Avian use of Old Man Saltbush (*Atriplex nummularia nummularia*) plantings in the fragmented agricultural landscapes of the South Australian Murray Mallee

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Cover photo: Storm clouds over rows of planted saltbush near Waikerie, South Australia. T. Richards.

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Table of Contents

List of Figures

Jacky Winter, SIH = Singing Honeyeater, SQ = Stubble Quail, STP = Striated Pardalote, SWF = Southern Whiteface, VFW = Variegated Fairy-wren, WBB = White-browed Babbler, WFC = White-fronted Chat, WW = Willie Wagtail, WWC = White-winged Chough, YRT = Yellow-rumped Thornbill and YTM = Yellow-throated Miner.

Figure 3.4. Two-dimensional non-metric multi-dimensional scaling (NMDS) ordination of vegetation structure based on percentage cover of canopy (Rem Can), sub-canopy (Rem F2-4 m), understorey (Rem U/S), fallen timber/leaf litter (Rem FT/Lit) and groundcover (Rem GC) within remnant vegetation; understorey (SB U/S) and groundcover (SB GC) in saltbush plantings; and groundcover (Ag GC) in agricultural land across the four study site types: SB-Rem, Rem-Iso, SB-Iso, Ag-Iso. Distances between sample units approximate dissimilarity in site composition and the angles and lengths of the radiating lines (vectors) indicate the direction and strength of relationships of the variables with the ordination scores (McCune and Grace 2002). Data were collected during spring (S) 2010 and autumn (A) 2011.

Figure 4.1. Percentage use of behaviours by White-browed Babblers (WBB), Chestnut-crowned Babblers (CCB) and Variegated Fairy-wrens (VFW) in remnant (R) and saltbush (SB) vegetation during spring 2011 (S11), autumn 2012 (A12) and spring 2012 (S12). Total number of observations shown above each column.

Figure 4.2. Percentage use of foraging substrates by White-browed Babblers (WBB), Chestnut-crowned Babblers (CCB) and Variegated Fairy-wrens (VFW) in remnant (R) and saltbush (SB) vegetation during spring 2011 (S11), autumn 2012 (A12) and spring 2012 (S12). Total number of observations shown above each column.

Figure 4.3. Percentage use of foraging heights by White-browed Babblers (WBB), Chestnut-crowned Babblers (CCB) and Variegated Fairy-wrens (VFW) in remnant (R) and saltbush (SB) vegetation during spring 2011 (S11), autumn 2012 (A12) and spring 2012 (S12). Total number of observations shown above each column.

Figure 5.1. Measurement of foliage cover across five height bands (horizontal dotted lines) and the location of foliage density measures (vertical dashed lines) along survey transect (thick horizontal line) taken during vegetation surveys conducted in hotspots and coldspots within bird home ranges.

List of Tables

Abstract

Much of southern Australia has endured widespread vegetation clearance which has, through habitat loss and fragmentation, induced declines in regional avifauna and confined remaining populations to small, isolated patches of remnant vegetation where their numbers continue to fall. Conserving populations of fauna in highly fragmented agricultural landscapes is increasingly reliant on developing systems which can serve production as well as biodiversity. In recent times, perennial monoculture plantings of native tree and shrub species have been advocated as a means to increase the amount of woody vegetation in fragmented agricultural landscapes, enhance connectivity and provide supplementary habitat for wildlife. In the South Australian Murray Mallee, plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) have been established as supplementary fodder for sheep. Preliminary research has recognised these plantings as a potential source of habitat and resources for native birds. The benefits these areas may provide to birds remain largely speculative and in depth investigations are required to fully understand the potential of saltbush plantings to contribute to the longevity of populations in highly fragmented agricultural zones.

This thesis represents a detailed ecological analysis of how birds use saltbush plantings. Initially the analysis identifies which species of birds use saltbush plantings before examining White-browed Babblers (*Pomatostomus superciliosus*), Variegated Fairy-wrens (*Malurus lamberti*) and Chestnut-crowned Babblers (*P. ruficeps*) in detail to determine the extent to which saltbush plantings are used, for what purposes, the resources provided by the plantings and the factors driving these patterns.

Repeated surveys of saltbush plantings and remnant vegetation showed the bird community found in plantings represented a significantly reduced suite of species compared to that found in remnant vegetation. Plantings did however represent areas of greater value to birds compared with cleared agricultural land. This value was substantially increased when adjacent to remnant vegetation which had the added benefit of encouraging greater numbers of bird species to make use of plantings. This study also identified White-browed Babblers,

Variegated Fairy-wrens and Chestnut-crowned Babblers as several of the species most common in these areas, confirming them as focal species for further study.

Direct observation of foraging by White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers revealed saltbush plantings represented substantial foraging habitat for these species. Babblers displayed highly plastic foraging ecologies, enabling them to exploit the foraging resources afforded by saltbush plantings. Despite this plasticity, babblers remained reliant on remnant vegetation for other elements, particularly those associated with breeding and nesting. Variegated Fairy-wrens remained solely within saltbush where they showed foraging ecology little changed from natural chenopod habitats. The highly plastic and adaptive foraging ecologies of these three species enable them to exploit saltbush plantings and hence they are among the most commonly encountered.

Detailed analysis of home range and internal patterns of spatial use exhibited by the focal bird species revealed key elements driving habitat selection. All showed clear selection toward areas with greater cover of dense shrub-level foliage, revealing an inherent dependence on cover presumably to minimise predation risk. The distribution of vegetative cover was found to be a key driver of foraging ecology, habitat use and patterns of spatial use in both saltbush plantings and remnant vegetation.

The distribution of foraging resources was examined by assessing the availability of invertebrate prey across the home ranges of the focal bird species. Invertebrate availability did not differ between intensely foraged areas and areas of no use, revealing prey distribution to be evenly distributed in both saltbush plantings and remnant vegetation. Cover dependence was therefore confirmed as the predominant driver of habitat selection patterns among these birds.

Saltbush plantings represent vegetation in which foraging resources can be found by a small number of bird species with highly plastic ecologies suited to exploiting a range of habitats. Despite their plasticity, several of these species, along with the majority of bird species in the region, remain reliant on remnant vegetation. In order to better manage saltbush plantings for biodiversity it is necessary to base practices on sound ecological research which demonstrates the importance of cover, heterogeneous vegetation and adjacency to remnant vegetation.

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Chapter 1 General Introduction

Plate 1.1. Rainclouds approaching from the south-west over saltbush plantings near Wanbi, South Australia. Photo: T. Richards.

1.1 The legacy of agriculture

Securing food resources for the global human population is deeply reliant on regions which are shared with much of the world's biodiversity (Raley and Anderson 1990, Benton *et al.* 2003). These agro-ecological landscapes have undergone immense change as increased agricultural production and expansion have driven widespread vegetation clearance and landscape alteration (Ehrlich 1993, Vitousek *et al.* 1997). Globally, 16 million square kilometres of land are currently are under cropland management (Ramankutty and Foley 1999) with an additional 33 million dedicated to grazing production (Asner *et al.* 2004). The loss and fragmentation of habitat resulting from these enterprises has induced vertebrate declines in many regions of the world (Gaston *et al.* 2003, Semwal *et al.* 2004). Among these, bird populations on agricultural landscapes have endured particularly severe declines (Benton *et al.* 2003, Green *et al.* 2005, Teyssedre and Couvet 2007) and continue to suffer substantial losses in many of the world's most productive regions including Europe (Donald *et al.* 2001), North America (Brennan and Kuvlesky 2005) and South America (Filloy and Bellocq 2007).

In Australia, the loss of habitat through widespread vegetation clearance for agriculture is the leading cause of bird declines in farming regions (Smith 1987, Pickard 1990, Recher 1993b, Robinson 1993, Ford *et al.* 2001, Hannah *et al.* 2007). Since European settlement, agricultural expansion has contributed to the extinction of four bird species (Garnett and Crowley 2000) and the decline or shift in distribution of a further 65 (Barrett *et al.* 2003). The coastal regions and southern temperate woodlands, due to their suitability for crop cultivation and grazing, have endured the most pervasive vegetation clearance (Paton *et al.* 1994, Barrett and Davidson 1999, Ford *et al.* 2001) and consequently, the most rapid and extensive bird declines (Robinson 1993, Saunders and Ingram 1995, Barrett *et al.* 2003, Attwood *et al.* 2009). These declines are pronounced across much of southern Australia, from Western Australia (Saunders 1989, Saunders and Ingram 1995), through South Australia (Paton *et al.* 1994, Possingham and Possingham 1997) and Victoria (Mac Nally *et al.* 2009) to southern Queensland (Woinarski *et al.* 2006). Persistent clearance has removed up to 90 percent of native vegetation in these regions (Ford *et al.* 2001), inducing fundamental changes in landscape composition and function and fragmenting once continuous vegetation into small, isolated patches (Saunders *et al.* 1991, Andren 1994, Fahrig 2003, Fleishman and Mac Nally 2007). Many bird species are confined to these remaining patches where they are further impacted by reduced dispersal opportunities and habitat degradation (May and Norton 1996, Ford 1999, Dorrough *et al.* 2004, Debus 2006). Isolation and degradation heavily limit genetic diversity and foraging opportunities and consequently bird populations in fragmented landscapes continue to contract (Saunders 1989, Fahrig 1997, Villard *et al.* 1999, Radford *et al.* 2005, Radford and Bennett 2007).

1.2 Broadening the conservation focus

Global biodiversity conservation has traditionally focused on protecting habitats with the highest levels of endemism and species diversity (Mittermeier *et al.* 1998, Myers *et al.* 2000). It is now acknowledged that these systems are insufficient to effectively preserve biodiversity (Ryan 1992, Moguel and Toledo 1998, Brooks *et al.* 2004) and the focus of conservation must broaden to recognise habitat patches that are essential to the survival of resident biota exist within the broader context of human-modified landscapes (Vandermeer and Perfecto 1997, Law and Dickman 1998, Margules and Pressey 2000, Bennett and Mac Nally 2004, Scherr and McNeely 2008, Wiens 2009).

Many species use several smaller habitat patches in fragmented agricultural landscapes as they disperse and interact with different sub-populations of the same species (Andren 1994, Wiens 1994). This dispersal and interaction, and the associated colonisation and extinction of sub-populations, are fundamental to the persistence of the regional population, the *metapopulation* (Levins 1969, Hanski and Gilpin 1991). Within metapopulation theory, sub-populations represent sub-units of the larger regional population, within which population parameters are affected by the same factors, which may in turn be different to factors affecting other sub-populations (Cale 1999).

The fundamental importance of dispersal in the persistence of metapopulations exemplifies the need to consider the structure and function of landscapes through which species disperse; that is *landscape ecology* (Merriam 1984). Landscape heterogeneity is a core component of this discipline (Cale 1999), and one which gives rise to the branch of *functional connectivity*. Functional connectivity is the degree to which the landscape facilitates or impedes movement among resource patches (Taylor *et al.* 1993, With and King 1997, Belisle 2005) and is therefore inextricably linked to the dispersal of individuals between sub-populations of a metapopulation.

Functional connectivity encompasses facilitation or impediment of movement through the landscape, as opposed to structural connectivity which concerns the physical connectedness of landscape elements (Tischendorf and Fahrig 2000, Baguette and Van Dyck 2007). Structural connectivity is relatively simple to measure and can lead to flawed conclusions regarding the suitability of a landscape to facilitate the movement of resident species (Tischendorf and Fahrig 2000). Functional connectivity by comparison is dependent on the perception and reaction of a particular species to the structure of a landscape at a range of spatial scales (Pither and Taylor 1998, D'Eon *et al.* 2002). The probability of an individual moving is dependent on the rate at which individuals gain resources through time in habitat patches, which on occasions may override the perceived level of functional connectivity (Belisle 2005). As a result, functional connectivity is species and situation-dependent (Pither and Taylor 1998, D'Eon *et al.* 2002).

The above paradigms underpin the abilities of wildlife to forage, disperse and colonise habitat elements within fragmented landscapes (Taylor *et al.* 1993, Baguette and Van Dyck 2007). Understanding the influence of the human-modified agricultural matrix on connectivity and wildlife ecology is a crucial prerequisite to developing and implementing sound conservation strategies (Wolff *et al.* 2002, Wiens 2009). The acute dependency of the human population on agriculture means the greatest gains to biodiversity in highly modified landscapes will be made through strategies supporting both commodity production and the persistence of wildlife (Pimentel *et al.* 1992, Hobbs *et al.* 1993, Haslem and Bennett 2008a, Wiens 2009). Researchers are increasingly aware of the need for robust principles to guide conservation strategies and facilitate the synthesis of production and conservation. Despite this awareness, our knowledge of agricultural elements which may support faunal populations remains deficient, as does our broader understanding of how to effectively construct and manage landscapes to support both agriculture and wildlife (Pimentel *et al.* 1992, Saunders 1994, Morton *et al.* 2009). Developing this understanding through detailed research remains a fundamental ecological issue, and one of ever increasing importance in the face of continuing species losses and a changing climate (Ruiz-Jaen and Mitchell Aide 2005, Haslem and Bennett 2008a, Mac Nally *et al.* 2009).

1.3 Conservation in Australian agricultural landscapes

The paradigm shift toward encompassing agro-ecological landscapes in Australian conservation strategies has gained prominence only in recent times (Saunders and Hobbs 1995, Haslem and Bennett 2008b, Lindenmayer *et al.* 2010a), following trends set in other heavily modified regions such as Europe (Vickery *et al.* 2002, Fuller *et al.* 2004) and central America (Hughes *et al.* 2002). Studies in the highly fragmented Western Australian wheatbelt by Hobbs *et al.* (1993) and Saunders (1994) highlighted the need to move away from managing individual landscape segments to landscape level conservation strategies integrating both production land and remnant vegetation. Landscape level conservation encompasses two broad strategies; the well established protection of remnant vegetation (Freudenberger and Harvey 2003, Lindenmayer *et al.* 2003, Lindenmayer *et al.* 2007, Cunningham *et al.* 2008) and the more recent need to increase the habitability and carrying capacity of production areas (Green *et al.* 2005, Teyssedre and Couvet 2007).

Several key principles have been presented to increase the carrying capacity of agricultural areas (see Hobbs *et al.* 1993, Fischer *et al.* 2006, Lindenmayer *et al.* 2008), of which increasing vegetative heterogeneity within the agricultural matrix is regarded as fundamental (Duelli 1997, Benton *et al.* 2003, Fischer *et al.* 2006, Radford and Bennett 2007, Fahrig *et al.* 2011). Within this principle, increasing vegetative cover by bolstering existing vegetation, establishing planted vegetation and improving landscape connectivity is considered the most prominent means to facilitate heterogeneous landscapes (Taylor *et al.* 1993, Saunders 1994, Benton *et al.* 2003, Radford and Bennett 2007, Lindenmayer *et al.* 2008, Fahrig *et al.* 2011).

Revegetating previously cleared landscapes with plantings aimed at replicating pre-clearance habitats is widely acknowledged as the primary method through which to initiate these channels (Hobbs *et al.* 1993, Recher 1993a, Saunders and Hobbs 1995, Paton *et al.* 2004, Vesk and Mac Nally 2006). Revegetation composed of a mixture of native plant species has been a feature in many southern Australian agricultural landscapes since the late 20th century and these areas serve as substantial habitat for a variety of native bird species (Recher 1993a, Ryan 1999, Martin *et al.* 2004, Kavanagh *et al.* 2007, Barrett *et al.* 2008, Paton *et al.* 2010a). However, the extent of mixed native species revegetation efforts remain heavily constrained by an assortment of economic, social and political limitations centralised around practical capacity and tradeoffs between production and conservation (Recher and Lim 1990, Recher 1993a, McNeely and Schroth 2006, Bhagwat *et al.* 2008, Mac Nally 2008, Gunnarsson and Indridadottir 2009, Prober and Smith 2009).

These constraints combined with the dire need to support biodiversity in ailing agricultural systems have induced many researchers to advocate commercial monoculture plantings of perennial native trees and shrubs as a means to increase the percentage of perennial vegetation in highly fragmented agricultural landscapes, boost landscape connectivity and augment the conservation of bird populations (e.g. Bennett *et al.* 2000, Lindenmayer *et al.* 2002, Lindenmayer and Hobbs 2004, McNeely 2004, Brockerhoff *et al.* 2008). Plantings of this nature return an income to land holders and aid in reversing some degrading processes, making them a more economically viable means of increasing perennial woody vegetation and enhancing the heterogeneity of agricultural landscapes (Moguel and Toledo 1998, Benton *et al.* 2003, Schroth and Harvey 2007).

1.4 Native species plantings in southern Australian landscapes

In southern Australian agricultural landscapes, commercial native tree-based monocultures (predominantly Eucalyptus species, Eldridge *et al.* 1994), are established primarily for timber, woodchips, industrial oils and biomass (Hobbs *et al.* 2003, Smith 2008). Much like mixed species revegetation, these plantings increase heterogeneity within the agricultural mosaic (Law and Dickman 1998) and have been found to serve as supplementary habitat for a range of bird species. When compared to mixed species revegetation however, simple structured tree-based monocultures support fewer specialised species and a suite dominated by generalists (Munro *et al.* 2011). Despite this limitation, Hobbs *et al.* (2003) showed eucalypt monocultures can still provide benefits to a range of species, documenting between 31 and 36 bird species in commercial plantings of Blue Gum (*E. globulus*), substantially more than surrounding agricultural land. Loyn *et al.* (2007) showed responses are species specific, recording a greater abundance of open ground foraging birds in plantings of Blue Gum, Shining Gum (*E. nitens*) and River Red Gum (*E. camaldulensis*) compared to remnant native eucalypt forest. Furthermore, canopy and tall shrub-feeding insectivores were as common in eucalypt plantings as remnant vegetation in this study; while nectarivorous, bark-foraging and low shrub-foraging birds were found almost exclusively in remnant vegetation. In addition to providing supplementary habitat, Smith (2009b) showed plantings of York Gum Mallee (*E. loxophelbe* subsp. *lissophloia*) aided dispersal through fragmented landscapes by serving as foraging and resting refuges for a suite of bird species moving between patches of remnant vegetation.

Many of the bird species documented within eucalypt plantings would otherwise be rare or absent from cleared agricultural land, illustrating these areas provide some benefit to bird populations. However, as the response of birds to monoculture plantings is heavily guild and species specific (Hobbs *et al.* 2003, Loyn *et al.* 2007), eucalypt monocultures represent only part of the spectrum of planted vegetation required to enhance landscape heterogeneity and benefit a far broader range of bird species (Bennett and Ford 1997, Bennett *et al.* 2000, Benton *et al.* 2003, Haslem and Bennett 2008a).

1.5 Fodder plantings of Old Man Saltbush

In recent decades plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) have been established in the wheat/sheep agricultural zones of southern Australia to serve as a grazing reserve for sheep to be drawn upon during drier periods (Lefroy 2002, Giumelli 2009, Monjardino *et al.* 2010). These shrub-based monocultures have recently been recognised as a potential source of foraging and shelter resources for native birds, similar to their tree-based counterparts (Lefroy and Smith 2004, Lefroy *et al.* 2005, Collard and Fisher 2010). Importantly, saltbush plantings represent areas of shrub-level vegetation which not only adds landscape heterogeneity and connectivity at the broader scale (Collard and Fisher 2010), but may provide structural elements missing from tree-based monocultures at the patch scale (Hobbs *et al.* 2003).

Research investigating the benefits that saltbush plantings may afford native birds remains in its infancy; however several studies illustrate considerable potential. Millsom (2002) used reported sightings of several bird species and greater spider abundance within mixed saltbush plantings to contend plantings may provide habitat and foraging resources for birds. Seddon *et al.* (2009) provided the first in depth analysis of birds within alley planted saltbush and found no significant difference in species diversity and abundance between saltbush sites and grazing/cropping land. Saltbush sites were dominated by open country species and shrubland species such as the Orange (*Epthianura aurifrons*) and Crimson (*E. tricolor*) Chat and held significantly fewer birds than remnant native vegetation. Remnant vegetation was also found to contain the highest species richness and abundance in the study conducted by Collard *et al*. (2011) which assessed bird communities across row-planted Old Man Saltbush, cleared pasture and remnant native vegetation. Importantly, the authors found significantly higher bird species richness and abundance in saltbush plantings compared to agricultural land, however, as also noted by Seddon *et al.* (2009), this assemblage was composed largely of generalist species. This preliminary research suggests saltbush plantings are likely to serve as habitat for a select suite of bird species most capable of exploiting these areas, mirroring the pattern established in tree-based monocultures (Hobbs *et al.* 2003, Loyn *et al.* 2007).

1.6 Research directions

The existing body of research examining bird communities within saltbush plantings is comprised of studies following a trend identical to many studies evaluating the effectiveness of tree-based plantings to support fauna that is a focus on simple measures of species presence or absence (Ruiz-Jaen and Mitchell Aide 2005, Lindell 2008). With regard to birds, such measures do not explain why some sites are used more than others or why some species are found within plantings while others are not (Ruiz-Jaén and Aide 2005, Morrison *et al.* 2010). Furthermore, these measures fail to provide detail on whether the bird species present reside within the planted vegetation, use it as supplementary habitat, or are simply transient species moving through the landscape.

Behavioural studies examining the ecology of individual species are highly valuable and yield far more detailed information on the use of planted areas, yet remain deficient in the current literature (Doerr *et al.* 2006, Lindell 2008). Studying the behavioural and habitat use patterns of individual birds allows comparisons of habitat quality within home ranges and between plantings and reference sites. Furthermore, these studies uncover reasons for differences, highlight the importance of certain resources for individual species, elucidate preferences toward particular areas, identify how species contribute to ecosystem function and allow the contribution of factors such as adjacency to native remnant vegetation to be measured (Pomara *et al.* 2003, Ruiz-Jaén and Aide 2005, Morrison *et al.* 2010). Such findings are of far greater value to conservation planning than simple presence/absence measures as they highlight habitat characteristics in need of preservation in reserves and inclusion in the construction of effective habitats (Van Horne 1983, Vickery *et al.* 1992, Doerr *et al.* 2006). This more detailed and comprehensive research is required to fully determine the contribution saltbush plantings may make toward supporting bird communities in fragmented agricultural landscapes and the role these areas may play in broader conservation strategies.

1.7 Current research project

The work contained in this thesis evaluates the use of Old Man Saltbush plantings by native birds in the wheat/sheep agricultural landscapes of the northern Murray Mallee region of South Australia. I initially establish which bird species are regularly found in saltbush plantings before examining the detailed behavioural and spatial ecology of several commonly encountered birds. This research extends beyond the traditional presence/absence paradigm of previous research to show precisely how these birds use saltbush plantings relative to remnant native vegetation. The study provides a detailed analysis of foraging ecologies and behaviours, use of home ranges and habitat selection patterns. To further evaluate resources within saltbush plantings, invertebrate availability and vegetation structure are examined across home ranges. In addition to providing insight into avian dynamics, this extends the research to three trophic levels, dramatically improving the assessment of the habitat value of saltbush plantings (Elmqvist *et al.* 2003, Dorren *et al.* 2004, Ruiz-Jaén and Aide 2005, Ruiz-Jaen and Mitchell Aide 2005). By analysing saltbush plantings relative to remnant native vegetation and agricultural land, this investigation provides an accurate estimate of the ability of plantings to support avian biodiversity in fragmented agricultural landscapes (Hobbs and Norton 1996, Passell 2000, Purcell *et al.* 2002).

Within this context, the overarching aim of this thesis is to determine whether plantings of Old Man Saltbush provide habitat and resources to birds in the highly fragmented agricultural landscapes of the South Australian Murray Mallee. The thesis comprises seven chapters, four of which are data chapters presented in the style of manuscripts. The first manuscript (Chapter 3) has been accepted for publication in *Australian Field Ornithology*, with the remaining three to be submitted in due course.

The chapter following this introduction (Chapter 2) details the climate, topography and history of the South Australian Murray Mallee study region, describes the focal bird species; the White-browed Babbler (*Pomatostomus superciliosus*), Variegated Fairy-wren (*Malurus lamberti*) and Chestnut-crowned Babbler (*P. ruficeps*), and outlines the overall design of the study. This is followed by the first data chapter (Chapter 3), the aim of which was to determine which bird species are commonly found in saltbush plantings by assessing bird abundance and species richness trends across remnant native vegetation with adjacent saltbush plantings, isolated remnant native vegetation, isolated saltbush plantings and previously vegetated land that has been cleared and is now under cropping or pasture treatments. Chapter 4 examines precisely how the focal bird species use saltbush plantings relative to remnant vegetation by examining their behaviour and foraging ecologies within each habitat. An examination of the patterns of spatial use displayed by the focal bird species while foraging (Chapter 5) follows, the specific aim of which was to determine the degree to which the focal bird species forage within saltbush plantings relative to remnant vegetation and identify habitat elements which drive spatial use and foraging patterns by examining the size and configuration of home ranges and vegetative differences between intensely foraged and unused areas. The last data chapter (Chapter 6) investigates prey distribution and abundance with the aim of determining the influence of invertebrate prey availability on differential patterns of spatial use displayed by the focal bird species by comparing prey availability between intensely foraged and unused areas and between saltbush and remnant vegetation. The final chapter, the general discussion (Chapter 7), completes the thesis. This concluding chapter provides an in depth discussion of the key findings of the thesis and their contribution to our understanding of avian use of saltbush plantings. Management implications are then discussed on the basis of this investigation, complemented by directions for further research.

Chapter 2 Study Region and Focal Bird Species

Plate 2.1. View of the surrounding agricultural landscape looking south-east from an isolated saltbush planting near Wanbi, South Australia. Photo: T. Richards.

2.1 The South Australian Murray Mallee

This study took place in the northern Murray Mallee region of South Australia (Figure 2.1), located approximately 200 km east of Adelaide, east of Swan Reach (34° 57' S, 139° 57' W), between Waikerie (34° 18' S, 139° 99' W) and Billiatt Conservation Park (35° 01' S, 140° 39' W). The region is characteristic of southern Australian broadacre wheat/sheep agricultural zones, having experienced wide-scale vegetation clearance during the 20th century (Foulkes and Gillen 2000). The present landscape is characterised by large tracts of cleared land interspersed with small patches of remnant vegetation dominated by mallee eucalypts, primarily *Eucalyptus incrassata, E. oleosa,* and *E. socialis* and understorey species of

Melaleuca, *Acacia*, *Exocarpos* and *Callitris* (Specht 1972, Foulkes and Gillen 2000). *Mallee* is an Australian Aboriginal term which refers to the multi-stemmed low trees and tall shrubs which define this habitat (Specht 1981).

2.1.1 Indigenous History

Indigenous occupation of the Murray Mallee is believed to be between 40 and 50 thousand years (Harris 1990 in Foulkes and Gillen 2000). Prior to European settlement, the Murray Mallee was occupied by two main Aboriginal groups; the Ngarkat who occupied much of the study region south and east of the Murray River and the Ngintait who occupied an area to the east of the Murray Mallee. Three smaller clans of the Ngarranjiri were also present in the area west of the river (Foulkes and Gillen 2000).

2.1.2 European History

Charles Sturt was the first European to enter the Murray Mallee during his 1829/30 expedition navigating the River Murray (Harris 1989 in Foulkes and Gillen 2000). The region was considered unsuitable for farming until the 1840s when the Western Murray Flats near the River Murray were taken up under annual occupational licences. During the 1850s these licences were cancelled and land was owned under either freehold or pastoral lease. The mallee east of the River Murray was first used for pastoral leases following the proclamation of hundreds in 1870 (Potter *et al.* 1973 in Foulkes and Gillen 2000).

2.1.3 Vegetation clearance

The Counties and Hundreds Proclamation Act (1870) initiated subdivision of land east and west of the River Murray for agricultural development, triggering extensive vegetation clearance. However large scale clearance was facilitated by the construction of the Adelaide to Melbourne railway in the 1880s. In the eight years following the completion of the line, some 461 978 acres were cleared (Foulkes and Gillen 2000). The extension of the railway to Paringa in 1913 and Loxton in 1914 provided access to the northern Murray Mallee, resulting in further vegetation clearance. Excessive clearance lead to severe wind erosion in the 1930s, a process not combated until the end of World War II when suitable crop rotations and dune stabilisation measures were introduced (Foulkes and Gillen 2000). Advances in machinery during this time resulted in further widespread losses of remnant vegetation (Foulkes and Gillen 2000), a trend which continued into the latter half of the 20th century.

