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Ecotones and fire and the conservation of the endangered eastern bristlebird

Jack Baker

University of Wollongong

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Ecotones and fire and the conservation of
the endangered eastern bristlebird

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy
from the University of Wollongong

by

Jack Baker
B Sc, Grad Dip Ed, B App Sc (Environmental Analysis)
Declaration

This thesis is submitted in accordance with the regulations of the University of Wollongong in fulfilment of the requirements of the degree of Doctor of Philosophy. The work in this thesis was carried out by me and has not been submitted to any other university or institution.

...... 31 July 1998

John Richard (Jack) Baker
Commonwealth of Australia

Declaration under s18.(1) of the
Endangered Species Protection Act 1992

I, ROBERT MURRAY HILL, Minister for the Environment, in pursuance of s18.(1) of the Endangered Species Protection Act 1992, hereby declare that Schedule 1 to that Act shall be deemed to be amended by:

adding

AMPHIBIANS
Sunset Frog *Litoria fluminicola*

BIRDS
Eastern Bristlebird *Dasyornis brachypterus*

MAMMALS
Kangaroo Island Dunnart *Sminthopsis aitkeni*
Karkarratul (Northern Marsupial-Mole) *Notoryctes oweni*
Yirraityjarri (Southern Marsupial-Mole) *Notoryctes typhlops*

INVERTEBRATES
Bathurst Copper Butterfly *Paralucia spinifera*

to 'Schedule 1 Part 1 - Species that are endangered' adding

BIRDS
Eastern Bristlebird *Dasyornis brachypterus*

from 'Part 2 - Species that are vulnerable'.

In accordance with s19 of the Endangered Species Protection Act 1992 the reasons for the above amendments are available at reasonable cost from the Director of National Parks and Wildlife on receipt of a written request.

Dated this 1st day of June 1998.

Robert Hill
Minister for the Environment
Acknowledgements

There is a story other than my dissertation. Briefly, 'tis this. From my grandparents came stubborn determination, stories and fun. My father taught me by example that I could simply do anything. By guile, my mother infused in me a sense of what was worth doing. Together, my parents introduced me to the bush. May Clarke said "you're never too old to learn"; good advice from my 85 year-old mother-in-law. My children and their children stand to inherit a world of uncivil societies in messed-up ecosystems. In this, the latter part of my life, I am working for the conservation of the childrens' world.

My re-introduction to university study was provoked by Bruce Gray and fostered by four excellent teachers at Charles Sturt University, Wagga Wagga, namely Tony Dare-Edwards, Ken Page, David Robertson and Helen Wood and some boisterous classmates, namely Danny Roberts and Geoff Russell. I was privileged to live and work at Barren Grounds where I met ground parrots, eastern bristlebirds, Kris French and Rob Whelan. Meeting Rob the biologist, not the other whiskey and whistle Rob, allowed my dream of post-graduate study to become a reality.

Being a member of the Biology Department at Wollongong Uni was very exciting and a bit scary sometimes, the way it made my brain fuzz and buzz. I tried to learn from all of my peers: students, researchers and lecturers alike. Mostly, they go unnamed. A few are special to me: Fiona Beynon, Justine Cox, Carl Gosper, Simon Heemstra, Tanya Llorens, Matt O'Mullane, Sue Murray-Jones, Suzanne Oppenheimer, Louise Rodgerson and Alex Watson.

Ken Russell, consultant statistician, University of Wollongong, assisted with the survey design and provided the analysis of proportions for the vegetation cover section of Chapter 5 and also gave advice about the ANOVA in Chapter 4 and the $\chi^2$ analyses in Chapter 6. John Marthick, consultant geoscientist, University of Wollongong, drove the home range and GIS computer applications used for data manipulation in Chapter 6 and provided digitized base maps for Figures 2.1, 3.2 and 6.1. Belinda Pellow and Gary Leonard, Janet Cosh Herbarium, University of Wollongong, assisted with plant identification. Jean Clarke, unpaid worker, used witchcraft to catch the bristlebirds for the radio-tracking reported in Chapter 6.

Another privilege for me during my studies, was to associate with many helpful people outside of the university. Most are variously acknowledged in previous reports and papers and, again, just a few are mentioned, those whose encouragement I especially valued: Ross Goldingay, Stephen Marchant, Les Mitchell and Ros Muston.
My greatest privilege was to be a student of Kris French and Rob Whelan. Their patience, enthusiasm, knowledge and scholarship have amazed and inspired me. And, they both have a great sense of fun.

My studies were financed partly by related consultancies undertaken for Environment Australia and NSW NPWS, partly by the University of Wollongong and mostly by Jean Clarke.

The studies reported in the thesis were conducted with Animal Ethics Approval No AE97/02 from the University of Wollongong; Australian Bird Banding Schemes Authorities A1863 and A1725; Booderee National Park Research Permit JR97/19; and NSW NPWS Scientific Investigation Licences A1320, C332 and C294.

During the course of my study, I had the opportunity to be involved in writing publications and reports, collaboratively and alone. In the thesis, these works are cited only in reference to the parts which were separate to my own research. My interest in the eastern bristlebird was stimulated and maintained by involvement with reviews (Bramwell and Baker 1990; Baker and Clarke 1991; Baker 1995; Whelan and Baker in press). The collection of eastern bristlebird data at Jervis Bay and Nadgee and the formulation of management recommendations for various consultancies, partially facilitated a number of works (Baker and French 1994; Baker 1996a; Baker and Whelan 1996; Whelan and Baker 1996; Gosper and Baker 1997; Baker 1997a; Baker 1998). The status of the eastern bristlebird was assessed by Baker (1996b) and this report was instrumental in changing the legal status of the species in NSW and nationally. Chapters 2 and 3 were condensed in Baker (1997b). My study of ecotones was stimulated by involvement with a study of forest powerline easements (Baker et al. 1998).

Throughout my studies my constant companions were the fine works of the descendants of Arth Guinness and the fine music from ABC Classic FM.

My very best mate and mentor has been and will remain my wife, Jean Clarke.
Ecotones and fire and the conservation of the endangered eastern bristlebird

Abstract

Conserving Australia's rich biodiversity should begin with a concern for individual species. This thesis explores the issues of threatened species status, fire as a threatening process and the significance of bird habitat at ecotones, with a focus on the eastern bristlebird as a case study. The dominant issue of ecotones is explored in relation to bird populations and heath-wood edges.

The biological status of the eastern bristlebird was clear by 1997. It was estimated that there were fewer than 2 000 individuals occupying less than 120 km². Their range covered 1 400 km from Conondale Range, south-eastern Queensland, to Croajingolong in north-eastern Victoria. They were confined to three disjunct regions. The 6-9 northern populations were on the brink of regional extinction. There was one small widely spread southern population at Nadgee-Croajingolong. The central populations were contained in two main areas, Barren Grounds-Budderoo and Bherwerre Peninsula, Jervis Bay, with possibly a few small fragments at Morton-Red Rocks. The fragmentation and decline that were probably ongoing for millennia, have apparently been hastened by European settlement.


Fire has been a feature of eastern bristlebird habitat in the regions where the species currently occurs. This thesis documents evidence to suggest that fire has caused the loss of populations in prehistoric, historic and recent times. By contrast, at Barren Grounds, in the absence of fire during 1992-7, the population almost doubled. There was a short to medium-term trend of density increasing from zero or low density immediately after fire, recovering to a plateau of approximately 2 birds per 5 ha, 10 years after fire. There was some evidence that the extent of a fire and the availability of fire refugia are important factors in the recovery of populations after fire. Eastern bristlebirds can occur and breed in relatively long-unburnt habitat, for example, at Nadgee, in habitat with fire-age older than 24 years.
Abstract

Two central theories have emerged from the concept of ecotones: "the edge effect" and "ecotonal species" (Odum 1958). Few studies have explored these concepts at natural edges between two contrasting vegetation communities. In the last decade, the eastern bristlebird has been called an ecotonal species, although Bramwell et al. (1992) have provided the only analytical test of this assertion. In the present thesis, bird populations across heath-wood edges were studied for evidence of edge effects and ecotonal species. When the ecotone was taken as a 50 m wide zone across the edge, there was no evidence for greater bird abundance or species richness at the ecotone. Rather, the general pattern was that the ecotone and the wood were similar and they had double the bird abundance and richness of the heath. There was an underlying pattern that the abundance and richness for the wood side of the edge were greatest at the ecotone and similarly the values for the heath side were greatest at the ecotone. However, this pattern was statistically significant only in one case. Bird abundance at the wood side of the ecotone was approximately 67% greater than in the wood. This was the strongest piece of evidence in the present study for the dogma of edge effect.

Bird species were categorized by Sisk and Margules (1993) according to whether they avoided or exploited habitat at edges between contrasting vegetation communities. I adapted their response models to describe the localized distribution patterns of the abundant species found across heath-wood edges. For 20 species, 45% fitted the model for ecotone ignorers, 35% fitted the model for ecotone exploiters and 20% fitted the model for ecotone avoiders. However, the pattern of specialization of bird species for the habitat on either side of the edge was more pronounced than the pattern of response to the ecotone. The eastern bristlebird fitted the model for a habitat generalist - ecotone exploiter but it was not restricted to the ecotone. There were no entirely ecotonal species at the heath-wood edges at Budderoo-Barren Grounds, Jervis Bay or Nadgee.

Past and present records show that the eastern bristlebird has been associated with most major vegetation communities in wetter parts of south-eastern Australia. Dense low cover was characteristic of all historic and recent eastern bristlebird habitat descriptions. This factor is common throughout the species' range in the various vegetation communities it inhabits. At Barren Grounds, layers of ground cover, low cover and tall shrub cover were shown to be important features which distinguished eastern bristlebird habitat from areas where bristlebirds were not detected. The species is often associated with heathland or heathy vegetation, however, its habitat specialization is not heath, it is dense low vegetation.

Vegetation structure was studied across heath-wood edges. There was no evidence for an overall pattern or even a single site where substantial areas of heath ecotone and wood ecotone had a vegetation structure different to that of the heath or the wood. The most
Abstract

usual pattern of vegetation structure at the ecotone was a simple grading from a highly uniform heath to a less uniform wood. Heath ecotone grouped most closely with heath and wood ecotone grouped most closely with wood.

The eastern bristlebird is a cryptic species. Individuals were radio-tracked in a detailed study of the species in its habitat at Jervis Bay and useful tracking data were obtained for 20 birds. Home range areas were estimated using minimum convex polygons and averaged 4 ha (range 1.5-6.6 ha) for one week (7 birds) and ≥ 10 ha for 2-6 weeks (2 birds).

The radio-tracking results supported previous studies which indicated that, at Jervis Bay, eastern bristlebird occur in a wide variety of habitats with relatively high densities in some areas. The highest density was 8 birds in 19 ha (2.1/5 ha) during May 1997. For the Jervis Bay population, the density estimates calculated using aural survey data were very similar to those calculated using radio-tracked birds. This result placed confidence in the validity of the aural surveys in all areas.

The tracking data for six birds at each of two heathland edge sites were investigated for habitat selection and edge affinity. Overall, there was significant selection by the birds among the habitat zones of heath, wood and the 50 m wide ecotone. However, individual birds varied in their preference and avoidance of these three habitats. Overall, the birds showed no attraction towards heath-wood edges.

The legal status of the eastern bristlebird has been changed during the past decade from Vulnerable to the more appropriate category of Endangered. This has happened in all states where the species occurs (Queensland, NSW and Victoria) and nationally, in recognition of its historic decline and current biological status.

This thesis concludes that the eastern bristlebird is cover-dependent and fire-sensitive but more a habitat generalist than a heath-wood ecotone exploiter. The existing larger eastern bristlebird populations (Barren Grounds-Budderoo, Jervis Bay and possibly Nadgee-Croajingolong) would probably grow and expand their local area of occupancy if they were protected from disturbance, particularly fire which kills individuals and removes the dense low vegetation in their habitat. Recovery planning for the eastern bristlebird requires not only strategies to increase the number of individuals but also strategies to rebuild or re-establish populations outside Barren Grounds-Budderoo, Bherwerre Peninsula and Nadgee-Croajingolong. Ku-ring-gai, Woronora Plateau, Morton and Beecroft Peninsula were suggested as possible translocation sites.

The management of fire in eastern bristlebird habitat is an important issue. The most sensible way to manage eastern bristlebird habitat would be to exclude fire unless site-
Peninsula and Nadgee-Croajingolong. Ku-ring-gai, Woronora Plateau, Morton and Beecroft Peninsula were suggested as possible translocation sites.

The management of fire in eastern bristlebird habitat is an important issue. The most sensible way to manage eastern bristlebird habitat would be to exclude fire unless site-specific population monitoring data demonstrate that this is detrimental. Management plans need to identify areas of eastern bristlebird habitat and develop strategies for protecting them from fire. Suggested strategies are slashing rather than prescription burning to create fuel-reduction zones, planning escape routes for eastern bristlebirds when prescription burns are used and aerial water-bombing to protect habitat when fires are out of control.

Individual eastern bristlebirds have a relatively large home range, overlapping home ranges and a considerable daily range. This implies that disturbances in the vicinity of eastern bristlebird habitat, such as vehicular traffic within 500 m, are likely to have an impact on a large proportion of the existing populations because these populations currently occupy relatively small areas.

This thesis concludes by suggesting that the management of threatened species recovery and biodiversity generally could benefit from an accountable administration concerned with species as a whole and biomes, whose assessment criteria should be improvements in conservation. Management at the local level should deal with populations "on the ground" through adaptive management rather than by prescription. The key to adaptive management is communication between researchers and managers and within the levels of management. Numerous research questions have arisen out of my studies. However, the fundamental tool of conservation management remains population and habitat monitoring.
# Contents

Acknowledgements i  
Abstract iii  
Table of Contents vii  
List of Figures x  
List of Tables xii

## Chapter 1 General Introduction  1

Status and the conservation of threatened species 1  
Birds and fire 3  
Ecotones 6  
Edge effect 7  
Ecotonal species 8  
Structure of the thesis 10

The eastern bristlebird 11  
Taxonomy 11  
Description 11  
Life history 12  
Potential threats 13

## Chapter 2 Status of the eastern bristlebird  14

Introduction 14  
Biological status of the eastern bristlebird 14  
Legal status of the eastern bristlebird 15  
Aims 16

Methods 16

Results 19  
Historic records 20  
Recent records for the northern populations 21  
Ku-ring-gai Chase National Park 22  
Woronora Plateau 22  
Mt Kembla 22  
Budderoo National Park 23  
Barren Grounds Nature Reserve 23  
Morton National Park and Red Rocks Nature Reserve 23  
Jervis Bay 24  
Ben Boyd National Park 25  
Nadgee Nature Reserve 25  
Recent records from Victoria 26

Discussion 26  
Status 26  
Interpreting the results 28
Chapter 3 A fiery problem: managing eastern bristlebird habitat 31

Introduction
The problem
A digression: the ground parrot
Serendipity: a longitudinal study of the eastern bristlebird at Barren Grounds
Aims

Methods

Results

Discussion
Post-fire density response
Pattern of fire: extent
Pattern of fire: refugia
Is fire necessary?

Chapter 4 Birds across heath-wood edges 45

Introduction
Ecotones and edge effect
Birds at edges: response models
Heath-wood edges and the eastern bristlebird
Aim

Methods
Site descriptions
Surveys
Data analysis

Results
Edge effect - bird abundance
Edge effect - average species richness
Edge effect - cumulative species richness
Edge effect - total species richness
Response of species across heath-wood edges
Ecotonal species

Discussion
Edge effects
Responses of species across heath-wood edges
Habitat specialization
Eastern bristlebird: ecotonal species? No
Any ecotonal species? None
Summary
## Contents

<table>
<thead>
<tr>
<th>Chapter 5 Eastern bristlebird habitat and vegetation structure across heath-wood edges</th>
<th>74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>74</td>
</tr>
<tr>
<td>Aims</td>
<td>76</td>
</tr>
<tr>
<td>Methods</td>
<td>77</td>
</tr>
<tr>
<td>Results</td>
<td>82</td>
</tr>
<tr>
<td>Eastern bristlebird habitat - vegetation community characteristics</td>
<td>82</td>
</tr>
<tr>
<td>Eastern bristlebird habitat - vegetation cover</td>
<td>86</td>
</tr>
<tr>
<td>Vegetation structure across heath-wood edges: each site</td>
<td>86</td>
</tr>
<tr>
<td>Vegetation structure across heath-wood edges: all sites combined</td>
<td>89</td>
</tr>
<tr>
<td>Discussion</td>
<td>93</td>
</tr>
<tr>
<td>Vegetation communities</td>
<td>93</td>
</tr>
<tr>
<td>Cover</td>
<td>94</td>
</tr>
<tr>
<td>Heath-wood ecotones</td>
<td>95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>99</td>
</tr>
<tr>
<td>On the song of a bird</td>
<td>99</td>
</tr>
<tr>
<td>Aims</td>
<td>100</td>
</tr>
<tr>
<td>Problematic bristlebirds</td>
<td>100</td>
</tr>
<tr>
<td>Study area</td>
<td>101</td>
</tr>
<tr>
<td>Trapping</td>
<td>101</td>
</tr>
<tr>
<td>Processing</td>
<td>103</td>
</tr>
<tr>
<td>Radio-tags and tracking</td>
<td>106</td>
</tr>
<tr>
<td>Mapping</td>
<td>109</td>
</tr>
<tr>
<td>Population density</td>
<td>110</td>
</tr>
<tr>
<td>Bird movements and the effects of radio-tagging</td>
<td>110</td>
</tr>
<tr>
<td>Home range</td>
<td>113</td>
</tr>
<tr>
<td>Habitat utilization</td>
<td>119</td>
</tr>
<tr>
<td>Discussion</td>
<td>127</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 7 General Discussion</th>
<th>133</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis of results</td>
<td>133</td>
</tr>
<tr>
<td>Conservation and management</td>
<td>138</td>
</tr>
<tr>
<td>Future research</td>
<td>142</td>
</tr>
</tbody>
</table>

