkers (2 km)	BA	186.77	1	186.77	0.68	0.412
	CI	10.02	1	10.02	0.03	0.849
	CI*BA	9.00	1	9.00	0.03	0.857
	BA*SITE(CI)	3048.0	10	304.8	1.11	0.368
	MBACI model	9.00	1	9.00	0.03	0.867
Non-yearly drinkers(2 km)	BA	3731.1	1	3731.1	5.54	0.022
	CI	91.84	1	91.84	0.13	0.713
	CI*BA	98.34	1	98.34	0.14	0.704
	BA*SITE(CI)	6227.7	10	622.7	0.92	0.517
	MBACI model	98.34	1	98.34	0.15	0.699

Diversity						
Diversity (0 km)	BA	180.0	1	180.0	7.68	0.007
	CI	3.06	1	3.063	0.13	0.719
	CI*BA	55.00	1	55.00	2.34	0.131
	BA*SITE(CI)	80.14	10	8.015	0.342	0.965
	MBACI model	55.01	1	55.01	6.86	0.026
Diversity (2 km)	BA	469.4	1	469.4	24.6	0.000
	CI	53.77	1	53.77	2.82	0.098
	CI*BA	7.11	1	7.111	0.37	0.543
	BA*SITE(CI)	44.70	10	4.47	0.23	0.991
	MBACI model	7.11	1	7.11	1.59	0.236

APPENDIX 5

Description of the fixed-point sampling procedure of Morgan (1986)

This method estimates density based on radial distances from an observer in which allowance is made for the effects of animal mobility (Morgan, 1986). The associated model used in this method applies a parametric model to the point census situation (Morgan & Headey, 1997) and has been successfully tested with a known helmeted honeyeater *Lichenostomus melanops cassidix* population (Headey, 1996). The model assumes that a population displays one or more types of mobility at any time, involving known proportions of the population, that the average speed of the animals in each of those proportions is known and remain approximately constant over the period of a census, and that the animals move in rectilinear paths in random directions with respect to the observer. In simpler terms, the model utilises the fact that all bird species in the study area move about continuously throughout the day, at rates which depend mainly on the species, although these rates of movement are affected to some extent by other factors such as weather conditions (Chambers, 2002). The principle of this method is that an observer is located at a predetermined point within the study area, remaining at that point for a given period of time. Detectability of animals from that point will be influenced by factors such as vegetation structure and topography, and will decrease with increasing distance. Over time animals move close enough to the observer to be detected and counted, and the detection distance measured, then in due course may move away again. The same individuals may in time return and be recounted, or others may move into the detectable area. Over a long period the number of contacts (detections) per unit time is expected to be constant.

The population density for a species is calculated using the equation:

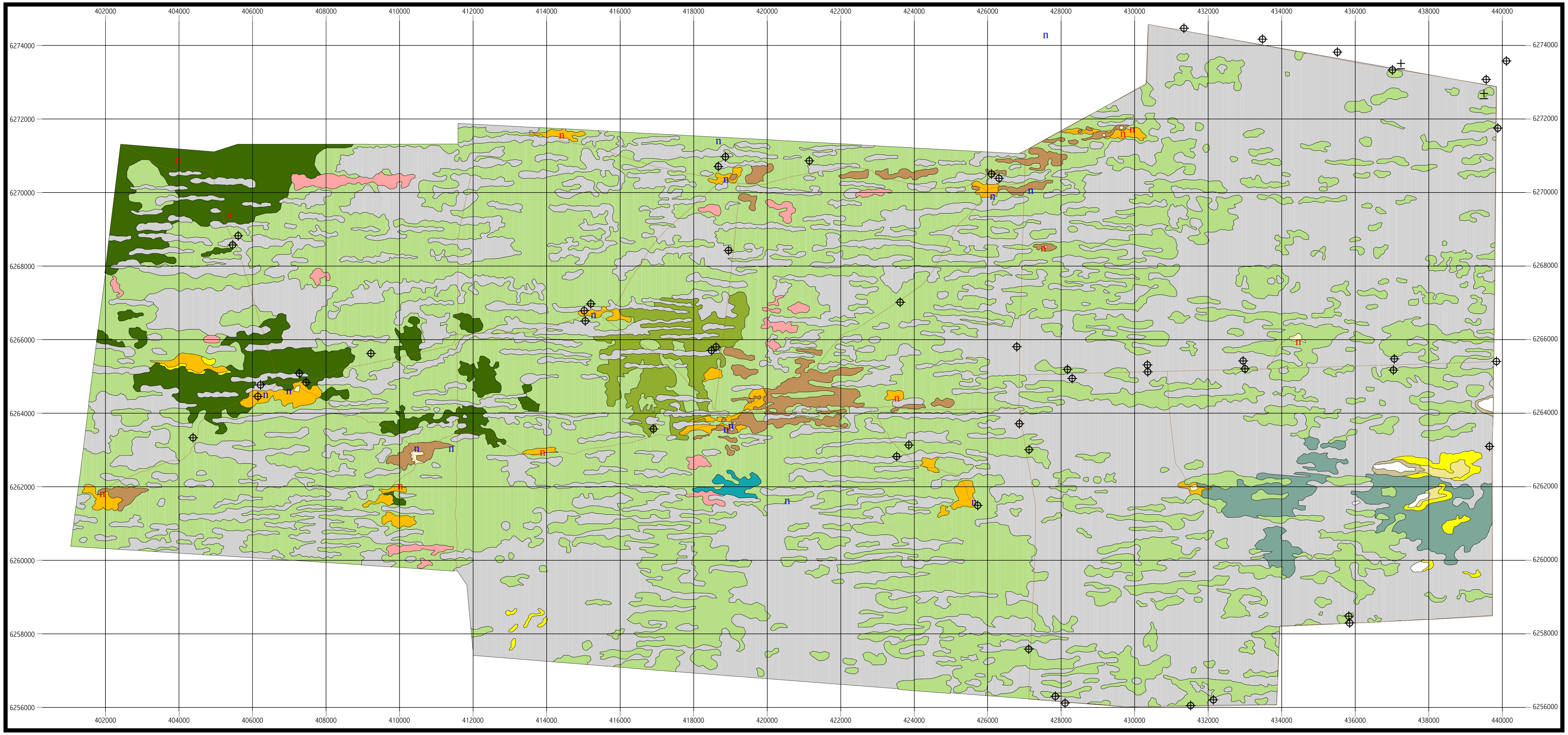
$$\mathbf{D = \frac{C.N}{2.U.t.P_D.P_S.S}}$$

where:

D = density
N = number of observations
C = a correction for area
S = area under the probability function curve relating frequency of contact to the direct-line sighting distance from the observer
U = average rate of movement
P_D and P_S are the proportions of the population available for study, and the proportion of a 360° plane swept in the fixed-point sample, respectively.
t = total observation time, in minutes

The total observation time is the sum of the times for all fixed-point samples taken. If the movement rate of a particular species is known, then the actual density of that species can be calculated and can be compared with other species whose density was calculated using the same methods. A fuller explanation of the procedure and assumptions of the model are given in Morgan & Headey (1997) and Headey (1996).

Appendix 6



n/n open/closed water point
⌖ site
road

vegetation associations

- ▨ mallee with triodia understorey on dunes
- 🟩 mallee with shrub understorey in interdunes
- 🟧 nitraria and lycium shrubland on floodpans
- 🟨 callitris and mallee on gypsum lunettes
- ▨ callitris and hakea shrubland on gypsum shores
- ☐ callitris and hibbertia on gypsum playas
- ▨ callitris and mallee with triodia understorey on buried gypsum playas
- 🟥 unknown
- 🟫 casuarina forest in drainage lines
- 🟩 mallee with very sparse understorey on limestone?
- 🟩 myoporum woodland on limestone
- ▨ bare earth (dams)
- 🟦 casuarina and mallee woodland on interdune flats
- ▨ mallee with triodia understorey on gypsaceous sand

Figure 10.1: Sampling sites and artificial water points in relation to the vegetation associations on Birds Australia Gluepot Reserve.

This map is the first edition
Further ground-truthing is required.
The Casuarina low forest association is more widespread than indicated,
but will require aerial inspection to map fully.

Taken from Hyde (2001)

4 0 4 8 12 Kilometers

N

Author/s:
Harrington, Rhidian

Title:
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