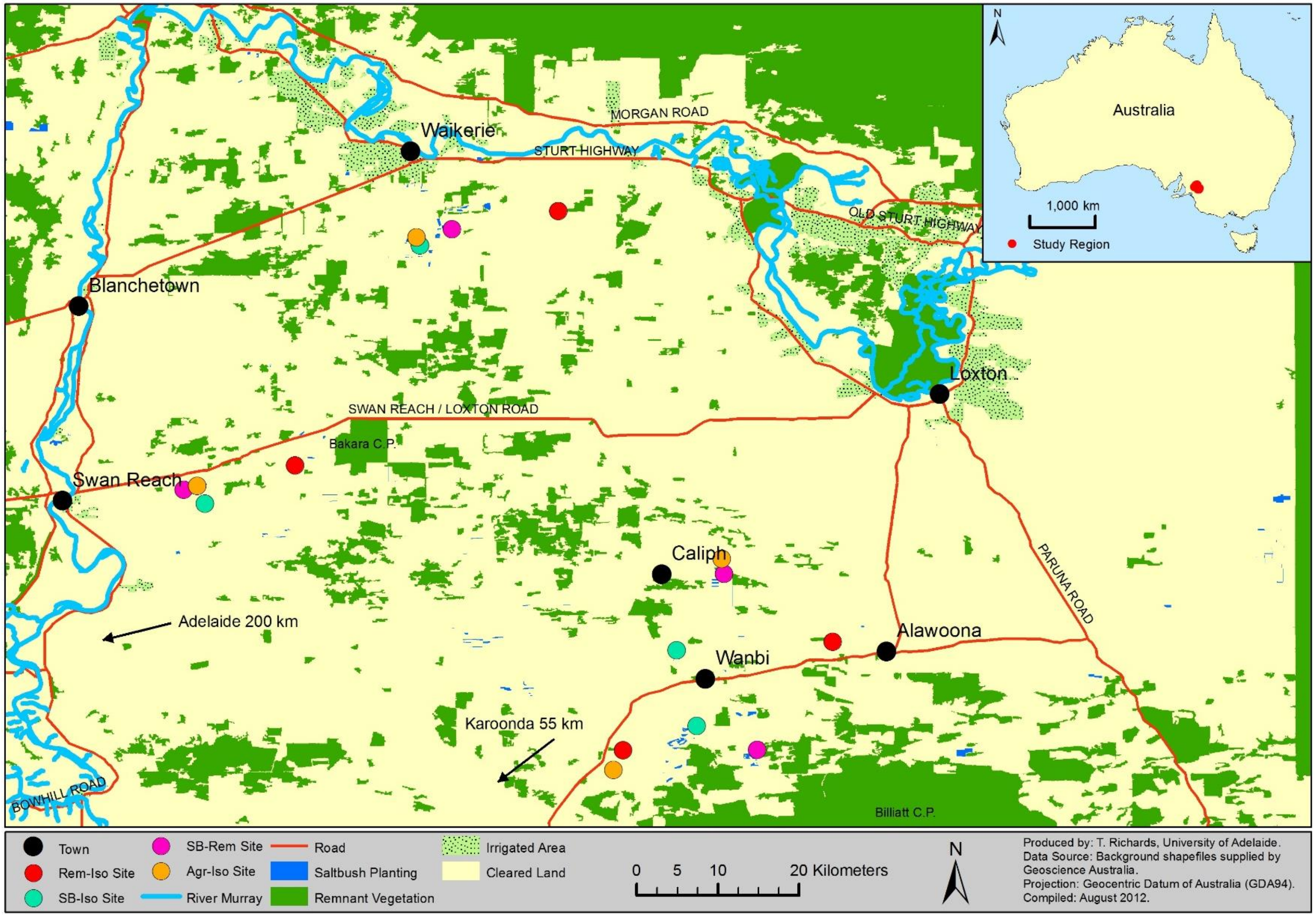


Figure 2.1. The study region and site locations (n = 16) in the South Australian Murray Mallee.

2.1.4 Climate and Topography

Climatically, the Murray Mallee experiences warm to hot summers (mean maximum 31.1 °C), cool to cold winters (mean maximum 16.2 °C) and highly variable diurnal and seasonal temperatures (Figure 2.2). Rainfall occurs mainly between May and September with an annual fall of between 250 and 300 mm. Rainfall was markedly higher at times across the study period, particularly during December 2010 (Figure 2.3). Topographically, soils form ridges of more coarse sand and shallow valleys occasionally containing sandy loams (Prescott and Piper 1932, Newell 1961). Soils are principally sandy with no heavy clay and are derived from fluviatile and lacustrine beds overlying marine tertiary deposits (Foulkes and Gillen 2000).

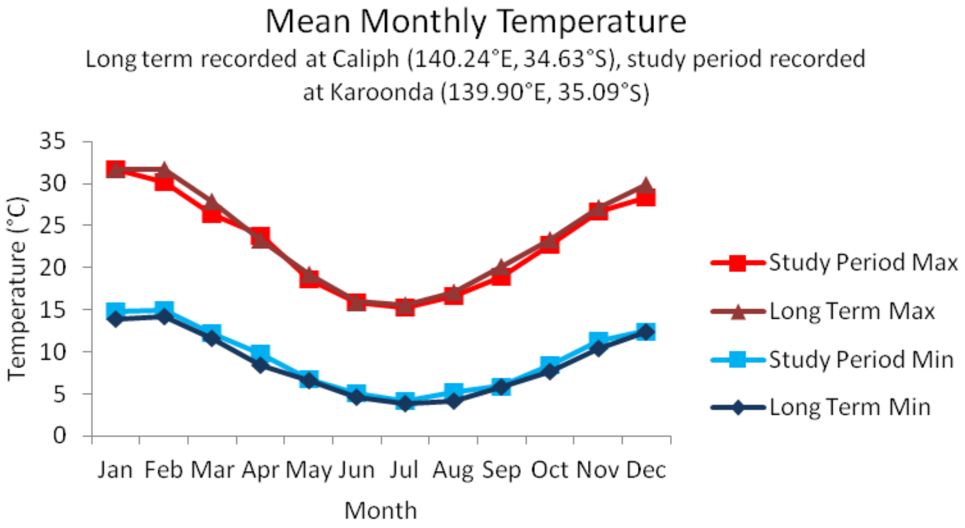


Figure 2.2. Mean monthly temperature maxima and minima across the study period (2010 to 2012) recorded at Karoonda and long term (1974 to 2003) recorded at Caliph (Bureau of Meteorology 2010).

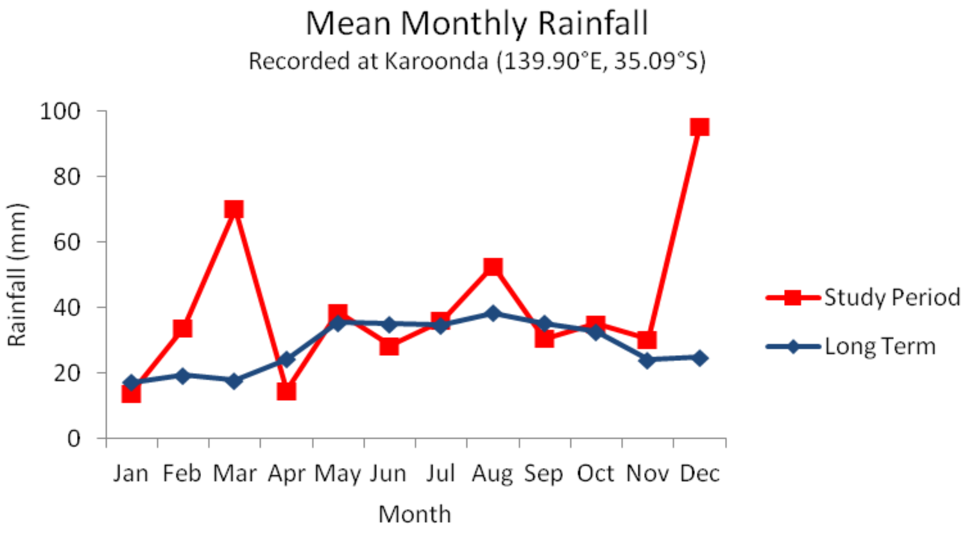


Figure 2.3. Mean monthly rainfall across the study period (2010 to 2012) and the long term (1914 to 2012) recorded at Karoonda (Bureau of Meteorology 2010).

2.2 Focal bird species

The White-browed Babbler (*Pomatostomus superciliosus*, Plate 2.2) and Variegated Fairy-wren (*Malurus lamberti*, Plate 2.3) were selected as focal species for chapters four, five and six as both species were frequently recorded in saltbush plantings and showed the greatest site fidelity (Chapter 3). In addition, these species are sedentary and have relatively small home ranges (Cale 1999, Higgins and Peter 2002a, Higgins and Peter 2002b, Taylor 2003), making them ideal candidates for study. At one isolated saltbush site, a group of Chestnut-crowned Babblers (*P. ruficeps*, Plate 2.4) was studied in place of White-browed Babblers due to an absence of the latter species.

2.2.1 White-browed Babbler

Plate 2.2. White-browed Babbler (*Pomatostomus superciliosus*). Photo: E. Hoffmann.

The White-browed Babbler is a relatively small (40 g) gregarious native passerine endemic to Australia and widespread across the southern mainland (Higgins and Peter 2002a). The other four species comprising the genus are the Australian endemic Chestnut-crowned Babbler (*P. ruficeps*) and Hall's Babbler (*P. halli*) and the Grey-crowned Babbler (*P. temporalis*) and Rufous Babbler (*P. isidori*), found in Australia and New Guinea and endemic to New Guinea respectively (Bell 1982, Higgins and Peter 2002a). Plumage is brown above with white underparts and a characteristic white stripe above the eye. The bill is black and curved downward while the tail is long and fan shaped with white outer retrices (Taylor 2003) (Plate 2.2). Sexes are similar with no seasonal variation (Higgins and Peter 2002a).

The species occurs across mainland Australia below 20° south latitude, west of the Great Dividing Range to Western Australia (Taylor 2003). Below this latitude the species is absent only from the south-eastern coast, south-western coast and Tasmania (Cale 1999). In South Australia the species is widespread except for Kangaroo Island and areas north of Lake Eyre

(Possingham and Possingham 1997, Higgins and Peter 2002a). Predominant habitats include dry sclerophyll woodlands, shrublands and open forests (Possingham and Possingham 1997). The species if often found in mallee shrublands and woodlands dominated by *Eucalyptus* species with low to tall shrub understorey of *Acacia*, *Cassia*, *Banksia*, *Grevillea*, *Hakea* and *Callitris* (Higgins and Peter 2002a).

The White-browed Babbler diet consists predominantly of invertebrates, largely of the order *Coleoptera*, with occasional seeds and fruit (Morris and Wooller 2001, Higgins and Peter 2002a). Foraging occurs throughout the day mainly on the ground by probing and gleaning leaf litter and fallen timber (Antos and Bennett 2006, Taylor and Paul 2006, Antos *et al.* 2008) but also low branches of shrubs and trees (Recher and Davis 1997, Recher and Davis 1998, Miller and Cale 2000).

White-browed Babblers live in groups of up to 15 which support one breeding pair and occupy a mutually exclusive home range during the breeding season which expands to overlap the territories of other groups during the non-breeding season (Cale 1999, Taylor 2003). Groups are largely sedentary and occupy home ranges from one year to the next (Cale 2003). Breeding occurs primarily between June and December with one to six eggs laid in large, dome-shaped nests located in low trees or shrubs, often in the centre of shrubs or crowns of trees in dense foliage of horizontal branches (Higgins and Peter 2002a). A number of nests are constructed by all group members across their home range for breeding and roosting (Higgins and Peter 2002a). Both nest types are generally well lined with fur, grass and feathers (Beruldsen 1980). All nests are constructed of tightly woven sticks and are very sturdy, often remaining in place for years after abandonment (Cale 1999).

2.2.2 Variegated Fairy-wren

Plate 2.3. Adult male Variegated Fairy-wren (*Malurus lamberti*) with breeding plumage. Picture: bushpea.com.

The Variegated Fairy-wren is a very small (7-8 g) gregarious species endemic to mainland Australia. The species is sexually dimorphic with adult breeding males are characterised by a black breast and hind-neck collar combined with blue cap, mantle and back while females are grey-brown all year (Higgins and Peter 2002b) (Plate 2.3). Non-breeding males are similar to females. The species occupies a wide distribution, mainly in the semi-arid and arid zones, but also temperate, subtropical and tropical zones. In South Australia the species is widespread except for the South-East, Fleurieu Peninsula, Mount Lofty Ranges and Kangaroo Island (Higgins and Peter 2002b). Variegated Fairy-wrens are strongly associated with the understorey of mallee woodlands, dense thickets with or without overstorey species and chenopod shrublands (Possingham and Possingham 1997, Higgins and Peter 2002b). The species feeds predominantly by gleaning insects from the foliage of understorey shrubs and lower parts trees. Foraging also occurs in leaf litter and bare ground at the base of low shrubs and among short and tall grasses (Tibbetts and Pruett-Jones 1999). In intact chenopod shrublands, Variegated Fairy-wrens spend most of their time foraging in the lower portion of dense shrubs (Tibbetts and Pruett-Jones 1999, Tidemann 2004). Family groups are typically composed of a female, a dominant male and several subordinate birds (Rowley and Russell 1997). Groups are highly sedentary and exhibit strong site fidelity from one year to the next (Higgins and Peter 2002b). Breeding occurs between August and December with clutches of three to five eggs laid in nests located close to the ground often in the centre of low shrubs (Tidemann and Marples 1987, Higgins and Peter 2002b).

2.2.3 Chestnut-crowned Babbler

Plate 2.4. Chestnut-crowned Babbler (*P. ruficeps*). Picture: birdlife.org.au.

The Chestnut-crowned Babbler is a medium sized (55 g) native passerine endemic to inland south-eastern Australia (Higgins and Peter 2002a). The species is slightly larger than the White-browed Babbler and is characterised by a broad chestnut cap, slim white brow, double white wing-bars on the upper wing and a white underside (Plate 2.4). Sexes are similar with no seasonal variation (Higgins and Peter 2002a). Chestnut-crowned Babblers are found from southern Queensland across western New South Wales to eastern South Australia. Within South Australia, the species has been recorded as far north as Cooper Creek (Wyndham 1978) but is mainly distributed east of the Mount Lofty Ranges from Leigh Creek in the north through the Murray Mallee to Lameroo in the south (Higgins and Peter 2002a). The species occupies areas with more bare ground and sparser tree cover than the White-browed Babbler, mainly low arid and semi-arid woodland and shrublands, usually with scattered dense or tall shrubs (Higgins and Peter 2002a). An association with open mallee woodlands and shrublands with an understorey of large domed shrubs one to two metres tall dominated by *Acacia*, *Cassia*, *Grevillea* and *Hakea* with and understorey of *Triodia* and *Acacia* shrublands has been documented (Higgins and Peter 2002a). Foraging occurs predominantly on the ground by digging in soil to extract invertebrates with occasional ventures into trees and shrubs, similar to the White-browed Babbler (Goodwin 1967). Chestnut-crowned Babblers are highly gregarious all year with groups of up to 13 birds, however these can amalgamate to form groups of 20 to 30 (Portelli *et al.* 2009). Breeding occurs cooperatively within groups of two to 13 from late winter to early summer (July to November) with up to two broods per season (Russell *et al.* 2010). Clutch sizes vary between two and five and are laid in nests high in trees or shrubs (Higgins and Peter 2002a, Russell *et al.* 2010).

2.3 Study Sites

2.3.1 Study design

Sixteen sites were selected as study sites from an original 20 identified from aerial photography (supplied by Rural Solutions South Australia, dated February 2009) after ground-truthing. The study sites represented four replicates of each of four treatments (Figure 2.4); remnant native vegetation with adjacent saltbush plantings (SB-Rem, Plate 2.5), isolated remnant native vegetation (Rem-Iso, Plate 2.6), isolated saltbush plantings (SB-Iso, Plate 2.7) and cleared agricultural land (Agr-Iso, Plate 2.8), a design derived from comparable studies of tree-based monoculture plantings (e.g. Hobbs *et al.* 2003, Loyn *et al.* 2007, Smith 2009a, Smith 2009b).

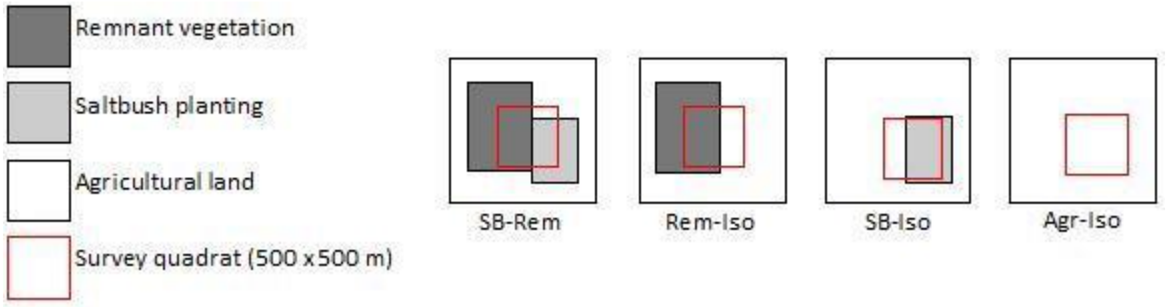


Figure 2.4. Study design consisting of four treatments; remnant native vegetation with adjacent saltbush plantings (SB-Rem), isolated remnant vegetation (Rem-Iso), isolated saltbush plantings (SB-Iso) and cleared agricultural land (Agr-Iso). Survey quadrats were used in Chapter 3 only.

2.3.2 Vegetation composition

Remnant native vegetation (SB-Rem and Rem-Iso sites) was dominated by *Eucalyptus incrassata*, *E. oleosa* and *E. socialis* with sparse to very sparse sub-canopy and shrub layers composed of *Melaleuca*, *Acacia* and *Triodia* species with minimal herbaceous and grassy groundcover (Specht 1972, Foulkes and Gillen 2000). All remnant vegetation had been subjected to grazing, however the practice had ceased between the 1970s and 1990s in remnant vegetation at all Rem-Iso sites and the SB-Rem site in landscape four. Subsequently shrub layers and groundcovers were well developed at these sites. By contrast, remnant vegetation at SB-Rem sites in landscapes one, two and three were almost entirely devoid of shrub-level and groundcover vegetation due to continued grazing (Table 2.1).

Saltbush plantings (SB-Rem and SB-Iso sites) were established in the 1990s and were exclusively row-planted Old Man Saltbush (*Atriplex nummularia nummularia*). Rows were evenly spaced at 4-5 m with individual plants spaced at 3-4 m. Areas between saltbush rows were sparsely covered in groundcover consisting of introduced grasses and weeds. Plantings were placed on sandy soils and dunes crests in an effort to stabilise these areas. Saltbush plantings generally had a very dense shrub layer from ground level to 2-3 m. Individual plants ranged from spreading, dome-shaped structures 2-2.5 m in radius to small, thinly foliated plants less than 1 m tall. All saltbush plantings except that at the SB-Rem site in landscape three were grazed at least once during the study with most grazed one to two times per year (Table 2.1).

Agricultural land (all sites) consisted of pasture (introduced grasses), fallow fields (weeds) or wheat crops. During summer and autumn, pasture sites were covered in dry grassy vegetation between 0.1 m and 0.2 m high, while in winter and spring these sites featured heavy cover by grasses and weeds up to 0.4 m high. Wheat sites were largely bare during the drier seasons except for a thin, patchy covering of 0.15 m tall stubble standing in rows approximately 0.2 m apart. During spring (prior to harvest) these sites were covered in 0.5-1 m tall wheat crops, also with 0.2 m row spacing.

Table 2.1. Grazing management, condition and size of remnant native vegetation patches, size of saltbush plantings and isolation distance (distance to nearest remnant vegetation) at each of the 16 study sites.

Site	Grazing Management	Remnant Native Vegetation Condition	Remnant Area (ha)	Saltbush Area (ha)	Isolation Distance (m)
SB-Rem LS1	Saltbush and remnant grazed	Very little understorey, disturbed groundcover and leaf litter	45.87	47.25	320
SB-Rem LS2	Saltbush and remnant grazed	Some understorey and leaf litter	81.72	47.25*	517
SB-Rem LS3	Saltbush ungrazed, remnant grazed	Very little understorey, disturbed groundcover and leaf litter	78.01	5.87	420
SB-Rem LS4	Saltbush grazed, remnant grazing ceased in 1970s	Well structured understorey, high leaf litter cover, some groundcover	582.87	12.76	460
Rem-Iso LS1	Grazing ceased 1980s	Well structured understorey, high leaf litter cover, some groundcover	362.54	0.00	624
Rem-Iso LS2	Grazing ceased 1970s	Some understorey and leaf litter	64.85	0.00	310
Rem-Iso LS3	Grazing ceased 1990s	Some understorey and leaf litter, little groundcover	112.09	0.00	2010
Rem-Iso LS4	Grazing ceased 1970s	Well structured understorey, high leaf litter cover, high groundcover	211.24	0.00	3716
SB-Iso LS1	Saltbush and nearest remnant grazed	Some understorey and leaf litter	20.25	10.92	150
SB-Iso LS2	Saltbush and nearest remnant grazed	Very little understorey, disturbed groundcover and leaf litter	11.07	40.40	1976
SB-Iso LS3	Saltbush ungrazed during study	Very little understorey, disturbed groundcover and leaf litter	82.96	36.06	760
SB-Iso LS4	Saltbush grazed	Some understorey and leaf litter, little groundcover	290.81	52.09	1427
Agr-Iso LS1	Ungrazed (cropped)		0.00	0.00	460
Agr-Iso LS2	Ungrazed (cropped)		0.00	0.00	954
Agr-Iso LS3	Ungrazed (cropped)		0.00	0.00	1295
Agr-Iso LS4	Pasture grazed		0.00	0.00	1710

*SB removed during early summer 2011

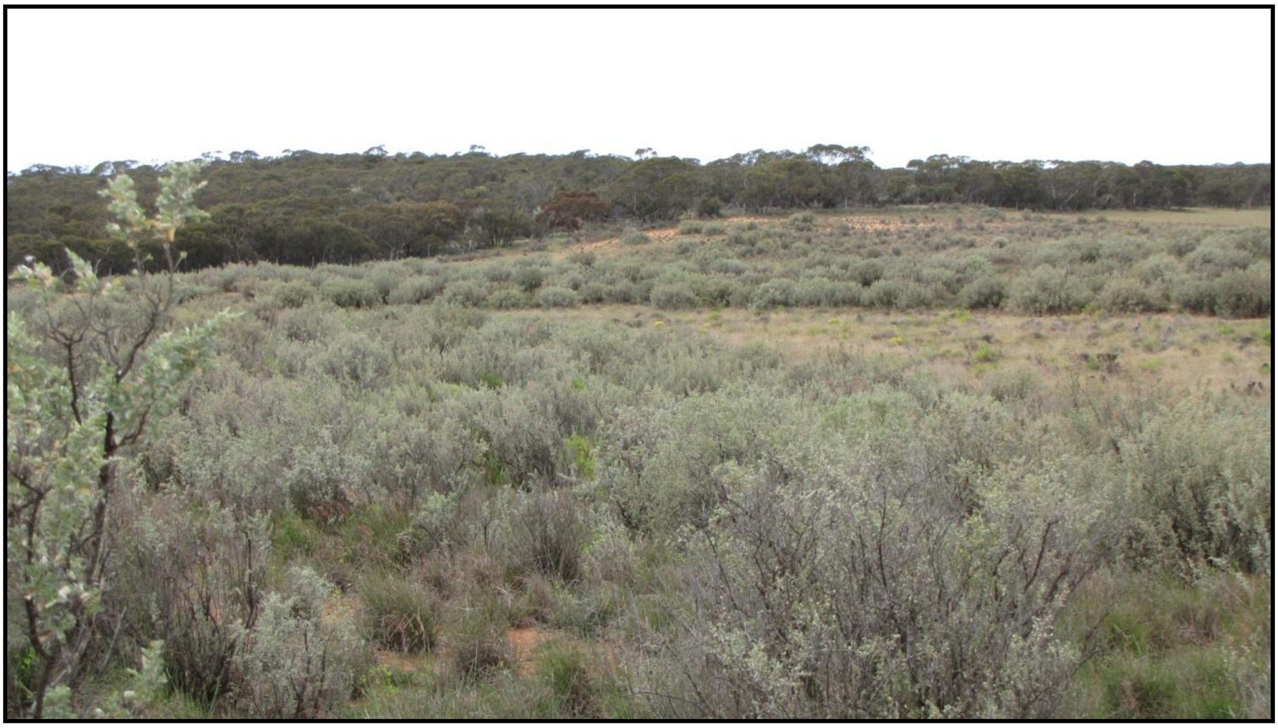


Plate 2.5. The remnant native vegetation site with adjacent saltbush (SB-Rem) in landscape four during spring 2012. Photo: T. Richards.

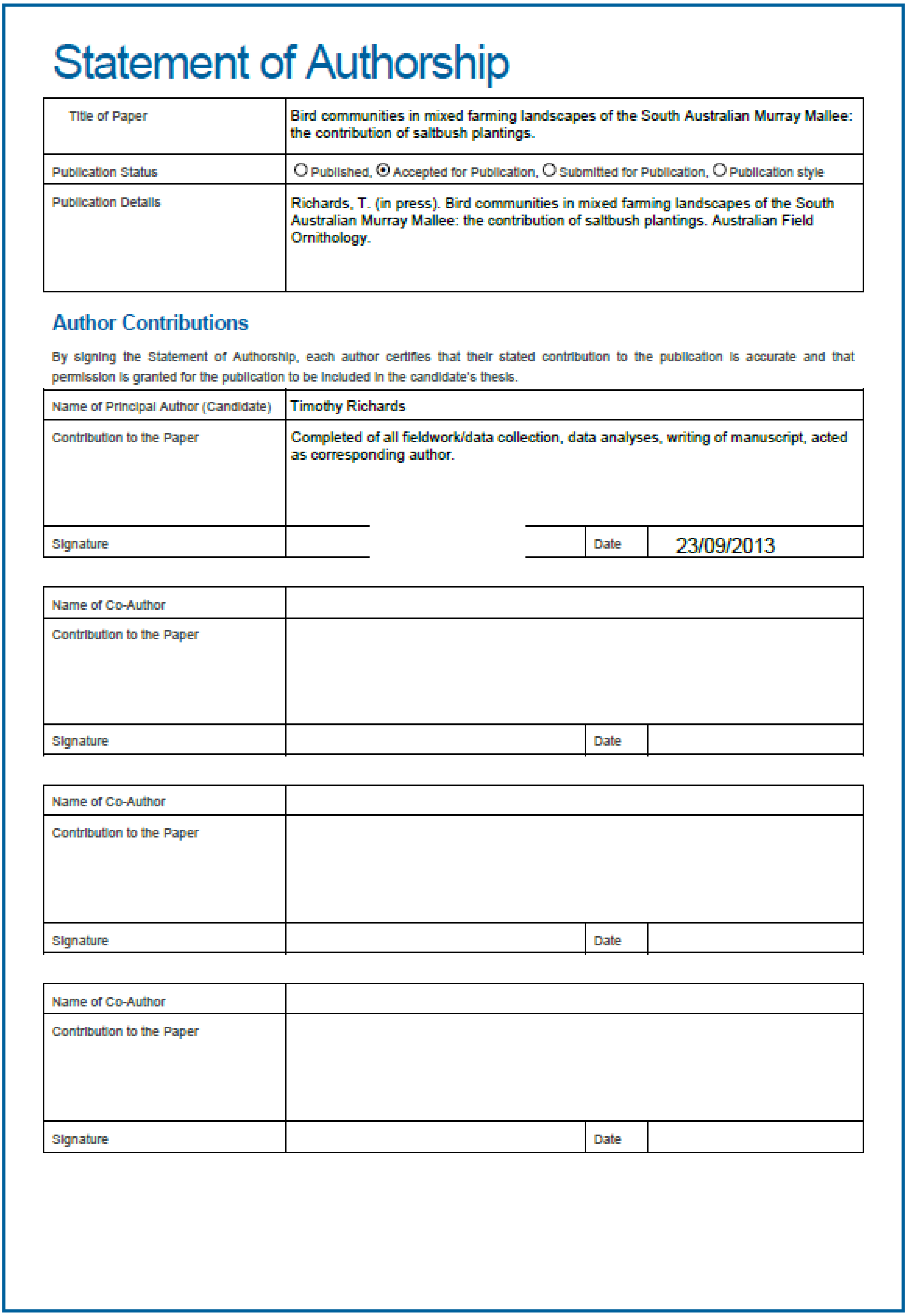
Plate 2.6. The isolated remnant native vegetation site (Rem-Iso) in landscape four during spring 2011. Photo: T. Richards.

Plate 2.7. The isolated saltbush site (SB-Iso) in a wheat cropping landscape one during spring 2012. Photo: T. Richards.

Plate 2.8. The wheat cropland site (Agr-Iso) in landscape two showing the same site during spring 2011 before harvest (left) and autumn 2012 after harvest (right). Photos: T. Richards.

Chapter 3 Bird communities in mixed farming landscapes of the South Australian Murray Mallee: the contribution of saltbush plantings.

Plate 3.1. View of planted saltbush adjacent to remnant native vegetation facing north-east near Wanbi, South Australia. Photo: T. Richards.



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Author Contributions

By signing the Statement of Authorship, each author certifies that their stated contribution to the publication is accurate and that permission is granted for the publication to be included in the candidate's thesis.

Name of Principal Author (Candidate)	Timothy Richards		
Contribution to the Paper	Completed of all fieldwork/data collection, data analyses, writing of manuscript, acted as corresponding author.		
Signature		Date	23/09/2013

Name of Co-Author			
Contribution to the Paper			
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of the thesis held in the University of Adelaide Library.

Chapter 4 Using saltbush plantings: foraging by birds in plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) in fragmented agricultural landscapes.

Plate 4.1. Rows of ungrazed saltbush representing key foraging structure for birds in an isolated saltbush planting near Waikerie, South Australia. Photo: T. Richards

4.1 Abstract

Agriculturally induced land clearance is a major cause of biodiversity loss worldwide. Conserving populations of fauna in highly fragmented landscapes is dependent on developing elements of agricultural systems which can serve biodiversity as well as production. In recent decades, plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) have been established in the marginal farming regions of southern Australia to supplement stock fodder.