References | 146 |
List of Figures

Figure 2.1 The Jervis Bay district showing the survey area 18
Figure 2.2 Past and present distribution of the eastern bristlebird 20
Figure 3.1 Ground parrot density at Barren Grounds 32
Figure 3.2 Barren Grounds: dates of the last fire and survey route 34
Figure 3.3 Eastern bristlebird densities against fire-age of habitat 36
Figure 3.4 Eastern bristlebird densities comparing parts of young and old fire-age 37
Figure 3.5 Eastern bristlebird recolonization of recently burnt areas 37
Figure 4.1 Models of bird responses across an edge 46
Figure 4.2 Model of ecotonal species response 47
Figure 4.3 Survey layout at each site showing 6 plots (or 3 pairs of plots) 49
Figure 4.4 Edge effect - bird abundance and species richness 54
Figure 4.5 Possible habitat generalist - ecotone ignorer 57
Figure 4.6 Wood specialist - ecotone ignorer 58
Figure 4.7 Heath specialist - ecotone ignorer 59
Figure 4.8 Habitat generalist - ecotone exploiter 59
Figure 4.9 Wood specialist - ecotone exploiter 60
Figure 4.10 Wood specialist - ecotone avoider 60
Figure 4.11 Heath specialist - ecotone avoider 61
Figure 4.12 (Improbable) ecotonal species 62
Figure 4.13 Eastern bristlebird density at each distance (plot) at each location 62
Figure 5.1 (a) Part of the survey trail showing birched sites (b) Arrangement of 1 m² quadrats for scoring vegetation cover at birched and non-birded sites 79
Figure 5.2 Survey design - vegetation structure across heath-wood edges 80
Figure 5.3 Barren Grounds-Budderoo site 1 - Cluster and ordination analyses 87
Figure 5.4 Jervis Bay site 4 - Cluster and ordination analyses 88
Figure 5.5 Barren Grounds-Budderoo site 2 - Cluster and ordination analyses 89
Figure 5.6 Patterns of vegetation structure for all sites combined 91
| Figure 6.1 | Location of study sites at Bherwerre Peninsula, Jervis Bay | 101 |
| Figure 6.2 | Period of radio-tag attachment for 22 birds | 108 |
| Figure 6.3 | Home range areas of bird #57 and bird #73 | 116 |
| Figure 6.4 | The effect of sample size on home range MCP area | 117 |
| Figure 6.5 | Daily cumulative home range MCP areas | 117 |
| Figure 6.6 | The effect of sample period on home range MCP area | 118 |
| Figure 6.7 | Site A - Vegetation communities | 124 |
| Figure 6.8 | Site B - Vegetation communities | 125 |
| Figure 6.9 | Habitat zones across the heath-wood edge at Sites A and B | 126 |
| Figure 7.1 | Eastern bristlebird habitat selection at heath-wood edges | 137 |
List of Tables

Table 2.1 Occurrence of the eastern bristlebird 19
Table 2.2 Historic records of the eastern bristlebird 21
Table 2.3 Decline of the northern populations 22
Table 2.4 Eastern bristlebirds at Bherwerre Peninsula 25
Table 2.5 Criteria for an Endangered species 28
Table 3.1 Eastern bristlebird population estimates for Barren Grounds 35
Appendix 3.1 Surveys of the eastern bristlebird at Barren Grounds 1992-8 44
Table 4.1 Analysis of variance summary table 50
Table 4.2 Bird records for Barren Grounds-Budderoo, Jervis Bay and Nadgee 56
Table 4.3 Summary of results compared to Sisk and Margules (1993) 66
Table 4.4 Bird diversity: wood compared to heath 66
Appendix 4.1 Study site descriptions 70
Table 5.1 Vegetation height classes in eastern bristlebird habitat 79
Table 5.2 Vegetation structural height classes across heath-wood edges 81
Table 5.3 Eastern bristlebird habitat - vegetation communities 84
Table 5.4 Nesting microhabitat of the eastern bristlebird 85
Table 5.5 Vegetation formations of eastern bristlebird habitat at Barren Grounds 85
Table 5.6 Pairwise tests of vegetation structure across the heath-wood edge 92
Table 5.7 Similarity (%) within and between distance groups 93
Appendix 5.1 Floristics of eastern bristlebird habitat at Barren Grounds 97
Table 6.1 Trapping results 103
Table 6.2 Eastern bristlebird densities 110
Table 6.3 Radio-tracking data collection and home range areas 115
Table 6.4 Percentage overlap of neighbour home range MCP areas 118
Table 6.5 Habitat of eastern bristlebird radio-tracking locations 122
Table 6.6 Habitat selection by 12 radio-tracked eastern bristlebirds 123
Appendix 6.1 Radio-tags on small to medium-sized birds 131
Chapter 1
General Introduction

The subject of my thesis is a small, short-winged, "hairy" bird, the eastern bristlebird. The overall aim of the studies reported in the thesis was to contribute to conservation biology through substantial scientific investigations into (i) the status of the eastern bristlebird, (ii) the effects of fire on the eastern bristlebird, (iii) bird populations across heath-wood edges and (iv) the significance of heath-wood ecotones, particularly with regard to the habitat of the eastern bristlebird.

Status and the conservation of threatened species

Conserving Australia's rich biodiversity has been a catch-cry for the 1990s. Almost 30 years have past since the poet, Judith Wright, saw "conservation as an emerging concept" (Wright 1970) and biodiversity conservation has emerged as an important issue, although perhaps not through a national shift toward more biocentric ethics. Rather, the enormity and urgency of environmental problems and the consequences of human activity and technology (Birch 1990; Suzuki 1990) have spurred public recognition and political action. Many patterns and processes characterize the threats to biodiversity (eg see Saunders et al. 1990) and conservation is inextricably linked to sustainable development (Garnett 1992; Craig 1997) and a healthy global environment (Suzuki 1997; Recher 1998).

At the hub of biodiversity conservation is concern for individual species, particularly those threatened with extinction. However, there is continuing socio-political apathy about global conservation (Suzuki 1997) and conservation of threatened species generally remains reactive rather than addressing causes (Craig 1997). Thus, threatened species often fail to attract conservation attention until they are at the edge of extinction. Being cute and cuddly may also help to attract socio-political attention!

"Status" is rarely defined in biological sciences. For example, it was not defined in a selection of dictionaries about ornithology (Campbell and Lack 1985), bioscience (Parker 1997), environmental science (Jones et al. 1990), environment and the law (Patton-Hulce 1995), natural history (Allaby 1985), biology (Hale 1991) and science (Lafferty and Rowe 1993). However, the term "status" is a useful concept in disciplines related to
biology. The Oxford Dictionary (Brown 1993) defines status as the "condition" or "legal standing" of things. In conservation biology, this definition can be used in two important contexts. Biological status is the condition or descriptive biology of taxa, populations and communities. Legal status is the legal standing. These types of status are similar to the biological and extrabiological considerations mapped by Clark (1996) to illustrate the causes of species extinction.

The biological status of a species can be considered simply as occurrence: abundance, number of populations and their distribution. Detailed consideration of biological status, particularly for threatened species, involves conservation genetics, population viability analysis (PVA), metapopulation theory and habitat requirements. Fragmented small populations are prone to deleterious genetic consequences related to their lack of genetic variability (Usher 1987). The study of minimum population sizes for the conservation of threatened species takes account of genetic as well as environmental and demographic stochasticity and natural catastrophes (Shaffer 1981) and PVA (Gilpin and Soule 1986) can help to reveal the relative importance of these threatening processes (Shaffer 1990). A metapopulation was first defined as a "population of populations" (Levins 1970). Metapopulation theory encapsulates the study of dispersal and dispersion, the waxing and waning of populations, extinction and recolonization (Hastings and Harrison 1994). Detailed genetic, PVA and metapopulation studies were beyond the scope of the present thesis. However, detailed studies of the habitat requirements of the eastern bristlebird are central to the thesis.

Legal status is important. For threatened taxa in Australia, the perceived conservation significance and the levels of political attention and funding are generally concomitant with the legal status. Hence, critically endangered species have a higher conservation significance than rare and vulnerable species. In this regard, the work of Garnett (1992) was a milestone. He described and categorized threatened Australian birds and his work became an authority on their biological and legal status. Thus, in the early 1990s, descriptions of the biological status of taxa moved from the subjective (Pizzey and Doyle 1980) and qualitative (Lindsay 1992) to become more quantitative. This allowed taxa to be placed in legally recognized categories on the basis of a set of numerical criteria.

The difference between biological status and legal status is bridged by defining categories, such as extinct, endangered, vulnerable, "insufficient data", into which taxa may be placed. The need for numerical criteria to categorize threatened species was recognized prior to 1990 (Recher and Lim 1990) and their use was being debated in the early 1990s (Mace and Collar 1994). Status defined by numbers does more than appease the petty accountant in bureaucrats and politicians; it promotes simple, objective legislation and provides a framework for prioritising conservation efforts. Mace and
Lande (1991) proposed numerical criteria appropriate for categorising the level of threat of most large vertebrates. Successive versions appropriate for all taxa resulted in acceptance by The World Nature Conservation Union of the IUCN Red List Categories (IUCN 1994).

A third status type, the socio-political status, also can be recognized in conservation biology. The koala is a national icon of considerable economic benefit and high socio-political status. Australian parrots also have a high socio-political status because they are brightly coloured and often very tame. Pertinent, because of its co-occurrence with the eastern bristlebird, is the beautiful and elusive ground parrot which is associated with a certain romantic lore in Australian ornithology. By comparison, the eastern bristlebird, aptly described as "a reclusive rat in a feather suit" (Chapter 2), has suffered from a very low socio-political status.

Conservation of threatened species is concerned with managing threatening processes. Habitat modification by fire was identified as a major threat to Australian birds including the eastern bristlebird (Garnett 1992). Hence, the effect of fire on birds is pertinent to this thesis.

**Birds and fire**

*Christmas Bells are a species which responds enthusiastically to fire* (Keith 1992)

The literature about the effects of fire on Australian avifauna is extensive and was recently reviewed by Woinarski and Recher (1997). The following notes introduce the temporal and spatial effects of fire with particular reference to fire-sensitive species. Unlike Christmas Bells, few birds respond to fire "enthusiastically".

The temporal effects of fire may be studied for the period during a fire and for the post-fire period. During a fire, the number of birds affected is likely to be proportional to the intensity and extent of the fire (Recher and Christensen 1981). Fires over small areas, slow moving fires and low-intensity fires are likely to cause few direct deaths or injuries because birds are able to flee ahead of the smoke and flames (Cooper 1975; Main 1981). Extensive, high-intensity fires can kill large numbers of birds (Fox 1978; Pescott 1983). Raptors, such as the black kite, may be attracted to feed on prey, including birds, which are killed, injured or fleeing from fire (Marchant and Higgins 1993).

The post-fire effects on avifauna are most likely to be noticeable in the short-term. Instances of short-term disadvantages include reduced numbers of individuals and species 8 months (Recher et al. 1985), one year (Turner 1992) and 2-38 months (Wooller and
Calver 1988) post-fire. Baker et al. (1997) found a reduction in the numbers of four cover-dependent species in the first 3 years post-fire. For Australian birds, breeding occurs mainly in spring and summer, although opportunistic breeding occurs throughout the year (Ford 1989). Hence, fire in any season, particularly spring and summer, is likely to disrupt breeding, with nests (Jackson 1907) and nesting habitat (Brooker and Rowley 1991; Marchant 1992) being destroyed. Instances of short-term advantages include increases in the number of individuals and species within a year post-fire, particularly ground foragers (Catling and Newsome 1981; Christensen et al. 1985) and sometimes honeyeaters and other species exploiting post-fire nectar abundance (Woinarski and Recher 1997).

In the medium-term, the effects of a single fire are generally expected to diminish. The vegetation is expected to recover, although there may be changes in the plant community structure (Whelan 1995). The pre-fire bird community is expected to be restored, although bird communities are not necessarily highly structured (Kikkawa 1982; Keast 1985). Populations may recover within 4 years (Rowley and Brooker 1987; Reilly 1991; Woinarski and Recher 1997) or, in the case of mallee woodlands, take longer than 30 years as summarized by Woinarski and Recher (1997). In some instances, pre-fire bird abundance may be exceeded, for example, in wet forest 3 years post-fire (Loyn 1997) and, in a mix of dry vegetation types, 8 years post-fire (Turner 1992).

Fire frequency strongly influences birds. Frequent fires may cause populations to decline and go locally extinct because of insufficient time to re-build between fires (Brooker and Brooker 1994) or through alteration or loss of habitat (Carter 1924). A single, very short inter-fire interval may substantially alter the floristics of an area and thereby the avifauna. For example, *Banksia ericifolia* is usually a fire-sensitive obligate seeder (Whelan and Muston 1991; Whelan 1995) which may take 7 years to start accumulating a seed bank (Benson 1985) and may become locally extinct due to a short inter-fire interval (Bradstock and Myerscough 1981). Then, the large and diverse winter congregations of honeyeaters in coastal and near coastal *B. ericifolia* heath and scrub (Recher 1975; Jordan 1984a; Jordan 1987a; Bramwell 1990a) would be expected to be adversely affected. Conversely, long inter-fire intervals allowed rainforest to invade wet sclerophyll forest in northern Queensland, with a concomitant increase in rainforest birds but a reduction in total bird species diversity (Chapman and Harrington 1997). Woinarski and Recher (1997) concluded that almost all bird species would benefit from longer fire-free periods.

In the long-term, recurrent fire is expected to affect the birds in most Australian ecosystems (Harrington 1997). Two outstanding questions in regard to the maintenance of bird populations and communities are: Is fire necessary? What happens if fire is excluded for a long time? The usual conjecture is that fire is necessary and that long-term
fire exclusion is likely to be detrimental (Woinarski and Recher 1997) rather than advantageous to avifauna. For instance, in the absence of long-term population studies, Smith (1977) speculated that fire exclusion for more than 30 years may be detrimental to the noisy scrub-bird and Ferrier (1985) speculated that a similar "optimal burning interval" would suit the rufous scrub-bird. Neither suggested that fire might be unnecessary nor that long-term fire exclusion might be beneficial, although such anti-burn speculation seems to be equally valid. Generally, there are few data to assess the effects of long-term fire exclusion and few bird species are recognized as fire-sensitive (Woinarski and Recher 1997). One exception is the noisy scrub-bird which now occupies habitat with a fire-age of > 60 years at Mt Gardner (Danks et al. 1996) and possibly > 100 years on Bald Island (Danks 1997). Another exception is the black-breasted button-quail for which long-term fire exclusion has been suggested as possibly the last hope to prevent extinction of the species (Hughes and Hughes 1991).

The spatial effects of fire on avifauna which relate to intensity and extent were mentioned above. It is increasingly important to understand the effects of fire, a potentially large-scale phenomenon, occurring in a greatly reduced, mostly modified and fragmented natural landscape. Strategies for the conservation of biodiversity and threatened species must consider the scale and pattern of fire in the context of the area being managed. Woinarski and Recher (1997) recommended that these strategies should include consideration of unburnt patches, fire exclusion areas and mosaics of burning with a range of fire regimes.

Fire-sensitive bird species typically lack one or more of the attributes generally ascribed to birds which would otherwise allow them to recover from the effects of fire. They may be ground dwelling, cover dependent, poor fliers, poor dispersers or low in fecundity and these traits are typical of species from habitats with high durational stability (Southwood 1977). The eastern bristlebird has all of these traits but it currently inhabits fire-prone areas with low durational stability and so it appears that it is poorly adapted to its habitat.

Conservation of habitat is fundamental to the conservation of biodiversity and to threatened species. In theory, the habitat at the junction of adjacent vegetation communities supports a diverse bird population. Heathland edges may be the preferred habitat of the eastern bristlebird (Bramwell et al. 1992). Hence, a study of the significance of heathland edges to bird populations, including the eastern bristlebird, is pertinent to this thesis.
Ecotones

Ecotone: oikos tonus (Greek) = home tension

An ecotone is the zone of transition between adjacent ecological communities (Harris 1988; Risser 1995). This definition is derived from the original "a stress line or ecotone" (Clements 1907 in Harris 1988). In simple theory, adjacent ecosystems meet at an edge line and overlap in a two-dimensional ecotone. The present thesis endeavours to maintain this distinction. In reality, neither the edge nor the ecotone are likely to be absolutely clear. They may even be treated collectively as edge (Yahner 1988). An obvious exception is the intertidal zone which is the ecotone between terrestrial and marine ecosystems.

An ecotone may vary in width from narrow to broad. Hence, the transition at an edge may be described as abrupt or gradual; violent (Lennon et al. 1997) or feathered (Ratti and Reese 1988); or as hard or soft edge transitions (Sisk and Margules 1993). The origin of an edge may be natural or anthropogenic, also called inherent or induced (Paton 1994) or artificial edges (Laurance and Yensen 1991). Some studies focus on the length of edges (eg Johnston and Bonde 1989; Berg and Part 1994), although the ecotone zone is generally of greater concern (Patton 1975).

As a concept, the ecotone is scale-independent (Risser 1995). However, the patterns and processes associated with ecotones are scale-dependent (Gosz 1993). A collection of patches viewed at a fine scale, may be an ecotone at an intermediate scale or heterogeneity at a landscape scale (Gosz 1991). For example, Battaglia and Williams (1996) showed that the relative abundance of two competing eucalypt species, was correlated with variation in soil depth at the local-scale and climate at the regional-scale because of the underlying determinant of water stress. In some studies, the distinction between heterogeneity and ecotone is unclear (eg Gates and Giffen 1991; Chan 1995; Trauttmansdorf 1996). For instance, Chan (1990, 1995) described a riverine-box ecotone that did not contain the dominant tree from either of the adjacent communities, the *Casuarina cunninghamiana* riverine woodland and the *Eucalyptus melliodora* box woodland. Jenik (1992) questioned the utility of the ecotone concept because of the potential for clashes with other ecological concepts such as heterogeneity and succession.