This vegetation is increasingly recognised as potential habitat for native fauna. This study explored how birds use saltbush plantings by examining the behaviour and foraging ecology of three bird species; White-browed Babblers (*Pomatostomus superciliosus*), Variegated Fairy-wrens (*Malurus lamberti*) and Chestnut-crowned Babblers (*P. ruficeps*), in the saltbush and patches of remnant native vegetation in the South Australian Murray Mallee. The foraging ecologies of White-browed and Chestnut-crowned Babblers broadly resembled their behaviour in natural habitats, with high foraging plasticity enabling them to forage extensively in both saltbush plantings and remnant vegetation. Variegated Fairy-wrens were found solely within plantings and also showed foraging plasticity by adjusting their behaviour seasonally. The highly plastic and well suited foraging ecologies of these three species enable them to forage extensively within saltbush plantings, however White-browed and Chestnut-crowned Babblers remain reliant on remnant vegetation. On their own, plantings of saltbush are unlikely to aid the persistence of these birds in the longer-term, however when combined with other conservation measures such as restoration of remnants, revegetation and other forms of perennial monocultures will contribute to biodiversity conservation in broadacre farming regions. When establishing saltbush plantings, landholders should consider placing plantings in close proximity to remnant vegetation to encourage birds to forage within them. Enhancing structural diversity within saltbush plantings by locating them around isolated trees, interspersing plantings with other native shrub and tree species and adding important foraging substrates such as fallen timber will provide a greater suite of resources to birds foraging in them.

4.2 Introduction

The intimate dependency of the human population on agro-ecological landscapes to secure food supplies has driven habitat conversion on a scale greater than any other human enterprise (Ehrlich 1993, Vitousek *et al.* 1997). The resultant widespread loss and fragmentation of habitat and subsequent declines in fauna have received substantial attention (Robinson 1993, Saunders and Ingram 1995, Ford *et al.* 2001, Attwood *et al.* 2009), however our understanding of landscapes which support both agricultural production and biodiversity remains poor (Morton *et al.* 2009). Developing this understanding is a fundamental ecological issue as biodiversity conservation becomes increasingly reliant on supporting native wildlife in human modified landscapes (Vandermeer and Perfecto 1997, Law and

Dickman 1998, Scherr and McNeely 2008), and one which will be exacerbated by the indeterminate effects of climate change (Howden *et al.* 2008).

Restoring vegetation with revegetation aimed at replicating pre-clearance habitats has traditionally been the primary means to support native fauna in agricultural landscapes (Hobbs *et al.* 1993, Recher 1993a, Paton *et al.* 2004, Johnson *et al.* 2007). However, the extent of these efforts remains constrained by a number of factors relating to cost and trade-offs between production and conservation (Recher and Lim 1990, McNeely and Schroth 2006, Bhagwat *et al.* 2008, Mac Nally 2008). This has lead many researchers to advocate perennial monoculture plantings of native trees and shrubs as a means to increase the percentage of woody vegetation in severely fragmented agricultural landscapes and boost landscape connectivity (e.g. Bennett *et al.* 2000, Lindenmayer and Hobbs 2004, McNeely 2004, Schroth and Harvey 2007, Brockerhoff *et al.* 2008).

In the highly fragmented agricultural zones of the South Australian Murray Mallee, plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) have been established to serve as a fodder reserve to be drawn upon during drier periods (Lefroy 2002, Collard and Fisher 2010). Saltbush plantings allow higher stocking rates and decrease feed costs while reducing salinity and erosion (Monjardino *et al.* 2010, Lancaster *et al.* 2012), benefits which have lead to the establishment of over 7000 ha of saltbush in this region over the past two decades (Lancaster *et al.* 2012). This increase in vegetative cover in these severely fragmented landscapes has lead a number of researchers to suggest saltbush plantings may provide shelter and resources for native fauna, aiding the persistence of a range of native bird species (e.g. Lefroy and Smith 2004, Lefroy *et al.* 2005, Collard and Fisher 2010).

Studies evaluating the benefits that saltbush plantings may provide to birds have generally focused on simple measures of species presence or absence (e.g. Seddon *et al.* 2009, Collard *et al.* 2011) (Chapter 3). These measures are unable to determine precisely how birds use plantings, the resources that can be obtained, explain why some sites are used more than others or whether individual birds found within plantings are residents or transients (Ruiz-Jaén and Aide 2005, Morrison *et al.* 2010).

By contrast, studies examining the behaviour and foraging ecology of individual species yield far more detailed information on the use of planted areas, yet are rarely undertaken in perennial monocultures (Doerr *et al.* 2006, Lindell 2008). Studying the behaviour, particularly the foraging patterns, of individual birds reveals ways in which they exploit resources and identifies habitat features key to survival (Recher *et al.* 1985, Weikel and Hayes 1999, Sierro *et al.* 2001, Pomara *et al.* 2003). Furthermore, these studies can reveal insights into the organisation of bird assemblages, elucidate preferences toward particular areas, identify how species contribute to ecosystem function and allow the effects of landscape factors such as adjacency to native remnant vegetation to be assessed (Recher and Davis 1997, Miller and Cale 2000, Pomara *et al.* 2003, Ruiz-Jaen and Mitchell Aide 2005, Morrison *et al.* 2010). Such findings are of greater value to conservation planning than simple presence/absence measures as they highlight habitat characteristics in need of preservation in existing habitats and that need to be included in restoration efforts (Van Horne 1983, Vickery *et al.* 1992, Doerr *et al.* 2006, Lindell 2008).

This study examines the behaviour, foraging ecology and substrates used by three bird species in saltbush plantings and remnant vegetation in the northern Murray Mallee, South Australia. These habitats differ strongly in vegetation structure; saltbush plantings consist solely of Old Man Saltbush with only shrub-level vegetation while remnants are largely devoid of understorey but have higher floristic diversity resulting in more complex sub-canopies and canopies (see Chapter 2 for full description). The information gained in this investigation provides guidance to better manage saltbush plantings for birds and enhance the contribution they can make toward sustaining populations in fragmented agricultural landscapes.

4.3 Methodology

4.3.1 Study sites

The study took place from September 2011 to November 2012 across eight sites in the northern Murray Mallee, South Australia (see Chapter 2 for detailed description). Sites comprised two ungrazed isolated remnant patches (Rem-Iso), three grazed isolated saltbush plantings (SB-Iso) and three grazed remnant patches with adjacent grazed saltbush plantings (SB-Rem) (Table 4.1). The canopy of remnant vegetation at Rem-Iso and SB-Rem sites was composed predominantly of *Eucalyptus incrassata*, *E. oleosa* and *E. socialis* (Specht 1972, Foulkes and Gillen 2000). The sub-canopy and shrub layers were sparse to very sparse and largely composed of *Melaleuca*, *Acacia* and *Triodia* species with minimal groundcover. All remnants were grazed by sheep historically, with those at SB-Rem sites still subjected to sheep grazing. Saltbush plantings were all at least 10 years old and featured an evenly spaced, row-planted shrub layer of *Atriplex nummularia nummularia* with no trees. Groundcover within plantings consisted of a variety of introduced grasses and weeds. All sites were surrounded by cleared land used for cereal crops or grazing.

4.3.2 Selection of target bird species

White-browed Babbler (*Pomatostomus superciliosus*) and Variegated Fairy-wren (*Malurus lamberti*) were selected as target species as they were repeatedly recorded (highest incidence) in saltbush plantings during surveys described in Chapter 3. Mist nets were used to capture individuals of these species present at sites during August 2011 (Table 4.1). Attempts were made to capture all individuals of a group but failing this banding was considered sufficient if at least one member of the group was captured and colour-banded. In most instances several were marked. One group of White-browed Babblers could not be captured and therefore remained unbanded. At one SB-Iso site an unbanded group of Chestnut-crowned Babblers (*P. ruficeps*) was observed in place of White-browed Babblers due to an absence of the latter species.

4.3.3 Foraging observations

Observations of foraging ecology were made by tracking colour-banded groups of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers at sites where each was present (Table 4.1). Sites were visited at fortnightly intervals on three occasions during September to November (spring) 2011, March to May (autumn) 2012 and September to October (spring) 2012.

As all three bird species forage throughout the day (Tidemann 2004, Taylor and Paul 2006, Portelli *et al.* 2009), tracking took place between dawn and dusk over two tracking periods; morning (dawn to midday) and afternoon (12:30 pm to dusk). During the first two visits, a different bird group was tracked during each period, with this order reversed for the second visit. Tracking during the third visit took place over the whole day, focusing solely on White-browed Babblers. Therefore, each group of White-browed Babblers were followed for a minimum of two half days and one full day each season while each group of Variegated Fairy-wrens and Chestnut-crowned Babblers were followed for a minimum of two half days.

Table 4.1. Composition of bird groups present at study sites (WBB = White-browed Babbler, VFW = Variegated Fairy-wren, CCB = Chestnut-crowned Babbler). Group size (no. of individuals) and number of colour-banded birds within each group are also shown. Remnant area at SB-Iso sites refers to size of nearest patch of remnant native vegetation. Blank areas indicate the group was absent.

Site	Remnant Area (ha)	Saltbush Area (ha)	Bird Group	Colour-banded Individuals	Group Size		
					Spr 2011	Aut 2012	Spr 2012
Rem-Iso LS2	64.85	0.00	WBB7	3	9	6	
Rem-Iso LS4	211.24	0.00	WBB1	1	9		
			WBB2	6	6	7	8
SB-Rem LS1	45.87	47.25	WBB3	4	6	4	2
			VFW1	1	6	6	4
SB-Rem LS2	81.72	47.25*	WBB5	3	7		
			WBB6	1	14	10	11
SB-Rem LS4	582.87	12.76	WBB8	9	9	7	9
			VFW5	9	10	10	
SB-Iso LS1	20.25	10.92	WBB4	0	5	2	
			VFW3	4	6	6	3
SB-Iso LS2	11.07	40.40	CCB4	0	15	15	13
			VFW4	7	7	7	
SB-Iso LS4	0.00	52.09	VFW6	8	8	5	6

*SB removed during early summer 2011

Bird groups were located by systematic searches and following calls. Upon locating a bird group, tracking commenced once at least one colour banded bird had been identified with records taken of all birds in the group. Unbanded groups were the sole occupants of their sites and thereby allowed correct identification.

When recording behaviour, preference was given to colour-banded individuals, however on most occasions several birds were observed simultaneously. At times when groups spread over a larger area, I directed my recording efforts towards areas where the majority of members were located. Records consisted of group number, individual colour-band combination (if banded), behaviour, foraging manoeuvre (adapted from Recher *et al.* 1985), food (if viewed) and substrate (Table 4.2). In addition, records were taken of plant species/genus, height (estimated to the nearest 0.1 m) and the location of the observed bird (the plant used or position on the ground) as a waypoint on a handheld global positioning system (GPS). Records and waypoints were recorded each time a bird moved to a different plant or further than 10 metres if on the ground. Records and locations were taken continuously while tracking to capture infrequent or subtle behaviours and reduce bias toward more conspicuous manoeuvres (Recher *et al.* 1985, Cale 1999, Miller and Cale 2000).

Group membership each season was defined as individuals that foraged together as a group and moved through the home range together. Individuals were counted as they moved continuously together through the home range to determine group size. Where birds mixed with other groups at home range boundaries, observations were made of colour banded birds only with unbanded birds considered once the two groups had separated.

Table 4.2. Variables recorded for each individual bird observed during group tracking. Behaviour and substrate were recorded on all occasions while foraging manoeuvre and food were recorded when observed.

Behaviour	Foraging Manoeuvre	Food	Substrate
Not recorded	Probe/Prize	Invertebrate	Not recorded
Perch	Pounce/Sally	Fruit	Ground
Forage	Glean/Hang-glean	Seed	Foliage
Hop	Hover	Mammal	Branch
Call	Hawk	Amphibian	Dead branch
Preen		Reptile	Trunk
Fly		Unidentified	Fallen timber
Chase			Nest
Roost			Wire/Fence
			Brushpile
			Other (water trough, road, etc)

Manoeuvre Definitions (derived from Recher *et al.* 1985)

Probe/Prize	Bird extracts prey from substrate with or without lifting part of substrate
Pounce/Sally	Bird flies from perch to take prey from nearby substrate before returning to different perch
Glean/Hang-glean	Standing or hopping bird takes prey from nearby substrate
Hover	Bird hovers while taking prey from a substrate
Hawk	Bird flies from perch to take flying insect

4.3.4 Data analysis

Count data were converted to percentages to reduce the sensitivity of analyses and account for variation in the total number of observations between bird groups and seasons. Chi-square (χ^2) tests using SPSS vers. 19.0 (SPSS Inc. Chicago, IL) with a significance level of 0.05 were used to test for significant differences in percentage use of behaviours and foraging substrates, manoeuvres and heights by individual groups of each bird species in each vegetation type (saltbush planting or remnant vegetation) across seasons. In addition, seasonal data were analysed separately to determine whether White-browed Babblers foraged differently in saltbush compared to remnant vegetation (data from all groups pooled) and whether individual groups differed. Seasonal data were also analysed separately to test for differences between Variegated Fairy-wren groups and between saltbush plantings and remnant vegetation among the Chestnut-crowned Babbler group. Categories with expected counts less than five were pooled, except when comparing manoeuvres which were made only between probing and gleaning as very few records were made of others.

4.4 Results

In total, 31 967 behavioural observations were obtained, of which 17 475 were of foraging birds. The largest number of observations were obtained for White Browed Babblers (22 361 total, 12 667 foraging), followed by Variegated Fairy-wrens (6 685 total, 3 747 foraging) and Chestnut-crowned Babblers (2 921 total, 1 061 foraging). One White-browed Babbler group could not be relocated during autumn 2012 and another four were absent during spring 2012 along with two Variegated Fairy-wren groups (Table 4.1). The cause of these absences could not be determined and as a result data were analysed only for bird groups present during at least the first two seasons.

4.4.1 White-browed Babbler

Foraging was the dominant behaviour in both saltbush plantings and remnant vegetation during each season among White-browed Babblers (Figure 4.1) and occurred predominantly on the ground in the leaf litter (Figure 4.2 and Figure 4.3). The majority of White-browed Babbler groups showed significant seasonal differences in percentage use of behaviours, foraging substrates, manoeuvres and heights in both saltbush plantings and remnant vegetation (Table 4.3). Percentage use of behaviours differed significantly between bird groups in both saltbush plantings and remnant vegetation during all seasons except spring 2011 in saltbush only (χ^2 = 6.17, d.f. = 9, P = 0.063). Percentage use of foraging substrates and heights was also significantly different between all bird groups in both saltbush and remnant vegetation during each season.

When saltbush plantings and remnant vegetation were compared directly (group data pooled), percentage use of behaviours was significantly different during all seasons except spring 2011 (χ^2 = 7.72, d.f. = 3, P = 0.052, Table 4.3). Use of substrates differed significantly between vegetation types during spring 2011 (χ^2 = 22.32, d.f. = 5, P <0.001) and 2012 (χ^2 = 15.75, d.f. = 3, P = 0.001) while foraging heights were significantly different during all seasons. The use of foraging manoeuvres was more consistent, differing significantly between vegetation types only during spring 2012 (χ^2 = 11.05, d.f. = 1, P = 0.001).

4.4.2 Variegated Fairy-wren

Variegated Fairy-wrens were recorded foraging during the largest percentage of observations; especially during spring 2011 and 2012 (Figure 4.1). Foraging took place predominantly on branches within the 0.3-0.9 m height range (Figure 4.2 and Figure 4.3) and all groups showed seasonal fluctuations in behaviour (Table 4.3). The use of foraging substrates and heights varied considerably among Variegated Fairy-wrens with significant differences between groups each season and seasonal differences among all but one group (Table 4.3).

4.4.3 Chestnut-crowned Babbler

The group of Chestnut-crowned Babblers showed significantly different use of behaviours in saltbush compared to remnant vegetation during all seasons (Figure 4.1, Table 4.3). Similarly to White-browed Babblers, Chestnut-crowned Babblers foraged mainly in leaf litter on the ground in saltbush plantings and remnant vegetation (Figure 4.2 and Figure 4.3); however the percentage use of foraging substrates and heights differed significantly between vegetation types during both spring and autumn 2012.

Table 4.3. Results of Chi-square tests of independence on percentage use of behaviours, foraging substrates, manoeuvres and heights by White-browed Babblers, Variegated Fairy Wrens and Chestnut-crowned Babblers during spring 2011 (Spr 2011), autumn 2012 (Aut 2012) and spring 2012 (Spr 2012). Comparisons of percentage use of behaviours, foraging substrates, manoeuvres and heights were made between seasons, bird groups in saltbush (SB) and remnant (R) vegetation separately and between saltbush and remnant vegetation overall. Data collected during spring 2011, autumn 2012 and spring 2012.

Species	Comparison between:	Behaviour			Substrate			Manoeuvre			Height		
		χ^2	d.f.	*p*	χ^2	d.f.	*p*	χ^2	d.f.	*p*	χ^2	d.f.	*p*
White-browed Babbler	Seasons - bird group 2 (R)	5.14	4	0.273	56.66	4	<0.001	26.26	2	<0.001	63.38	4	0.018
	Seasons - bird group 3 (R)	14.80	6	0.022	31.03	4	<0.001	1.26	2	0.532	18.59	4	0.001
	Seasons - bird group 3 (SB)	24.45	6	<0.001	54.35	4	<0.001	20.62	2	<0.001	15.91	2	<0.001
	Seasons - bird group 4 (SB)	29.52	6	<0.001	7.30	2	0.026	0.95	1	0.329	0	1	1
	Seasons - bird group 6 (R)	19.10	6	0.004	20.33	4	<0.001	15.18	2	0.001	25.26	4	<0.001
	Seasons - bird group 7 (R)	8.91	3	0.031	5.98	2	0.05	0.11	1	0.744	3.46	4	0.177
	Seasons - bird group 8 (R)	9.59	6	0.143	78.97	4	<0.001	98.61	2	<0.001	58.57	4	<0.001
	Seasons - bird group 8 (SB)	29.52	6	<0.001	43.27	4	<0.001	2.98	2	0.226	36.53	2	<0.001
	Groups in R - Spr 2011	20.21	18	0.035	118.43	10	<0.001	11.55	5	0.042	59.03	5	<0.001
	Groups in SB - Spr 2011	16.17	9	0.063	86.37	6	<0.001	20.29	5	<0.001	33.61	3	<0.001
	Groups in R - Aut 2012	42.03	12	<0.001	32.92	8	<0.001	24.99	4	<0.001	29.70	8	<0.001
	Groups in SB - Aut 2012	22.29	6	0.001	12.85	6	0.045	7.38	3	0.061	41.49	6	<0.001
	Groups in R - Spr 2012	64.67	9	<0.001	182.07	6	<0.001	198.67	3	<0.001	160.19	3	<0.001
	Groups in R - Spr 2012	30.63	3	<0.001	71.46	2	<0.001	8.67	1	0.003	3.53	1	0.06
	Vegetation types - Spr 2011	7.72	3	0.052	7.23	2	0.027	0.13	1	0.724	22.32	5	<0.001
	Vegetation types - Aut 2011	12.36	3	0.006	5.58	2	0.275	0.57	1	0.451	18.83	3	<0.001
	Vegetation types - Spr 2012	21.55	3	<0.001	8.63	2	0.013	11.05	1	0.001	15.75	3	0.001
Variegated Fairy-wren	Seasons - Group 1	31.13	4	<0.001	65.26	6	<0.001				13.72	4	0.008
	Seasons - Group 3	60.97	4	<0.001	3.17	6	0.787				7.25	4	0.123
	Seasons - Group 4	43.38	2	<0.001	13.35	3	0.004				12.85	2	0.002
	Seasons - Group 5	41.92	6	<0.001	22.22	3	<0.001				32.32	2	<0.001
	Seasons - Group 6	19.59	6	0.003	43.98	6	<0.001				45.91	4	<0.001
	Bird groups - Spr 2011	10.24	8	0.249	85.07	12	<0.001				31.724	8	<0.001
	Bird groups - Aut 2012	13.18	8	0.106	80.91	12	<0.001	5.51^	4	0.239	30.112	8	<0.001
	Bird groups - Spr 2012	24.83	4	<0.001	58.60	6	<0.001				23.377	4	<0.001
Chestnut-crowned Babbler	Vegetation types - Spr 2011	10.16	3	0.017	9.45	2	0.009	0.65	1	0.421	0.31	1	0.579
	Vegetation types - Aut 2012	46.92	3	<0.001	37.60	2	<0.001	111.20	1	<0.001	40.50	1	<0.001
	Vegetation types - Spr 2012	30.08	3	<0.001	7.02	2	0.018	11.61	1	0.001	6.95	1	0.008

χ^2: Pearson Chi-square

d.f: Degrees of freedom

p : Probability (0.05 significance)

^Analysis conducted across all groups concurrently due to expected counts of <5 for probing among all groups

*Significant at the *p* <0.05 level

**Significant at the *p* <0.01 level

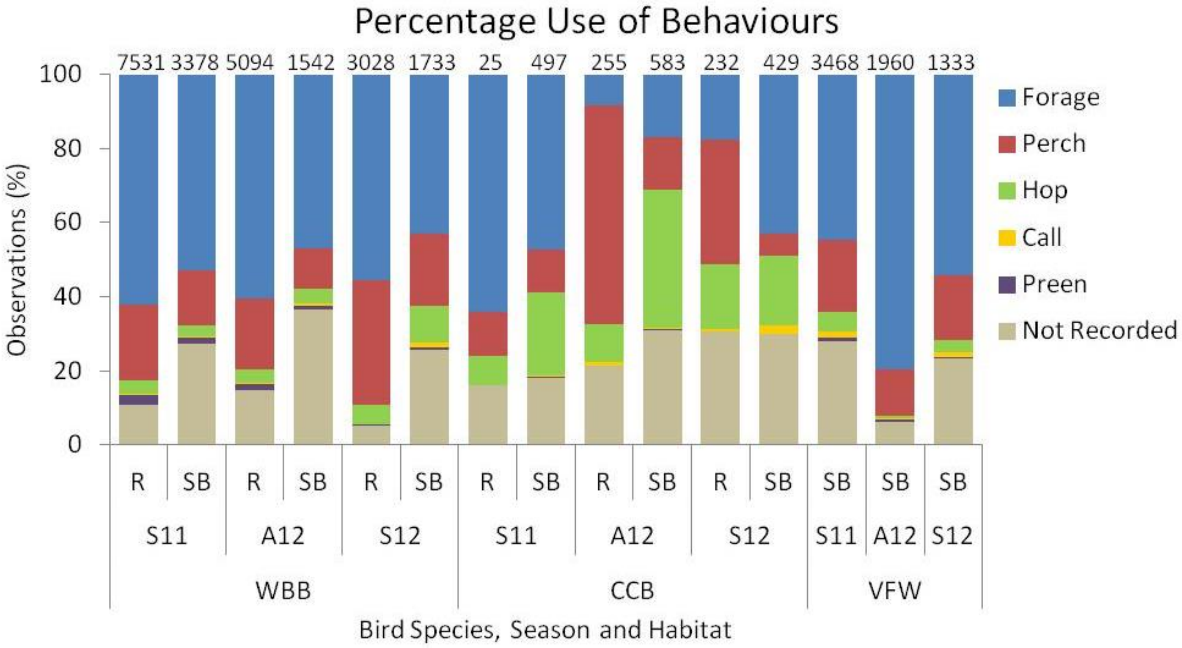


Figure 4.1. Percentage use of behaviours by White-browed Babblers (WBB), Chestnut-crowned Babblers (CCB) and Variegated Fairy-wrens (VFW) in remnant (R) and saltbush (SB) vegetation during spring 2011 (S11), autumn 2012 (A12) and spring 2012 (S12). Total number of observations shown above each column.

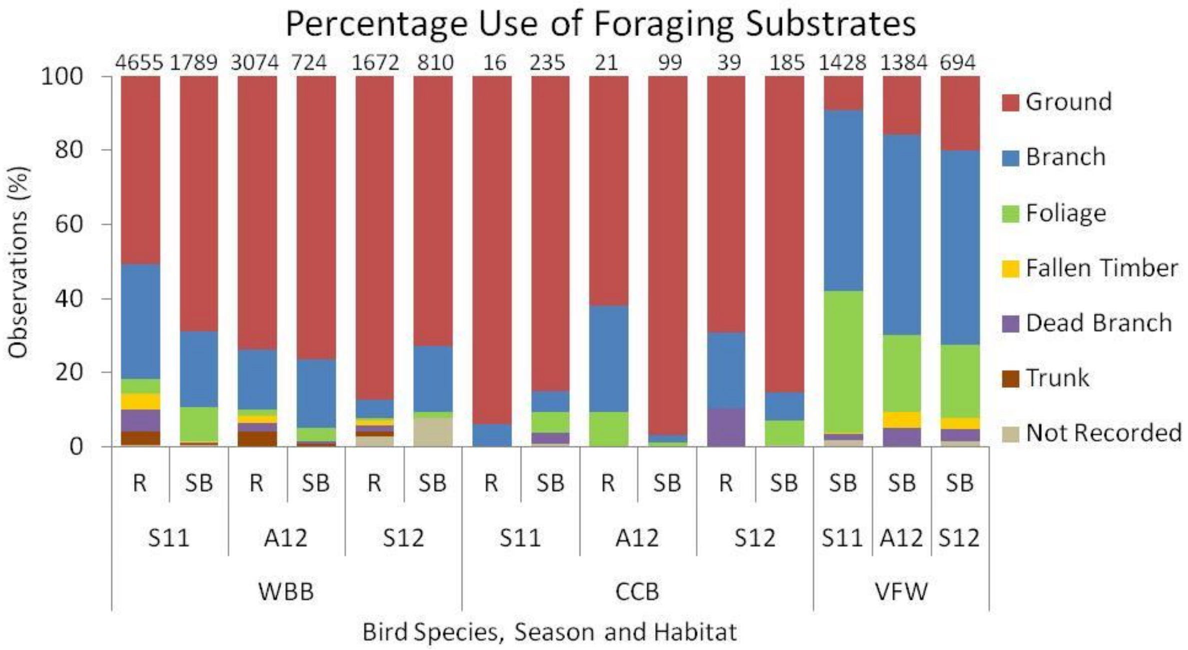


Figure 4.2. Percentage use of foraging substrates by White-browed Babblers (WBB), Chestnut-crowned Babblers (CCB) and Variegated Fairy-wrens (VFW) in remnant (R) and saltbush (SB) vegetation during spring 2011 (S11), autumn 2012 (A12) and spring 2012 (S12). Total number of observations shown above each column.

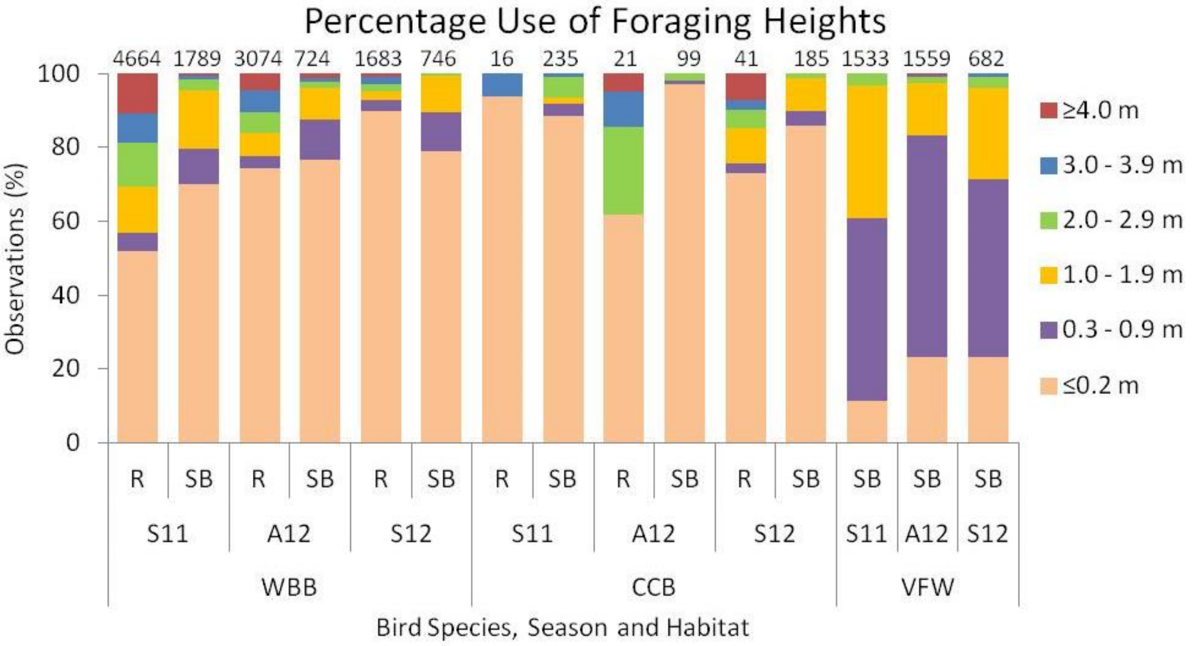


Figure 4.3. Percentage use of foraging heights by White-browed Babblers (WBB), Chestnut-crowned Babblers (CCB) and Variegated Fairy-wrens (VFW) in remnant (R) and saltbush (SB) vegetation during spring 2011 (S11), autumn 2012 (A12) and spring 2012 (S12). Total number of observations shown above each column.

4.5 Discussion

In many southern Australian agricultural landscapes, perennial shrub plantings are promoted as foraging habitat for a range of bird species (Lefroy and Smith 2004, Lefroy *et al.* 2005, Collard and Fisher 2010). This study has shown plantings of Old Man Saltbush can provide foraging habitat for three bird species, however for two of these, remnant vegetation remains crucial to their survival through its importance for foraging, nesting and cover.

The broad foraging patterns of White-browed and Chestnut-crowned Babblers were similar across all sites. Foraging was the predominant behaviour and occurred throughout the day. The babblers foraged mainly by probing leaf litter on the ground, mirroring the foraging ecologies of White-browed Babblers in natural woodlands (Recher and Davis 1998, Morris and Wooller 2001, Antos and Bennett 2006) and shrublands (Woinarski 1989, Recher and Davis 1997, Brooker 1998) and Chestnut-crowned Babblers in natural chenopod shrublands (Portelli *et al.* 2009). The general behaviour of Variegated Fairy-wrens was similar among bird groups, which foraged predominantly on branches in the lower section of saltbushes.

This behaviour again closely resembled that documented in natural chenopod systems where the species is naturally found (Tidemann 1990, Tibbetts and Pruett-Jones 1999, Tidemann 2004).

Despite these general foraging trends, all species showed significant differences in the use of behaviours, foraging substrates and heights at a range of levels. Nearly all groups of White-browed Babblers and Variegated Fairy-wrens showed significant seasonal variation in use of saltbush plantings and, among babblers only, remnant vegetation. Food availability is a major driver of foraging patterns (Hutto 1990) and temporal changes in prey abundance are commonly reflected in avian foraging patterns (Ford *et al.* 1990). Both Cale (1999) and Taylor (2003) found White-browed Babblers shifted from foraging in litter in winter to fallen logs and foliage respectively in response to increased invertebrate abundances on these substrates during spring. Variegated Fairy-wrens are also known to modify their foraging ecology in response to changes in food availability (Tidemann 2004). Seasonal abundances of invertebrates were not assessed during this study, yet fluctuations in prey abundance are likely to account for the seasonal shifts in foraging exhibited by all three bird species.

This study found White-browed Babblers foraged over a broader suite of substrates at a wider range of heights in remnant vegetation compared to saltbush plantings, leading to significant differences between the two habitats. The vast differences in vegetation structure between saltbush plantings and remnant vegetation (Chapter 2) are likely to underpin the variation in foraging ecology in several ways. Firstly, vegetation structure has a fundamental influence on the composition and distribution of invertebrate communities (Lawton 1983, Johnson 2000, Johnson 2007). Saltbush plantings had very low structural diversity as they consisted of a single plant species planted at regular intervals in rows. This contrasted sharply with the diverse floristic and structural complexity of remnant vegetation (Chapter 2). The strong correlation between vegetation complexity and invertebrate diversity is well established (Murdoch *et al.* 1972, Southwood *et al.* 1979, Lawton 1983) and may mean a reduced suite of invertebrates occur within the more homogeneous saltbush plantings. In addition, Woinarski and Cullen (1984) found marked differences in invertebrate composition between *Eucalyptus* and non-*Eucalyptus* plant species, a factor they concluded would have a profound effect on birds. Taken together, these relationships may mean the less complex saltbush plantings contain a reduced or different selection of invertebrates compared to remnant vegetation, forcing White-browed Babblers to restrict their foraging ecologies in response to changed food resources (Miller and Cale 2000).

Vegetation structure is also a key determinant of the ability of birds to detect and capture prey (Hutto 1990, Wolda 1990, Whelan 2001). Cale (1999) attributed differences in foraging by White-browed Babblers between *Allocasuarina* and mixed shrublands in part to differences in the detectability and availability of invertebrates on the different shrub structures. The substantially different vegetation structures of saltbush plantings compared to remnant vegetation could similarly affect the success of foraging attempts on different substrates and at different heights, contributing to the differences in White-browed Babbler foraging ecology between the two habitats.

Vegetation structure may be further linked to the differences in the use of foraging substrates and heights by White-browed Babblers between saltbush plantings and remnant vegetation through substrate availability. Antos and Bennett (2006) found significant differences in the use of foraging substrates by ground-feeding woodland birds between different woodlands which they attributed to structural differences in the vegetation. The authors concluded that the availability of different substrates reflected the degree to which they were used. This is supported in the present study as White-browed Babblers foraged over a considerably broader suite of substrates at a greater range of heights in the more structurally complex remnant vegetation.

Dissimilarities in vegetation structure and concomitant invertebrate communities may also explain why White-browed Babbler groups and Variegated Fairy-wren groups tended to differ significantly from one another in how they foraged in saltbush and, for babblers, also remnant vegetation. The size and density of saltbushes varied substantially between plantings with some consisting of small, sparsely foliated shrubs and others containing large, densely foliated plants (Chapter 2). Similarly, the structural composition of remnants differed between sites with several lacking understorey species due to heavy degradation from grazing and others containing a suite of regenerating plants. Plant architectural complexity is strongly correlated with invertebrate diversity (Lawton 1983) which is likely to fluctuate with these differences in vegetation structural complexity. The reduced structural complexity in some saltbush plantings and grazed remnants may therefore represent habitats with reduced invertebrate diversity, causing the birds to respond by adjusting their foraging ecologies (Miller and Cale 2000).

The high variation in foraging displayed by White-browed and Chestnut-crowned Babblers between saltbush plantings and remnant vegetation suggests they are adjusting their foraging ecology in response to differences in vegetation structure and resource availability to forage successfully within both habitats. The foraging ecologies of ground-associated species are broad and largely determined by habitat characteristics and, although not measured in this study, prey availability (Wheeler and Calver 1996, Recher *et al.* 2002). Foraging plasticity among White-browed Babblers in response to vegetation structure and prey availability has been documented in a range of habitats. Cale (1999) found White-browed Babblers were able to respond to spatial and temporal changes in food availability by using different substrates in fragmented remnants. Similarly, he also found this plasticity enabled babblers to continue to acquire sufficient food under disturbance from grazing. Taylor (2003) and Antos and Bennett (2006) attributed the abilities of babblers to forage over a wide variety of substrates in different woodlands to their inherently plastic foraging ecology.

Foraging plasticity was also evident among Variegated Fairy-wrens through the different foraging patterns of each group. This species is tolerant of a variety of conditions in natural systems (Tidemann *et al.* 1989, Tidemann 2004), suggesting the differences between groups are in response to dissimilarities between saltbush plantings. In addition to their foraging plasticity, the behaviour of Variegated Fairy-wrens was very similar to that documented in chenopod shrublands in which they are naturally found (Tidemann 1990, Tibbetts and Pruett-Jones 1999, Tidemann 2004). Chestnut-crowned Babblers also foraged in similar ways to their natural habitat (Portelli *et al.* 2009). These similarities indicate the foraging ecologies of the two species translate well to exploiting saltbush plantings.

This study has shown plantings of Old Man Saltbush can provide substantial foraging habitat for White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers. The highly plastic and inherently suitable foraging ecologies of these species make them well suited to exploiting planted vegetation and hence they commonly occur in saltbush plantings (Chapter 3). Bird species with more specialised foraging requirements are less likely to find foraging opportunities and adequate resources within saltbush plantings and will therefore remain confined to the more heterogeneous remnant vegetation (Seddon *et al.* 2009, Collard *et al.* 2011) (Chapter 3). Even highly adaptable White-browed and Chestnut-crowned Babblers are heavily reliant on remnant vegetation, not only for foraging, but also for the construction and location of nests. The addition of saltbush plantings alone may not support native birds in these landscapes, as demonstrated by the disappearance of several groups over the course of this study. This is a familiar conclusion of studies of a variety of perennial monocultures (e.g. Hobbs *et al.* 2003, Loyn *et al.* 2007, Seddon *et al.* 2009) and one which highlights the need for a combination of monocultures, mixed species revegetation and remnant protection and restoration in order to support bird populations and production in broadacre agricultural landscapes (Fisher and Goldney 1998, Bennett *et al.* 2000, McNeely 2004, Watson *et al.* 2005).

In terms of managing saltbush plantings for birds, adjusting the timing and intensity of grazing regimes to confine the defoliation of saltbushes to precise areas within plantings will maintain some intact areas for birds to use. This mosaic-grazing could be further facilitated by interspersing plantings with other native shrub species which vary in grazing tolerance (Lancaster *et al.* 2012). A greater diversity of plant species in saltbush plantings will also boost structural diversity, as has been suggested for plantings of Australian Sandalwood (*Santalum spicatum*) (see Smith *et al.* 2012), improving the suite of foraging resources for birds (Barton *et al.* 2009, Barton *et al.* 2011). When establishing plantings, locating them in areas adjacent to remnant vegetation to reduce the gaps between remnants to within the 1100 m dispersal threshold suggested by Doerr *et al.* (2010) will allow birds to move between the habitats and encourage additional species to forage within plantings (Brooker and Brooker 2002, Chapter 3). Further spatial context considerations such as placing plantings in configurations to connect isolated remnants, therefore enhancing functional connectivity are also of high importance (Lancaster *et al.* 2012).

The present study highlights the different ways birds forage in habitat of varying structural complexity. Fluctuations in habitat structure and food availability, either separately or together, almost certainly underpin these patterns. Further research investigating the spatial patterns at which birds forage within saltbush and remnant vegetation is required to identify habitat factors associated with foraging activity. Combining these investigations with an assessment of invertebrate communities and their availability across saltbush plantings and remnant vegetation will determine the influence of these factors on bird foraging. This will enable the formulation of more detailed management options to enhance the contribution saltbush plantings can make to supporting native fauna.

Chapter 5 Cover is crucial: Spatial patterns of foraging birds in planted saltbush and remnant vegetation are driven by shrub-level cover.

Plate 5.1. Saltbush plantings adjacent to remnant vegetation, habitats between which White-browed Babblers frequently moved near Wanbi, South Australia. Photo: T. Richards.

5.1 Abstract

Efforts to conserve biodiversity affected by agricultural expansion and intensification are increasingly reliant on supporting populations in landscapes crucial for food production. In the South Australian Murray Mallee, plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) are established to provide additional stock fodder but can also serve as supplementary foraging habitat for a suite of birds. Of these, White-browed Babblers

(*Pomatostomus superciliosus*), Variegated Fairy-wrens (*Malurus lamberti*) and Chestnut-crowned Babblers (*P. ruficeps*) forage extensively in saltbush plantings but exhibit highly varied foraging patterns which differ from those used in remnant vegetation. The distribution of particular habitat elements may underpin these patterns and in turn influence the degree to which birds forage within saltbush plantings compared to remnant vegetation. This study examined the home ranges and activity patterns within home ranges of White-browed Babblers, Variegated Fairy-wren and Chestnut-crowned Babblers using saltbush plantings and remnant vegetation from September 2011 to November 2012. Factors driving patterns of spatial use were investigated by comparing habitat elements in frequently foraged areas and areas of no use. White-browed and Chestnut-crowned Babblers used saltbush plantings extensively but relied on remnant vegetation for the full suite of required resources at all sites. Variegated Fairy-wrens maintained small home ranges solely within saltbush plantings. All species showed a strong dependency on vegetation cover to escape predation and clearly selected to forage most frequently in areas with more shrub-level vegetation. A dependence on cover was the key driver of patterns of spatial use in both saltbush plantings and remnant vegetation among these birds. Saltbush plantings can provide substantial foraging habitat for these species, however the degree to which they are used is highly dependent on adequate vegetation cover. Within plantings, maintaining areas of dense vegetation by adjusting grazing regimes and interspersing plantings with native *Melaleuca*, *Acacia* and *Exocarpos* shrub species will provide increased cover for foraging birds and broaden the suite of available resources. Saltbush plantings can provide a limited contribution to conservation in agricultural landscapes and will best serve native fauna when established alongside other tree and shrub-based perennial monocultures and when combined with more direct conservation measures such as remnant protection and restoration and mixed species revegetation.

5.2 Introduction

Securing food supplies for the global human population is deeply reliant on agro-ecological landscapes (Howden *et al.* 2008). Agricultural expansion and the subsequent loss and fragmentation of habitat has caused dramatic biodiversity declines in these regions (Donald *et al.* 2001, Gaston *et al.* 2003, Green *et al.* 2005, Butchart *et al.* 2010). Despite continuing declines, recommendations for the maintenance of landscape connectivity and recovery of resident biota in agricultural zones remain deficient (Morton *et al.* 2009, Lancaster *et al.*

2012). Facilitating the persistence of wildlife while maintaining production in these areas remains a fundamental ecological issue, particularly when exacerbated by continuing species losses and the effects of climate change (Howden *et al.* 2008, Morton *et al.* 2009).

Traditionally, establishing revegetation aimed at replicating pre-clearance habitat on cleared land has been the primary approach to bolster reserve networks and support native fauna in fragmented agricultural zones (Hobbs *et al.* 1993, Recher 1993a, Paton *et al.* 2004, Johnson *et al.* 2007). However, the extent of these efforts continues to be constrained by lack of land and funding. This has lead many researchers to promote plantings of native perennial tree and shrub species as a more feasible means of providing habitat and resources to native species and boosting connectivity in extensively cleared farming landscapes (Lindenmayer *et al.* 2002, Hobbs *et al.* 2003, Brockerhoff *et al.* 2008, Smith 2008).

In the farming landscapes of the South Australian Murray Mallee, plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) have been established to serve as a fodder reserve for stock to be drawn upon when traditional sources are low (Lefroy 2002, Collard and Fisher 2010). These plantings allow increased stocking rates, reduce feed costs and ameliorate erosion and salinity (Monjardino *et al.* 2010), benefits which have resulted in substantial uptake of saltbush in recent decades (Lancaster *et al.* 2012). This increase in shrub-level vegetation in these extensively cleared landscapes has lead a number of authors to suggest saltbush plantings may also provide shelter and resources for a range of native bird species, supporting the persistence of regional populations (e.g. Lefroy and Smith 2004, Lefroy *et al.* 2005, Collard and Fisher 2010).

Preliminary research has documented a reduced suite of birds in saltbush plantings which is dominated by species with flexible resource requirements (Seddon *et al.* 2009, Collard *et al.* 2011) (Chapter 3). The White-browed Babbler (*Pomatostomus superciliosus*), Variegated Fairy-wren (*Malurus lamberti*) and Chestnut-crowned Babbler (*P. ruficeps*) are several of the species most commonly found in saltbush plantings whose highly adaptable and plastic ecologies enable them to forage extensively within these areas (Chapter 3 and Chapter 4).

However the foraging patterns of these birds are highly varied within both saltbush plantings and remnant vegetation and differ markedly between each habitat (Chapter 4).

Within their home ranges, animals inherently use space disproportionately and preference is often given to particular habitat features or core areas. Analysing these patterns of spatial use (termed utilisation distributions, Samuel *et al.* 1985, Orians and Wittenberger 1991) and comparing habitat features such as vegetation cover within core areas with non-core areas enables key habitat attributes and vegetation structures to be identified (Adams and Davis 1967, Marzluff *et al.* 2004, Barg *et al.* 2005).

For White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers, foraging is the dominant diurnal activity (Recher and Davis 1997, Higgins and Peter 2002a, Higgins and Peter 2002b, Tidemann 2004) (Chapter 4). Delineating core and non-core areas based on foraging activity enables identification of habitat attributes associated with particular foraging manoeuvres and the successful acquisition of food (Antos *et al.* 2008). Studying the home ranges and patterns of spatial use of these three species will aid in determining habitat elements essential for foraging, the distribution of which may underpin their foraging ecology and indeed the degree to which saltbush plantings are used relative to pre-existing native vegetation (Ryan and Jamieson 1998, Rhodes *et al.* 2005).

This study examines the home ranges and internal utilisation distributions of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers in saltbush plantings and remnant vegetation as dictated by their foraging movements. These two vegetation types differ strongly in structure; with saltbush plantings consisting solely of Old Man Saltbush with no trees and remnants largely devoid of understorey with higher floristic diversity generating more complex sub-canopies and canopies (see Chapter 2 for full description). By examining the size and configuration of home ranges and differences between intensely foraged and unused areas, this study aims to identify structural habitat elements which drive spatial use and foraging patterns and influence the degree to which birds forage in saltbush plantings relative to remnant vegetation.

5.3 Methodology

5.3.1 Study sites

The study was conducted between September 2011 and November 2012 across eight sites in the South Australian Murray Mallee (see Chapter 2 for detailed description). Study sites were those in which the study bird species had been most frequently observed during bird surveys described in Chapter 3. The eight sites were comprised of two isolated patches of ungrazed remnant native vegetation (Rem-Iso), three grazed isolated saltbush plantings (SB-Iso) and three grazed remnants with adjacent grazed saltbush plantings (SB-Rem), as shown in Table 5.1.

5.3.2 Colour-banding

I used mist nets to capture White-browed Babblers and Variegated Fairy-wrens at sites during August 2011. At one isolated saltbush site a group of Chestnut-crowned Babblers was colour-banded and observed in place of White-browed Babblers due to an absence of the latter species. Attempts were made to capture all individuals of a group but banding was considered sufficient if at least one member of the group was colour-banded, however in nearly all groups several individuals were marked.

5.3.3 Bird tracking

Tracking of colour-banded birds took place during visits conducted fortnightly on three occasions during each of three seasons; spring (September to November) 2011, autumn (March to May) 2012 and spring (September to November) 2012 (Table 5.1). As all three species forage throughout the day (Tidemann 2004, Taylor and Paul 2006, Portelli *et al.* 2009) (Chapter 4), tracking took place between dawn and dusk over two periods; morning (dawn to midday) and afternoon (12:30 pm to dusk). During the first two visits, a different bird group was tracked during each period, with this order reversed for the second visit. During the third visit tracking focused solely on White-browed Babblers for the entire day, resulting in a minimum of two half days and one full day of tracking for this species each season and two half days for Variegated Fairy-wrens and Chestnut-crowned Babblers.

Group membership each season was defined as individuals that foraged with one another and moved through the home range together (Taylor 2003). Individuals were counted as they moved continuously together through the home range to determine group size.

Tracking commenced upon locating a bird group and once at least one colour banded bird had been identified. Unbanded bird groups were the sole occupants of their sites, allowing their correct identification for tracking. Locations of observed birds (the plant or position on the ground) were recorded using a handheld Global Positioning System (GPS) in conjunction with behaviours described in Chapter 4. Preference was given to colour-banded individuals, however on most occasions several birds were observed simultaneously with waypoints and foraging records taken after each bird moved to a different plant or further than 10 metres if on the ground. At times when groups spread over a larger area, I directed my efforts towards areas where the majority of members were located. Occasionally colour banded bird groups mixed with other groups at home range boundaries. To ensure records were made of the correct group, observations were made of colour banded birds only with unbanded birds considered once the two groups had separated. Records and locations were taken continuously while tracking to capture infrequent or subtle behaviours and reduce bias toward the more conspicuous (Recher *et al.* 1985, Cale 1999, Miller and Cale 2000). In addition, continuously recording observations accounted for the continuous movement of groups through their home ranges, providing a more accurate representation of home range use (De Solla *et al.* 1999).

5.3.4 Home range and utilisation distribution estimation

Collecting location data continuously with short sampling intervals has been criticised for producing autocorrelated datasets (Swihart and Slade 1985, Harris *et al.* 1990). However when autocorrelation is eliminated, statistical power and the accuracy of home range analyses are reduced and biologically relevant information is lost (De Solla *et al.* 1999). Furthermore, Barg *et al.* (2005) argued independence should be defined biologically rather than statistically and this has minimal effect on home range area estimates (Andersen and Rongstad 1989, McNay *et al.* 1994). This is particularly relevant in the present study which defined patterns of spatial use through non-random movements which require autocorrelated data to sufficiently model (De Solla *et al.* 1999).

To account for autocorrelation, home range boundaries were calculated using 95 percent minimum convex polygons (MCPs) using the ArcMap (ArcGIS version 9.3, Environmental Systems Research Institute Inc.) extension Hawth's Analysis Tools (ver. 3.27, 2002-2006). Non-statistical methods such as MCPs are more appropriate for autocorrelated data than statistical home range estimates and become increasingly accurate with larger sample sizes collected over longer periods (Swihart and Slade 1985, De Solla *et al.* 1999), as was the case in the present study.

Utilisation distributions were delineated using the Point Density Spatial Analyst tool in ArcMap 9.3 from which areas of high waypoint density (hotspots) and no use (coldspots) were identified. Point Density calculates the density of point features per unit area by defining a neighbourhood around each raster cell centre, totalling the points that fall within the neighbourhood, then dividing the number of points by the neighbourhood area. The search radius for point density was set to 10 m to account for variation in bird movements, output cell size to 1 map unit and area units to square metres. Point density outputs were displayed using a standard deviation stretch of $n = 9$ as this reduced the sensitivity of density analyses equally across all bird groups and confined hotspots to areas of greatest waypoint density. This method of density estimation was chosen over other similar probability density functions such as kernel estimators because it allows more precise location of areas of high point density. Precision was particularly important as hotspots frequently represented specific areas such as small clusters of trees or shrubs. Kernel outputs are represented by isopleths which can express densities uniformly over areas too large to enable identification of specific areas such as individual plants. Identifying hotspots with high precision enabled correct placement of vegetation survey plots to accurately measure habitat attributes associated with hotspots and coldspots.

The majority of bird groups displayed a maximum of three hotspots within their home ranges. On the few occasions where more than three hotspots were evident, the standard deviation stretch of the point density output was increased until the three areas with the highest waypoint density were revealed. To allow comparison between areas of high waypoint density and areas of no use, an equal number of coldspots were selected within each home range. Coldspots were placed within areas devoid of waypoints and located equidistant from surrounding waypoints and a minimum of 20 m within home range boundaries to minimise edge effects. Only coldspots within either saltbush or remnant vegetation were selected as birds did not land in agricultural land at any point during the study. Where multiple coldspots existed in saltbush plantings and remnant vegetation, the number selected in each vegetation type reflected the number of corresponding hotspots in the same vegetation.

5.3.5 Vegetation survey

Following the completion of the bird tracking in each season, vegetation surveys were conducted to measure habitat variables within hotspots and coldspots. Within a circular plot (r = 15 m) placed at the centre of each hotspot or coldspot, two 30 m transects (tape measures) were laid, running north-south and east-west, centred at the plot centre. For each plant intersecting a transect, records were made of foliage cover (horizontal length of tape covered) and foliage density (touches on a 6 m pole of radius 15 mm at three equidistant points along the section of the tape covered by the plant) within five height bands (0-1 m, 1-2 m, 2-3 m, 3-4 m, and >4 m, Figure 5.1). Density was not recorded for foliage >4 m as this height band had no upper limit and was therefore considerably wider than all others. In addition to cover and density measures, the maximum height of each plant was estimated to the nearest 0.5 m and the amount of leaf litter cover along each transect recorded.

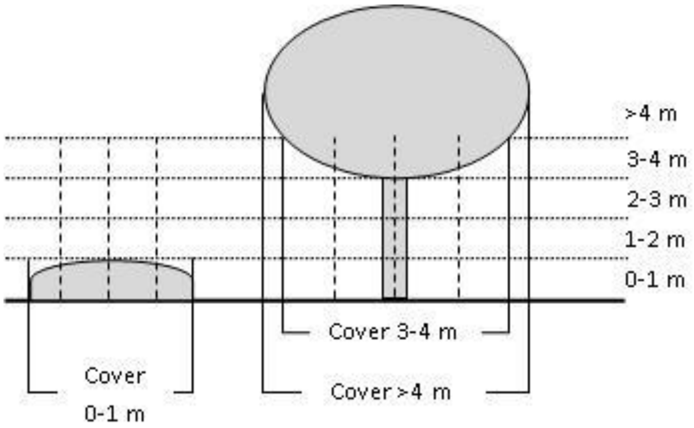


Figure 5.1. Measurement of foliage cover across five height bands (horizontal dotted lines) and the location of foliage density measures (vertical dashed lines) along survey transect (thick horizontal line) taken during vegetation surveys conducted in hotspots and coldspots within bird home ranges.

To accurately reflect true home ranges, adequate location data collected over all hours of the day is required from a sufficient number of different days (Seaman *et al.* 1999, Börger *et al.* 2006). To determine whether sufficient waypoint data had been collected to allow estimation of home ranges and utilisation distributions, random waypoints were selected from a bird groups' home range in increasing increments of five (from 10 to 100) using the sampling selection application in Hawth's Analysis Tools (Beyer 2006) in ArcMap 9.3. Hawth's Analysis Tools were used to create a 95% MCP for each five waypoint increment and the area of each plotted against cumulative waypoint increase. Separate cumulative home range area curves were plotted for White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers and all tended to an asymptote, revealing the number of waypoints collected was sufficient to accurately determine their home range (Harris *et al.* 1990).

Home ranges were compared using the number of individuals within each bird group along with home range area (measured to the nearest 0.01 ha) and linear dimension (the straight line distance between the farthest two points on the boundary polygon of the home range, measured to the nearest metre, Cale 1999).

5.3.6 Data analysis

All data were tested for normality with Kolmogorov-Smirnov tests and transformed as required prior to analyses (see footnotes of Table 5.2). Differences in home range area and linear dimension between seasons and bird groups were analysed for each species using ANOVA and correlations between group size and home range area examined with Spearman correlation coefficients (Cale 1999) using SPSS version 19.0 (SPSS Inc. Chicago, IL).

Foliage and leaf litter cover data collected during vegetation surveys were summed within each survey plot and converted to percentage. Foliage density measures were used to calculate mean foliage density within each height band except >4 m. Foliage and leaf litter cover and foliage density data were then compared between hotspots and coldspots with *t*-tests and Mann-Whitney (*U*) tests depending on their distribution (Antos *et al.* 2008).

Multiple regression analyses are frequently employed in non-experimental studies to infer causality and identify variables most likely to affect the response variable (Mac Nally 2002, Smyth *et al.* 2002). However when analysing datasets with high multicollinearity, regression models are not the most effective way of identifying variables most likely to influence variation in the response variable and single model approaches fail to account for suppression of potentially important predictor variables by other predictors (Mac Nally 2000). In this circumstance, Mac Nally (2000) endorsed the use of hierarchical partitioning (HP), a protocol in which all possible models (2^Q for Q predictor variables) in a multiple regression setting are jointly considered in a hierarchy to attempt to identify the most likely causal predictor variables affecting the response variable (Chevan and Sutherland 1991, Smyth *et al.* 2002). This method allows identification of variables whose independent correlation with the dependent variable is strong, in contrast to variables that have little independent effect but have a high correlation with the dependent variable resulting from joint correlation with other independent variables (Walsh *et al.* 2004). Mac Nally's (2002) HP randomisation method was used with 500 repeated randomisations to calculate z-scores and assess the statistical significance (based on the upper 95% confidence limit ($Z \geq 1.65$), Mac Nally 2002) of the independent contribution of each predictor variable.

5.4 Results

5.4.1 Group dynamics and home ranges

In all seasons and at all times of the day, groups of all species moved through home ranges as a unit, occasionally splitting into sub-groups which maintained a short distance from one another before re-grouping. Two White-browed Babbler groups could not be relocated during autumn 2012 and a further four were absent during spring 2012, while two Variegated Fairy Wren groups were absent during spring 2012 (Table 5.1). Home range spatial data were analysed only for bird groups present during at least the first two seasons.

Home range size among White-browed Babblers was relatively consistent across treatments during spring 2011 (mean = 22.12 ha) which contrasted sharply with autumn and spring 2012 (mean = 19.79 ha and 13.82 ha respectively) during which home range sizes were much more varied (Table 5.1). Despite this, the area of home ranges did not differ significantly between seasons (F = 0.855, P = 0.433). Home range area was significantly correlated with group size among White-browed Babblers (Spearman 0.592, P <0.05), however differences in area between groups were not significant (F = 1.613, P = 0.243). Linear dimension was noticeably different between seasons and bird groups (Table 5.1), however these differences were not significant (F = 1.481, P = 0.259 and F = 1.333, P = 0.326 respectively).

Home range areas and linear dimensions among Variegated Fairy-wrens were relatively consistent across seasons (F = 0.088, P = 0.916 and F = 0.200, P = 0.822, respectively, Table 5.1). Despite significant differences in home range area (F = 8.165, P = 0.006) and linear dimension (F = 7.586, P = 0.008) between groups, no correlation between group size and home range area was found (Spearman 0.234, P >0.05).

Chestnut-crowned Babblers showed a marked increase in home range area during autumn 2012 compared to spring 2011 and 2012 which were smaller (Table 5.1). As only one group of Chestnut-crowned Babblers was present, statistical differences in home range and correlations with group size were not examined.

Table 5.1. Home range summary table showing group size, home range area and linear dimension, percentage of saltbush (SB) and remnant (Rem) vegetation within and total number of waypoints collected for each group of White-browed Babblers (WBB), Variegated Fairy-wrens (VFW) and Chestnut-crowned Babblers (CCB). Some home ranges contained a percentage of agricultural land which is not shown as birds did not use these areas. Data collected during spring 2011 (Spr 2011), autumn 2012 (Aut 2012) and spring 2012 (Spr 2012).