Ecotones have been the subject of international meetings and they have inspired collections of publications (eg Holland et al. 1991). The concept of ecotones has been broadened to consider biotic and abiotic factors at various scales (Holland and Risser 1991; Risser 1995) and a considerably refined definition has become accepted (Holland and Risser 1991; Risser 1993): an ecotone is the zone of transition between adjacent
ecological systems, having a set of characteristics uniquely defined by space and time scales and by the strength of the interactions between the systems (Holland 1988). Two central theories have emerged from the concept of ecotones: (i) the edge effect and (ii) ecotonal species.

**Edge effect**

The edge effect was first defined as the “tendency for increased variety and density at community junctions” (Odum 1958). This formalized the general interpretation of Leopold's work which considered that ecotones were beneficial to wildlife diversity (Leopold 1933 in Harris 1988). However, more recently, the potential for edges to have a deleterious effect on wildlife diversity has become a conservation issue, particularly in regard to anthropogenic edges and fragmentation.

Fragmentation may be defined as a "change in the boundary condition of an ecological system" (Haila et al. 1993). Hence, the study of fragmented ecosystems is closely related to the study of ecotones. The effects of fragmentation have been studied extensively (e.g. Saunders et al. 1987; Saunders et al. 1993; Saunders and Hobbs 1991). In their review of ecosystem fragmentation, Saunders et al. (1991) argued that fluxes in radiation, wind, water and nutrients mostly have a detrimental influence on the biota in remnants of native vegetation, particularly at the edge. Murcia (1995) concluded that there were differences in the results among the 24 studies that she reviewed and that there was no general pattern in the direction or intensity of edge effects. Haila et al. (1993) and Murcia (1995) both suggested that the study of edge effect and fragmentation lacked sufficient experience and that further study was needed before generalizations could be drawn. There is a notable exception to this suggestion.

There has been a strong research focus on the impact of predation and nest parasitism at forest edges, founded on the studies of Gates and Gysel (1978) and Best (1978). Gates and Gysel (1978) proposed the ecological trap hypothesis to explain that increased bird density along narrow field-forest ecotones led to increased predation and nest parasitism which in turn resulted in a net loss of habitat suitability. The research focus has broadened to include predation in fragmented habitats and to date there have been four published reviews which cover the topic (Paton 1994; Andren 1995; Major and Kendal 1996; Hartley and Hunter 1998). There were some difficulties with comparisons among studies and some reservations about results obtained in studies utilizing artificial eggs and nests (Major and Kendal 1996; Hartley and Hunter 1998). Also, some studies found that there was no edge effect of predation (e.g. Vickery et al. 1992; Latta et al. 1995) or nest parasitism (Chasko and Gates 1982). Nevertheless, there is an overwhelming pattern that
increased predation and parasitism occurs at ecotones and that this represents a detrimental edge effect.

There have been few attempts "to disprove" Leopold's (1933) principle of edge (Guthery 1992) and few studies in which bird diversity has been measured across habitat edges (Sisk and Margules 1993). Laudenslayer and Balda (1976) studied the birds at a 14 ha pinyon pine/juniper woodland - ponderosa pine forest ecotone in Arizona, south-western USA. They concluded that the bird diversity in the ecotone was not greater than in the habitats adjacent to the ecotone.

**Ecotonal species**

Odum (1958) not only predicted the edge effect of increased diversity at ecotones, he also proposed that some species would inhabit only the ecotone and he called these edge species or ecotonal species. This notion of ecotonal species is often cited in general texts (eg Frith 1979; Brewer 1988) and in journals (eg Gates and Gysel 1978; Chan 1995). However, two important questions arise: (i) What was Odum's definition of an ecotonal species? and (ii) What was Odum's evidence for the existence of ecotonal species?

Odum's (1958) definition of an ecotonal species is spread through three paragraphs of text and may be paraphrased as follows. The ecotonal community commonly contains habitats and organisms which are characteristic of and often restricted to the ecotone. Organisms which occur primarily or most abundantly or spend the greatest amount of time in junctions between communities are often called edge species. Ecotones have characteristic species and they may be considered primarily or entirely ecotonal. Hence, Odum's definition of an ecotonal species is a continuum from entirely ecotonal to an imprecise primarily ecotonal. Yahner (1988) noted that classifying a species as an edge species was problematic because edges may serve different purposes among species and intraspecific utilization of edges may vary seasonally and geographically.

Odum (1958) presented three pieces of evidence for ecotonal species. (i) A study of marsh and upland plant communities by Beecher (1942) found that the number of bird nests per quarter-acre quadrat (33 m x 33 m) increased when the number of plant communities per quadrat increased from one to four. (ii) "Common knowledge" dictated that there were more songbirds (Passerines) where mixed habitats provided more edge than uniform vegetation types. (iii) A study by Johnston and Odum (1956) found that of an expected 50 regionally common bird species only 30 species occurred commonly in homogenous plots of eight different vegetation types. Odum reasoned that the remaining 20 species occurred infrequently (7 species) or were not recorded (13 species) because they required habitat with more than one vegetation type. Thus, Odum concluded that
40% of the regionally common birds "may be considered primarily or entirely ecotonal". These three pieces of evidence may support the notion that diversity of bird species is related to heterogeneity of habitats but they offer no conclusive evidence for the existence of ecotonal species.

Johnston (1947) studied the birds in two forest fragments, each approximately 20 ha, in Illinois, central USA. He concluded that 15 species were primarily forest-edge birds and his study has been used as evidence for ecotonal species. However, for at least three reasons, the study does not justify this conclusion. (i) Johnston (1947) does not define the areal extent of the forest edge. It should be noted that if the forest edge zone had been defined as 100 m wide, which is the impression gained from the diagrams Johnston used to illustrate the areas occupied by forest-edge species, then the fragments would have been predominantly edge with an edge to interior area ratio of 3 : 1. In this case, most of the birds in the study would be expected to be found at the forest edge. (ii) Johnston (1947) defined a forest-edge bird as a species which was "confined to the boundary of the forest or which used both the forest and the surrounding fields". This definition is imprecise. (iii) Johnston (1947) provided no quantitative hypothesis testing to substantiate his claim that some of the species were forest-edge birds. For the above reasons, Johnston's (1947) study should be regarded as a descriptive work about the effects of forest fragmentation on birds which were habitat generalists or forest habitat specialists but not necessarily forest-edge species.

In the literature, there is no strong evidence for any bird species which is entirely ecotonal and I found only two analytical studies specifically designed to test for ecotonal species. The first study was conducted in a "very narrow" (no dimensions given) 14 ha pinyon pine/juniper woodland - ponderosa pine forest ecotone in USA (Laudenslayer and Balda 1976) as noted above. Six common birds and five rare birds bred at the ecotone but Laudenslayer and Balda (1976) concluded that these were best described as woodland or forest or ubiquitous species and that none were ecotonal. In the second study, Bramwell et al. (1992) surveyed 66 ha at Barren Grounds, NSW. They detected a significantly higher proportion of eastern bristlebirds in the 40 m wide ecotone than the adjacent heathland and woodland and they concluded that the species was ecotonal, although, from their evidence, it was not entirely ecotonal.
Structure of the thesis

This thesis explores the issues of threatened species status, fire as a threatening process and the significance of bird habitat at ecotones with a focus on the eastern bristlebird as a case study. The dominant issue, ecotones, is explored in relation to bird populations and heath-wood edges. The principal theoretical components of status, fire and ecotones have been introduced and Chapter 1 concludes with a description of the eastern bristlebird. The species' range, distribution, abundance, historic decline and current legal status are detailed in Chapter 2. Throughout their range, eastern bristlebirds inhabit fire-prone areas and the effect of fire on the species is studied in Chapter 3. The eastern bristlebird has been called an ecotonal species. However, there is a paucity of evidence about ecotonal birds and the effects at natural habitat edges on avifauna and so Chapter 4 pursues a study of this subject. In Chapter 5, the topic of ecotones is studied further in relation to heath-wood edges and the habitat of the eastern bristlebird. Radio-tracking of eastern bristlebirds was used to validate earlier results. This study, together with a detailed methodology of radio-tracking is presented in Chapter 6. Chapter 7 has a synthesis of the results from Chapters 2-6, a discussion about conservation and management, leading from the case study of the eastern bristlebird to a more general discussion, and the thesis concludes with recommendations for further research.

Throughout the thesis, common names are used for animals. Nomenclature of Australian birds follows Christidis and Boles (1994). Otherwise, animal names follow the given citations. Plant taxonomy follows Harden (1990-1993). The main study sites were Budderoo National Park and the adjacent Barren Grounds Nature Reserve, Nadgee Nature Reserve and, at Jervis Bay, the NSW Jervis Bay National Park and Booderee National Park, Jervis Bay Territory. Generally, once they are introduced, National Parks and Nature Reserves are given their place names only.
The eastern bristlebird

Surely the Bristle-bird must be regarded as one of the most temperamental of birds!
(Chaffer 1954) [on the eastern bristlebird]

Taxonomy

Bristlebirds belong to the Australasian family Pardalotidae (Christidis and Boles 1994). There are three species of bristlebirds: *Dasyornis brachypterus* (Latham), *D. longirostris* Gould, and *D. broadbenti* (McCoy), the eastern, western and rufous bristlebirds respectively (Christidis and Boles 1994). The eastern bristlebird was first named *Turdus brachypterus* by Latham in 1801 from a drawing by Watling and underwent five scientific name changes to 1923 (Mathews 1923). *Dasyornis* means "hairy bird" which describes the characteristic stiff rictal bristles at the base of the upper mandible. The genus is also characterized by very small wings, *brachypterus* meaning "short-winged".

Description

The following description is based mostly on my own field experience. Eastern bristlebirds are well camouflaged. They are a dull brownish colour above with lighter grey-brown below. Average length is 210 mm (Pizzey and Doyle 1980) with the broad tail accounting for about half the bird's length. The average weight is 42 grams (Bramwell 1990b); Chapter 6). The wings are very small and the legs are long and strong.

Sexual dimorphism is not apparent. There are no published data on the morphological features which might be used to distinguish the age of eastern bristlebirds. On one occasion at Barren Grounds, in mid-March 1992, two eastern bristlebirds were captured simultaneously. One had the characteristic dark red iris and the other had a paler brown iris thought to be characteristic of a juvenile or immature bird.

Eastern bristlebirds are generally shy and cryptic. They are usually detected singly or in pairs, rarely as a group of three or four and never in a flock. The species was presumed to be sedentary and territorial (McNamara 1946; Blakers et al. 1984; Holmes 1989). Eastern bristlebirds are semi-flightless terrestrial birds and occasionally they may be glimpsed scampering in the open or making low laboured flights of up to 20 m. They have also been clearly observed running rapidly along tracks for more than 100 m in less than one minute. When alarmed, a bird may move to a lookout perch a metre or more above the ground then disappear into thick vegetation. Although eastern bristlebirds are generally secretive, the quiet presence of an intruder often causes them to show themselves and to call.
The calls are mostly loud but some expertise is required to recognize eastern bristlebird calls and to distinguish them from the calls of other species. Careful consideration of the calls is necessary because much of the present study and other studies relied upon detecting this cryptic species from its call. The A-call, "pretty birdie", is the most characteristic call, although the presence of an eastern bristlebird is often signalled by a single-note call, a loud, strident "prist" (the B-call) or a softer "chip". The four-syllable A-call is often varied by individuals and among individuals by changes in the intonation and by adding and subtracting syllables. These variations seem most frequent during the post-breeding period and may be associated with juvenile birds.

Duetting, particularly A-B-call duetting, and other calling interactions between birds in distinctly different places often occur and are often initiated by an A-call. Duets may comprise one A-call followed by 1-4 B-calls but more usually A-B duets comprise ten or more cycles lasting for 1-3 minutes. Individual eastern bristlebirds using both the A-call and the B-call have been detected. Smith (1991) noted similar call-swapping in the western whipbird and the seminal reference on antiphonal male-initiated duetting in the eastern whipbird (Watson 1969), appears to be based on a circular argument. Levin (1996a, 1996b) used laparotomies to determine the gender of monomorphic bay wrens and was then able to ascertain that the female always initiated duets and the male replied. Langmore (1998) argued that this phenomenon may be widespread. For the eastern bristlebird, there is no evidence that the A-call is made exclusively by the male and, in order to avoid spurious conclusions, it is better not to make this assumption.

The diet is currently being studied and my preliminary results suggest that ants are a regular food item and that other insects, including beetles and weevils, are also taken. Earlier reports (Gould 1865; North 1904) suggested a diet of insects of various orders and Barker and Vestjens (1990) reported a single stomach sample containing insects of the order Hemiptera (bugs). When feeding, eastern bristlebirds peck at the ground and vegetation but do not use their feet to scratch the ground.

**Life history**

Low fecundity appears to be a feature of the species. Ten documented records, dating from Ramsay (1882) to Adams and Coontz (1989), suggest that eastern bristlebirds generally lay a clutch of two eggs from August to February and raise only one fledgling. The clutch size is lower than the average of 2.7 for Australian passerines (Yom-Tov 1987). There are no records of double clutches, so attempts to replace abandoned or otherwise unsuccessful clutches may explain the continuation of breeding into late summer. Breeding failure appears to be symptomatic of the genus. Nest and/or chick desertion were reported after human interference with eastern (Chaffer 1954; Hartley and
Kikkawa 1994), rufous (J Seymour pers. comm.) and western bristlebirds (Smith 1987). Presumably, bristlebirds are also sensitive to other disturbances such as intrusion by potential predators. Eastern bristlebird nests are elliptical domes constructed in low dense vegetation, usually in tufted plants. One retrap of a banded eastern bristlebird indicated that longevity may be at least 6 years.

Potential threats

Loss of habitat, including indirect loss due to unsuitable fire regimes, has been recognized as the main process which reduced the occurrence of the eastern bristlebird in the last few centuries (Chaffer 1954; Garnett 1992).

Fragmentation and isolation are characteristic of eastern bristlebird populations and may be adversely affecting the species. Small isolated populations are prone to local extinction through demographic and environmental stochasticity (Burgman et al. 1994; McCallum 1994; McCarthy 1994) and they may suffer because of their lack of genetic variability (Usher 1987).

Predation by native and introduced predators is a potential threat but its extent is unknown. The remains of eastern bristlebirds have been found at Barren Grounds, Booderee and Nadgee and this is taken as evidence that predation does occur. Suggested predators are the cat, fox, dingo, large birds such as currawongs, snakes, goannas and dasyurid marsupials. The curious behaviour of eastern bristlebirds to call and show themselves may cause individuals and their nests to be easy prey and their occasional inclination to "play" on tracks may make them vulnerable to predation.

Other potential threats can be summarized as follows. Nest parasitism by cuckoos has not been recorded but it may be a threat. The fan-tailed cuckoo occurs commonly throughout the eastern bristlebird's range. Road-kills of eastern bristlebirds by vehicles occurs in the Jervis Bay area but the extent of this threat to the local population is unknown. For example, during spring-summer 1994-5, six road-kills were recovered. Wildlife road-signing has been erected in the hope that this may assist in reducing road-kills. Grazing by livestock is a threat to the northern populations because it tramples habitat (Holmes 1989). Off-road vehicles (four-wheel-drives and motor bikes) have damaged habitat in some eastern bristlebird locations. Dieback disease due to the pathogenic fungus Phytophthora spp. is not recorded as a threat to eastern bristlebird habitat, although potentially it could become a threat. Dieback is already a concern to managers of western bristlebird habitat (Cale and Burbidge 1993) because it affects plant community structure and composition and reduces projective foliage cover (Wills 1993).
Chapter 2

Status of the eastern bristlebird

*from the recluse nature of its disposition it is a species familiar to few* (John Gould 1865)

*like a rat in a feather suit* (Ford Kristo 1997, Booderee National Park)

Introduction

**Biological status of the eastern bristlebird**

The disjunct distribution of the eastern bristlebird in south-eastern Australia suggests that it was once more numerous and populations continuous, perhaps during the wetter Tertiary Period (Smith 1977). However, the eastern bristlebird is one of many avian taxa reduced to isolated populations, possibly during the climatic fluctuations of the Quaternary Period. Bristlebirds (Keast 1957), scrub-birds (Smith 1977), the western whipbird (Smith 1977; Schodde and Mason 1991) and white-tailed and yellow-tailed black-cockatoos (Saunders 1979) are examples of taxa which now have disjunct populations. Although environmental conditions have been relatively stable for the past 5 000 years (Kershaw 1981), Smith (1977) considered that poor flying ability, sedentary nature and specialized habitat requirements prevented remnant populations of the eastern bristlebird from expanding. This scenario was supported by Baird (1992) whose interpretation of cave deposit fossils showed that approximately 5 000 years ago the range of the eastern bristlebird extended west at least to Nelson, Victoria (location shown in Figure 2.2 in Results).

The declining abundance of the eastern bristlebird since European settlement can be sensed from the literature. Around the developing city of Sydney at the turn of the century, the species was perceived as going from "not common" (North 1898), to "scarce" (Campbell 1901), to "near Sydney...it is now extremely rare" (North 1904). The last record for Sydney was in 1921 (Chaffer 1954). By the 1930s, when extensive searching by bird-watchers failed to find eastern bristlebirds at any former locations in and around Sydney, it was "feared that the species was nearing extinction" (Chaffer 1954).

Many factors have been recognized as contributing to the decline of the species. Direct loss of habitat to urban land-use appears to have been the ultimate factor in the local extinction of the eastern bristlebird in the Sydney area. Indirect loss of habitat through unsuitable fire regimes (Chaffer 1954) and trampling by stock (Holmes 1989) have also been cited as a possible causes for the decline. Predation, road-kills, the species' low fecundity and propensity for breeding failure (Chapter 1) militate against population
growth. Fire has been implicated in the extinction of local populations and it is a substantial threat to remaining populations (Chapter 3).

By 1990, the paucity of information about the status of the eastern bristlebird was apparent. Smith (1977) had reported that the species was contained in six populations from Cunninghams Gap, south-eastern Queensland, to Nadgee-Mallacoota, on the NSW-Victorian border, and that all appeared to be small and "probably fewer than 50 pairs". However, this estimation was not based upon systematically collected field data. Blakers et al. (1984) had noted that the species appeared to have declined due to the spread of settlement. However, once again, this assessment was not supported by systematic documentation. The population strongholds were thought to be Barren Grounds-Budderoo and Jervis Bay, south-eastern NSW, and Jordan (1990) had estimated that the total of these populations was probably 1 000-2 000 individuals. However, no systematic field data were presented to substantiate this estimate. Holmes (1989) thoroughly documented the small number of individuals in each of 14, apparently separate, populations in north-eastern NSW/south-eastern Queensland. This highlighted the need for a more detailed study to quantify the biological status of the eastern bristlebird throughout the remainder of its range.

**Legal status of the eastern bristlebird**

In Australia, native fauna are generally afforded some legal status and protection and the legal status of a taxon is greatly enhanced if it is classified as threatened with extinction. An increasing level of threat is indicated by the categories of Vulnerable, Endangered and Critical (Mace and Lande 1991). The eastern bristlebird was widely recognized as a threatened species by the early 1990s. It was classified as Vulnerable nationally (Brouwer and Garnett 1990; ANZECC 1991) and as Vulnerable in Queensland (Nature Conservation Act 1992), Vulnerable in NSW (Schedule 12, gazette dated 18 December 1992, of the National Parks and Wildlife Act 1974) and Vulnerable in Victoria (Flora and Fauna Guarantee Act 1988).

Garnett (1992) adapted the Mace and Lande (1991) criteria and threat categories to assess the status of Australian birds. He categorized the eastern bristlebird as Vulnerable, although the information he presented appeared to be consistent with the criteria for an Endangered species listing. However, at the time, the available data were inadequate to address basic questions about the number of individuals and populations and about the trends in population sizes.
Aims

The aims of this chapter are (i) to report on the past biological status of the eastern bristlebird as recorded in the literature, (ii) to report on the present biological status based on a detailed field study and (iii) to review the legal status of the species.

Methods

Past occurrence

Historic records were sought from the literature and from records of the Australian Museum, Sydney; the CSIRO collection, Canberra; The Natural History Museum, Tring, England; and Liverpool Museum, England. Unpublished reports and anecdotal records were obtained by establishing a network of contacts, initially through my employment at the Birds Australia, Barren Grounds Bird Observatory. All recent records for the northern populations and most recent records for Victoria were obtained from unpublished documents supplied by the authors, as cited in the Results. The location of all named places is shown in the Results (Figure 2.2).

Present occurrence

For the present study, field surveys were undertaken at Budderoo, Barren Grounds, the Jervis Bay district, Nadgee and locations of anecdotal or historic records from Sydney south to Nadgee. Approximately 75% of the data reported from these surveys was based on detecting eastern bristlebirds by their calls. Using calls to survey for cryptic, terrestrial birds is a common research method that has been used successfully with the noisy scrub-bird (Smith and Forrester 1981), rufous scrub-bird (Ferrier 1985), western whipbird and western bristlebird (McNee 1986) and eastern bristlebird (Holmes 1989; Bramwell et al. 1992; Pyke et al. 1995).

Eastern bristlebird detections were made while walking at 0.5-4 km per hour on tracks and, occasionally, through vegetation where there were no tracks. The method of mapping eastern bristlebird positions using calls, relied on the birds’ co-operation. Typically, at dawn during spring and summer, a bird began A-calling (described in Chapter 1). This often led to duetting and/or was followed by other birds A-calling or duetting. Sometimes, my presence appeared to trigger calling from nearby birds. The ideal situation was walking relatively quickly along a track as the birds began bouts of calling ahead of the observer. This allowed unambiguous detection and mapping of individuals which were calling simultaneously or in quick succession. When calling was
less frequent or there was a period of no calling, walking was slowed and occasionally stopped. Then, if successive detections were ambiguous, they were assumed to be different individuals only if there was at least 200 m between them. The basis for this assumption was 3 years of personal field observations and the consequences of this assumption will be reviewed in the Discussion. Surveys were not conducted when there was little eastern bristlebird activity, particularly during heavy rain or hot or windy weather. However, all opportunistic detections were mapped.

At Barren Grounds, systematic surveys were undertaken from 1992-1997 and the population was estimated by extrapolation of mean densities of eastern bristlebirds within each of five areas with different fire-ages. This was part of a larger study which is reported in Chapter 3. During January-February 1997, a survey route of 20.5 km was walked twice over a period of 10 days and average densities were used to calculate the total population.

At Budderoo, Jervis Bay and Nadgee, surveys were undertaken from 1990-1997. All detections were mapped at a scale of 1: 25 000 using topographic maps. Populations were estimated using maximum densities obtained on surveys, extrapolated across coarse estimates of potential habitat based on vegetation maps: CMA (1986a) for Budderoo, Ingwersen (1976), CMA (1986b) and CMA (1986c) for Jervis Bay and CMA (1976), Gilmour (1983) and SMV (1994) for Nadgee-Croajingolong.

The area of the distribution of eastern bristlebirds was estimated using the "area of occupancy" (IUCN 1994), defined as the area of habitat occupied and measured at a fine scale relative to the total range of the species. Groups of eastern bristlebirds were considered to be separate populations if the distance and/or the extent of unsuitable habitat between them suggested that they were reproductively isolated. For the northern populations, the area of occupancy was inferred from the product of the number of individuals and their expected territory size of 2 ha which Holmes (1989) defined as the "defended core area of home range". For the remaining populations, their area of occurrence was calculated using a grid cell size of 100 ha over the maximum probable areas of habitat. Consideration of the Nadgee-Croajingolong maps and a one-day field reconnaissance to Howe Flat, Croajingolong, in December 1995, suggested that the potential eastern bristlebird habitat was probably continuous and that the area could be considered to support a single population.

For the Jervis Bay district, surveys were divided into three logistic areas: Beecroft Peninsula, at the northern side of Jervis Bay and bounded in the north by Caramarma Creek, including the Royal Australian Navy's Beecroft Weapons Range; Bherwerre Peninsula, at the southern side of Jervis Bay and bounded in the north by The Wool Road and
Vincentia Road, including Jervis Bay Territory and a small area of NSW; and the land area between Beecroft and Bherwerre Peninsulas in the vicinity of the declared and proposed parts of NSW Jervis Bay National Park (Figure 2.1).

Using audio-tape replay of species-specific bird calls is a technique commonly used to attract and elicit a response from cryptic species (Kavanagh and Peak 1993; Goldingay et al. 1995; Clarke and Bramwell 1998). This method was used opportunistically in attempts to detect eastern bristlebirds at locations for which there were unconfirmed records or potential habitat, as detailed in the Results. The tapes utilized calls of duetting eastern bristlebirds recorded at Barren Grounds. They were broadcast loudly 1-5 times
for one minute at each location, with a 5-30 minute listening period after each broadcast. To avoid biasing data, tape replay was not used while mapping the positions of eastern bristlebirds to estimate densities.

Results

The most recent estimates indicate that eastern bristlebird populations occur at three disjunct locations and that the continued survival of some populations is in doubt. There are 6-9 northern populations in south-eastern Queensland/north-eastern NSW, 3-4 central populations in the Illawarra-Shoalhaven region and most likely only one southern population located in the vicinity of the NSW/Victoria border coastal area. The total of all populations was fewer than 2 000 individuals and the area of occupancy was less than 11 600 ha (< 120 km²) (Table 2.1). The species range spans over 1 400 km from Conondale Range, south-eastern Queensland, to Croajingolong in north-eastern Victoria.

The present research showed that the distribution of the eastern bristlebird has contracted during the past two centuries, although the range seems little altered. The records strongly suggest that within this period there was a continuous distribution from north of Sydney Harbour south to Ulladulla.

The results of my field and literature studies are summarized below and the past and present distribution of the eastern bristlebird is illustrated in Figure 2.2.

Table 2.1 Occurrence of the eastern bristlebird (see text for details)

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of populations</th>
<th>Area of occupancy</th>
<th>Latest estimate</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern populations</td>
<td>6-9</td>
<td>200 ha</td>
<td>Sept 1997</td>
<td>&lt;100</td>
</tr>
<tr>
<td>(Queensland/NSW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central populations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barren Grounds-Budderoo</td>
<td>1</td>
<td>1 600 ha</td>
<td>Feb 1997</td>
<td>600</td>
</tr>
<tr>
<td>Jervis Bay</td>
<td>1</td>
<td>&lt;2 500 ha</td>
<td>Jan 1996</td>
<td>250</td>
</tr>
<tr>
<td>Morton-Red Rocks</td>
<td>1-2</td>
<td>4 300 ha</td>
<td>Feb 1996</td>
<td>&lt;700</td>
</tr>
<tr>
<td>Southern populations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NSW/Victoria)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nadgee-Croajingolong</td>
<td>1</td>
<td>&lt;3 000 ha</td>
<td>Sept 1997</td>
<td>220</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>very small</td>
<td>1995</td>
<td>few</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>&lt;11 600 ha</td>
<td>Sept 1997</td>
<td>&lt;2 000</td>
</tr>
</tbody>
</table>
Historic records

Historic records, from 1810 to 1952, indicate that the eastern bristlebird was widely distributed in near-coastal south-eastern Australia within the last two centuries. Given the cryptic nature of the bird, it is likely that it went unnoted in other locations within its range during this period. Conversely, there is some uncertainty regarding the accuracy of some records. Wakefield (1958) regarded the rufous bristlebird records for Marlo, Victoria, of Howe (1947) and Tarr (1947) as either eastern bristlebirds or pilotbirds. Chaffer (1954) was unable to authenticate the records of Mathews (1930) for Victoria. The historic records are listed geographically from north to south in Table 2.2 and the locations are illustrated in Figure 2.2.
Table 2.2 Historic records of the eastern bristlebird

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northern populations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cunningham's Gap</td>
<td>1952</td>
<td>Chaffer (1954)</td>
</tr>
<tr>
<td>Nth Macpherson Range</td>
<td>pre 1931</td>
<td>Favaloro (1931)</td>
</tr>
<tr>
<td></td>
<td>1943-4</td>
<td>Robertson (1946)</td>
</tr>
<tr>
<td></td>
<td>1947</td>
<td>Chisholm (1948)</td>
</tr>
<tr>
<td>Near Lismore</td>
<td>1870</td>
<td>French (1925)</td>
</tr>
<tr>
<td>Near Grafton</td>
<td>1900</td>
<td>Jackson (1907)</td>
</tr>
<tr>
<td>Dorrgo</td>
<td>1910</td>
<td>Chisholm (1958)</td>
</tr>
<tr>
<td>Wootton</td>
<td>1922</td>
<td>Chisholm (1958)</td>
</tr>
<tr>
<td>Sydney</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newport to Manly</td>
<td>pre 1904</td>
<td>North (1904)</td>
</tr>
<tr>
<td>Middle Harbour</td>
<td>1903</td>
<td>Jackson (1907)</td>
</tr>
<tr>
<td>near Parramatta</td>
<td>1810</td>
<td>Vigors and Horsfield (1827); Chaffer (1954)</td>
</tr>
<tr>
<td>Bondi to La Perouse</td>
<td>pre 1904</td>
<td>North (1904)</td>
</tr>
<tr>
<td>Port Hacking</td>
<td>pre 1898</td>
<td>North (1898)</td>
</tr>
<tr>
<td>Wattamolla</td>
<td>1880</td>
<td>North (1904)</td>
</tr>
<tr>
<td><strong>Illawarra-Shoalhaven region</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maddens Plains</td>
<td>1885</td>
<td>Australian Museum, Sydney</td>
</tr>
<tr>
<td>Mt Kembla</td>
<td>1944</td>
<td>McNamara (1946)</td>
</tr>
<tr>
<td>Cambewarra</td>
<td>1923</td>
<td>Australian Museum, Sydney</td>
</tr>
<tr>
<td>Clyde River</td>
<td>1864</td>
<td>Australian Museum, Sydney</td>
</tr>
<tr>
<td>Ulladulla</td>
<td>1866</td>
<td>Australian Museum, Sydney</td>
</tr>
<tr>
<td><strong>Southern populations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mallacoota</td>
<td>1914</td>
<td>White (1915)</td>
</tr>
</tbody>
</table>

Recent records for the northern populations

In the north of their range, spreading over 700 km from the Conondale Range in Queensland to the Wootton in NSW, 23 areas for which there were historic, recent or anecdotal records were surveyed from December 1987 to May 1989 by Holmes (1989). Holmes documented 14 populations, 103 territories and a minimum of 154 individual eastern bristlebirds over 200 km between the Conondales and the Border Ranges, NSW. Three successive surveys have shown a precipitous decline in each of these three abundance parameters (Table 2.3). Furthermore, the largest population documented by Holmes in 1989, the population at Spicers Gap which was affected by drought followed by a wildfire in October 1991, now appears to be extinct (Stewart 1997).

From this evidence, it is estimated that at September 1997 there were fewer than 100 eastern bristlebirds in 6-9 northern populations and that their area of occupancy was very small.
Table 2.3 Decline of the northern populations

<table>
<thead>
<tr>
<th>Survey</th>
<th>Known populations</th>
<th>Territories Known</th>
<th>Surveyed</th>
<th>Occupied</th>
<th>Birds</th>
<th>Territories at Spicers Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 87-May 89(^1)</td>
<td>14</td>
<td>?</td>
<td>?</td>
<td>103</td>
<td>153</td>
<td>35</td>
</tr>
<tr>
<td>Spring 1992(^2)</td>
<td>≥ 8</td>
<td>110</td>
<td>95</td>
<td>39</td>
<td>≥ 39</td>
<td>10</td>
</tr>
<tr>
<td>Nov-Dec 1996(^3)</td>
<td>9</td>
<td>117</td>
<td>117</td>
<td>29</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>June-Sep 1997(^4)</td>
<td>≥ 6</td>
<td>128</td>
<td>97</td>
<td>10</td>
<td>12</td>
<td>0</td>
</tr>
</tbody>
</table>

1 Holmes (1989); 2 Holmes (1992) and Lamb et al. (1993); 3 Holmes (1997a); 4 Stewart (1997)

Ku-ring-gai Chase National Park

Ku-ring-gai Chase is adjacent to the north shore suburbs of Sydney from Newport to Manly where the eastern bristlebird was recorded pre-1904 (North 1904). Between 1930 and 1954, Ku-ring-gai was one of many "previously-known haunts" to be surveyed for eastern bristlebirds without success (Chaffer 1954). There was a recent report of the species from Ku-ring-gai Chase (Saunders 1986). However, this has not been substantiated by any other recent record. It was considered improbable that a population is extant in the vicinity of Ku-ring-gai Chase and no field surveys were conducted in this area for the present study.

Woronora Plateau

In the vicinity of Woronora Plateau, a specimen was collected from Maddens Plains in 1885 (records of the Australian Museum) but there are no more recent confirmed records for the area. Surveys, using tape replay, at Maddens Plains during one day in March 1993, near Cataract Dam during one day in November 1994 and at Holsworthy during two days in November 1996 detected no eastern bristlebirds. There was a sighting in the vicinity of Darkes Forest in February 1997 which "looked like a bristlebird" (D Goldrick, pers. comm.). However, from this evidence it was considered improbable that a population is extant in the vicinity of the Woronora Plateau.

Mt Kembla

At Mt Kembla, the eastern bristlebird was recorded in 1944 by McNamara (1945, 1946). The exact location of this record, at the head of Wattle Creek, was given to me in 1993 (J McNamara, pers. comm.). Subsequent surveys of this location and areas of potential habitat within 4 km during two days in spring 1993, one day in spring 1994 and one day
in summer 1995, including tape replay, failed to detect the species. From this evidence it was considered improbable that a population is extant in the vicinity of Mt Kembla.

**Budderoo National Park**

Budderoo is contiguous in the east with Barren Grounds. It extends the Barren Grounds eastern bristlebird population considerably, although this has been somewhat overlooked in the past. There are recent records near the western side of Budderoo at Upper Kangaroo Valley (L Mitchell, NPWS, pers. comm.) and Carrington Falls (IBOC 1994) and near the northern side of Budderoo at Knights Hill (NPWS-db undated).

For the present field study, observations were made in all seasons over 16 days from October 1990 to July 1996 and 159 eastern bristlebird detections were mapped. The highest density was recorded over a three day period in January 1996 when 30 eastern bristlebirds were recorded in an area of 300 ha. This was extrapolated across the estimated maximum of 2 500 ha of potential habitat in Budderoo and the surrounding area to give a maximum population estimate of 250 individuals at January 1996.

**Barren Grounds Nature Reserve**

The results from the present field study gave a population estimate for Barren Grounds at February 1997 of 600 individuals with an area of occupancy of approximately 1 600 ha. Further details are given in Chapter 3.

**Morton National Park and Red Rocks Nature Reserve**

At Morton, the eastern bristlebird has been especially elusive. It was reported in montane areas (Humphries 1982) including Tianjara Plateau in the south-east of Morton. Surveys at Tianjara Plateau from December 1981 to May 1982 failed to detect the species (Thackway et al. c1984), although it was reported there again in 1989 (NPWS-db undated). For the present study, the exact location and the surrounding area of this latter record was surveyed using tape replay during three days in September 1994 with no eastern bristlebirds detected. Two eastern bristlebirds were detected in the south of the Park at Quiltys Mountain in January 1990. However, surveys during 29 days from January 1991 to August 1994 at Quiltys Mountain, Little Forest Plateau and other parts of Morton failed to make another detection. During spring 1995, one eastern bristlebird was reported to be detected by its call in the vicinity of Sassafras (G Daly, pers. comm.), another was detected at Red Rocks (B Gray, NPWS, pers. comm.) and two were reported from Bendella (IBOC 1995). Hence, it appears that in the vicinity of Morton and Red Rocks there may be a small number of eastern bristlebirds. However, the viability of
any populations in these areas is uncertain and their area of occupancy is considered to be very small.