Bird Group	Site	Individuals			Area (ha)			Linear Dimension (m)			Percentage Composition									Total Waypoints		
		Spr 2011	Aut 2012	Spr 2012	Spr 2011	Aut 2012	Spr 2012	Spr 2011	Aut 2012	Spr 2012	Spr 2011			Aut 2012			Spr 2012			Spr 2011	Aut 2012	Spr 2012
											SB	Rem	Agr	SB	Rem	Agr	SB	Rem	Agr			
WBB1	Rem-Iso LS4	9			24.51			713			0	86.4	13.6							1187		
WBB2	Rem-Iso LS4	6	7	8	22.18	37.54	14.67	705	1085	693	0	100	0	0	94.0	6.0	0	95.1	4.9	903	1358	1406
WBB3	SB-Rem LS1	6	4	2	21.41	18.00	4.11	813	773	381	61.7	20.8	17.5	56.6	41.0	2.4	37.2	62.8	0	893	624	407
WBB4	SB-Iso LS1	5	2		34.98	5.26		1085	535		37.2	16.0	46.8	96.7	0	3.3				1265	719	
WBB5	SB-Rem LS2	7			10.33			490			28.8	71.2	0							1315		
WBB6	SB-Rem LS2	14	10	11	11.13	12.58	6.47	551	592	319	26.4	73.6	0	16.5	83.5	0	0	100	0	1112	1400	1335
WBB7	Rem-Iso LS2	9	6		22.00	18.37		718	663		0	100	0	0	100	0				2282	744	
WBB8	SB-Rem LS4	9	7	9	30.41	28.47	30.04	947	811	805	23.3	57.8	18.9	26.2	14.5	59.4	94.2	5.8	0	1997	1568	1564
	Mean	**7.3**	**6.0**	**7.5**	**22.12**	**20.04**	**13.82**	**752.8**	**743.3**	**549.2**	**22.2**	**65.7**	**12.1**	**32.7**	**55.5**	**11.8**	**32.8**	**65.9**	**1.2**	**1369.3**	**1068.8**	**1178.0**
VFW1	SB-Rem LS1	6	6	4	5.56	7.61	7.87	331	378	441	76.5	23.5	0	82.8	17.2	0	83.3	16.7	0	213	479	474
VFW3	SB-Iso LS1	6	6	3	3.08	2.42	1.74	368	251	234	100	0	0	100	0	0	100	0	0	656	432	198
VFW4	SB-Iso LS2	7	7		2.22	2.90		252	269		100	0	0	100	0	0			0	471	206	
VFW5	SB-Rem LS4	10	10		3.65	2.78		327	298		100	0	0	100	0	0			0	701	225	
VFW6	SB-Iso LS4	8	5	6	6.64	8.88	4.57	428	536	484	100	0	0	100	0	0	100	0	0	1458	624	505
	Mean	**7.4**	**6.8**	**4.3**	**4.23**	**4.92**	**4.73**	**341.0**	**346.2**	**386.2**	**95.3**	**4.7**	**0**	**96.6**	**3.4**	**0**	**94.4**	**5.6**	**0**	**699.8**	**393.2**	**392.3**
CCB4	SB-Iso LS2	15	15	13	19.99	38.51	22.85	687	1197	826	88.9	7.4		19.5	5.2		82.9	17.1		528	875	676

5.4.1 Utilisation distributions

All species showed a strong pattern of using some parts of their home ranges more intensively than others. There was also variation in the location of hotspots and coldspots between seasons and bird groups. Among White-browed Babblers, groups at Rem-Iso sites showed marked differences in the location of hotspots during autumn 2012 compared to both spring 2011 and 2012 (Figure 5.2, Appendix 2). Groups at SB-Rem sites used both saltbush and remnant vegetation with hotspots and coldspots occurring in both vegetation types. Nests were predominantly located in remnant vegetation and constructed in *Exocarpos aphyllus*. Although occasional nests were found in larger saltbushes, very few of these were in use. Hotspots within the home range of White-browed Babbler group three were located largely within the same area in all seasons, especially during autumn and spring 2012 as the group sized decreased (Appendix 3). This contrasted sharply with other groups which showed considerable seasonal variation in hotspot location (Figure 5.3, Appendix 4). Despite traversing cropland to access remnant vegetation, hotspots and coldspots within the home range of White-browed Babbler group four at the SB-Iso site in landscape one remained confined to saltbush plantings (Figure 5.4).

Variegated Fairy-wrens showed similar fluctuations in the location of hotspots and coldspots between seasons and remained solely within saltbush plantings at all sites (Figure 5.3, Appendix 5, Appendix 6, Appendix 7 and Appendix 8). Within the Chestnut-crowned Babbler home range, hotspots were largely located in roadside remnant vegetation where they centralised around nesting sites, particularly during autumn and spring 2012 (Appendix 9). Coldspots were predominantly located in saltbush.

Figure 5.2. White-browed Babbler home range and utilisation distributions (point density) at Rem-Iso site in landscape four (group two, n = 3667) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).

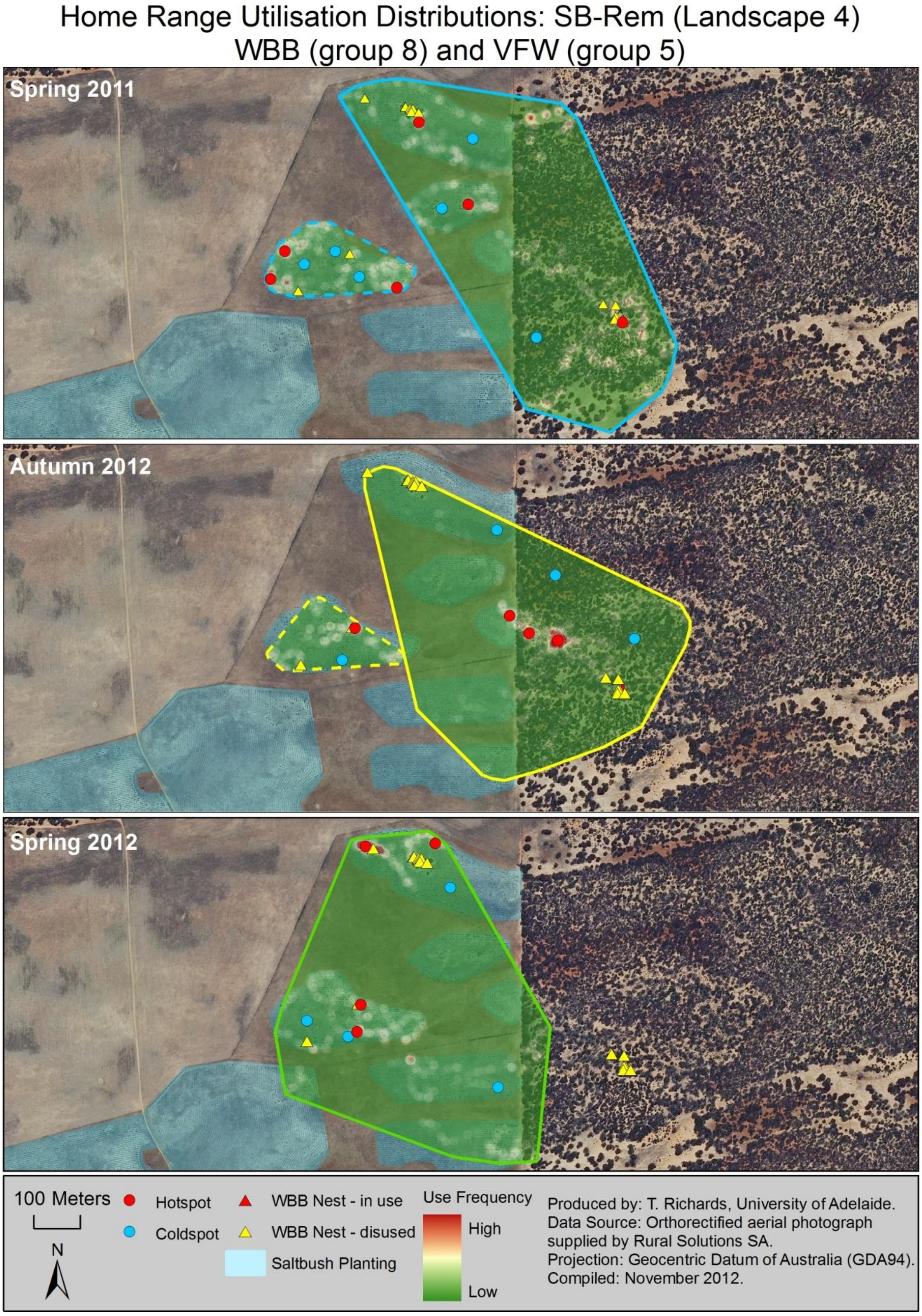


Figure 5.3. White-browed Babbler (group eight, solid line, n = 5129) and Variegated Fairy-wren (group five, dashed line, n = 926) home ranges and utilisation distributions (point density) at SB-Rem site in landscape four (groups eight and five respectively) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline). Variegated Fairy-wren group five could not be located during spring 2012.

Figure 5.4. White-browed Babbler home range and utilisation distributions (point density) at SB-Iso site in landscape one (group four, n = 1984) during spring 2011 (blue outline) and autumn 2012 (yellow outline). Group size declined from five to two individuals during autumn 2012 before absence of the group prior to spring 2012.

5.4.2 Vegetation structure within hotspots and coldspots

Within White-browed Babbler home ranges, all habitat variables except mean foliage density 3-4 m, percent cover ≥4 m and mean maximum height were significantly greater in hotspots compared to coldspots (*t*-tests, Mann-Whitney *U*, *P* <0.05, Figure 5.5). All vegetation measures were significantly higher in hotspots within Variegated Fairy-wren home ranges (*t*-tests, Mann-Whitney *U*, *P* <0.05), while conversely, no significant differences in the vegetation were found between hotspots and coldspots within the Chestnut-crowned Babbler home range (*t*-tests, Mann-Whitney *U*, *P* >0.05). Percent cover ≥4 m was omitted from analysis of Chestnut-crowned Babbler vegetation data as it contained too few records.

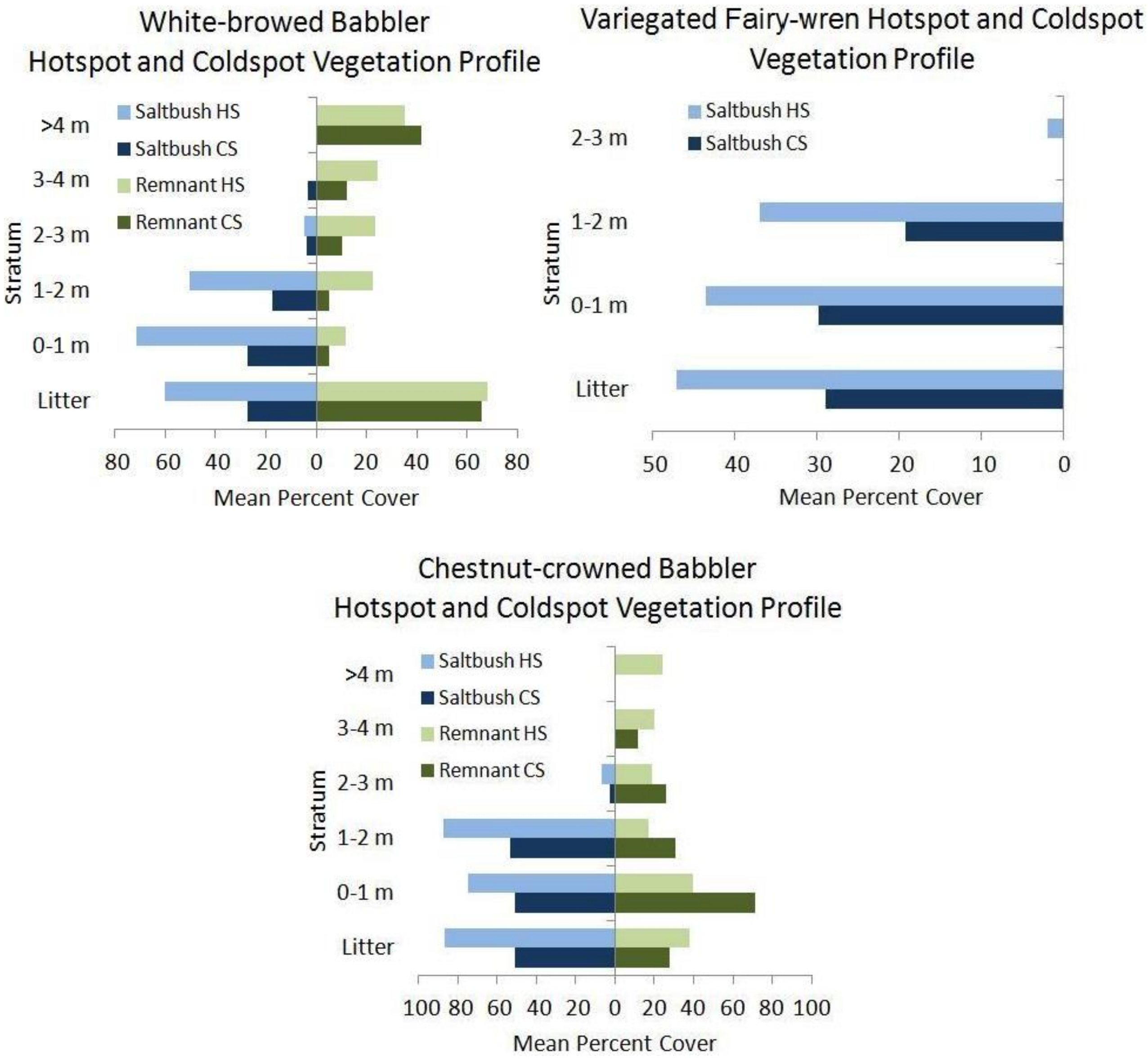


Figure 5.5. Mean percentage cover of vegetation strata in hotspots and coldspots within home ranges of White-browed Babblers and Chestnut-crowned Babblers in saltbush plantings and remnant vegetation and Variegated Fairy-wrens in saltbush plantings only. Data collected in spring 2011, autumn 2012 and spring 2012.

Hierarchical partitioning showed five habitat variables were statistically significant in explaining the variance between hotspots and coldspots in White-browed Babbler home ranges, all of which had negative *J* values indicating their joint contribution with the other variables explained more variation (Table 5.2). Of these, percent foliage cover at 1-2 m explained the most variation between hotspots and coldspots, followed by mean foliage density at 1-2 m and percent foliage cover at 2-3 m. Similarly, the joint contribution of percent leaf litter cover, the only statistically significant variable among Variegated Fairy-wrens, with the other variables was greater than the independent explanatory power. This contrasted with the Chestnut-crowned Babblers where the independent explanatory power of the sole significant variable, percentage foliage cover 3-4 m, was greater than the joint explanatory power in explaining the variation between hotspots and coldspots.

Table 5.2. Results from hierarchical partitioning analyses of habitat data for White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers based on seven, six and nine habitat variables respectively.

Variable or Bird Species	I_A	Z	J_A	Total	% Var
White-browed Babbler					
Percent Foliage Cover 0-1 m^b	**0.166**	3.43	-0.044	-0.210	10.498
Percent Foliage Cover 1-2 m^a	**0.577**	14.64	-0.523	-1.100	36.536
Percent Foliage Cover 2-3 m^b	**0.253**	6.00	-0.221	-0.475	16.052
Mean Foliage Density 1-2 m^c	**0.333**	8.66	-0.445	-0.778	21.064
Mean Foliage Density 2-3 m^a	**0.127**	2.45	-0.116	-0.244	8.070
Mean Maximum Height^c	0.052	0.61	0.048	-0.004	3.269
Percent Leaf Litter Cover^c	0.071	1.06	-0.041	-0.112	4.512
Variegated Fairy Wren					
Percent Foliage Cover 0-1 m^c	0.074	0.72	-0.160	-0.234	15.273
Percent Foliage Cover 1-2 m^c	0.104	1.33	-0.227	-0.332	21.621
Mean Foliage Density 0-1 m^c	0.075	0.67	-0.083	-0.158	15.608
Mean Foliage Density 1-2 m^c	0.042	0.06	-0.149	-0.191	8.788
Mean Maximum Height^c	0.053	0.20	-0.176	-0.229	10.961
Percent Leaf Litter Cover^c	**0.134**	1.68	-0.222	-0.356	27.750
Chestnut-crowned Babbler					
Percent Foliage Cover 0-1 m^c	0.096	0.20	-0.090	-0.186	7.953
Percent Foliage Cover 1-2 m^c	0.107	1.63	-0.031	-0.138	18.535
Percent Foliage Cover 2-3 m^c	0.224	1.26	0.128	-0.097	15.512
Percent Foliage Cover 3-4 m^c	**0.123**	2.32	0.050	-0.073	24.575
Mean Foliage Density 0-1 m^c	0.188	0.31	0.096	-0.092	8.807
Mean Foliage Density 1-2 m^c	0.071	0.66	-0.093	-0.165	10.177
Mean Foliage Density 2-3 m^a	0.298	-0.05	0.009	-0.289	5.874
Mean Maximum Height^c	0.051	-0.31	0.050	-0.002	4.322
Percent Leaf Litter Cover^c	0.052	-0.33	0.050	-0.002	4.246

I_A: independent explanatory power of variable.

Z: Standard normal Z-score derived from randomisations of data matrix.

J_A: joint explanatory power of variable with other variables.

Total: $I_A + J_A$

Statistically signifcant amounts of independent explanatory power in **bold**

Transformations for HP analyses: ^{a}ln (x+1), ^{b}√x, ^{c}no transformation required

%Var: Percentage of variance in spot type explained by each of the vegetation variables independently

5.5 Discussion

All birds in this study were clearly selective in their use of foraging sites. Foraging was concentrated in particular areas of their home ranges within which the vegetation structure differed markedly from unused areas. At SB-Rem sites, the home ranges of White-browed Babblers encompassed both saltbush plantings and remnant vegetation while at Rem-Iso sites bird groups remained within remnant vegetation. Saltbush composed a large portion of the Chestnut-crowned Babbler home range; however the group used roadside remnant vegetation extensively. At all sites, both babbler species focused their foraging in areas of greater shrub and sub-canopy vegetation cover. Similarly, Variegated Fairy-wrens foraged predominantly in areas with dense, shrub-level vegetation, yet remained solely within saltbush plantings.

Many Australian woodland birds display selectivity toward foraging sites which contain vegetation structures different to those in unused areas (Antos *et al.* 2008). Vegetation structure has a crucial influence on the assemblage of potential invertebrate prey (Lawton 1983, Johnson 2000, Johnson 2007), the availability and ease at which these can be captured by birds (Robinson and Holmes 1982, Robinson and Holmes 1984, Hutto 1990) and the predation risk birds face while foraging (Lima 1987, Valone and Lima 1987, Lima 1990). These factors can independently or jointly affect habitat selection by foraging birds and consecutively underpin utilisation distributions within their home ranges (Blake and Hoppes 1986, Antos *et al.* 2008, Brown *et al.* 2011).

The abundance of prey is a key driver of habitat selection patterns among foraging birds (Holmes *et al.* 1986, Johnson and Sherry 2001) and more complex structures often support a greater diversity of invertebrates (Lawton 1983, Webb *et al.* 1984, Catterall *et al.* 2001). Blake and Hoppes (1986) captured significantly more foraging birds in tree-fall gaps compared to understorey areas in woodland forest in Illinois, USA. Tree-fall gaps contained significantly greater invertebrate resources compared to understorey sites to which the birds responded in their selection of foraging sites. Similarly, Brown *et al.* (2011) found the abundance of leaf litter invertebrates was significantly greater in areas occupied by foraging Swainson’s Warblers, concluding litter arthropod richness and abundance was the best predictor of warbler presence. In the context of the present study, it is possible the more complex vegetation structures of hotspots may support a greater abundance of invertebrates, causing the birds to focus their foraging efforts in these areas.

Fluctuations in invertebrate abundance may also account for the seasonal shifts in utilisation distributions and the subsequent location of hotspots and coldspots within the home ranges of White-browed Babblers and Variegated Fairy-wrens. Taylor (2003) found White-browed Babblers changed from foraging significantly more on the ground during winter to foliage during spring, changes she attributed to the relative availability of invertebrate prey. Recher *et al.* (2006) documented marked seasonal changes in the abundance of a range of invertebrate taxa, many of which are likely to be taken by babblers and fairy-wrens (Tidemann *et al.* 1989, Cale 1999, Morris and Wooller 2001). Invertebrate abundance was not examined in this study, however, an assessment of these resources in hotspots and coldspots across different seasons may provide crucial information to further explain the location of hotspots and coldspots and the seasonal shifts in their position.

In addition to influencing invertebrate assemblages, vegetation structure has a discernible effect on bird behaviour, with frequently used areas often structurally suited to particular behaviours (Samuel *et al.* 1985, Barg *et al.* 2006). In terms of foraging, the ability of birds to detect and capture prey is heavily influenced by the structure of the vegetation (Majer *et al.* 1990, Wolda 1990, Poulin and Lefebvre 1997). A number of authors have concluded that particular foraging manoeuvres and techniques are more amenable to greater foraging success on particular vegetation structures (e.g. Robinson and Holmes 1982, Robinson and Holmes 1984, Whelan 2001). In natural systems, White-browed and Chestnut-crowned Babblers forage by probing and gleaning leaf litter and occasionally bark on branches (Recher and Davis 1997, Miller and Cale 2000, Morris and Wooller 2001, Portelli *et al.* 2009) while Variegated Fairy-wrens prefer to glean foliage close to the ground (Tibbetts and Pruett-Jones 1999). It is possible these behaviours and foraging techniques are conducive to greater foraging success in the vegetation structures associated with hotspots, resulting in more frequent foraging in these areas.

Many smaller bird species forage within close proximity to denser vegetation in which they can seek cover from predation (Lima *et al.* 1987, Valone and Lima 1987, Lima 1990, Lima and Dill 1990, Whittingham and Evans 2004). In both saltbush and remnant vegetation, White-browed Babblers foraged in close proximity to dense vegetation into which they retreated when startled, behaviour documented and experimentally confirmed as cover dependent by Taylor (2003). Variegated Fairy-wrens and Chestnut-crowned Babblers also showed cover-dependence behaviour resembling that displayed in natural chenopod systems (Tibbetts and Pruett-Jones 1999, Tidemann 2004, Portelli *et al.* 2009), with hotspots located in areas of dense shrub-level vegetation. The strong predilection of the birds to forage near dense vegetation is the primary driver of utilisation distributions. Given this, the heterogeneity of dense vegetation cover across home ranges determines the locations of foraging birds, giving rise to hotspots of use.

Several White-browed Babbler and Variegated Fairy-wren groups declined or disappeared over the course of the study. White-browed Babblers naturally disperse during the non-breeding period in fragmented systems; however they are much more likely to do so from smaller patches (Cale 1999). Food is often less available in smaller patches as lower abundances of prey mean birds must spend more time searching, resulting in reduced foraging efficiency (Morrison *et al.* 2010). In addition, predation risk may be higher in smaller patches due to the reduced availability of cover (Suhonen 1993), further reducing foraging efficiency as birds must spend more time being vigilant (Elgar 1989, Morrison *et al.* 2010). Taken together, these factors indicate some configurations of saltbush plantings and remnant vegetation patches may be insufficient for long term occupation by these bird species.

The size of remnants is likely to be more important to White-browed Babblers than the size of saltbush plantings as remnant vegetation was used extensively at all sites and no groups were found in saltbush plantings without nearby native vegetation. In addition, the group at the SB-Rem site in landscape two was present for the duration of the study despite the removal of the saltbush in early summer 2011. Babbler groups declined only at sites with small remnants (<81 ha), irrespective of whether large (47 ha) or small (<12 ha) saltbush plantings were present (Table 4.1). Group size remained constant or increased only at the sites with remnants of 211 ha and 582 ha, indicating in terms of minimum size, remnants exceeding 200 ha are crucial to the persistence of White-browed Babblers in this region.

Despite groups of Variegated Fairy-wrens remaining solely within saltbush plantings, the decline or loss of groups in all saltbush plantings suggests none were sufficiently large to support these birds in the long term. The smallest declines in group size occurred in saltbush plantings of 47 ha and 52 ha, despite home ranges of only four to five hectares. New plantings well exceeding these values may better support Variegated Fairy-wrens; however the exact minimum size remains unclear.

The results of this study clearly illustrate White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers are selective in their use of foraging sites, preferring areas with greater vegetation cover. Primary management options should aim to increase the provision of cover through more precise and controlled sheep grazing regimes which graze only sections of plantings at one time, thereby retaining some areas of densely foliaged saltbushes. Interspersing plantings with other native shrub species which vary in grazing tolerance will facilitate this mosaic-like structure (Lancaster *et al.* 2012) and enhance structural diversity, improving the suite of resources available to birds (Barton *et al.* 2010, Barton *et al.* 2011). Both measures will however represent opportunity costs to landholders in the form of subdivisional fencing and the displacement of more palatable plant species. Larger saltbush plantings placed adjacent to remnant vegetation will provide greater habitat for Variegated Fairy-wrens while allowing babblers to move between habitats and encouraging additional species to forage within plantings (Arnold 2003, Martin *et al.* 2004, Vesk and Mac Nally 2006) (Chapter 3). Furthermore, enlarging plantings to connect isolated patches of vegetation will enhance landscape and functional connectivity, aiding dispersal of fauna through the landscape (Lancaster *et al.* 2012).

Further research should aim primarily to assess the invertebrate communities within hotspots and coldspots in saltbush plantings and remnant vegetation. This information will determine the degree to which patterns of spatial use are driven by food abundance, quantify the foraging resources available within saltbush plantings relative to remnant vegetation and potentially provide information on means by which they could be increased. Secondly, the lifespan of the bird species studied exceeds the duration of the present study (Higgins and Peter 2002a, Higgins and Peter 2002b). Monitoring these populations over longer time periods will reveal how groups of these birds disperse through the landscape and the role saltbush plantings play in their long term survival. Finally, many bird species other than those examined here are found less frequently in saltbush plantings (Chapter 3). Examining how these less common birds, and indeed other taxa, use saltbush plantings will help determine the full contribution that the planted areas can make to biodiversity conservation in southern Australian farming landscapes.

Chapter 6 Prey availability and its influence on the spatial patterns of foraging birds in planted saltbush and remnant vegetation in the Murray Mallee, South Australia.

Plate 6.1. Saltbushes adjacent to remnant vegetation representing a key foraging location for White-browed Babblers near Wanbi, South Australia. Photo: T. Richards.

6.1 Abstract

Biodiversity conservation is increasingly reliant on supporting populations in landscapes cleared and fragmented by agriculture. Perennial farming systems represent an opportunity for production elements to contribute to maintaining populations of native fauna in intensive agricultural zones. In the South Australian Murray Mallee, plantings of Old Man Saltbush

(*Atriplex nummularia nummularia*) have been established as fodder reserves, leading to increased shrub-level vegetation in these extensively cleared landscapes. Recent research has shown bird species which forage extensively within saltbush plantings do so disproportionately across their home ranges, focusing their efforts in defined areas and on particular substrates. The heterogeneous distribution of vegetation cover is a key driver of differential spatial use among these species; however the distribution and availability of invertebrate prey may also contribute to these patterns. To investigate the influence of prey availability on foraging patterns, invertebrates were sampled on key foraging substrates in intensely foraged and unused areas within the home ranges of three bird species; White-browed Babblers (*Pomatostomus superciliosus*), Variegated Fairy-wren (*Malurus lamberti*) and Chestnut-crowned Babblers (*P. ruficeps*), across plantings of Old Man Saltbush and patches of remnant vegetation. Invertebrate communities did not differ between intensely foraged and unused areas but varied substantially between seasons and in saltbush plantings compared to remnant vegetation. Invertebrate prey distribution does not reflect differential spatial patterns shown by birds when foraging in saltbush plantings or remnant vegetation. The distribution of dense shrub-level vegetation in which cover from predators can be sought is the primary determinant of foraging microhabitat selection within these habitats. Efforts aimed at encouraging avian use of saltbush plantings should be directed toward interspersing plantings with additional native shrub species to enhance heterogeneity and provide greater shrub-level cover and an abundance of key foraging substrates.

6.2 Introduction

Agricultural landscapes are the foundation for global food security. Their dramatic expansion in many regions of the world has resulted in widespread loss and fragmentation of habitat and subsequent declines in biodiversity (Gaston *et al.* 2003, Semwal *et al.* 2004, Green *et al.* 2005, Butchart *et al.* 2010). In Australia our understanding of how to develop farming landscapes which support biodiversity conservation remains deficient (Morton *et al.* 2009, Lancaster *et al.* 2012), despite the agriculturally induced declines of fauna receiving widespread attention (e.g. Robinson 1993, Saunders and Ingram 1995, Ford *et al.* 2001, Attwood *et al.* 2009). The increasing reliance of biodiversity conservation on supporting wildlife populations in human modified landscapes (Vandermeer and Perfecto 1997, Law and

Dickman 1998, Scherr and McNeely 2008) emphasises the need for ecologists to develop this understanding, particularly in the face of climate change (Howden *et al.* 2008).

In southern Australia, revegetating cleared land with plantings aimed at replicating pre-clearance habitats has been the primary method to support native fauna in agricultural regions (Hobbs *et al.* 1993, Recher 1993a, Paton *et al.* 2004, Johnson *et al.* 2007). In recent decades, researchers have advocated monoculture plantings of native perennial trees and shrubs as a more viable alternative to increase vegetative cover in highly cleared landscapes and provide resources for native fauna (e.g. Bennett *et al.* 2000, Lindenmayer and Hobbs 2004, McNeely 2004, Schroth and Harvey 2007, Brockerhoff *et al.* 2008).

In the Murray Mallee farming region of South Australia, plantings of Old Man Saltbush (*Atriplex nummularia nummularia*) have been established as a fodder reserve for stock to fill the summer/autumn feed gap (Lefroy 2002, Collard and Fisher 2010). Saltbush plantings allow increased stocking rates, reduce feed costs and ameliorate erosion and salinity (Monjardino *et al.* 2010) and have consequently been established by many landholders across the region (Lancaster *et al.* 2012). These patches of shrub-level vegetation have been identified as a source of habitat and resources for a range of native fauna (Lefroy and Smith 2004, Lefroy *et al.* 2005), with particular emphasis on the potential of saltbush plantings to support the persistence of bird species within agricultural regions (Seddon *et al.* 2009, Collard and Fisher 2010, Collard *et al.* 2011).

Recent research has shown that birds are commonly found within saltbush plantings (Seddon *et al.* 2009, Collard *et al.* 2011) (Chapter 3) and for species with flexible resource requirements such as the White-browed Babbler (*Pomatostomus superciliosus*), Variegated Fairy-wren (*Malurus lamberti*) and Chestnut-crowned Babbler (*P. ruficeps*), these areas can serve as substantial foraging habitat (Chapter 4). When foraging within their home ranges, these species use space disproportionately; concentrating their efforts in particular areas within which they focus on a number of key substrates (Chapter 4 and Chapter 5). White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers have an inherent dependency on dense shrub vegetation in which they can seek cover from predators, the distribution of which undoubtedly plays a key role in determining these patterns (Chapter 5). However, the availability of invertebrate prey may further dictate areas of high and low foraging, particularly as these are predominantly insectivorous birds which forage throughout the day (Tidemann 2004, Taylor and Paul 2006, Portelli *et al.* 2009) (Chapter 4).