**Jervis Bay**

Beecroft Peninsula was visited by Hindwood and several other bird-watchers for a week in 1932 (Hindwood 1933). They noted ground parrots and other heathland birds, including the southern emu-wren, tawny-crowned honeyeater and the elusive chestnut-rumped heathwren, but they did not note the eastern bristlebird. More recently, there were three anecdotal records of eastern bristlebirds in this area: two were recorded calling in May 1984 (C Chafer, pers. comm.), one was recorded running across a road in April 1992 (M Fortescue, BNP, pers. comm.) and one was reported calling on several occasions during October 1995 (F Beynon, pers. comm.). For the present study, Beecroft Peninsula was surveyed over three days in 1992 and 12 days from November 1995 to February 1996. Tape replay was used at approximately 30 locations, including the areas of the previous records, on every survey day. No eastern bristlebirds were detected. This result was consistent with Braithwaite et al. (1988) who surveyed extensively in the north-eastern part of the Peninsula during 1987-8 and failed to detect the eastern bristlebird. From this evidence, it was considered that the presence of the eastern bristlebird at Beecroft Peninsula remains unconfirmed.

For the area between Beecroft and Bherwerre Peninsulas, surveys were conducted over 11 days between October 1995 and February 1996. Tape replay was used at 10-40 locations per day. One eastern bristlebird was detected in December 1995, 100 m north of Vincentia Road. In March 1997, there was a confirmed record of an eastern bristlebird at Huskisson, 3 km north of the 1995 record (B Gray, NPWS, pers. comm.).

For Bherwerre Peninsula, surveys were undertaken over 21 days during 1992-1994 and 29 days from January 1995 to February 1996 and 352 eastern bristlebird detections were mapped. The density of eastern bristlebirds increased from sparse at the Peninsula neck near Vincentia Road to relatively high in the eastern part of the peninsula and the total area of habitat was estimated to be 4 300 ha. For the purpose of calculating the population size, this area was divided into four large and five small sections which contained most of the eastern bristlebird detections and the large remaining section, where there were few detections (Figure 2.1). The survey data for December 1994 to February 1996 were scrutinized. For each large section, the maximum density recorded during any survey of part of the section was extrapolated to calculate the maximum number of eastern bristlebirds in the total area of the section. For each of the small sections, the highest number of detections was taken as the maximum number of birds in the section. Thus,
the total Bherwerre Peninsula population was estimated to be < 700 at February 1996 (Table 2.4).

Table 2.4 Eastern bristlebirds at Bherwerre Peninsula

<table>
<thead>
<tr>
<th>Section</th>
<th>Survey area (ha)</th>
<th>Maximum density (per 100 ha)</th>
<th>Estimate of maximum number of birds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murrays Hill</td>
<td>330</td>
<td>27</td>
<td>89</td>
</tr>
<tr>
<td>East Airfield</td>
<td>470</td>
<td>32.5</td>
<td>152</td>
</tr>
<tr>
<td>South of Border</td>
<td>680</td>
<td>20</td>
<td>136</td>
</tr>
<tr>
<td>NSW</td>
<td>1000</td>
<td>15</td>
<td>150</td>
</tr>
<tr>
<td>Cape St George</td>
<td>10</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Steamers Head</td>
<td>30</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>South Bristol wetland</td>
<td>15</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Green Patch wetland</td>
<td>65</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>West Golf wetland</td>
<td>50</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Remainder</td>
<td>1650</td>
<td>6</td>
<td>99</td>
</tr>
<tr>
<td>Total</td>
<td>4300 ha</td>
<td></td>
<td>659</td>
</tr>
</tbody>
</table>

*aSee text for the method of calculating the maximum number of birds.*

Ben Boyd National Park

At Ben Boyd (south), no eastern bristlebirds were detected during spring surveys in 1994 (one day) and 1995 (three days). There was an unconfirmed report of an eastern bristlebird 2 km west of the Park at Bulls Flat in 1980 (J Shields, pers. comm.). From this evidence, it was considered that the presence of the eastern bristlebird at Ben Boyd (south) is unconfirmed and unlikely.

Nadgee Nature Reserve

Nadgee was surveyed during 47 days from October 1994 to June 1997. Tape replay was used during 1994 but did not result in any eastern bristlebirds being detected. Eastern bristlebirds were only detected in 11 km of coastal lowland from 1 km north of Little River, south to the Bunyip Hole, 1.5 km from the Victorian border. A total of 113 detections were mapped. In October 1995, parts of a 20 km route were walked 2-6 times over 6 days and there were 38 detections of eastern bristlebirds representing a maximum of 26 possible individuals. The maximum density was 9 eastern bristlebirds in 150 ha, directly south of Nadgee Lake on 17 October 1995. This density was extrapolated across the 2 000 ha of probable habitat in the Nadgee area and a very approximate estimate of the total southern eastern bristlebird population was a maximum of 120 individuals at October 1995. From October 1995 to June 1997 eastern bristlebird detections at Nadgee were at a similar rate.
Recent records from Victoria

For Victoria, Clarke and Bramwell (1998) documented ten locations from Howe Flat to Lake Tyres for which there were accurate positions for records of eastern bristlebirds, dating from 1977 to 1990. A further two locations, Wilsons Promontory and Tarwin have unconfirmed records (BOCA 1995). Surveys of these 12 locations and ten other areas of similar habitat during 1990-1995 (Bramwell 1997) detected eastern bristlebirds at only one location, Howe Flat, Croajingolong National Park. A minimum of six were detected here during 1994 (M Bramwell, DNRE, pers. comm.). During September 1997, an intensive survey detected a minimum of 30 birds in approximately a third of the potential habitat at Howe Flat (M Bramwell, DNRE, pers. comm.). This suggested a concentration of perhaps 100 eastern bristlebirds at Howe Flat and an area of approximately 1 000 ha of potential habitat at Croajingolong. From this evidence, the total Nadgee-Croajingolong population was estimated to be in the order of 220 eastern bristlebirds in 3 000 ha of potential habitat at September 1997.

Discussion

Status

The biological status of the eastern bristlebird was relatively clear by 1997. There were fewer than 2 000 individuals occupying less than 120 km², ranging over 1 400 km from Conondale Range to Croajingolong. They were confined to three disjunct regions. The documented decline of the fragmented northern populations indicates that the species is on the brink of extinction in that region. A similar decline was apparent for the southern populations except at Nadgee-Croajingolong. The central populations were contained in two main areas, Barren Grounds-Budderoo and Bherwerre Peninsula, Jervis Bay, and possibly a few small fragments at Morton-Red Rocks. The fragmentation and decline that were probably ongoing for millennia, were apparently hastened by European settlement (Keast 1957).

Comparisons of the biological status among threatened bird species is difficult because of the variability in ecological patterns and threatening processes. Also, comparisons are complicated because the legal status of threatened birds in Australia may be assessed at the international, national or state level. Nevertheless, the following comparisons are made in an attempt to highlight the relative biological and legal status of the eastern bristlebird.
The ground parrot and eastern bristlebird were both listed as Vulnerable in NSW under the Threatened Species Conservation Act, 1995. However, the ground parrot is a strong flier, which implies that it is capable of escaping from fires and dispersing among populations; it is found at more locations in NSW and its population exceeds 2,000 (Baker 1997c); the Queensland population is known to be in the order of 5,000 (McFarland 1991b); the Victorian population in the order of 1,000 (Meredith and Jaremovic 1990); and the Tasmanian population in the order of 100,000 (Bryant 1991). Hence, although the eastern bristlebird and the ground parrot have similar abundances in NSW, the range and mobility of the eastern bristlebird is considerably more restricted and nationally their abundance is two orders of magnitude smaller than that of the ground parrot.

The hooded plover and the little tern were both listed as Endangered in NSW and the little tern was listed as Endangered nationally under the Endangered Species Protection Act 1992. Nationally, population estimates are 5,000 for both the hooded plover (Watkins 1993) and little tern (Garnett 1992). This is double the size of the eastern bristlebird population.

The regent honeyeater is also listed as Endangered in NSW and nationally and its total population was estimated to be less than 1,000 (Garnett 1992). Hence, it is likely that the eastern bristlebird is more abundant than the regent honeyeater but their population sizes are of the same order. From these comparisons, it is argued that the eastern bristlebird should be listed as Endangered.

In order to address the apparent inconsistency in the categorization of the eastern bristlebird by Garnett (1992), the Mace and Lande (1991) threat characteristics and numerical criteria (Table 2.5) are used to argue further that the status of the species should be changed to Endangered. A taxon is assigned to Endangered if it meets any two of the four criteria in Table 2.5. The total of all eastern bristlebird populations in 1996 was less than 2,500 individuals and the distribution was fragmented with only two populations exceeding 500 individuals. Therefore, the species meets the first two criteria and should be categorized as Endangered. Furthermore, although there were insufficient data to calculate an overall rate of population decline for the last century, there is evidence that the northern and southern populations have declined at rates > 5% per annum over periods longer than five years and the species probably meets the third Endangered criterion. The habitat of all of the remaining populations is fire-prone and there are sufficient data (Chapter 3) to suggest that the extent and frequency of catastrophic fires meets the fourth of the Endangered criterion.
Chapter 2 Status of the eastern bristlebird

The legal status of the eastern bristlebird was changing by 1996. The species was re-categorized from Vulnerable to Endangered in Queensland (Nature Conservation (Wildlife) Regulation 1994 of the Nature Conservation Act 1992) and Victoria (Flora and Fauna Guarantee Act 1988 as amended (CNR 1995)). However, deliberation over the legal status of the eastern bristlebird in NSW was delayed because the Scientific Committee established under the NSW Threatened Species Conservation Act 1995 used IUCN (1994) which modified the Mace and Lande (1991) characteristics and numerical criteria for the categorization of threatened taxa. This was unexpected because it was not specified in the Act, nor anticipated in the literature (eg Brebach 1996).

Table 2.5 Criteria for an Endangered species summarized from Mace and Lande (1991)

<table>
<thead>
<tr>
<th>Threat characteristic</th>
<th>Numerical criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Total population (N)</td>
<td>N &lt; 2500</td>
</tr>
<tr>
<td>2 Extent of fragmentation</td>
<td>n (populations with &gt;500 individuals) &lt; 6</td>
</tr>
<tr>
<td>3 Rate of population decline</td>
<td>&gt; 5% / year for 5 years</td>
</tr>
<tr>
<td>4 Extent and frequency of catastrophes</td>
<td>&gt; 20% reduction in population / 5 to 10 yrs or</td>
</tr>
<tr>
<td></td>
<td>&gt; 50% reduction in population / 10 to 20 yrs</td>
</tr>
</tbody>
</table>

The IUCN (1994) criteria have more detailed prescriptions and they are more conditional and more numerically stringent than the criteria used by Mace and Lande (1991). For instance, one of the Endangered criteria is that the number of mature individuals is less than 250. Another criterion is that if the number of individuals is less than 2 500 there must also be a severe population decline or extreme fragmentation. The eastern bristlebird did not meet either of these criteria. However, to be categorized as Endangered, a taxon need only satisfy one of the IUCN criteria. The results of the present study showed that the eastern bristlebird could be categorized as Endangered because its area of occupancy was estimated to be less than 500 km² and it was severely fragmented and continuing to decline in extent of occurrence and number of subpopulations. Eventually, the status of the eastern bristlebird was changed from Vulnerable to Endangered by a Final Determination (Gazetted 31 January 1997) under the NSW Threatened Species Conservation Act 1995.

The national status of the eastern bristlebird, under the Endangered Species Protection Act 1992, was amended to Endangered on 1 June 1998.

Interpreting the results

Confirmed records of isolated eastern bristlebirds which are more than a few kilometres away from known populations can be interpreted in two ways. Eastern bristlebirds may be dispersing and expanding their areas of occupancy as suggested by the 1997 record at
Huskisson, Jervis Bay. Alternatively, the records may represent individuals from small, sparsely distributed populations which are approaching local extinction. This is the most likely scenario with the northern and southern populations which have disappeared in the past decade and probably the case for some of the records from Morton.

Some eastern bristlebird records were described in the Results as unconfirmed. Where it is sparsely distributed, the chance of finding it are likely to be very low. The eastern bristlebird is a very cryptic species and considerable expertise is required to confirm its presence and distinguish it from species similar in appearance, behaviour or calls. For instance, the eastern bristlebird and the pilotbird co-occur and are very similar. Clarke and Bramwell (1998) noted that the pilotbird responded to a replayed tape of an eastern bristlebird call and that some eastern bristlebird records for Victoria may be misidentified pilotbirds. Although the A-call is characteristic, it is highly variable and eastern bristlebirds have a number of other calls, calling interactions and duets, as discussed in Chapter 1. Hence, confirmation by experts is desirable before eastern bristlebird records enter the ornithological literature or reputable databases.

The validity of the population estimates reported in the present chapter is difficult to assess. A problem with cryptic species such as bristlebirds is that some individuals are likely to go undetected and population densities could be under-estimated. On the other hand, the methods used in my study may have over-estimated the effective population sizes. For Barren Grounds, average densities were used but the survey period was late summer when a lot of calling seemed to be associated with the presence of immature birds, some of which would not be expected to survive to breeding age. For Budderoo, Jervis Bay and Nadgee, populations were calculated using maximum density estimates extrapolated over maximum areas of probable habitat.

The assumptions underlying demographic studies of the eastern bristlebird need to be interpreted with particular regard to the research method employed. McNamara (1946) "always found them within 50 yards" and attributed the A-call to the male of a pair. This begot the notion that eastern bristlebirds occur in pairs established in small, fixed, exclusive territories which underlies the abundance and density estimates made for the northern populations (Holmes 1989; Lamb et al. 1993; Holmes 1997a; Stewart 1997) and the central populations (Jordan 1990).

The assumption that eastern bristlebirds could always be found within 50 yards, hence their territories are relatively small, may be wrong. Perhaps the birds always found McNamara within 50 yards and they moved towards him because they had large and/or overlapping territories. As discussed in Chapter 1, eastern bristlebirds are likely to show themselves and/or to call near intruders and they can move more than 100 m in less than a
minute. In the present field study, during a day of surveying, I assumed that eastern bristlebird detections ≥ 200 m apart represented different individuals. Consequently, my population estimates may be too high if the same birds were recounted and too low if birds were closer than 200 m but not detected.

The first population estimate published for Barren Grounds (Blakers et al. 1984) was based on a brief (2 day), small-scale (24 ha) study in one vegetation type of uniform fire-age (P Fullagar, unpubl. data). The study reported a maximum density of 2 birds per ha and possibly 13 pairs in 24 ha but the study appeared to assume that territories were small (approximately 1 ha) and may have double-counted some birds. These estimates were used by Jordan (1990) and Garnett (1992) which largely accounts for the legal status initially being under-stated as Vulnerable. However, if maximum densities for very small areas are extrapolated across very large areas of sparsely utilized habitat, then populations may be grossly over-estimated. By contrast, the population estimate calculated for Barren Grounds in the present study was based on a 10 day survey of 410 ha covering all vegetation types and fire-ages with a high degree of certainty that double-counting did not inflate the estimate.

The assumption that A-calls are made only by males may be wrong, as discussed in Chapter 1. Assuming that all A-calls are made by a male and that each male represents a pair of eastern bristlebirds may lead to populations being over-estimated. Even if the assumption is correct, detecting A-calling males may not necessarily be a useful population index. For instance, the rate of calling may not be directly proportional to the number of individuals or to breeding success; or the sex-ratio may not be even. Future studies based on detecting A-calls should attempt to relate the amount of A-calling to the number of birds and should report the number of A-calling birds not the number of presumed males or pairs. Alternatively, studies could report total numbers including sightings and birds detected by any of their calls, although results would be dependent on the expertise of the observer. This method was utilized in all data collected for the present thesis and by Bramwell et al. (1992) and Pyke et al. (1995).
Chapter 3

A fiery problem: managing eastern bristlebird habitat

_bush fire ... carried away with it my rare nest_ (Jackson 1907)

was the ironic lament of a thwarted egg-collector and

the earliest mention of the effects of fire on the eastern bristlebird

Introduction

The problem

Fire is a feature of all areas where eastern bristlebirds occur. An inappropriate fire regime is the most demonstrable catastrophe and the main threat to the species (Garnett 1992; Baker 1997a). The problem is considerable. The species is Endangered and has declined in historic and recent times (Chapter 2). Chaffer (1954) was the first to speculate that the causes included frequent fire. Few eastern bristlebirds would be expected to survive the passage of a fire because they are poor fliers. Populations are isolated, with negligible chance of recolonization after habitat recovers from fire. Even if local extinction does not occur as a result of a fire, the rate of population recovery is expected to be slow because of their apparently low fecundity. Previous studies have been limited in extent and have not focused on planning fire management strategies for the species. Achieving a fire management prescription is difficult because the habitat is flammable and the potential sources of ignition are numerous. A strategy to favour eastern bristlebirds may conflict with other management objectives.

A digression: the ground parrot

Despite the ground parrot being much studied, there remains debate about its response to fire (Craig 1997) and about the appropriate fire management of the species (Baird et al. 1994; Whelan and Baker 1996; Woinarski and Recher 1997). However, the adaptive style of management advocated by Baker and Whelan (1994) is implicit in all major ground parrot research (Meredith and Isles 1980; Burbidge et al. 1989; McFarland 1989; Bryant 1991) all of which recognized the need for long-term studies to guide management.

At Barren Grounds, in January 1983, approximately 280 ha burned in an unplanned fire and a longitudinal study was established to census ground parrots annually in an 80 ha plot. The expectation (Jordan 1987b) was that the population would rebuild and then decrease to zero within 12 years (Figure 3.1) in accordance with the Meredith model (Meredith and Isles 1980; Meredith 1984; Meredith et al. 1984) which proposes that frequent fire is necessary to maintain habitat for ground parrots. However, ground
Chapter 3 A fiery problem: managing eastern bristlebird habitat

Years after fire

Figure 3.1 Ground parrot density data (○) since fire in January 1983 at an 80 ha site at Barren Grounds (after Baker and Whelan 1994 and unpub. data for 1994-7) compared to the prediction of Jordan (1987b) (—).

parrots remained abundant (Figure 3.1) and this study became influential in encouraging the current management practice of planning no fires at Barren Grounds from August 1991 to February 1998.