The availability of food resources has a fundamental influence on habitat selection patterns among birds (Blake and Hoppes 1986, Holmes *et al.* 1986, Johnson and Sherry 2001, Brown *et al.* 2011). Prey availability differs from pure abundance and is dependent on detectability, ease of capture and consumption, and identity of the potential prey species which are in turn affected by bird behaviour, physiology and hunting techniques (Cooper and Whitmore 1990, Hutto 1990, Wolda 1990, Johnson 2000, Moorman *et al.* 2007). In addition, habitat attributes such as invertebrate distribution, season, time of day, habitat type and vegetation structure further influence the amount of invertebrate prey available (Robinson and Holmes 1982, Raley and Anderson 1990).

This study compares the availability of potential invertebrate prey between areas of concentrated foraging and unused areas within the home ranges of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers occupying plantings of Old Man Saltbush and patches of remnant native vegetation. By assessing invertebrate availability through several sampling techniques closely matching the foraging ecologies and substrates preferred by White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers (Cooper and Whitmore 1990, Dahlsten *et al.* 1990, Hutto 1990) (Chapter 4), this study aims to determine whether the availability of invertebrate prey contributes to the disproportionate foraging patterns displayed by these species (Chapter 5).

6.3 Methodology

6.3.1 Invertebrate Sampling:

Invertebrate sampling took place during autumn (April to May) and spring (October to November) 2012 within survey plots (*r* = 15 m, selected to account for the radius used in Point Density analyses, see Chapter 5) placed over intensely foraged areas (hotspots) and unused areas (coldspots) within White-browed Babbler, Variegated Fairy-wren and Chestnut-crowned Babbler home ranges. Hotspots and coldspots were identified from studies of differential use of space (Chapter 5). Within each plot, pitfall trapping and branch clipping (adapted from Morrison and Lindell 2011) were used to sample ground and foliage invertebrates respectively, along with timed visual observations of both substrates to record more mobile taxa (Cooper and Whitmore 1990, Majer *et al.* 1990). These techniques are adequate to capture invertebrates > 3mm in length, the predominant size of those foraged by White-browed Babblers and Variegated Fairy-wrens (Cale 1999), from the ground and low foliage (Cooper and Whitmore 1990, Majer *et al.* 1990), the principal foraging substrates and microhabitats used by the three species (Wooller and Calver 1981, Recher and Davis 1997, Recher and Davis 1998, Tibbetts and Pruett-Jones 1999) (Chapter 4).

Pitfall trapping was undertaken in White-browed and Chestnut-crowned Babbler home ranges due to the predominance of ground foraging by these species (Chapter 4). Six pitfalls were placed randomly within each survey plot, three in leaf litter below shrubs or trees and three on bare ground. Pitfalls consisted of a 70 mm diameter, 250 mL container one third filled with Gault's solution (Hunt and Millar 2001) and buried to ground level. Pitfalls remained open for three days prior to collection.

Due to the high incidence of foliage foraging displayed by Variegated Fairy-wrens (Chapter 4), four branch clippings were collected within each plot, two at 0.5 m, one at 1.0 m and one at 1.5 m while two clippings were taken within each plot in White-browed and Chestnut-crowned Babbler home ranges at 1.0 m and 1.5 m to reflect predominant heights when foraging above the ground (Chapter 4). Samples were collected by placing a 50 litre plastic bag over the foliage at the end of a branch, closing the bag around the stem, and clipping the branch from the plant. Insecticide was then sprayed through the bag opening before the bag was sealed for transport to the laboratory.

To accompany foliage and pitfall sampling, visual surveys of invertebrates were undertaken within each survey plot. These surveys consisted of randomly locating and examining a 1 x 1 m quadrat of foliage, litter, or bare ground for one minute and recording all invertebrates seen. Two visual surveys took place on foliage within Variegated Fairy-wren home ranges at 0.5 m and 1 m, while in White-browed and Chestnut-crowned Babbler home ranges, two visual surveys were undertaken on foliage at 1 m and 1.5 m in addition to one on leaf litter and one on bare ground.

6.3.2 Laboratory Identification:

In the laboratory the contents of each pitfall trap were emptied into a tray from which all invertebrates were collected, identified to Order as described by Tilling (1986) and classified according to size (0-2 mm, 2-5 mm, 5-10 mm, 10-15 mm, >15 mm, Brown *et al.* 2011) under a dissecting microscope. Where the abundance of specimens 0-2 mm was too numerous, counts were estimated to the nearest 50 individuals (Cale 1999).

Invertebrates from branch clippings were identified in the same way as pitfall traps with the clipping extracted from the bag and shaken vigorously over a tray to dislodge and collect specimens. The bags were also shaken to remove any additional specimens. Branches and dislodged foliage from trays were then placed in paper bags and oven-dried at 70° C for four days. Dried foliage samples were then weighed to calculate the abundance of invertebrates per gram of dry foliage (Morrison *et al.* 2010).

6.3.3 Data Analysis:

For statistical analyses of pitfall trapping data, invertebrate size class data were pooled separately for litter and bare ground and the 10 most abundant orders selected for White-browed Babbler home ranges and six most abundant for Chestnut-crowned Babbler home ranges. When foliage data were analysed, the eight most abundant invertebrate orders were selected for White-browed Babblers, seven for Variegated Fairy-wrens and three for Chestnut-crowned Babblers. Data for pitfall traps and foliage samples were not normally distributed (Kolmogorov-Smirnov tests, $P < 0.05$). Permutational multivariate analysis of variance (PERMANOVA Anderson 2001, McArdle and Anderson 2001) was used to test for differences in the abundance of pitfall and foliage invertebrates of different sizes and orders. PERMANOVA is a non-parametric univariate or multivariate analysis of variance which uses permutation procedures to calculate probability values and does not rely on the assumption of multivariate normality (McNatty *et al.* 2009).

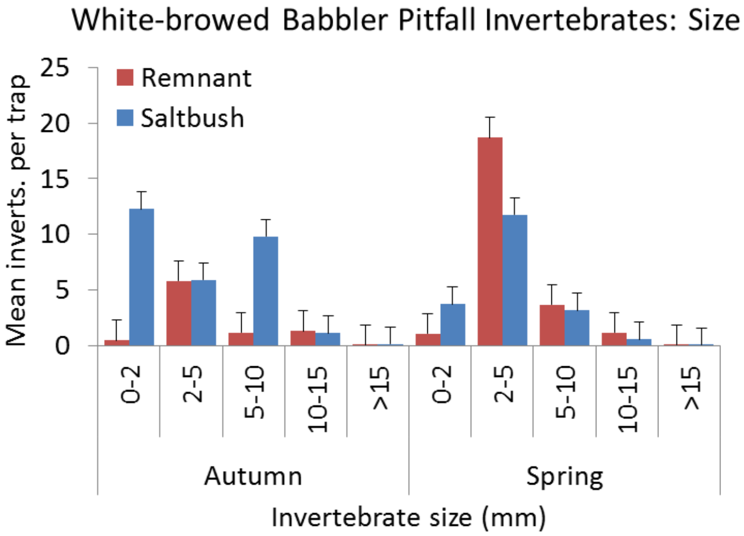
All data were square-root transformed to reduce the significance of very abundant sizes and orders prior to PERMANOVA analysis (Primer-E, vers. 6.1.6, Primer Ltd, UK). A four factor design (1-seasons, 2-habitats (saltbush plantings and remnant vegetation), 3-spot type (hotspots and coldspots) and 4-location (litter and bare ground)) was used to test pitfall invertebrates from White-browed Babbler home ranges while a three factor design (1-season, 2-habitat and 3-spot type) was used for foliage invertebrates. A three factor design (1-seasons, 2-spot type and 3-foliage sample height) was used for foliage invertebrates within Variegated Fairy-wren home ranges. The saltbush planting in the Chestnut-crowned Babbler home range was cleared prior to sampling during spring 2012, preventing comparisons between hotspots and coldspots. As a result, one (seasons) and two (1-seasons and 2-habitat) factor designs were used to test for differences among pitfall and foliage invertebrates respectively. Analyses were conducted with the Bray-Curtis measure of similarity and 999 permutations per test, sufficient for a significance level of 0.05 (Manly 1997, McArdle and Anderson 2001).

6.4 Results

6.4.1 Invertebrates in White-browed Babbler home ranges

Within White-browed Babbler home ranges, the abundance of pitfall and foliage invertebrates did not differ significantly between hotspots and coldspots (Table 6.1). The abundance of size classes among pitfall invertebrates were significantly different between seasons and habitats (PERMANOVA: Pseudo-F 6.386, $P = 0.001$ and Pseudo-F 2.614, $P = 0.036$, respectively) with considerably more 2-5 mm invertebrates present in remnant vegetation during spring and 0-2 mm and 5-10 mm invertebrates in saltbush plantings during autumn. The abundances of pitfall invertebrate orders also differed significantly between seasons and habitats (PERMANOVA: Pseudo-F 5.142, $P = 0.002$ and Pseudo-F 6.392, $P = 0.001$, respectively). Formicidae were most abundant throughout the study, particularly in remnant vegetation during spring while Hemiptera were highly abundant in saltbush plantings during autumn (Figure 6.1).

Foliage invertebrates were also significantly different between season and habitats in terms of size (PERMANOVA: Pseudo-F 5.252, $P = 0.007$ and Pseudo-F 3.767, $P = 0.015$, respectively) and order (PERMANOVA: Pseudo-F 3.554, $P = 0.005$ and Pseudo-F 6.454, $P = 0.001$, respectively) (Table 6.1). Among foliage invertebrates, sizes 0-2 mm and 2-5 mm were more abundant in saltbush compared to remnant vegetation throughout the study. Interestingly, the abundance of Orthoptera, Hemiptera and Lepidoptera shifted from being higher in remnant vegetation during autumn to saltbush plantings during spring (Figure 6.2).



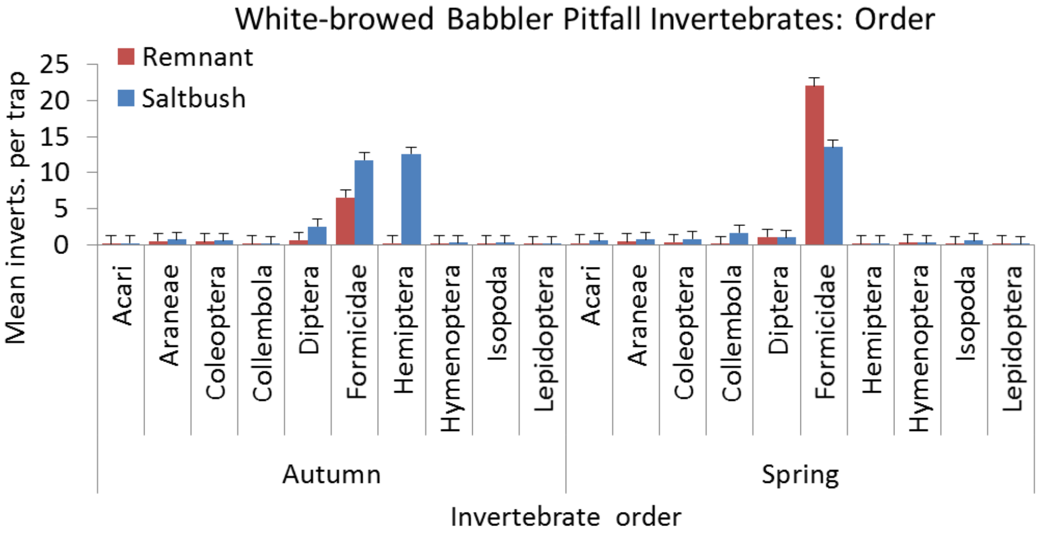
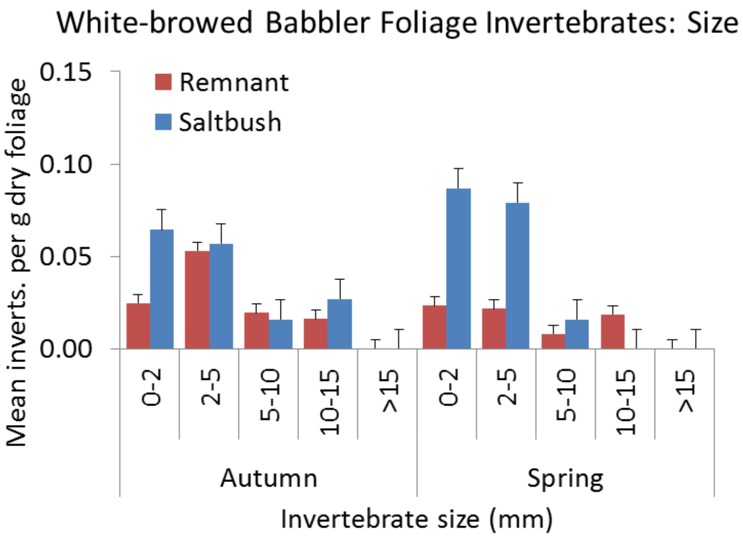


Figure 6.1. Mean abundance of pitfall invertebrates (inverts.) per trap as classified by size and order. Specimens collected within White-browed Babbler home ranges during autumn and spring 2012.



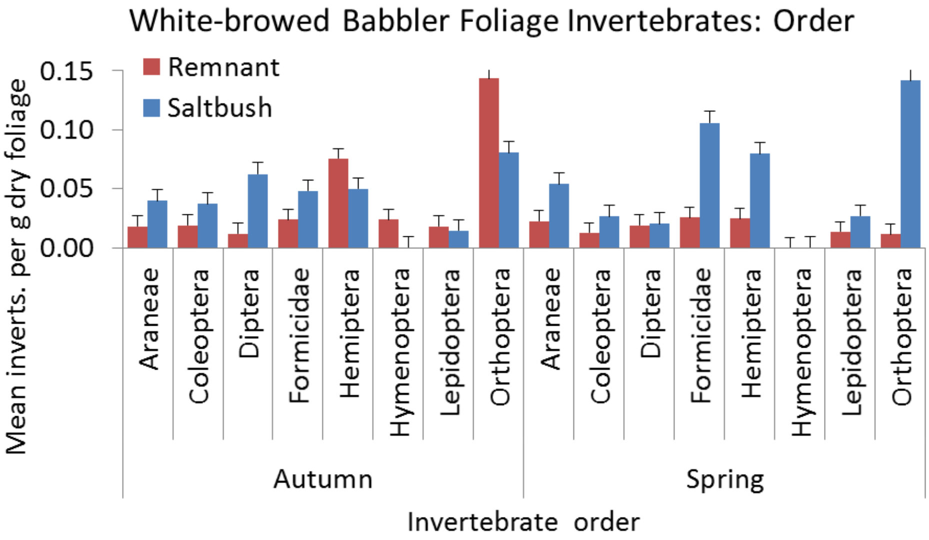


Figure 6.2. Mean abundance of invertebrates (inverts.) per gram (g) of dry foliage as classified by size and order. Specimens collected within White-browed Babbler home ranges during autumn and spring 2012.

6.4.2 Invertebrates in Variegated Fairy-wren home ranges

As Variegated Fairy-wrens solely occupied saltbush plantings, comparisons of foliage invertebrates were made only between seasons and hotspots and coldspots. When foliage invertebrate sizes were compared there was a significant interaction between season and spot type (PERMANOVA: Pseudo-*F* 3.304, *P* = 0.048) (Table 6.1). Invertebrates in the 0-2 mm and 2-5 mm size classes were most common throughout the study while larger invertebrates were captured only during autumn (Figure 6.3). By comparison, no significant differences in the abundance of invertebrate orders were apparent between hotspots and coldspots

(PERMANOVA: Pseudo-*F* 1.355, *P* = 0.228), however significant differences did occur between seasons (PERMANOVA: Pseudo-*F* 4.751, *P* = 0.002). Orthoptera was most abundant throughout the study while no Coleoptera or Formicidae were captured during autumn.

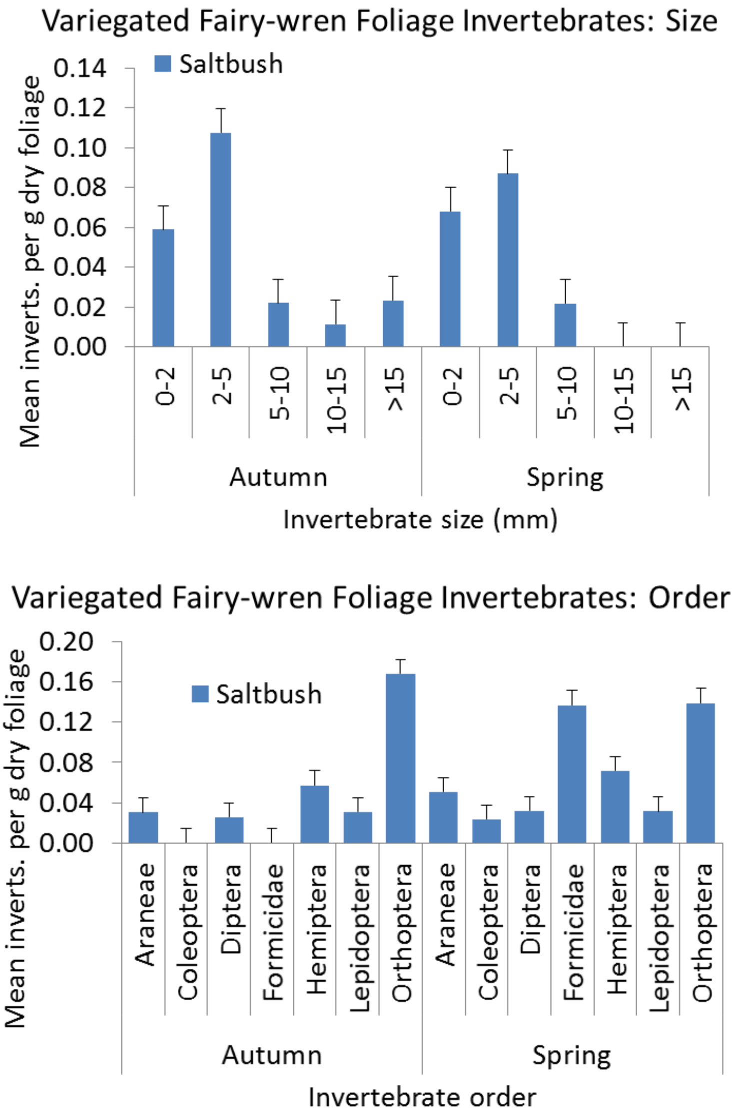


Figure 6.3. Mean abundance of invertebrates (inverts.) per gram (g) of dry foliage as classified by size and order. Specimens collected within Variegated Fairy-wren home ranges during autumn and spring 2012.

6.4.3 Invertebrates in the Chestnut-crowned Babbler home range

The abundances of pitfall invertebrate size classes and orders within the Chestnut-crowned Babbler home range were significantly different between seasons (PERMANOVA: Pseudo-*F*

2.795, *P* = 0.024 and Pseudo-*F* 5.47, *P* = 0.001, respectively) (Table 6.1) with considerably more 0-2 mm, 2-5 mm and 5-10 mm invertebrates and Formicidae and Diptera during spring (Figure 6.4). The abundances foliage invertebrate size classes and orders did not differ significantly between seasons or habitats (Table 6.1). A greater number of smaller invertebrates were present in saltbush plantings, particularly Orthoptera, although these differences were not significant (Table 6.1, Figure 6.5).

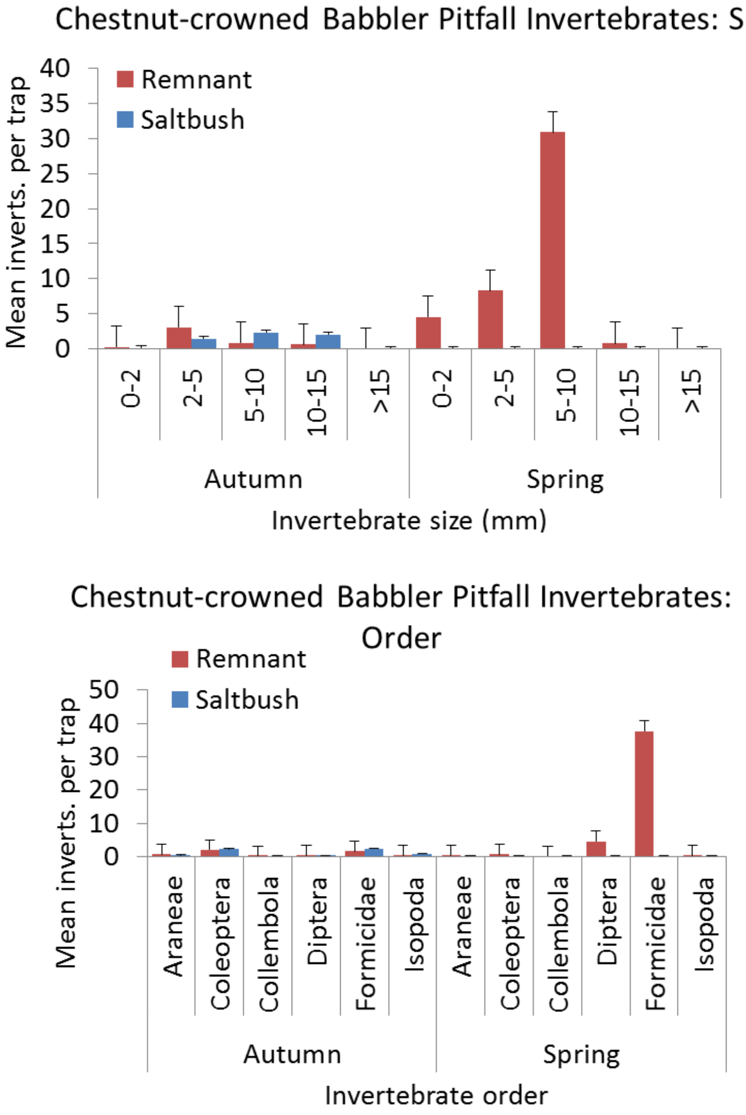
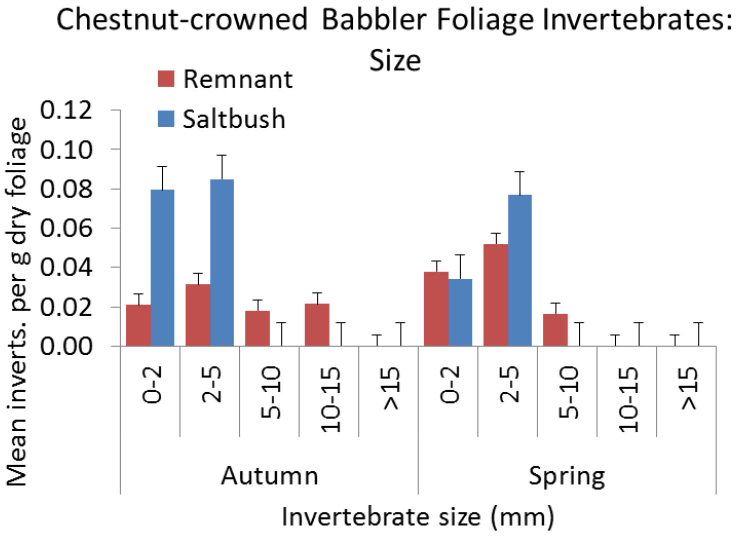


Figure 6.4. Mean abundance of pitfall invertebrates (inverts.) per trap as classified by size and order. Specimens collected within the Chestnut-crowned Babbler home ranges during autumn and spring 2012.



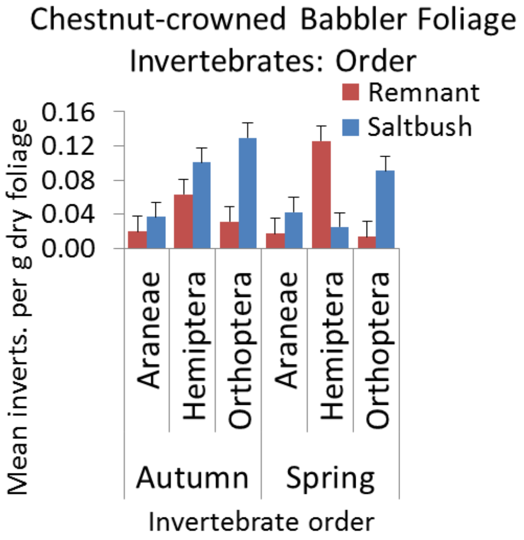


Figure 6.5. Mean abundance of invertebrates (inverts.) per gram (g) of dry foliage as classified by size and order. Specimens collected within the Chestnut-crowned Babbler home range during autumn and spring 2012.

Table 6.1. Full output from PERMANOVA analyses examining invertebrate sizes and taxonomy across seasons, saltbush plantings and remnant vegetation, hotspots and coldspots, litter and open ground (pitfall traps) and heights (foliage samples). Data collected during autumn and spring 2012.

Bird Species	PERMANOVA Test	Factor	df	Pseudo-*F*	*p*	Perumtations
White-browed Babbler	Pitfall Invertebrates - Size	Season	1	6.386	**0.001**	999
		Habitat	1	2.614	**0.036**	996
		Spot Type (Habitat)	2	0.502	0.865	997
		Season x Habitat	1	1.687	0.139	997
		Location (Spot Type (Habitat))	4	0.554	0.937	999
		Season x Spot Type (Habitat)	2	0.277	0.989	998
		Season x Location (Spot Type (Habitat))	4	0.985	0.455	997
	Pitfall Invertebrates - Order	Season	1	5.142	**0.002**	999
		Habitat	1	6.392	**0.001**	997
		Spot Type (Habitat)	2	0.886	0.553	999
		Season x Habitat	1	1.078	0.362	999
		Location (Spot Type (Habitat))	4	0.586	0.959	999
		Season x Spot Type (Habitat)	2	0.985	0.431	999
		Season x Location (Spot Type (Habitat))	4	0.886	0.575	998
	Foliage Invertebrates - Size	Season	1	5.252	**0.007**	999
		Habitat	1	3.767	**0.015**	999
		Spot Type (Habitat)	2	1.339	0.204	997
		Season x Habitat	1	1.245	0.242	998
		Season x Spot Type (Habitat)	2	0.784	0.552	999
	Foliage Invertebrates - Order	Season	1	3.554	**0.005**	998
		Habitat	1	6.454	**0.001**	997
		Spot Type (Habitat)	2	0.688	0.765	999
		Season x Habitat	1	1.625	0.136	997
		Season x Spot Type (Habitat)	2	1.092	0.385	998

Table 6.1 continued.

Variegated Fairy-wren	Foliage Invertebrates - Size	Season	1	5.631	**0.009**	999
		Spot Type	1	0.793	0.439	995
		Height Class (Spot Type)	4	0.778	0.626	998
		Season x Spot Type	1	3.304	0.048	999
		Season x Height Class (Spot Type)	4	0.726	0.669	998
	Foliage Invertebrates - Order	Season	1	4.751	**0.002**	999
		Spot Type	1	1.355	0.228	999
		Height Class (Spot Type)	4	0.737	0.758	999
		Season x Spot Type	1	1.324	0.235	997
		Season x Height Class (Spot Type)	4	0.919	0.532	998
Chestnut-crowned Babbler	Pitfall Invertebrates - Size	Season	1	2.795	**0.024**	998
	Pitfall Invertebrate - Order	Season	1	5.470	**0.001**	999
	Foliage Invertebrates - Size	Season	1	2.292	0.104	999
		Habitat	1	1.307	0.255	999
		Season x Habitat	1	0.566	0.61	998
	Foliage Invertebrates - Order	Season	1	0.300	0.793	999
		Habitat	1	0.875	0.426	998
		Season x Habitat	1	0.335	0.744	998

Statistically signifcant differences shown in **bold**
Nested factors indicated by parenthesis

6.4.4 Visual Surveys

Visual survey data contained too few cases for multivariate analysis. Formicidae was the most abundant order on the ground in both hotspots and coldspots in White-browed and Chestnut-crowned Babbler home ranges while foliage was dominated by unidentified invertebrates (Other) in both spot types. The Other category also dominated foliage in Variegated Fairy-wren home ranges in both hotspots and coldspots, followed by Diptera in hotspots and Formicidae in coldspots (Table 6.2).

Table 6.2. Mean abundance of main invertebrate orders on foliage and ground substrates within hotspots and coldspots in home ranges of White-browed Babblers (*n* = 6), Variegated Fairy-wrens (*n* = 5) and Chestnut-crowned Babblers (*n* = 1) recorded during visual surveys of one minute duration (*n* = 264 in White-browed Babbler home ranges, *n* = 86 in Variegated Fairy-wren home ranges and *n* = 40 in the Chestnut-crowned Babbler home range). No visual surveys were conducted on the ground in Variegated Fairy-wren home ranges. Data collected during autumn and spring 2012.

	White-browed Babbler				**Variegated Fairy-wren**				**Chestnut-crowned Babbler**			
	Foliage		**Ground**		**Foliage**		**Ground**		**Foliage**		**Ground**	
	HS	**CS**	**HS**	**CS**	**HS**	**CS**	**HS**	**CS**	**HS**	**CS**	**HS**	**CS**
Coleoptera	0	1	0	1.25	0	0			0	1	2	1
Orthoptera	0	0	1	0	0	0			0	0	0	0
Araneae	1	1	1	1	1.08	1.18			1.33	2	1	0
Formicidae	2.33	1	6.52	5.08	1.13	1			1	0	9	3.2
Diplopoda	0	0	0	0	0	0			0	0	0	0
Lepidoptera	0	1	0	1	1	1			0	0	0	1
Diptera	1.32	1.14	1.11	1.13	1.87	1.39			1	1.2	1	1
Hymenoptera	0	0	0	0	1	1.5			0	3	0	0
Gryllidae	0	0	2	0	0	0			0	0	0	0
Other	2.05	3.86	1.22	1.44	4.89	3.07			5.33	4.75	4	0

6.5 Discussion:

The availability of invertebrate prey has a key influence on habitat selection among birds, often leading to disproportional use of space (Blake and Hoppes 1986, Holmes *et al.* 1986, Johnson and Sherry 2001, Brown *et al.* 2011). For many smaller species, the risk of predation faced while foraging is the primary determinant of habitat selection patterns (Hutto 1990, Lima 1990, Lima and Dill 1990, Wolda 1990), overriding the distribution of prey (Moorman *et al.* 2007). For these species, particular vegetation structures which offer increased cover are frequently associated with areas of concentrated foraging which consecutively underpin patterns of spatial use within their home ranges (Samuel *et al.* 1985, Barg *et al.* 2006, Antos *et al.* 2008) (Chapter 5). Abundances of invertebrate size classes and orders did not differ significantly between hotspots and coldspots within the home ranges of White-browed Babblers or Variegated Fairy-wrens, strongly suggesting the differential use of space by these birds was driven not by food resources, but by the distribution of different vegetation structures. The same is also likely to be true of Chestnut-crowned Babblers, despite differences between hotspots and coldspots not being tested statistically.

In the home ranges of all three species, the vegetation within hotspots was dense and provided high levels of cover which contrasted sharply with the sparse, thin vegetation of coldspots (Chapter 5). Smaller birds often display a dependency on cover and often only forage within easy retreating distance of denser vegetation as an anti-predation response (Lima *et al.* 1987, Valone and Lima 1987, Lima 1990, Lima and Dill 1990). In eucalypt woodland, White-browed Babblers forage in close proximity to cover to which they retreat when disturbed (Taylor 2003) (Chapter 4). In natural chenopod systems, Portelli *et al.* (2009) documented a clear preference of Chestnut-crowned Babblers to forage in drainage areas with substantially more shrub-level cover. In the same systems, Variegated Fairy-wrens forage in dense shrubs, the centre of which provides escape from predators (Tibbetts and Pruett-Jones 1999, Tidemann 2004). These trends were clearly evident in saltbush plantings where the propensity of these species to remain near cover was even greater (Chapter 5). White-browed and Chestnut-crowned Babblers foraged almost exclusively in litter either directly below or in very close proximity (<1 m) to cover provided by large, dense saltbushes. Variegated Fairy-wrens displayed similar cover dependency, concentrating their efforts above the ground within saltbush foliage (Chapter 4 and Chapter 5).

In finding little difference in arthropod availability between canopy gaps and surrounding forest, Moorman *et al.* (2007) concluded cover dependence became a greater determinant of the location of foraging sites among forest birds when food resources were not limiting. The lack of difference in invertebrate availability between hotspots and coldspots in the present study indicates food is not limiting in the selection of foraging sites, allowing the inherent dependency of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers on vegetative cover to emerge as the key driver of differential use patterns within their home ranges. The heterogeneous distribution of such cover reflects the differential use of space by these species in both saltbush plantings and remnant vegetation, further supporting this conclusion (Chapter 5).

The lack of dissimilarity in invertebrate prey availability between hotspots and coldspots may also relate to the size of the sampling plots (Antos *et al.* 2008). The 15 m radius plots used here may not detect finer scale differences in invertebrate prey availability while conversely, differences in the invertebrate community may be more apparent at larger spatial scales. For example, Digweed *et al.* (1995) found more Coleoptera were caught in pitfall traps spaced at larger intervals 25 m and 50 m compared with those at 10 m intervals. In addition, increasing the size of the sampling area can greatly increase the chance of catching patchily distributed species (Weaver 1995). In the present study the scale at which invertebrates were collected may have reduced the chance of detecting differences between hotspots and coldspots. However differences were not detected in any of the three sampling techniques, suggesting if scale was a factor, its effect was minimal.

The size and composition of pitfall and foliage invertebrates differed significantly between saltbush plantings and remnant vegetation in White-browed Babbler home ranges. These habitats differ markedly in structural and floristic complexity (Chapter 5) which has a fundamental influence on the composition of invertebrate communities and underpins their distribution (Lawton 1983, Johnson 2000, Johnson 2007). More complex vegetation frequently supports greater invertebrate diversity (Hatley and Macmahon 1980, Lawton 1983, Webb *et al.* 1984). For example, Murdoch *et al.* (1972) illustrated a positive correlation between vegetation complexity and insect diversity, documenting that plant species and foliage height (structural) diversity accounted for 79 percent of the variance in insect diversity. Similarly, Southwood *et al.* (1979) showed as plant species richness and structural diversity increased, so too did the diversity of species of Heteroptera and Coleoptera. These patterns are partially due to associations between particular invertebrate and plant species (Hatley and Macmahon 1980, Crisp *et al.* 1998). Woinarski and Cullen (1984) found the strong association of psyllids with *Eucalyptus* accounted in part for the marked dissimilarities between the invertebrate communities present on *Eucalyptus* foliage compared to the foliage of other plant species. In the context of the present study, substantial differences in vegetation structure combined with invertebrate/plant species associations are very likely to drive the differences observed between saltbush plantings and remnant vegetation.

Significant seasonal differences in invertebrate abundance were apparent in all samples except foliage invertebrates collected from the Chestnut-crowned Babbler home range. Woinarski and Cullen (1984) documented increased abundances of nectarivorous and pollen using invertebrates on flowering plants compared to plants that were not flowering. The increased abundance of Lepidoptera, Hemiptera and Orthoptera on foliage within White-browed Babbler and Variegated Fairy-wren home ranges during spring is consistent with this pattern. Woinarski and Cullen (1984) also postulated increases in predacious taxa such as Formicidae and Araneae may result from an increase in flower-associated prey species, a pattern again reflected in the present study. The seasonal fluctuations in invertebrate abundance may have also contributed to the seasonal shifts in foraging ecologies of all three bird species documented in Chapter 4 and potentially the decline or disappearance of some groups documented in Chapter 5.

The results of this study complement and reinforce those of Chapter 4 and Chapter 5, demonstrating the differential patterns of spatial use exhibited by White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers when foraging are primarily driven by the distribution of dense shrub-level vegetation in which they can seek cover. Saltbush plantings provide an abundant suite of potential invertebrate prey different to that found in remnant vegetation. This resource (among others) allows Variegated Fairy-wrens to reside entirely within plantings which also serve as supplementary foraging habitat for White-browed and Chestnut-crowned Babblers. Babblers along with many other species remain reliant on remnant vegetation for other essential resources such as nesting sites, nest materials and a well developed leaf litter in which to forage.

Based on the results of this study, management options should primarily aim to increase the provision of vegetative cover available to birds. This can be achieved by adjusting the timing and intensity of grazing and confining stock to sub-sections of plantings at one time with subdivisional fencing (which represents an opportunity cost to the landholder). This will retain some areas of densely foliaged saltbushes and create a ‘mosaic’ pattern of vegetation density within plantings. Interspersing plantings with other native *Exocarpos, Melaleuca* and *Acacia* shrub species which vary in grazing tolerance will enhance structural diversity and improve the suite of resources available to birds (Barton *et al.* 2010, Barton *et al.* 2011, Lancaster *et al.* 2012) but again, this will represent an opportunity cost to landholders. Finally, establishing saltbush plantings adjacent to remnant vegetation will allow White-browed and Chestnut-crowned Babblers to exploit the resources available in each habitat and encourage a greater diversity of birds into plantings.

This study focused on invertebrate availability within areas of high foraging intensity and unused areas in an effort to identify drivers of differential use of space by three species of birds. To fully understand the suite of invertebrates available in saltbush plantings, future research should sample invertebrates across entire plantings, rather than focusing on particular areas. Employing a broader array of sampling techniques will allow the full invertebrate community present within saltbush plantings to be documented. In addition, detailed analysis of the foraging ecologies of other bird species found in saltbush may aid in determining the full suite of foraging resources available in these areas. However other species were not as abundant or frequent in their use of saltbush plantings (Chapter 3) suggesting that the three species studied here were the species best adapted to exploiting existing saltbush plantings and provided a robust indication of their value to birds.

Chapter 7 General discussion

Plate 7.1. View to the south across a large patch of remnant native vegetation near Mindarie, South Australia. Photo: T. Richards

Prior to the current investigation, the contribution that plantings of Old Man Saltbush may make to supporting birds in the highly fragmented agricultural landscapes of the South Australian Murray Mallee remained largely speculative, based on simple, short term presence/absence measures and the extension of findings from studies of tree-based plantings (Palmer *et al.* 1997, Lefroy and Smith 2004, Williams 2004, Lefroy *et al.* 2005, Collard and Fisher 2010, Collard *et al.* 2011). Simple presence/absence measures fail to account for why some species are found in plantings while others are not, cannot determine the level of fidelity displayed by some birds toward particular areas and are unable to identify factors contributing to these patterns (Ruiz-Jaén and Aide 2005, Morrison *et al.* 2010). It is critical to understand patterns and process of biotic use of planted vegetation in farming systems as farmers forego financial opportunities to maintain farmland biodiversity and planted vegetation is an expensive change in land use. The present study examined the avifauna using saltbush plantings in detail, extending beyond the limitations of previous studies and determining for which species saltbush serves as habitat and how a focal set of these birds exploit plantings and acquire the resources necessary for survival. The study employed a sound framework through which a broader spectrum of the avian community could be examined in future investigations. The following discussion synthesises the key findings of the thesis and their contribution to our understanding of avian use of saltbush plantings. Management implications are then discussed on the basis of this investigation, complemented by directions for further research.

7.1 Key findings

In addition to the limitations of presence/absence survey methods, previous studies investigating the avifauna of saltbush plantings were undertaken over short time periods and small survey areas, isolated within particular vegetation types (e.g. Seddon *et al.* 2009, Collard *et al.* 2011). These constraints produced limited insight into which species were regularly found within saltbush plantings and the influence adjacency to remnant vegetation may have on the species assemblage. Chapter 3 addressed these deficiencies by repeatedly evaluating the suite of bird species present at sites with isolated saltbush plantings, isolated remnant vegetation, cleared agricultural land and importantly, sites with saltbush plantings adjacent to remnant vegetation. The study found birds showing high fidelity toward saltbush plantings represented a reduced suite of species compared to the broader assemblage present in remnant vegetation, and one dominated by open country generalists and shrub-associated species. These results broadly concur with previous presence/absence studies of saltbush plantings (e.g. Seddon *et al.* 2009, Collard *et al.* 2011) and illustrate these areas are of limited biodiversity value and provide little benefit for declining woodland birds (Munro *et al.* 2011). Nevertheless, saltbush plantings may form important additional or supplementary habitat for some birds and, as evidenced by the results of Chapter 3, can enhance the broader avian assemblage when established adjacent to remnant vegetation.

The study on foraging ecology of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers (Chapter 4) confirmed that not only are saltbush plantings regularly used by these species, but that these areas serve primarily as foraging habitat. Prior to this study, several authors had extended the findings of studies of tree-based plantings to suggest saltbush may serve as foraging habitat for birds and provide additional cover and nesting resources (e.g. Lefroy and Smith 2004, Lefroy *et al.* 2005, Collard and Fisher 2010, Collard *et al.* 2011), however precisely how birds used saltbush plantings and for what purpose remained unknown. Key findings of this study were the high variation in foraging substrates and heights between saltbush and remnant vegetation among White-browed and Chestnut-crowned Babblers and the consistency of Variegated Fairy-wrens foraging ecology with that documented natural chenopod systems. Taken together, these results illustrated that the foraging ecologies of these species were highly plastic and suited to exploiting the limited resources within saltbush plantings and hence these species were especially common in saltbush areas (Chapter 3). In addition, the results provided strong evidence that although babblers were able to forage extensively within saltbush plantings; they did not survive solely in these areas and were heavily reliant on continued access to remnant vegetation.

The dependence of White-browed and Chestnut-crowned Babblers on continued access to remnant vegetation was confirmed by the results of Chapter 5 which examined their home range and spatial utilisation distributions along with those of Variegated Fairy-wrens. The extent to which these commonly occurring species used saltbush plantings relative to remnant vegetation was previously unknown and whether birds resided solely within the plantings, used them as supplementary habitat, or were simply transient remained unconfirmed (Seddon *et al.* 2009, Collard and Fisher 2010, Collard *et al.* 2011). The investigation detailed in Chapter 5 showed groups of these birds were largely sedentary and saltbush plantings comprised a substantial portion of White-browed and Chestnut-crowned Babbler home ranges and the entirety of Variegated Fairy-wrens home ranges. More significantly, this study revealed a strong inherent dependency on cover to escape predation among the birds studied. The distribution of cover in the form of dense shrub vegetation was the primary determinant of habitat selection and spatial utilisation patterns. Finally, Chapter 5 found several bird groups decreased in size or disappeared between seasons, suggesting some configurations of saltbush and remnant vegetation represented sub-optimal habitat that was unable to sustain bird populations in the long term. The results of this study highlighted the importance of providing extensive cover and enhancing the structural complexity of saltbush plantings, a finding consistent with recommendations for enhancing tree-based monocultures (e.g. Hobbs *et al.* 2003, Loyn *et al.* 2007). In addition, maintaining connectivity between saltbush plantings and large tracts (>200 ha) of remnant vegetation was found to be crucial to facilitate greater use of saltbush plantings by birds.

The availability of invertebrate prey has a crucial influence on habitat selection by birds in other systems (Blake and Hoppes 1986, Holmes *et al.* 1986, Johnson and Sherry 2001, Brown *et al.* 2011) and may influence avian foraging and patterns of spatial use in saltbush plantings and remnant vegetation in the agricultural areas of the South Australian Murray Mallee (Chapter 4 and Chapter 5). Only one assessment of saltbush plantings in this context had previously been made by Collard *et al.* (2011) which focused on simple abundance measures of several taxa. By tailoring sampling techniques to the foraging ecologies of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers (Cooper and Whitmore 1990, Dahlsten *et al.* 1990, Hutto 1990), the availability of invertebrate prey within hotspots and coldspots across home ranges was assessed to determine the role prey availability may play in influencing patterns of spatial use (Chapter 6). These assessments found prey availability to be relatively evenly distributed across home ranges in both saltbush plantings and remnant vegetation. This confirmed, along with the findings of Chapter 4 and Chapter 5, that differential use of space within home ranges was primarily driven by the amount of cover provided by the vegetation.

7.2 Synthesis

The research contained in this thesis incorporates behavioural ecology, foraging ecology, spatial ecology, habitat selection, metapopulation theory, functional connectivity and landscape ecology, all of which provide detailed information to inform conservation biologists and guide management practices. Previous studies have largely focused on bird communities within tree-based plantings (e.g. Arnold 2003, Hobbs *et al.* 2003, Kinross 2004, Loyn *et al.* 2007, Munro *et al.* 2011), the general trends of which suggest that planted vegetation supports a reduced suite of bird species composed predominantly of those with more generalised ecologies. This pattern of reduced bird diversity was strongly pronounced in saltbush plantings (Chapter 3). For the few birds that used saltbush plantings regularly, the saltbush provided additional foraging habitat within their home ranges (Chapter 4 and Chapter 5) and provided an abundance of invertebrate prey (Chapter 6). Despite these benefits, remnant vegetation remains the most critical habitat, supporting more specialised species and providing essential resources such as nesting sites and nest materials to bird species common in saltbush plantings (Chapter 4 and Chapter 5). The lack of floristic and structural complexity inherent among monocultures is clearly apparent within saltbush plantings and consequently the value of these areas to biodiversity is limited (Munro *et al.* 2011).

Given their limited biodiversity value, saltbush plantings will not contribute significantly to conserving bird species in fragmented agricultural landscapes. The loss of several groups of birds over the course of the present study suggests some configurations of saltbush and remnant vegetation, particularly smaller patches, are unsuitable for long term occupation. Nevertheless, saltbush plantings can boost the species assemblage when adjacent to remnant vegetation (Chapter 3) and provide long term supplementary habitat for species with highly plastic foraging ecologies (Chapter 4), especially when established across large areas (>50 ha) and adjacent to large remnants (>200 ha, Chapter 5). Remnant native vegetation networks remain crucial to supporting rural bird populations (Fisher and Goldney 1998, Kavanagh *et al.* 2007, Barrett *et al.* 2008, Cunningham *et al.* 2008, Haslem and Bennett 2008a). However saltbush plantings, like their tree-based counterparts, represent a small component of the broader collection of perennial monocultures which when combined will enhance landscape heterogeneity and facilitate connectivity between remnants, providing benefits for an albeit small range of bird species (Hobbs *et al.* 2003, Watson *et al.* 2005, Loyn *et al.* 2007, Seddon *et al.* 2009).

7.3 Management implications

The intimate link between social and ecological systems demands the integration of research with policy, management, on-ground implementation and human livelihoods (Morton *et al.* 2009). Research into environmental states, trends and performance are central to the integration of environmental and socio-economic management through adaptable policies to address ecological issues while maintaining human health, wellbeing and social stability (Morton *et al.* 2009). Furthermore, the unknown effects of global environmental issues such as climate change exacerbate the need to develop guiding principles based on sound scientific research (Howden *et al.* 2008). The ever increasing reliance of biodiversity on agro-ecological landscapes emphasises the need to examine whether production elements afford benefits to regional wildlife and which modifications may increase their capacity to do so (Morton *et al.* 2009).

Perennial farming systems are recognised as a means to increase vital landscape components such as heterogeneity (Duelli 1997, Fischer *et al.* 2006, Radford and Bennett 2007, Fahrig *et al.* 2011), connectivity (Taylor *et al.* 1993, Saunders 1994, Wolff *et al.* 2002, Lindenmayer *et al.* 2008) and the provision of resources (Hobbs *et al.* 2003, Lefroy and Smith 2004, Lefroy *et al.* 2005, Collard and Fisher 2010). The present study illustrates precisely how Old Man Saltbush plantings are used by birds and the benefits that can be gained from these areas. Crucially, this research represents a significant progression toward determining the contribution these areas can make to the conservation of bird populations in fragmented agricultural zones. Furthermore, this study has identified several key drivers underpinning avian use of saltbush plantings which can be actively enhanced through improved management regimes. The information presented in this thesis is an essential contribution to the broader global issue of integrating production and biodiversity conservation on agro-ecological landscapes.

The results of this study clearly highlight the importance of vegetative cover to birds foraging in saltbush plantings within which refuge from predation can be sought, concurring with numerous studies of small birds in a variety of habitats (e.g. Lima *et al.* 1987, Valone and Lima 1987, Lima 1990, Lima and Dill 1990). Furthermore, the richer avifauna found in the more floristic and structurally diverse remnant vegetation suggests increasing the heterogeneity of saltbush plantings may facilitate use by a broader array of species. Remnant vegetation is also not only the source of crucial habitat elements missing from saltbush plantings, but of avian guilds considerably more likely to make use of plantings when the two habitats are adjacent. Habitat complexity and adjacency must therefore lie at the core of management practices aimed at supporting birds in saltbush plantings and remnant patches in the highly fragmented Murray Mallee region of South Australia.

The primary means to facilitate greater cover within saltbush plantings will be implementing more precise and controlled grazing regimes. Modifying the current practice of crash-grazing entire saltbush plantings to a regime where subdivisions are grazed rotationally will result in a mosaic pattern, with areas of both densely and sparsely foliated shrubs. Adjusting to mosaic-grazing has the added benefit of minimal cost and effort for landholders and potentially benefitting other taxa (Lancaster *et al.* 2012). Simply shortening grazing periods or sectioning plantings with additional fencing will, at a minor opportunity cost to landholders, allow more precise control of grazing stock which can be rotated over time, limiting impacts to defined areas.

The link between heterogeneous habitat and a greater diversity of species is well established (MacArthur 1960, MacArthur and MacArthur 1961, MacArthur *et al.* 1966, Freemark and Merriam 1986). Increasing the floristic and structural complexity of saltbush plantings with the addition of tree, shrub and possibly groundcover plant species or initially establishing plantings with a broader array of plants will not only generate habitat of greater value to bird species already found within saltbush plantings, but provide a wider spectrum of resources to cater for a suite of additional species (Smith *et al.* 2012). This is successfully demonstrated by mixed-species revegetation which attracts a much wider suite of bird species, including more specialised guilds, compared to monoculture plantings (Recher 1993a, Ryan 1999, Martin *et al.* 2004, Kavanagh *et al.* 2007, Barrett *et al.* 2008, Barrett *et al.* 2010, Paton *et al.* 2010a).

In addition, more floristically and structurally diverse saltbush plantings will provide a wider variety of locations in which the birds studied here can establish nests for breeding or roosting. In remnant vegetation White-browed Babblers frequently constructed nests in *Exocarpos aphyllus* and *Melaleuca lanceolata*, while Chestnut-crowned Babblers appeared to prefer *Callitris gracilis* for nesting. These are three plant species which differ from saltbushes in foliage structure, foliage density and overall size and height meaning their establishment within plantings would provide increased cover and structural heterogeneity. Evidence of this was seen at the SB-Rem site in landscape four where several large *M. lanceolata* shrubs formed a stand in a saltbush planting within which a collection of new and old White-browed Babbler nests were found. In addition this area was frequently visited during all seasons and formed a hotspot during spring 2011 (Figure 5.3), suggesting that these plants provided added cover and foraging resources for the birds.

The reliance of babblers (among other species) on continual access to remnant vegetation was clearly evident throughout the study and highlights the importance of not only retaining remnant native vegetation, but establishing saltbush plantings adjacent to these areas. In addition to providing required resources, remnant vegetation will provide source populations of various bird species to enter and forage within saltbush plantings (Arnold 2003, Martin *et al.* 2004, Vesk and Mac Nally 2006). Furthermore, impacts to remnants such as those associated with edge effects are likely to be reduced as adjacent saltbush may serve as a buffer against disturbances such as weed invasions and microclimatic changes (Hobbs 1993, Bennett *et al.* 2000, Haslem and Bennett 2008b).

Remnants could be directly managed by eliminating livestock grazing. All remnants in the present study had been grazed historically, however only those at SB-Rem sites in landscapes one, two and three and near SB-Iso sites in landscapes one and two were still subjected to the practice. These remnants were largely devoid of understorey and groundcover vegetation, resulting in very low levels of cover. In addition, the presence of stock in these areas had damaged and reduced the litter layer, a key foraging substrate for babblers (Recher and Davis 1998, Morris and Wooller 2001, Antos and Bennett 2006) (Chapter 4). By comparison, the isolated remnants, despite historical grazing, had well developed understoreys as a result of stock removal late last century. Removing stock from all remnants will allow understorey plants and other key elements to recover (Prober and Thiele 2005), broadening the range of resources available to birds. In turn this will increase the capacity of these areas to support bird groups in the long term, reducing the risk of mortality associated with moving between patches (Fahrig 2002). Furthermore, as White-browed and Chestnut-crowned Babblers nest largely within *Exocarpos aphyllus* which is found only within remnant vegetation, removing stock from these habitats will minimise disturbance during the breeding season, potentially increasing reproduction and population expansion.

The recovery of shrub level vegetation in remnants may be hastened by seeding or planting understorey species and introducing managed fire regimes. In addition to low densities of shrub species, the long history of grazing may have resulted in the depletion of the seed bank in some remnants (Taylor 2003). Furthermore, the absence of fire for decades in many of these remnants is likely to have prevented germination conditions required by many plant species (Gill 1981). Fire, if used, will need to be carefully managed to avoid destroying essential elements such as shrub-level vegetation and leaf litter over entire home ranges (Taylor 2003) and risking farming assets, however precise patch burning in small areas remains a viable management option to complement the outcomes of this research and secure species recovery.

On their own, plantings of saltbush are unlikely to aid the persistence of native birds in the longer-term, however when combined with a diversity of monoculture plantings and more direct conservation measures, these areas will contribute to biodiversity conservation in broadacre farming regions. A diversity of approaches which efficiently implement wide-scale revegetation while successfully addressing required conservation and design parameters and operating within economic and management constraints are needed if the best outcomes for both productivity and biodiversity are to be achieved (Saunders *et al.* 1991, Bennett *et al.* 2000, Bennett and Mac Nally 2004, Radford and Bennett 2010). A multi-pronged adaptive approach with areas of structurally and floristically diverse mixed native species revegetation, mixed-species agroforestry, commercial monoculture plantations and retained cropping and/or pasture will boost landscape connectivity and heterogeneity while retaining potential for modification as knowledge of faunal responses to revegetation is improved (Fisher and Goldney 1998, Bennett *et al.* 2000, McNeely 2004, Watson *et al.* 2005).

7.4 Research directions

This thesis provides substantial information on the use of saltbush plantings by three focal bird species which has direct application for guiding and modifying management practices.

Further research examining the minimum resource requirements of White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers would enable management recommendations to be fine-tuned.

The majority of findings in this thesis are based on the study of three focal bird species commonly found within saltbush plantings. Studying a number of focal species can be a successful exercise blending elements of ecosystem and species specific frameworks to yield valuable information applicable to a wider spectrum of populations (Lambeck 1997). However, Lambeck (1997) argued these need to be species whose requirements for persistence define the attributes that must be present if a landscape is to meet the requirements of other species. White-browed Babblers, Variegated Fairy-wrens and Chestnut-crowned Babblers are some of the most common species in saltbush plantings with highly plastic ecologies whose requirements for persistence are broad and may not include those of more specialised and rare species. Designing or modifying saltbush plantings based on the requirements of these species must therefore be done cautiously so as not to omit elements critical to the survival of other species (Franklin 1994). The methodology on which this thesis is based provides a sound framework through which other bird species less common in saltbush plantings could be examined to determine habitat elements necessary for their survival. These elements could then be incorporated into plantings to broaden their contribution to avian conservation.

The ease at which grazing practices can be modified to a mosaic regime through timing adjustment or subdivisional fencing suggests this is the management option which could be assessed most readily. Evaluating whether changed grazing practices lead to greater provision of dense vegetation will require experimental analysis and comparison of bird behaviour, patterns of spatial use and vegetation structure across saltbush plantings subjected to mosaic and crash-grazing. Comparing these results will determine the effectiveness of altered grazing regimes and possibly uncover means through which they can be further improved.

Despite extensive effort, reproduction and nesting success of the three focal bird species could not be examined during the present study. Assessing the production and survival of young allows productivity of a group or sub-population to be measured, providing a crucial indication of its persistence in an area (Holmes *et al.* 1992, Dunn and Ralph 2004). Productivity has not been measured in native tree or shrub-based monoculture plantings and consequently it is unknown whether these plantings can support bird populations in the long term. Research examining the productivity of birds found in saltbush plantings will reveal the potential of these areas to support their persistence in highly fragmented landscapes. In addition, continual monitoring of resident and dispersing bird species over a term longer than this study will clarify whether populations are expanding or contracting, further evaluating the contribution of saltbush plantings to supporting rural bird populations.

Saltbush plantings, along with all planted vegetation, increase the amount of vegetative cover in highly fragmented landscapes, thereby increasing structural connectivity (Benton *et al.* 2003, Lefroy *et al.* 2005, Prober and Smith 2009). The research documented in this thesis, combined with the findings of tree-based studies, illustrates that birds do indeed use planted vegetation, however whether these areas actually facilitate movement through extensively cleared landscapes remains unknown. Functional connectivity is crucial to the dispersal of individuals between sub-populations and persistence of the species at the metapopulation level (Levins 1969, Hanski and Gilpin 1991). Investigations are required to characterise landscape and functional connectivity within the Murray Mallee and determine the role saltbush plantings play in the dispersal of individual birds through fragmented landscapes and whether these areas contribute to functional connectivity, dispersal between sub-populations and the maintenance of metapopulations.

In addition to the above short-term investigations, long-term monitoring of bird species across regions that include species found in saltbush and those confined to remnant vegetation, is essential to uncover population trends. Monitoring programs are crucial to informing adaptive management regimes which are of particular importance in the face of increased agricultural demand and climate change (Howden *et al.* 2008). Continual and adaptive ecological science is fundamental to developing sound policies and frameworks which allow landscapes to support both production and biodiversity and the broader integration of social and ecological systems (Morton *et al.* 2009).

7.5 Concluding remarks

The results of the present study illustrate saltbush can indeed provide foraging resources to a reduced suite of bird species with more plastic ecologies suited to exploiting a variety of habitats. These species tend to use plantings in conjunction with remnant vegetation on which they remain reliant to acquire essential reproduction and shelter resources. These findings echo those of numerous studies of tree-based monocultures (e.g. Arnold 2003, Hobbs *et al.* 2003, Martin *et al.* 2004, Loyn *et al.* 2007, Smith 2009b) and illustrate both single-species shrub and tree-based plantings represent habitat of limited biodiversity value.

This study has revealed an inherent dependence on cover among the three focal bird species examined. This dependence on cover is the underlying factor determining both the degree to which saltbush plantings are used and the locations where foraging efforts are concentrated. Management will therefore involve practices which increase the amount of available cover and enhance the floristic and structural complexity of plantings. In addition, unimpeded access between saltbush and adjacent remnant vegetation must be facilitated to support resident birds and encourage a greater suite of species to venture into plantings. Implementing these management options in conjunction with studies on the less common bird species and monitoring of sub-populations are crucial for enhancing biodiversity conservation in the fragmented agricultural landscapes of the South Australian Murray Mallee. More broadly these steps are fundamental to the synthesis of production and biodiversity conservation and enhancing the outcomes of both domains.