Serendipity: a longitudinal study of the eastern bristlebird at Barren Grounds

The study of eastern bristlebirds reported in this chapter began as a snap-shot survey in 1992. Then, at Barren Grounds for two years, there were no planned or unplanned fires and ground parrots remained abundant. In January 1994, my casual observations suggested that the number of eastern bristlebirds had increased considerably. Also, during 1992-4, there was a growing awareness that the biological status of the eastern bristlebird was considerably more threatened than the legal status suggested. The outcome was that there were no planned fires and, coincidentally, no unplanned fires at Barren Grounds to February 1998 and a longitudinal study of the eastern bristlebird population was possible.

Aims

The aims of this chapter are (i) to investigate and interpret the effects of fire on the eastern bristlebird through a longitudinal study of the species' post-fire density response at Barren Grounds and (ii) to study eastern bristlebird recolonization after fire.
Methods

Post-fire density response

At Barren Grounds, in 1992, a survey route of 17.5 km was established along existing trails. This was lengthened to 20.5 km in 1995 and included 1.5 km along a route where there was no trail (Figure 3.2). Historically, trails have been used as fire-breaks and opposite sides of a trail often have different fire-ages. Contiguous 5 ha transects were confined to one side of the route, 100 m wide and 500 m long. For some transects, the fire-age was uncertain or not uniform (16 of the 70 transects for 1992 and 1994; 17 of the 82 transects for 1995-7). The survey route was walked twice per year over January-February at an average speed of 1.5-2 km per hour, within four hours of sunrise. Surveys were not conducted when there was little eastern bristlebird activity, particularly during heavy rain or hot or windy weather. All eastern bristlebirds detected within 100 m of the survey route were mapped at a scale of 1:10 000 as described in Chapter 2. The density of eastern bristlebirds in a given year along each transect was taken as the mean of two surveys, except in 1996 when data were collected only once for 32 transects (Table 3.1). In 1998, data were only collected for seven transects in the Saddleback part. The population each year was estimated by summing the number of eastern bristlebirds in each of the five parts with different fire-ages. The number of birds in each part was estimated by the product of the area and the mean transect density (Appendix 3.1). The sizes of the areas with different fire-ages were calculated by Marthick (1995).

Changes in eastern bristlebird densities between years were compared using paired-sample one-tailed tests (Zar 1984). For each comparison, the distribution of differences in density for each transect was checked for normality using the Shapiro-Wilk test ($\alpha = 0.05$). The paired-sample t test was used to test the significance of the changes when the differences could be assumed to come from a normal distribution. Otherwise, nonparametric tests were used. The distribution of differences was checked by visual assessment of the histogram plots for each comparison and when they were symmetrical about the median, the Wilcoxon paired-sample test was used. Otherwise, the normal approximation to the binomial test of the sign test was used. Data manipulation and statistical calculations were performed using JMP Version 3 (SAS 1994).

The change in the Barren Grounds population was also calculated as a population growth rate using the exponential growth equation $N_t = N_0e^{rt}$ (Brewer 1988).
Recolonization after fire

Eastern bristlebird recolonization after fire was studied in four ways. Firstly, the average density in young heath (fire-age 3 years) was compared with old heath (≥ 9 years) for 1992 and 1995. Secondly, density data were compared between recently burnt transects adjacent to transects in older fire-age areas and recently burnt transects adjacent to transects of the same fire-age. For both sets of comparisons, the differences between the densities were tested with the two-sample nonparametric Mann-Whitney test ($\alpha = 0.05$). Thirdly, microhabitat was described where eastern bristlebirds were detected in recently burnt areas. Fourthly, evidence was sought opportunistically for eastern bristlebirds utilizing relatively long-unburnt habitat. Care was taken to verify the fire-age of the putative long-unburnt areas.

Tape replay was not used to detect eastern bristlebirds for the present study because it was thought that this could attract birds onto the transects and result in an over-estimate of densities.
Results

Post-fire density response

For the period of the present study, 1,430 eastern bristlebirds detections were mapped. The estimate of the total population for Barren Grounds almost doubled from 310 in 1992 to 600 in 1997 (Table 3.1). The population increase of 39% from 310 in 1992 to 430 in 1994 was highly significant and this supports my casual observation prior to the 1994 survey. The overall population increase from 430 in 1994 to 600 in 1997 suggests that there was a real, steady annual increase in the population during that period, although these increases showed low statistical significance.

Table 3.1 Eastern bristlebird population estimates for Barren Grounds

<table>
<thead>
<tr>
<th>Year</th>
<th>Population estimate (two significant figures)</th>
<th>Average number of detections for n transects</th>
<th>Paired-sample test of the increase in the number of detections between consecutive years for n transects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n = 70</td>
<td>n = 82</td>
</tr>
<tr>
<td>1992</td>
<td>310</td>
<td>84.5</td>
<td>t = 2.46; n = 70; P = 0.008</td>
</tr>
<tr>
<td>1994</td>
<td>430</td>
<td>113</td>
<td>aZ = 1.05; n = 70; 0.1 &lt; P &lt; 0.25</td>
</tr>
<tr>
<td>1995</td>
<td>470</td>
<td>116</td>
<td>121.5</td>
</tr>
<tr>
<td>1996</td>
<td>560</td>
<td>138</td>
<td>t = 1.49; n = 82; P = 0.070</td>
</tr>
<tr>
<td>1997</td>
<td>600</td>
<td>157</td>
<td>t = 1.59; n = 82; P = 0.058</td>
</tr>
</tbody>
</table>

aNormal approximation to the binomial test of the sign test

For the period 1992-8, the five parts of Barren Grounds with different fire-ages showed a trend of eastern bristlebird density from zero to low density immediately after fire, recovering to a plateau of approximately 2 birds per 5 ha within 10 years after fire (Figure 3.3). Most (13/21) of the changes in eastern bristlebird density were increases. Although few of these increases and none of the decreases were statistically significant (α = 0.05), the general trend of increases reflects the steady increase in the overall population. The results are detailed in Appendix 3.1. The relative importance of rates of movement and reproduction among the parts of Barren Grounds is uncertain. However, it is assumed that the overall increase in the population is due to reproductive success.
Chapter 3 A fiery problem: managing eastern bristlebird habitat


The population exponential growth rate was calculated to be 13.2% per annum for the five years from 1992 to 1997. The validity of this estimate is limited because it does not account for regulatory factors such as limiting resources and eastern bristlebird movements. For instance, the lack of significant increases in density in the North-west (△), Griffiths Trail (●) and Saddleback (○) parts from 1994 to 1996 may due to lack of reproductive success or emigration to the Fox (○) part (symbols as per Figure 3.3).

Recolonization after fire

The density of eastern bristlebirds in young heath (fire-age 3 years) was significantly lower than in old heath (≥ 9 years) for the comparisons made for both 1992 and 1995 (Figure 3.4).

The recolonization of recently burnt areas in the Fox part of Barren Grounds showed a trend of greater eastern bristlebird densities in habitat where it was adjacent to old fire-age areas compared with habitat that was adjacent to recently burnt areas of the same fire-age (Figure 3.5), although the difference was statistically significant only for the third year after fire (Mann-Whitney U = 22; P < 0.05).
Figure 3.4 Eastern bristlebird densities at Barren Grounds, comparing parts of young (■) and old (□) fire-age. For 1992, the density on the young transects (mean ± se = 0.60 ± 0.21; fire-age 3 years; n = 15) compared with the old (1.43 ± 0.18; 9-12 years; n = 38) was significantly lower (normal approximation to the Mann-Whitney statistic Z = 2.69; P < 0.005). For 1995, the density on the young transects (0.39 ± 0.11; 3 years; n = 9) compared with the old (1.91 ± 0.16; 12-15 years; n = 41) was significantly lower (Z = 3.92; P < 0.0001).

In the Noorinan part of Barren Grounds, the pattern of differences was inconsistent and none of the differences was statistically significant, although five years post-fire, the density of eastern bristlebirds in habitat that was adjacent to old-age areas (mean = 1.75) was high compared with habitat that was adjacent to same-age transects (mean = 0.75) (Figure 3.5). For both Fox and Noorinan, the power of the Mann-Whitney test was low because of the small sample sizes.

Figure 3.5 Eastern bristlebird recolonization of recently burnt areas adjacent to old fire-age areas (■) and adjacent to areas of the same fire-age (□) at two parts of Barren Grounds: Fox (mean bristlebird density for 3 transects adjacent to old-age areas and 8 transects adjacent to same-age areas) and Noorinan (2 transects adjacent to old-age areas and 6 transects adjacent to same-age areas). *significant difference
There was evidence that in the recently burnt areas, eastern bristlebirds generally avoided regenerating low vegetation in favour of unburnt clumps, rapidly regenerating mallee or scrub, particularly *M. squarrosa* in wet areas, and patchily burnt areas which may be associated with escarpment edges. Three years post-fire in the Fox part of Barren Ground, eastern bristlebirds were noted at 11 locations: six unburnt patches of dense *Banksia ericifolia, Melaleuca squarrosa, Leptospermum* scrub and/or *Eucalyptus dendromorpha* mallee to 3 m tall; four locations where vegetation of the same type had regenerated rapidly to 1-2 m; and the remaining location was in low (<1 m) regenerating heath <20 m away from dense vegetation with fire-age 12 years. In the Noorinan part, three years post-fire, eastern bristlebirds were noted at seven locations: two of patchily burnt woodland at the edge of the escarpment, four of wet areas where *M. squarrosa* had regenerated to a height >1 m and one of low (0.5 m) heath. At the latter location, the bird flushed and flew 20 m to the cover of taller, denser vegetation along a creek. Four years post-fire, eastern bristlebirds were noted at 13 locations in the Noorinan part: one in woodland at the edge of the escarpment, seven in regenerating *M. squarrosa* <2 m, three in regenerating mallee <1.5 m and two in low (0.5 m) heath <20 m away from dense vegetation with fire-age 15 years. There are no estimates for the extent of the patchiness of the fires at Barren Grounds but in the recently burnt parts, Noorinan-Drawing Room Rocks and Fox, the burns were relatively thorough (I Smith, NPWS, pers. comm.), removing all of the foliage from at least 99% of the areas.

In recently burnt habitat at Jervis Bay, there were two noteworthy records of eastern bristlebirds. On one occasion, one bird was calling from an unburnt patch of dense scrub at the edge of a 50 ha block in which there was a patchy fire two weeks earlier. In another block of approximately 100 ha, 18 months after a patchy fire, a relatively high density was detected with nine eastern bristlebirds in 30 ha. This was a considerably higher density than occurred at Barren Grounds (Figure 3.3) for up to five years post-fire.

In relatively long-unburnt habitat, there were numerous records of eastern bristlebirds during the present study. The records from the oldest fire-ages at each location were as follows: At Budderoo, near Gerringong Falls, in an area last burned in August 1976 (NPWS 1986; Marthick 1995), one record was obtained 17.4 years post-fire. In the east of Barren Grounds, in the area last burned in September 1979 (NPWS 1986; Marthick 1995), there was a relatively high density (2.4 birds per 5 ha) recorded in February 1998 (Figure 3.3), 18.4 years post-fire. At Jervis Bay, in the eastern part of Bherwerre Peninsula, in Fire Compartment # 6, the last fire occurred in December 1972 (R Rudd, pers. comm.; BNP-database 1998). There was a relatively high density of eastern bristlebirds in this area and seven individuals were radio-tracked here in April 1997 (Chapter 6), 24.3 years post-fire. At Nadgee, in an area immediately north of Nadgee
Lake, which has not burned since before 1972 (H Recher, pers. comm.; Gilmour 1983), eastern bristlebirds were most recently detected in December 1996. In October 1996, three bristlebirds were detected in this area, one was seen carrying food and this was taken as a confirmed breeding record in an area with fire-age > 24 years.

Discussion

Fire affects eastern bristlebird populations and the results of the present study support the claim that it is a fire-sensitive species. At Barren Grounds, in the absence of fire for 5 years, the population almost doubled and there was a short to medium-term trend of increasing bristlebird density with increasing fire-age of habitat. There is evidence that the extent of a fire and the availability of fire refugia are important factors in the recovery of populations after fire. Eastern bristlebirds can occur and breed in relatively long-unburnt habitat. The management of fire in eastern bristlebird habitat is an important conservation issue and the following discussion supports the claim that the species is fire-sensitive.

Post-fire density response

The pattern of results at Barren Grounds (1992-8) indicated a trend of eastern bristlebird density: zero to low density immediately after fire, recovering to a plateau of approximately 2 birds per 5 ha, 10 years after fire (Figure 3.3). This trend does not represent a definitive model because it relies on data from one location over a relatively short study period. However, because there were five parts all with different fire-ages followed over 5-6 years, the synchronic and diachronic approaches to population study (Whelan 1995) have been combined to give added strength to the results. A similar technique was used previously in the study of plant (Auld 1986) and mammal (Twigg et al. 1989) populations. Hence, the results for the present study can be used generally as a coarse guide to the species' potential to recover from fire in its habitat depending on other factors, particularly the pattern of fire.

Pattern of fire: extent

To estimate the effect of fire on eastern bristlebird populations, it could be assumed that the area of habitat burned is directly proportional to the reduction in population size. The following examples indicate the extent of fires through areas of known habitat and the inferred population declines. At Barren Grounds, in November 1968, all but 4 ha was burned by a wildfire (Forshaw et al. c1969; Rogers 1970). Presumably, some eastern bristlebirds found refuge as a few were detected within one year (Rogers 1970) and subsequently Barren Grounds was repopulated. Since then, in the 30 years to mid-1998,
there have been fires in six years and in each of these years an average of 30% (range: 10-50%) of the potential habitat was burned. This pattern of fires has apparently enabled Barren Grounds to retain a viable eastern bristlebird population. In the period 1992-7, there were no fires and the density of eastern bristlebirds rebuilt in the habitat of younger fire-age and was maintained at a relatively high density in the areas of older fire-age.

At Booderee, since 1977, the fire management prescription has resulted in a mosaic of fire-ages in 109 small compartments (0-442 ha; mean approximately 65 ha) (BNP-database 1998). The intended fire prescription (Ingwersen 1977), which was to burn woodland and heathland areas about every 10 years, fell behind schedule (R Rudd, pers. comm.). It is likely that this combination of small-area burns and relatively long periods between fires has enabled Bherwerre Peninsula to retain a viable population.

At Nadgee, in 1972 and 1980, almost all of the Reserve was burned by consecutive severe wildfires (Gilmour 1983). There are no eastern bristlebird population data for Nadgee prior to 1972 but it is likely that the population was severely depleted by the 1972 fire. In 1979, Recher (1981) located only three eastern bristlebirds despite a large effort of 110 surveys each of 30 minutes plus other opportunities for observations. The results of my 1994-7 field study (Chapter 2), indicate that the eastern bristlebird density at Nadgee was relatively low compared to Barren Grounds-Budderoo and Bherwerre Peninsula. Assuming the 1995 population estimate for Nadgee of 120 eastern bristlebirds (Chapter 2) and the annual growth rate of 13.2% calculated for the Barren Grounds population, then, based on exponential growth, the Nadgee population has rebuilt from 17 individuals in 1980 and will take until the year 2006 to attain 500 individuals. While these calculations are speculative they strongly suggest that the population at Nadgee is recovering slowly from near-extinction and that a decade of sustained growth is needed for Nadgee's population to become comparable in size to Barren Grounds-Budderoo and Jervis Bay.

Fire has been implicated in the local extinction of eastern bristlebird populations. In Victoria, extensive wildfire which thoroughly burned eastern bristlebird habitat was considered by Bramwell (1997) and Clarke and Bramwell (1998) to have caused the local extinction of five populations. For the northern populations, Holmes considered that fire was at least partly the cause of five of the nine local extinctions documented to 1989 (Holmes 1989) and a further two of the three documented to 1996 (Holmes 1997a). In these cases, the authors implied that repeated fire caused declines and/or that populations were destroyed outright by a single fire or that individuals which may have survived a fire were unable to survive in the post-fire conditions. By contrast, the two eastern bristlebird populations which are currently the largest, Barren Grounds-Budderoo and Jervis Bay,
are characterized by a recent history of long fire-free periods over much of their available habitat.

**Pattern of fire: refugia**

Generally, because of their ability to fly, birds are able to recolonize areas quickly even after widespread catastrophes. For example, Recher (1981) reported that the effect of the 1972 Nadgee fire was intense but that most species recovered fully within a few years, probably by recolonizing from outside the Reserve. However, eastern bristlebirds are semi-flightless and seem to be cover-dependent. Hence, their repopulation of an area after fire is likely to depend on dispersal of emigrants from nearby unburnt areas or by rebuilding from the individuals which survive in unburnt patches within the burnt area. For a refuge to be effective during a fire, it must be close and be accessible under the prevailing fire conditions. In the present study, no data were obtained about how eastern bristlebirds survive the passage of a fire and so discussion about refugia is confined to the post-fire period.

The present study offers some evidence that the proximity of unburnt areas is important for recolonization after fire. At Barren Grounds, in some situations, eastern bristlebird density was higher where recently burnt areas were adjacent to old fire-age habitat rather than recently burnt habitat. For Jervis Bay, Pyke *et al.* (1995) found no significant difference in eastern bristlebird densities between areas with fire-age 0-7 years and 13-14 years and concluded that this was due to the proximity of unburnt habitat to recently burned areas which allowed easy movement between the areas of different fire-ages.

Unburnt patches may result from topographic features such as wet depressions, creek-lines and escarpments (Whelan 1995). In the present study, in habitat that was 0-4 years post-fire, eastern bristlebirds were located in unburnt patches and dense regrowth of mallee and shrubs. At Barren Grounds, Jordan (1984b) located eastern bristlebirds in dense stands of burnt shrubs two months after fire.