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Appendices

Appendix 1. Bird species names, codes, mean abundances (*A*) and incidence (*I*) across all treatments (seasons combined) for all 67 bird species documented. Data collected during spring 2010 and autumn 2011.

Species	Site type							
	SB-Rem		*Rem-Iso*		*SB-Iso*		*Ag-Iso*	
	A	*I*	*A*	*I*	*A*	*I*	*A*	*I*
Australasian Pipit								
Anthus novaeseelandiae	0.1	0.03	1.0	0.34	2.3	0.53	1.0	0.31
Australian Magpie								
Cracticus tibicen	3.6	0.00	4.8	0.09	3.2	0.00	2.3	0.00
Australian Owlet-nightjar								
Aegotheles cristatus	0.0	0.25	0.1	0.28	0.0	0.06	0.0	0.09
Australian Raven								
Corvus coronoides	0.4	0.00	0.8	0.06	0.1	0.00	0.3	0.00
Australian Ringneck								
Barnardius zonarius	5.7	0.09	5.2	0.06	0.2	0.09	0.0	0.06
Black Shouldered Kite								
Elanus axillaris	0.1	0.03	0.0	0.13	0.1	0.19	0.0	0.03
Black-faced Cuckoo-shrike								
Coracina novaehollandiae	0.0	0.00	0.1	0.00	0.0	0.03	0.0	0.00
Blue Bonnet								
Northiella haematogaster	0.1	0.03	0.4	0.03	0.6	0.00	0.1	0.00
Brown Songlark								
Cincloramphus cruralis	0.0	0.13	0.0	0.13	0.0	0.09	0.0	0.00
Brown Thornbill								
Acanthiza pusilla	0.2	0.31	0.4	0.31	0.0	0.00	0.0	0.00
Brown Treecreeper								
Climacteris picumnus	0.7	0.25	1.4	0.03	0.0	0.00	0.0	0.00
Brown-headed Honeyeater								
Melithreptus brevirostris	0.6	0.03	0.0	0.00	0.0	0.00	0.0	0.00
Buff-rumped Thornbill								
Acanthiza reguloides	0.0	0.91	0.0	0.69	0.0	0.00	0.0	0.00
Chestnut-rumped Thornbill								
Acanthiza uropygialis	5.7	0.00	6.7	0.03	0.0	0.00	0.0	0.00
Cockatiel								
Nymphicus hollandicus	0.0	0.13	0.0	0.72	0.0	0.00	0.0	0.00
Common Bronzewing								
Phaps chalcoptera	0.2	0.00	1.3	0.03	0.0	0.03	0.0	0.06
Common Starling								
Sturnus vulgaris	0.0	0.59	0.1	0.41	0.1	0.59	0.1	0.03
Crested Pigeon								
Ocyphaps lophotes	2.6	0.03	0.9	0.00	2.4	0.00	0.1	0.00
Diamond Dove								
Geopelia cuneata	0.1	0.00	0.0	0.09	0.0	0.00	0.0	0.00
Dusky Woodswallow								
Artamus cyanopterus	0.0	0.00	0.1	0.03	0.0	0.00	0.0	0.00

Appendix 1 continued.

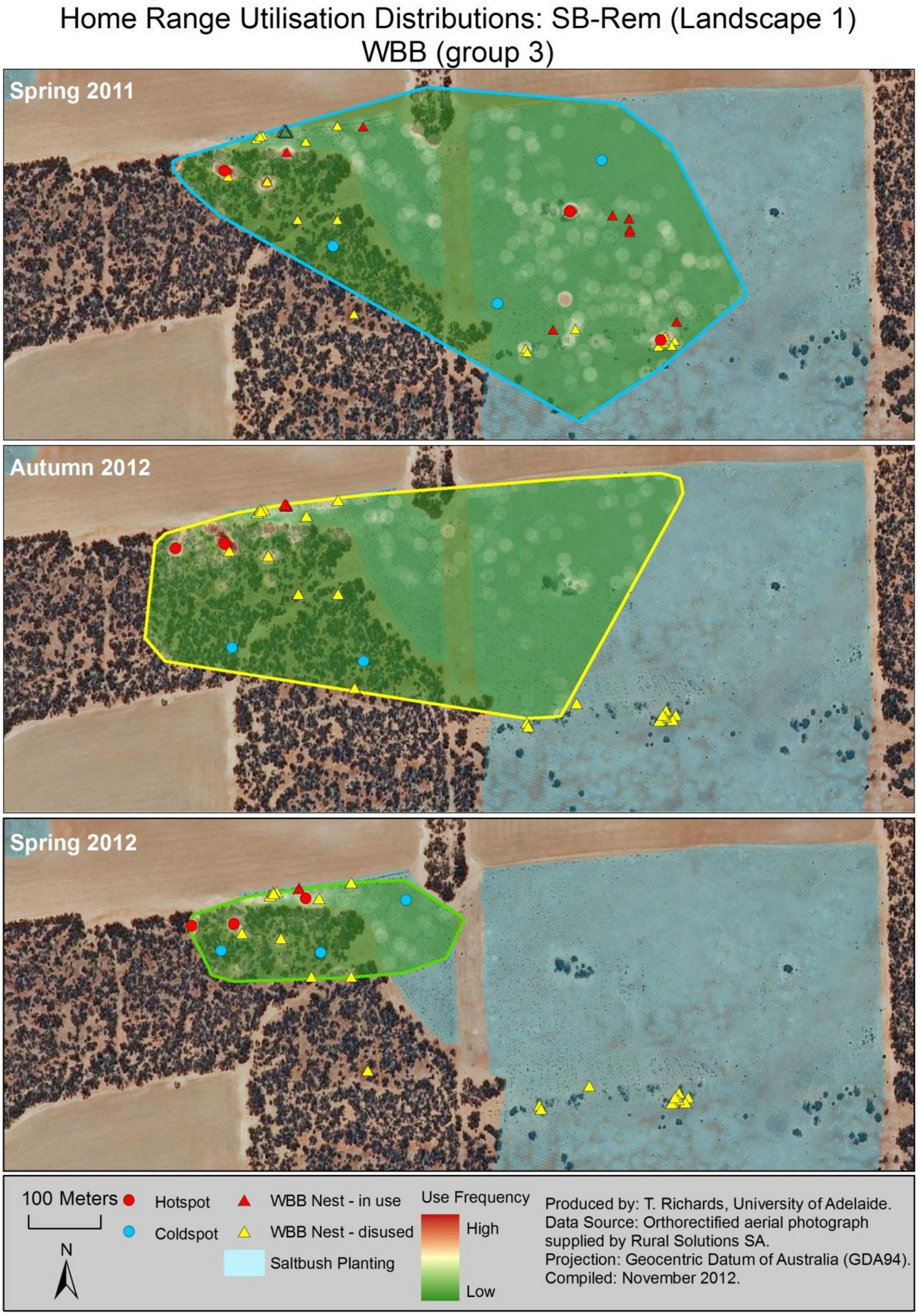
Elegant Parrot								
Neophema elegans	0.0	0.00	0.0	0.00	0.2	0.03	0.0	0.00
Emu								
Dromaius novaehollandiae	0.1	0.78	0.1	0.72	0.0	0.16	0.0	0.00
Eurasian Skylark								
Alauda arvensis	0.1	0.09	0.0	0.13	0.0	0.00	0.0	0.00
Galah								
Eolophus roseicapillus	4.7	0.16	4.3	0.03	0.4	0.00	0.0	0.00
Grey Butcherbird								
Cracticus torquatus	0.2	0.03	0.1	0.00	0.0	0.00	0.0	0.00
Grey Currawong								
Strepera versicolor	0.2	0.44	0.1	0.50	0.0	0.03	0.0	0.00
Grey Fantail								
Rhipidura albiscarpa	0.0	0.19	0.0	0.09	0.0	0.00	0.0	0.00
Grey Shrike-thrush								
Colluricincla harmonica	0.9	0.13	1.0	0.00	0.1	0.03	0.0	0.00
Hooded Robin								
Melanodryas cucullata	0.5	0.09	0.1	0.06	0.0	0.00	0.0	0.00
House Sparrow								
Passer domesticus	0.9	0.31	0.0	0.19	0.1	0.03	0.0	0.00
Inland Thornbill								
Acanthiza apicalis	0.2	0.00	0.1	0.00	0.0	0.03	0.0	0.00
Jacky Winter								
Microeca fascinans	0.9	0.84	0.3	0.88	0.0	0.53	0.0	0.41
Little Eagle								
Hieraaetus morphnoides	0.0	0.78	0.0	0.91	0.0	0.06	0.0	0.00
Masked Woodswallow								
Artamus personatus	0.1	0.09	0.1	0.06	0.0	0.00	0.0	0.00
Mulga Parrot								
Psephotus varius	0.3	0.06	0.0	0.00	0.0	0.00	0.0	0.00
Nankeen Kestrel								
Falco cenchroides	0.0	0.00	0.0	0.00	0.1	0.03	0.0	0.00
Noisy Miner								
Manorina melanocephala	0.2	0.09	0.2	0.09	0.1	0.03	0.0	0.00
Pallid Cuckoo								
Cacomantis pallidus	0.0	0.00	0.1	0.03	0.0	0.00	0.0	0.00
Rainbow Bee-eater								
Merops ornatus	0.1	0.03	0.3	0.16	0.0	0.00	0.0	0.00
Red Wattlebird								
Anthochaera carunculata	0.2	0.09	0.2	0.16	0.0	0.00	0.0	0.00
Red-capped Robin								
Petroica goodenovii	0.1	0.06	0.2	0.13	0.0	0.00	0.0	0.00
Restless Flycatcher								
Myiagra inquieta	0.1	0.06	0.2	0.16	0.0	0.00	0.0	0.00
Rufous Whistler								
Pachycephala rufiventris	0.3	0.16	0.1	0.09	0.0	0.00	0.0	0.00
Singing Honeyeater								
Lichenostomus virescens	2.8	0.66	0.3	0.09	5.0	0.88	0.0	0.00
Southern Boobook								
Ninox novaeseelandiae	0.0	0.00	0.0	0.03	0.0	0.00	0.0	0.00

Appendix 1 continued.

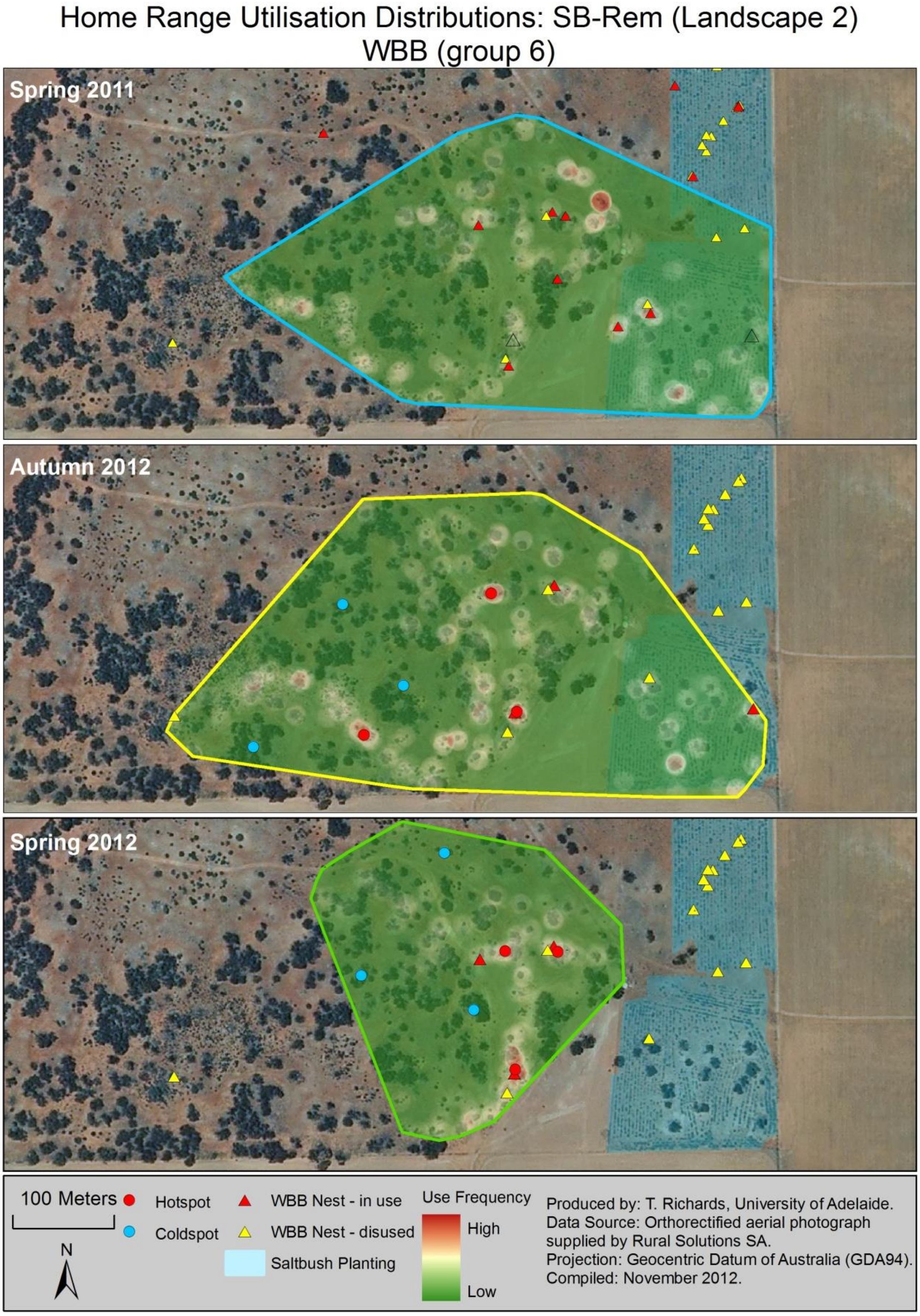
Southern Whiteface *Aphelocephala leucopsis*	1.3	0.41	0.4	0.09	0.0	0.03	0.0	0.00
Spiny-cheeked Honeyeater *Acanthagenys rufogularis*	0.3	0.16	0.2	0.06	0.0	0.00	0.0	0.00
Splendid Fairy Wren *Malurus splendens*	0.5	0.16	0.0	0.00	0.0	0.00	0.0	0.00
Spotted Pardalote *Pardalotus punctatus*	0.2	0.13	0.3	0.06	0.0	0.00	0.0	0.00
Striated Pardalote *Pardalotus striatus*	1.1	0.22	1.0	0.25	0.0	0.00	0.0	0.00
Stubble Quail *Coturnix pectoralis*	0.0	0.00	0.0	0.00	0.4	0.28	0.1	0.09
Superb Fairy Wren *Malurus cyaneus*	0.3	0.09	0.1	0.03	0.2	0.03	0.0	0.00
Tree Martin *Petrochelidon nigricans*	0.0	0.00	0.0	0.03	0.0	0.00	0.0	0.00
Varied Sitella *Daphoenositta chrysoptera*	0.3	0.06	0.1	0.03	0.0	0.00	0.0	0.00
Variegated Fairy Wren *Malurus lamberti*	1.6	0.41	0.5	0.09	4.3	0.84	0.0	0.00
Wedge-tailed Eagle *Aquila audax*	0.0	0.00	0.0	0.03	0.0	0.00	0.0	0.00
Weebill *Smicrornis brevirostris*	0.0	0.03	0.0	0.00	0.0	0.00	0.0	0.00
Welcome Swallow *Hirundo neoxena*	0.3	0.09	0.0	0.00	0.1	0.00	0.1	0.03
White-browed Babbler *Pomatostomus superciliosus*	4.4	0.59	2.4	0.38	1.6	0.25	0.0	0.00
White-browed Woodswallow *Artamus superciliosus*	0.8	0.03	8.2	0.16	0.0	0.00	0.0	0.00
White-fronted Chat *Epthianura albifrons*	0.3	0.06	0.0	0.00	5.5	0.41	0.0	0.00
White-winged Chough *Corcorax melanorhamphos*	5.5	0.66	0.0	0.03	0.0	0.00	0.0	0.00
Willie Wagtail *Rhipidura leucophrys*	0.9	0.44	1.1	0.50	0.9	0.22	0.0	0.00
Yellow Thornbill *Acanthiza nana*	0.1	0.06	0.2	0.13	0.0	0.00	0.0	0.00
Yellow-plumed Honeyeater *Lichenostomus ornatus*	0.3	0.09	0.4	0.19	0.0	0.00	0.0	0.00
Yellow-rumped Thornbill *Acanthiza chrysorrhoa*	7.9	0.91	8.0	0.78	1.7	0.19	0.0	0.00
Yellow-throated Miner *Manorina flavigula*	2.2	0.31	0.5	0.13	0.2	0.06	0.0	0.00

Produced by: T. Richards, University of Adelaide.
Data Source: Orthorectified aerial photograph supplied by Rural Solutions SA.
Projection: Geocentric Datum of Australia (GDA94).
Compiled: November 2012.

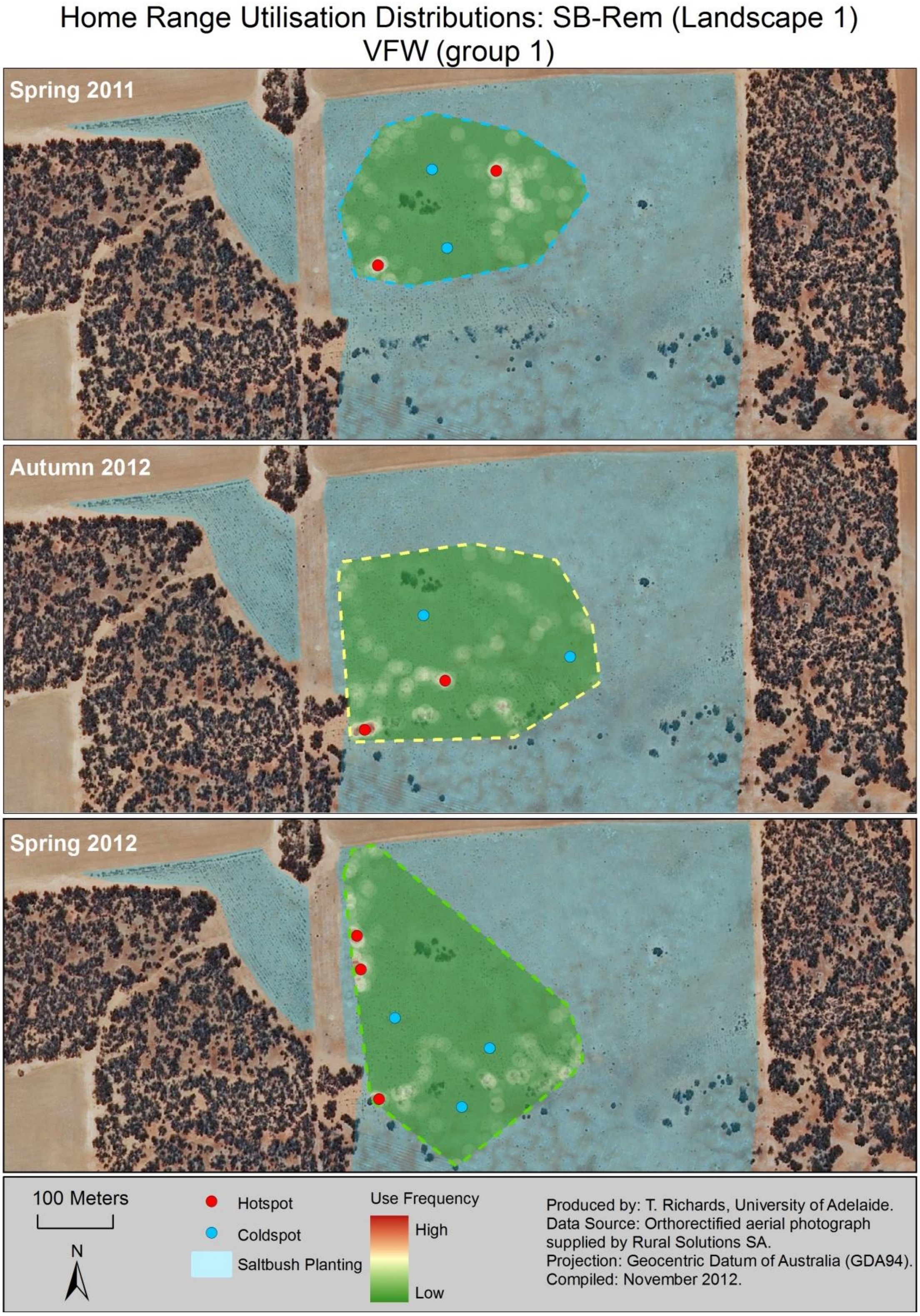
Appendix 2. White-browed Babbler home range and utilisation distributions (point density) at Rem-Iso site in landscape two (group seven, n = 3026) during spring 2011 (blue outline) and autumn 2012 (yellow outline).



Appendix 3. White-browed Babbler home range and utilisation distributions (point density) at SB-Rem site in landscape one (group three, n = 1924) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).

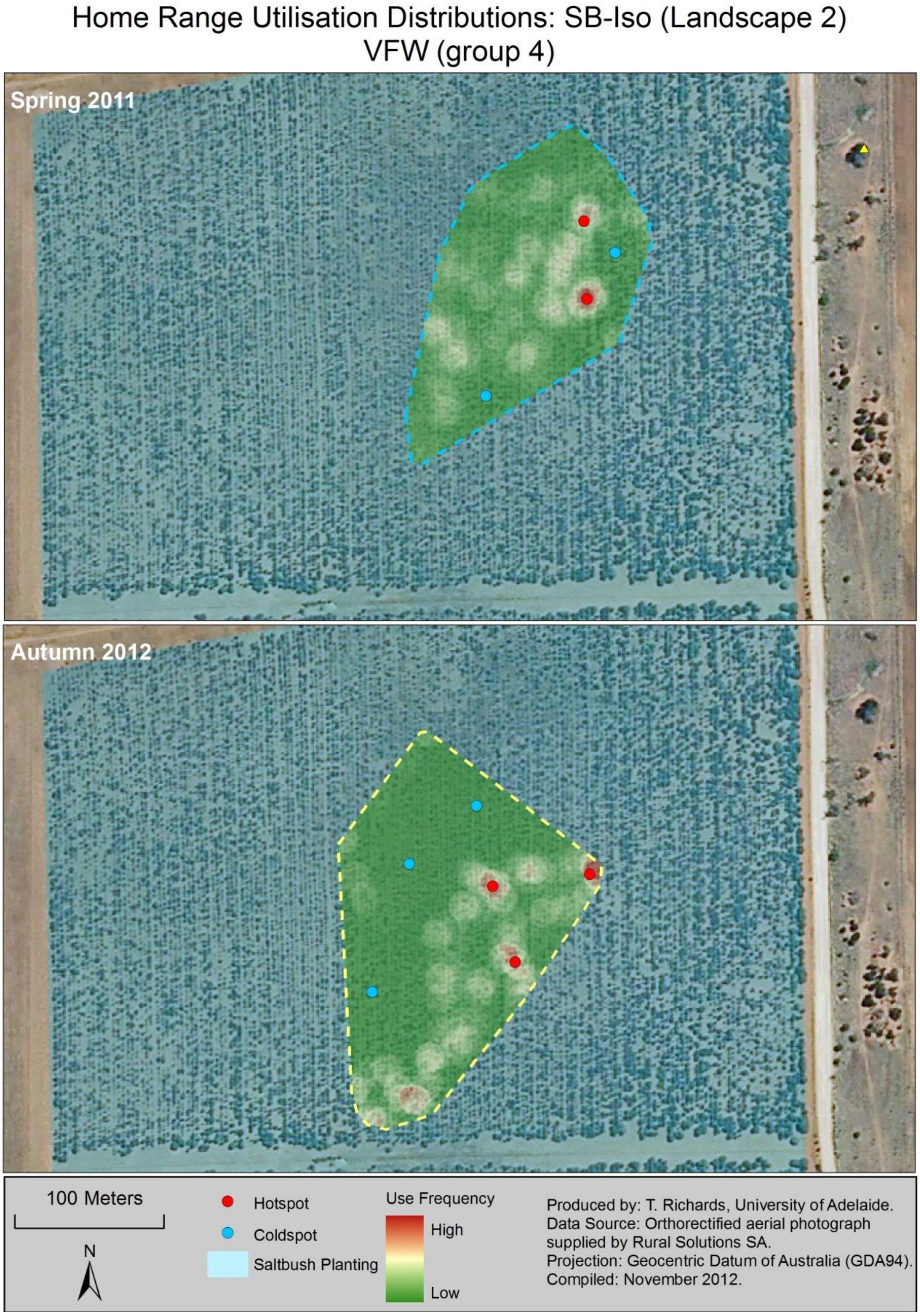


Appendix 4. White-browed Babbler home range and utilisation distributions (point density) at SB-Rem site in landscape two (group six, n = 3847) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).

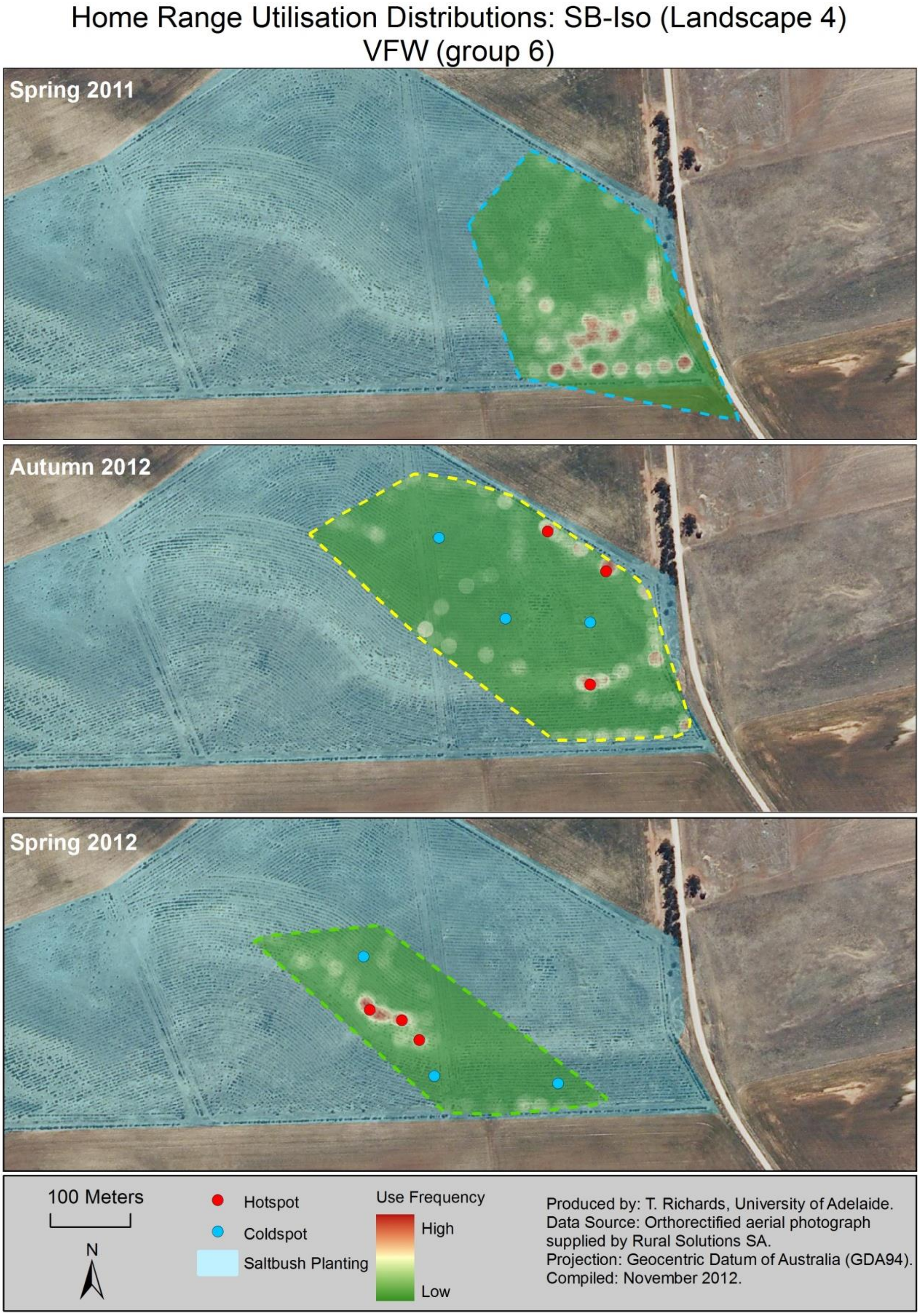


Appendix 5. Variegated Fairy-wren home range and utilisation distributions (point density) at SB-Rem site in landscape one (group one, n = 1166) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).

Appendix 6. Variegated Fairy-wren home range and utilisation distributions (point density) at SB-Iso site in landscape one (group three, n = 1286) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).



Appendix 7. Variegated Fairy-wren home range and utilisation distributions (point density) at SB-Iso site in landscape two (group four, n = 677) during spring 2011 (blue outline) and autumn 2012 (yellow outline).



Appendix 8. Variegated Fairy-wren home range and utilisation distributions (point density) at SB-Iso site in landscape four (group six, n = 2587) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).

Produced by: T. Richards, University of Adelaide.
Data Source: Orthorectified aerial photograph supplied by Rural Solutions SA.
Projection: Geocentric Datum of Australia (GDA94).
Compiled: November 2012.

Appendix 9. Chestnut-crowned Babbler home range and utilisation distributions (point density) at SB-Iso site in landscape two (group four, n = 2079) during spring 2011 (blue outline), autumn 2012 (yellow outline) and spring 2012 (green outline).