For the northern populations of the eastern bristlebird, Holmes (1989) speculated that rainforest acted as a refuge from fire. At Spicers Gap, which, until recently, was the largest of the northern populations (see Chapter 2), the fire in 1991 was implicated in the subsequent 74% reduction (Lamb *et al.* 1993; Hartley and Kikkawa 1994) and probable local extinction (Holmes 1997a; Stewart 1997) of the population. Together, the backburn and the wildfire it contained, burned less than 300 ha of habitat but this represented more than 75% of the habitat being utilized by the bristlebirds (Hartley and Kikkawa 1994). Furthermore, the backburn burned thoroughly uphill with a moderate intensity, burning-out some rainforest areas, particularly the narrow wet gullies which were expected to act
as refuge areas (Lamb et al. 1993). Whereas prescription burns may be planned to create a pattern of accessible unburnt refuges, at Spicers Gap, the prevailing fire conditions appear to have caused potential refuges to burn with disastrous results for the population. This scenario is further evidence that relatively extensive fires can be deleterious and that refuge from fire can be critical to eastern bristlebird populations.

Is fire necessary?

Previously, prescriptions for management of eastern bristlebird populations (NPWS 1986; Holmes 1989; Avis 1993; Bramwell et al. 1993; Lamb et al. 1993) have assumed that fire is necessary for the long-term maintenance of suitable habitat, despite a paucity of evidence and despite the demonstrated adverse impacts of fire. For the northern populations, based on "limited but compelling evidence" from one site, Holmes (1989) assumed that maintaining the dense tussocky understorey was dependent on a 10-20 year fire frequency. More frequent burning was thought to cause the tussocks to be replaced by rhizomatous herbs and infrequent burning was thought to allow the lower stratum to become dominated by woody shrubs. Lamb et al. (1993) prescribed a fire frequency of 5-15 years for Spicers Gap because they "suspected" that intervals longer than 15 years might allow fuel loads to increase, resulting in intense and thorough fires which would be detrimental to the eastern bristlebird. However, they recognized that "how long these habitats remained suitable remains unknown". Holmes (1997) provided an unsubstantiated proposal that earlier prescriptions should be modified to a fire frequency of 7-10 years in habitat of the northern populations. For Barren Grounds, NPWS (1986) proposed to "carry out a program of prescribed burns" to "maximize the population of the eastern bristlebird". For Victoria, despite the apparent decline of the eastern bristlebird and the fact that "no information exists on appropriate fire regimes" (Avis 1993), management prescriptions for ground parrot habitat were considered to be appropriate for eastern bristlebird habitat (Avis 1993; Bramwell et al. 1993): a fire-free period of 12-18 years on average, with an 8 year minimum.

In old fire-age habitat, eastern bristlebirds can breed and can occur at relatively high densities. There is no evidence for any population that lack of fire has caused a decline in eastern bristlebird numbers. Perhaps even infrequent fire is not necessary for the maintenance of eastern bristlebird habitat. Probably the species was widespread and successful during the wetter Tertiary Period (Smith 1977) in the absence of fire. It seems likely now that exclusion of fire would allow the remnant populations of eastern bristlebirds to increase naturally through breeding as occurred at Barren Grounds from 1992-7 and would allow expansion of their areas of occurrence through dispersal. Collecting population data in areas where fire is excluded will allow better informed management in the future.
At Two Peoples Bay, Western Australia, to allow the critically endangered noisy scrub-bird population to recover, the area has been protected from fire since being made a reserve in 1966 (Smith 1985a; Danks 1998). The expectation that the vegetation at the Reserve would reach a maximum fire-age beyond which it became unsuitable as noisy scrub-bird habitat (Smith 1977), focused attention on the need to monitor the population. During this period the noisy scrub-bird population in the Reserve has increased and expanded through natural breeding success (Danks 1998). Populations of two other threatened birds, the western bristlebird and western whipbird also appear to have increased due to the exclusion of fire from Two Peoples Bay (Danks et al. 1996). In particular, the western bristlebird inhabits areas not burned for more than 50 years. For the rufous bristlebird in southern Victoria, the highest population density was recorded at Loch Ard Gorge which was unburnt for more than 25 years (Belcher 1992).
## Appendix 3.1

### Surveys of the eastern bristlebird at Barren Grounds 1992-8

<table>
<thead>
<tr>
<th>Parts of Barren Grounds&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Survey period (year)</th>
<th>Fire-age at 1 Jan</th>
<th>n(transects)</th>
<th>Mean (± se) density Birds/5 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Noorinan-</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room Rocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>August 1991</td>
<td>1992</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>August 1991</td>
<td>1994</td>
<td>2</td>
<td>1.0 (0.5)</td>
</tr>
<tr>
<td></td>
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<td>1995</td>
<td>3</td>
<td>0.39 (±0.11)</td>
</tr>
<tr>
<td></td>
<td>January 1983</td>
<td>1996</td>
<td>4</td>
<td>0.89 (±0.23)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1997</td>
<td>5</td>
<td>1.1 (±0.26)</td>
</tr>
<tr>
<td><strong>Fox</strong></td>
<td></td>
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</tr>
<tr>
<td>502 Area</td>
<td>August 1988</td>
<td>1992</td>
<td>3</td>
<td>0.60 (±0.21)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1994</td>
<td>5</td>
<td>0.73 (±0.16)</td>
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<tr>
<td></td>
<td>September 1979</td>
<td>1995</td>
<td>6</td>
<td>1.3 (±0.20)**</td>
</tr>
<tr>
<td></td>
<td>September 1980</td>
<td>1996&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7</td>
<td>1.9 (±0.17)**</td>
</tr>
<tr>
<td></td>
<td>September 1980</td>
<td>1997</td>
<td>8</td>
<td>1.7 (±0.16)</td>
</tr>
<tr>
<td><strong>North-west</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>278 Area</td>
<td>January 1983</td>
<td>1992</td>
<td>9</td>
<td>1.8 (±0.34)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1994</td>
<td>11</td>
<td>2.4 (±0.29)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1995</td>
<td>12</td>
<td>2.1 (±0.23)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1996&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13</td>
<td>2.1 (±0.29)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1997</td>
<td>14</td>
<td>2.4 (±0.26)</td>
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<tr>
<td><strong>Griffiths Trail</strong></td>
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</tr>
<tr>
<td>429 Area</td>
<td>October 1980</td>
<td>1992</td>
<td>11</td>
<td>1.0 (±0.19)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1994</td>
<td>13</td>
<td>1.6 (±0.33)</td>
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<tr>
<td></td>
<td>September 1979</td>
<td>1995</td>
<td>14</td>
<td>1.8 (±0.27)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1996&lt;sup&gt;d&lt;/sup&gt;</td>
<td>15</td>
<td>1.6 (±0.26)</td>
</tr>
<tr>
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<td>September 1979</td>
<td>1997</td>
<td>16</td>
<td>2.1 (±0.17)</td>
</tr>
<tr>
<td><strong>Saddleback</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>156 Area</td>
<td>September 1979</td>
<td>1992</td>
<td>12</td>
<td>2.0 (±0.54)</td>
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<tr>
<td></td>
<td>September 1979</td>
<td>1994</td>
<td>14</td>
<td>1.9 (±0.31)</td>
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<td>September 1979</td>
<td>1995</td>
<td>15</td>
<td>1.6 (±0.39)</td>
</tr>
<tr>
<td></td>
<td>September 1979</td>
<td>1996&lt;sup&gt;e&lt;/sup&gt;</td>
<td>16</td>
<td>2.3 (±0.33)</td>
</tr>
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<td>1997</td>
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<tr>
<td></td>
<td>September 1979</td>
<td>1998</td>
<td>18</td>
<td>2.6 (±0.21)</td>
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</tbody>
</table>

Parts of Barren Grounds<sup>a</sup> are shown in Figure 3.2. 1996<sup>b</sup> = one transect surveyed once only; 1996<sup>c</sup> = 11 transects surveyed once only; 1996<sup>d</sup> = all transects surveyed once only; 1996<sup>e</sup> = one transect surveyed once only.

Significant increase from previous year. \( P < 0.01^{**} \) for Wilcoxon paired-sample test. \( P > 0.05 \) for all other changes in density between years.
Chapter 4

Birds across heath-wood edges

In terrestrial communities the concept of edge effect has been shown to be especially applicable to bird populations. (Odum 1958)

Introduction

Ecotones and edge effect

The concepts of ecotone and edge effect were introduced in detail in Chapter 1. Briefly, an ecotone is a zone of transition between adjacent ecological systems (Holland 1988). The edge effect was first defined as the "tendency for increased variety and density at community junctions" (Odum 1958) and was generally interpreted to mean that ecotones are beneficial to wildlife. However, more recently, the potential for edges to have a deleterious effect on wildlife diversity has become a conservation issue, particularly in regard to anthropogenic edges. An intriguing adjunct to the ecotone concept is that some species may be edge specialists or "ecotonal" species which Odum (1958) proposed would inhabit only the ecotone. This notion of ecotonal species is well established in the literature, although there is little supporting empirical evidence. Also, there is some uncertainty about the definition of ecotonal species. The present chapter focuses on species which may be entirely ecotonal.

Recently, the concept of the ecotone has been considerably refined (Risser 1993) and authors (eg Holland et al. 1991; Risser 1995) have developed the theory of ecotones to consider biotic and abiotic factors at various spatial and temporal scales. There is also a large body of literature about effects at anthropogenic edges (Chapter 1). However, there remains a dearth of studies at the local population level which investigate the edge effect and ecotonal species in natural systems. The present chapter studies local bird populations which occur across some naturally occurring heath-wood edges.

Birds at edges: response models

Intuitively, bird species could be categorized as (i) unaffected by an edge, (ii) an edge exploiter or (iii) an edge avoider (Sisk and Margules 1993). Further division of species into habitat generalists or specialists allowed Sisk and Margules (1993) to propose models for the six hypothetical responses of the density of bird species across the edge between two habitats. Ecotones have traditionally been considered as the transition zone between adjacent vegetation types (Risser 1995) which is appropriate for the study of local bird populations. The model responses have been adapted to show the response of
birds across an ecotone between two vegetation types, hereafter called habitats (Figure 4.1).

Ecotone exploiters are characterized by increased density at the ecotone, whereas ecotone avoiders have decreased density at the ecotone. The density of ecotone ignorers is unchanged across the ecotone, except for species which are habitat specialists. Habitat specialists - ecotone ignorers, maintain their density only for that part of the ecotone which is similar to their preferred habitat. The response of ecotonal species, for which the theory predicts high density at the ecotone and negligible density in the habitats either side of the edge (Figure 4.2), was not considered by Sisk and Margules (1993). This is a special case of a habitat specialist which is found only in the transition zone between two adjacent habitats and it is of particular interest in the present chapter.
Chapter 4 Birds across heath-wood edges

Heath-wood edges and the eastern bristlebird

Historical records described eastern bristlebird habitat as "scrubby" (Vigors and Horsfield 1827), "scrubby undergrowth" (North 1904) and "swampy heathlands" (Chaffer 1954) around Sydney and in the Illawarra region and as heathy ridge-tops and creek-lines near Binna Burra in south-eastern Queensland (Robertson 1946). The notion that the eastern bristlebird might be ecotonal was inferred by Blakers et al. (1984) "lives in rank vegetation bordering on heath", Jordan (1987a) "common resident in areas where woodland adjoins heath" and Garnett (1992) "occupies a variety of heath or tussock grass habitat, usually on the boundary of woodland or forest". Holmes (1989); Bramwell et al. (1992) and Pyke et al. (1995) asserted that it was an ecotonal species. However, Bramwell et al. (1992) has been the only analytical test of this assertion. In a 66 ha study area at Barren Grounds, they detected a significantly higher proportion of eastern bristlebirds in the ecotone than the adjacent heathland and woodland.

The eastern bristlebird has substantial populations at three locations: Barren Grounds Nature Reserve and the adjacent Budderoo National Park (Barren Grounds-Budderoo), Bherwerre Peninsula at Jervis Bay (Jervis Bay) and Nadgee Nature Reserve (Nadgee) (Chapter 2). These locations are characterized by a variety of extensive intergrading heathland, sedgeland and swamp communities (Burrough et al. 1977; Gilmour 1983; Taws 1997), hereafter called heath. In places, the heath makes relatively long and distinct edges with adjacent woodland and forest, hereafter called wood. These sites were suitable to test hypotheses about avian responses across heath-wood edges, particularly the response of the eastern bristlebird.
Aim

The aim of this chapter is to investigate the response of bird populations across heath-wood edges by addressing the following questions: (i) Is there an edge effect? (ii) How do individual species respond across a heath-wood edge? (iii) Is the eastern bristlebird or any other species an entirely ecotonal species?

Methods

Site descriptions

The study was conducted at 11 sites spread among the three locations. Four sites were established at Barren Grounds-Budderoo, four at Jervis Bay and three at Nadgee. Across the sites, the heath was closed heathland, closed sedgeland and closed wet heathland with variable heights of 0.4-0.8 m and emerging shrub clumps at 0.6-1.4 m and the wood was forest, open forest, woodland and open woodland with variable heights of 10-35 m (Appendix 4.1). The sites were chosen because they had distinct, relatively straight heath-wood edges at least 600 m long dividing relatively large, homogenous areas of vegetation extending for at least 200 m each side of the edge and because of the presence of eastern bristlebirds. The sites were separated by 0.25-2.2 km at Barren Grounds-Budderoo, 1.3-3.1 km at Jervis Bay and 1.5-2.7 km at Nadgee.

Surveys

At each site, pairs of plots 25 m × 400 m were marked on either side of three parallel transects: along the heath-wood edge and 100 m either side of the edge, in the wood and the heath areas (Figure 4.3). A bird survey was conducted at every site during eight periods between September 1995 and July 1997, at approximately three-monthly intervals. Each survey was completed within 4 hours post-sunrise in suitable weather conditions. The order in which the transects were walked was varied systematically to avoid bias. Each pair of plots was surveyed for 1 hour and all birds were counted in the first plot where they were detected. Care was taken to avoid double-counting individuals along a transect. Species were identified by sight or by their calls. Occasionally, when mixed flocks of small honeyeaters and silvereyes were encountered feeding and moving quickly across a site, the numbers of individuals were estimated conservatively to the nearest 10 birds. Overflying birds were not counted unless they attempted to prey upon animals in or a few metres above the vegetation.
Data analysis

(i) Is there an edge effect?

To explore this question, the total data set was used in two ways. Firstly, for each survey period, the data for each pair of plots were combined to allow consideration of the ecotone as one zone, the transition zone, separate from the wood and the heath. Secondly, all six plots at each site were considered in order to separate the edge effect on the opposite sides of the heath-wood edge.

Bird abundance was derived from the mean density of individuals per plot (or pair of plots) of the eight repeat surveys. Species richness was assessed in two ways. The mean density of species per plot (or pair of plots) of the eight repeat surveys was indicative of the number of species per hour and called the average species richness. The cumulative number of species for the eight repeat surveys was indicative of the species richness at each plot (or pair of plots) over the 2 years of the study. Nested, three-factor ANOVAs (α = 0.05) were conducted on abundance and average and cumulative species richness.
Chapter 4 Birds across heath-wood edges

data with location, site within location and distance (plot or pair of plots) as the factors. GENSTAT 5 (Genstat 5 Committee 1987) was used to obtain the ANOVA table and the appropriate F ratios for testing the effects of location and distance (Table 4.1). The number of sites within locations was unequal and so successive sites from each of Barren Grounds-Budderoo and Jervis Bay were paired at random and excluded from the data set (after Underwood 1997). Iterations of balanced ANOVAs with three sites within locations were performed, generally four times. This allowed a sensible interpretation of the ANOVAs without the need to create a dummy set of data for Nadgee to balance the number of sites within locations. The Tukey "honestly significant difference" (HSD) test (a multiple comparison test) was used ($\alpha = 0.05$) where the ANOVAs found significant differences among means, although this procedure is less powerful than ANOVA and may fail to detect differences between any pair of means (Zar 1984).

The data were not transformed because each of the data sets met the ANOVA assumptions of normality, homoscedasticity and additivity (Zar 1984). To check for normality, the residuals from each data set were examined via a normal probability plot using GENSTAT 5 (Genstat 5 Committee 1987) and straight-line patterns were observed. The null hypothesis that the residuals come from a Normal distribution was tested using the Shapiro-Wilk test and was retained for each data set ($P > 0.05$). To check for homoscedasticity, each data set was inspected and the variances were found to be similar among locations and among distances. To check for additivity, the plot of the residuals versus the fitted (predicted) values was examined for each data set using GENSTAT 5 (Genstat 5 Committee 1987) and none suggested the need for transformation.

Table 4.1 Analysis of variance summary table

<table>
<thead>
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<tr>
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<tr>
<td>Distance</td>
<td>Distance MS / Site within Location x Distance MS</td>
</tr>
<tr>
<td>Location x Distance</td>
<td>Location x Distance MS / Site within Location x Distance MS</td>
</tr>
<tr>
<td>Site within Location</td>
<td></td>
</tr>
<tr>
<td>Site within Location x Distance</td>
<td></td>
</tr>
</tbody>
</table>

A third indication of species richness was to graph the total number of species across all plots (or pairs of plots) for the total period of the study.

(ii) How do individual species respond across heath-wood edges?

This question was explored by comparing the density histogram pattern for each species to the models of ecotone response (Figures 4.1 and 4.2). Bird density was derived from the mean density of individuals per plot of the eight repeat surveys. Species' histograms
were constructed using mean densities across the locations (usually three) where the species occurred.

Analysis was based on the method outlined by Sisk and Margules (1993). For each species, response across the edge was tested by comparing the histogram values with a uniform distribution using the $\chi^2$ goodness of fit test ($\alpha = 0.10$) (Zar 1984). For all but 20 species there was no discernible response. To distinguish habitat selection from response to the ecotone, the density data for each of these 20 species plus two of particular interest, were compared by ANOVA. The two additional species, the ground parrot and striated fieldwren, are of interest because they are listed as threatened species in NSW and, although they were rarely detected, they were expected to be heath specialists. For each of the 22 selected species, nested, three-factor ANOVAs ($\alpha = 0.05$) were conducted on bird density data as described above for the total data set. Exceptions, which occurred at only one location, were the striated fieldwren and white-eared honeyeater. For these, single-factor ANOVAs ($\alpha = 0.05$) were conducted. All the data were transformed using $\sqrt{x + 0.375}$ because the variances were proportional to the means and because some data were small or zero (Zar 1984). The Tukey HSD test was used ($\alpha = 0.05$) where ANOVAs found significant differences among means.

(iii) Is the eastern bristlebird or any other species an entirely ecotonal species?

Following the comparisons described in (ii) above, species were identified as potentially ecotonal if their density pattern fitted the model for either an ecotone exploiter or ecotonal species. The density distribution of each species across the heath-wood edge was checked to see if it was entirely ecotonal and further described using the data for each location, site and/or survey period.

Results

Edge effect - bird abundance

Using three pairs of plots, the ANOVAs of bird abundance showed an ambiguous result for the effect of distance (16 iterations gave a range of $F_{2,12} = 3.18-6.32$; $0.17 > P > 0.03$), no effect of location (four iterations: range of $F_{2,6} = 0.3-1.3$; $P > 0.5$) and no interaction (four iterations: range of $F_{4,12} = 0.1-0.3$; $P > 0.5$). The Tukey HSD test showed that the abundance per 2 ha (mean ± se) at the ecotone (34.4 ± 4.04) and the wood (28.2 ± 2.59) were similar and both significantly greater than at the heath (14.7 ± 2.73) (Figure 4.4a). This pattern of the ecotone and the wood being similar and approximately double the abundance at the heath was consistent across all sites.
Using six plots, four iterations of the ANOVAs of bird abundance showed a significant effect of distance (range of $F_{5, 30} = 3.90$-$4.97; 0.01 \geq P \geq 0.005$), no effect of location (range of $F_{2, 6} = 0.3$-$1.4; P > 0.5$) and no interaction (range of $F_{4, 12} = 0.3$-$0.5; P > 0.5$). The Tukey HSD test showed that the abundance per ha (mean $\pm$ se) at the wood side of the ecotone ($23.5 \pm 2.53$) was significantly greater than at all other distances and approximately 67% greater than at the wood plots. The remaining paired comparisons gave ambiguous results with the abundances for two wood plots ($15.4 \pm 1.64$ and $12.8 \pm 1.12$), the heath side of the ecotone ($10.8 \pm 1.93$) and the two heath plots ($8.17 \pm 1.43$ and $6.55 \pm 1.35$) not clearly separable (Figure 4.4b). The pattern of the wood side of the ecotone having greater abundance than both of the wood plots was consistent across all of the sites. Abundance at the heath side of the ecotone was approximately 47% greater than at the heath plots but this difference was not significant and while the pattern held across the three locations it did not hold across all sites.

**Edge effect - average species richness**

Using three pairs of plots, four iterations of the ANOVAs of the average species richness showed a significant effect of distance (range of $F_{2, 12} = 8.92$-$15.4; 0.01 \geq P \geq 0.005$), no effect of location (range of $F_{2, 6} = 0.3$-$2.2; P \geq 0.4$) and no interaction (range of $F_{4, 12} = 0.1$-$0.8; P > 0.5$). The Tukey HSD test showed that the average richness per 2 ha (mean $\pm$ se) at the wood ($10.7 \pm 0.699$) and the ecotone ($10.6 \pm 0.724$) were similar and both significantly greater than at the heath ($4.19 \pm 0.647$) (Figure 4.4c). This pattern of the ecotone and the wood being similar and approximately double the average species richness at the heath was consistent across all sites.

Using six plots, four iterations of the ANOVAs of the average species richness showed a significant effect of distance (range of $F_{5, 30} = 8.64$-$14.0; P < 0.001$), no effect of location (range of $F_{2, 6} = 0.4$-$1.9; P > 0.4$) and no interaction (range of $F_{4, 12} = 0.3$-$1.1; P > 0.5$). The Tukey HSD test showed that the average species richness per ha (mean $\pm$ se) at the two wood plots ($7.36 \pm 0.548$ and $6.41 \pm 0.374$) and the wood side of the ecotone ($8.86 \pm 0.586$) were significantly greater than at the heath side of the ecotone ($4.11 \pm 0.537$) and the two heath plots ($2.75 \pm 0.472$ and $3.15 \pm 0.481$) (Figure 4.4d). This pattern of the three wood plots having a greater average species richness than the three heath plots was consistent across all sites. Also, the pattern of the average species richness at the wood side of the ecotone exceeding the two wood plots and the heath side of the ecotone exceeding the two heath plots was consistent across all locations.
**Edge effect - cumulative species richness**

Using three pairs of plots, four iterations of the ANOVAs of the cumulative species richness showed a significant effect of distance (range of $F_{2,12} = 8.17-17.2$; $P < 0.01$), no effect of location (range of $F_{2,6} = 0.4-1.8$; $P > 0.5$) and no interaction (range of $F_{4,12} = 0.1-1.2$; $P > 0.5$). The Tukey HSD showed that the cumulative richness per 2 ha (mean ± se) at the ecotone (30.1 ± 1.61) and the wood (28.6 ± 1.67) were similar and both significantly greater than at the heath (13.0 ± 1.91) (Figure 4.4e). This pattern of the ecotone and the wood being similar and approximately double the cumulative species richness at the heath was consistent across all sites.

Using six plots, four iterations of the ANOVAs of the cumulative species richness showed a significant effect of distance (range of $F_{5,30} = 7.32-10.4$; $P < 0.001$), no effect of location (range of $F_{2,6} = 0.7-2.7$; $P > 0.3$) and no interaction (range of $F_{4,12} = 0.1-0.6$; $P > 0.5$). The Tukey HSD test gave an ambiguous result with the cumulative species richness per ha (mean ± se) at the wood side of the ecotone (29.2 ± 1.43), the two wood plots (24.9 ± 2.05 and 22.1 ± 1.14), the heath side of the ecotone (16.8 ± 1.27) and the two heath plots (11.1 ± 1.81 and 10.3 ± 2.05) not clearly separable (Figure 4.4f). However, the pattern of the cumulative species richness at the wood side of the ecotone exceeding the two wood plots and the heath side of the ecotone exceeding the two heath plots was consistent across all but one of the sites.

**Edge effect - total species richness**

The total species richness for the pairs of plots clearly groups the wood (69 species) with the ecotone (68 species) being approximately double the 40 species at the heath (Figure 4.4g). Using six plots, the two wood plots with 61 and 58 species group with the wood side of the ecotone (65 species) and these are approximately double the number of species at the heath side of the ecotone (37) and the two heath plots (36 and 33) (Figure 4.4h).
Figure 4.4 Edge effect - bird abundance and species richness. Figures (a - h) show the mean ± standard error of bird abundance or species richness at each distance (plot or pair of plots). The ANOVA results (summarized) are shown for differences among the means at significance levels of $P < 0.05^*$, $P < 0.01^{**}$ and $P < 0.001^{***}$. From the Tukey HSD test, unambiguously different means at plots (or pairs of plots) are shown by separate levels of underlining.
Response of species across heath-wood edges

Eighty-six species were recorded in the study and some were able to be categorized as heath (7 species) or wood (20 species) specialists on the basis of field observations, species lists (Anon 1986; Jordan 1987c; Gosper and Baker 1997) and reference texts (Pizzey and Doyle 1980; Blakers et al. 1984). Twenty species showed a non-uniform density response across the heath-wood edge ($\chi^2 > 9.24$, df = 5, $P < 0.10$) (Table 4.2). Two species were included in the analysis because they were of particular interest. For these 22 species, the ANOVAs showed significant differences among the distances for only five species (Table 4.2) and for these the effect of location and the interaction were not significant. The Tukey HSD tests made unambiguous distinctions among the means for two of these species. The white-throated treecreeper had significantly higher density in the two wood and wood ecotone plots than in the heath ecotone and the two heath plots. The southern emu-wren had significantly higher density in the two heath and heath ecotone plots than in the two wood and the wood ecotone plots. The examples presented by Sisk and Margules (1993) suggest that they could definitively assign few species to their models on the basis of unambiguously different mean bird densities across an edge.

In the present study, most of the selected species occurred in low and variable numbers (Table 4.2). Some, despite their apparently close resemblance to one of the models showing a response to the ecotone, failed to show significantly different means among the distances in the three-factor ANOVAs. By considering the means and variances at the six plots, histograms for individual species were grouped with the ecotone response model which best described their density pattern across the heath-wood edge. Wood and heath habitat specialists are shown separately with the models for heath specialists, the reverse of those for the wood. For the species which showed no discernible response across the edge, few had densities suggestive of a habitat generalist - ecotone ignorer. The most convincing example was the little wattlebird (Figure 4.5). The 22 selected species provided examples of all of the possible model types except the habitat generalist - ecotone avoider (which may be considered an oxymoron anyway) and the heath specialist - ecotone exploiter. Almost half of the species ($n = 9$) showed a marked change in density across the edge in response to the change in habitat which was not a response to the ecotone (Figures 4.6 and 4.7). Seven species appeared to be ecotone exploiters (Figures 4.8 and 4.9) and four ecotone avoiders (Figures 4.10 and 4.11). Two species, although they were questionable examples, were compared to the model for an ecotonal species (Figure 4.12).
Table 4.2 Bird records (total number of detections) for each species at Barren Grounds-Budderoo (B), Jervis Bay (J) and Nadgee (N) and at the six plots across the heath-wood edge. The species considered to be wood (w) and heath (h) habitat specialists are indicated.

<table>
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<th>Species</th>
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<td>B J N</td>
<td>Wood</td>
<td>Ecotone</td>
<td>Heath</td>
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<td>0 0 0</td>
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<td>&lt; 5</td>
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<tr>
<td>Brush Bronzewing</td>
<td>1 0 4</td>
<td>0 1 2</td>
<td>0 0 2</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Yellow-tailed Black-Cockatoo</td>
<td>4 19 0</td>
<td>6 7 0</td>
<td>0 0 6</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Gang-gang Cockatoo</td>
<td>w 27 20 2</td>
<td>9 18</td>
<td>22 0</td>
<td>0 0 7.5</td>
</tr>
<tr>
<td>Galah</td>
<td>0 1 0</td>
<td>1 0 0</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Rainbow Lorikeet</td>
<td>0 11 2</td>
<td>11 0 2</td>
<td>0 0 5.6</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Musk Lorikeet</td>
<td>0 19 0</td>
<td>12 7 0</td>
<td>0 0 5.2</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Little Lorikeet</td>
<td>0 0 4</td>
<td>4 0 0</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Australian King-Parrot</td>
<td>w 0 5 8</td>
<td>4 1 8</td>
<td>0 0 3</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Crimson Rosella</td>
<td>135 124 8</td>
<td>114 73</td>
<td>100 29</td>
<td>5 19</td>
</tr>
<tr>
<td>Ground Parrot</td>
<td>h 4 13 3</td>
<td>0 0 0</td>
<td>12 8</td>
<td>8.5 &gt;0.05</td>
</tr>
<tr>
<td>Fan-tailed Cuckoo</td>
<td>11 10 12</td>
<td>10 2 13</td>
<td>3 3 3</td>
<td>2 &lt;5</td>
</tr>
<tr>
<td>Horsfield’s Bronze-Cuckoo</td>
<td>0 5 1 3</td>
<td>1 0 2</td>
<td>3 2</td>
<td>12 &lt;5</td>
</tr>
<tr>
<td>Shining Bronze-Cuckoo</td>
<td>0 6 8</td>
<td>5 2 6</td>
<td>0 0 1</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Southern Boobook</td>
<td>w 0 0 1</td>
<td>1 0 0</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Tawny Frogmouth</td>
<td>0 1 0</td>
<td>0 1 0</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Laughing Kookaburra</td>
<td>4 18 0</td>
<td>10 5 6</td>
<td>1 0 5</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Sacred Kingfisher</td>
<td>0 1 2</td>
<td>0 1 2</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Dollarbird</td>
<td>0 1 0</td>
<td>0 0 1</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>White-throated Treecreeper</td>
<td>w 70 39 52</td>
<td>68 39</td>
<td>53 1</td>
<td>0 0 22 &lt;0.01</td>
</tr>
<tr>
<td>Superb Fairy-wren</td>
<td>10 26 58</td>
<td>14 5 32</td>
<td>34 0 9 8.1</td>
<td></td>
</tr>
<tr>
<td>Variegated Fairy-wren</td>
<td>66 156 1</td>
<td>54 10</td>
<td>85 44</td>
<td>21 9 15 &gt;0.05</td>
</tr>
<tr>
<td>Southern Emu-wren</td>
<td>h 141 192 190</td>
<td>0 4 14 103 167</td>
<td>235</td>
<td>69 &lt;0.001</td>
</tr>
<tr>
<td>Spotted Pardalote</td>
<td>w 24 31 19</td>
<td>25 20 29</td>
<td>0 0 9.7 &gt;0.05</td>
<td></td>
</tr>
<tr>
<td>Striated Pardalote</td>
<td>w 0 0 2</td>
<td>0 0 2</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Eastern Bristlebird</td>
<td>90 75 20</td>
<td>11 9 63</td>
<td>58 19 25</td>
<td>11 &gt;0.05</td>
</tr>
<tr>
<td>Pilotbird</td>
<td>w 12 0 2</td>
<td>4 6 4</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>White-browed Scrubwren</td>
<td>99 56 78</td>
<td>48 79</td>
<td>60 26</td>
<td>14 6</td>
</tr>
<tr>
<td>Chestnut-rumped Heathwren</td>
<td>1 0 0</td>
<td>1 0 0</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Striated Fieldwren</td>
<td>h 0 0 20</td>
<td>0 0 0</td>
<td>11 9</td>
<td>5.1 &lt;0.05</td>
</tr>
<tr>
<td>Brown Thornbill</td>
<td>230 165 256</td>
<td>191 166</td>
<td>185 90</td>
<td>9 10</td>
</tr>
<tr>
<td>Striated Thornbill</td>
<td>38 44 97</td>
<td>64 45</td>
<td>43 27</td>
<td>0 0 14 &gt;0.05</td>
</tr>
<tr>
<td>Red Wattlebird</td>
<td>34 66 9</td>
<td>30 29 31</td>
<td>9 6</td>
<td>4 5.9</td>
</tr>
<tr>
<td>Little Wattlebird</td>
<td>9 111 33</td>
<td>28 21 50</td>
<td>14 13 27</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Noisy Friarbird</td>
<td>1 38 0</td>
<td>12 14 10</td>
<td>1 1 1</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Lewin’s Honeyeater</td>
<td>w 6 5 0</td>
<td>5 3 3</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Yellow-faced Honeyeater</td>
<td>87 323 107</td>
<td>85 68</td>
<td>219 98</td>
<td>28</td>
</tr>
<tr>
<td>White-eared Honeyeater</td>
<td>67 0 0</td>
<td>9 7 39</td>
<td>8 2 2</td>
<td>11 &gt;0.05</td>
</tr>
<tr>
<td>Fuscous Honeyeater</td>
<td>0 1 0</td>
<td>0 0 1</td>
<td>0 0 0</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Brown-headed Honeyeater</td>
<td>2 25 6</td>
<td>2 4 19</td>
<td>5 1 2</td>
<td>5.2</td>
</tr>
<tr>
<td>White-naped Honeyeater</td>
<td>46 59 20</td>
<td>7 7 84</td>
<td>27 0 32 &gt;0.05</td>
<td></td>
</tr>
<tr>
<td>Crescent Honeyeater</td>
<td>19 0 5 5</td>
<td>22 15 29</td>
<td>8 0 0 7.1</td>
<td></td>
</tr>
<tr>
<td>New Holland Honeyeater</td>
<td>179 445 222</td>
<td>84 69</td>
<td>293 140</td>
<td>116 144</td>
</tr>
<tr>
<td>White-cheeked Honeyeater</td>
<td>11 175 0</td>
<td>12 7 52 41</td>
<td>36 38 6.3</td>
<td></td>
</tr>
<tr>
<td>White-crowned Honeyeater</td>
<td>h 0 20 84</td>
<td>1 0 4</td>
<td>4 40</td>
<td>55 21 &lt;0.01</td>
</tr>
</tbody>
</table>
Figure 4.5 Possible habitat generalist - ecotone ignorer. Figures 4.5-4.12 show the mean (± standard error) density for each species at each distance (plot). The ANOVA results (summarized) are shown for differences among the means at significance levels of Tukey HSD test, unambiguously different means at plots are shown by separate levels of underlining.

Easton Spinebill 141 196 112 130 119 122 53 16 9 26 >0.05
Scarlet Honeyeater 0 3 0 3 0 0 0 0 0 <5 -
Scarlet Robin 0 0 4 0 0 1 3 0 0 <5 -
Flame Robin 3 0 0 0 1 0 1 1 0 <5 -
Rose Robin w 1 0 2 2 0 1 0 0 <5 -
Eastern Yellow Robin w 7 15 48 29 29 12 0 0 11 >0.05
Eastern Whipbird 34 22 23 22 24 29 2 2 0 8.2 -
Varied Sittella w 0 22 14 17 8 11 0 0 0 5.4 -
Crested Shrike-tit w 0 0 2 0 0 2 0 0 <5 -
Olive Whistler w 1 0 0 0 1 0 0 0 0 <5 -
Golden Whistler w 12 17 58 37 22 28 0 0 0 12 <0.05
Rufous Whistler 20 10 33 12 13 32 5 1 0 8.4 -
Grey Shrike-thrush 30 9 36 14 8 39 7 1 6 9.3 >0.05
Black-faced Monarch w 0 0 10 2 4 4 0 0 0 <5 -
Lead Flycatcher w 1 2 1 1 2 1 0 0 0 <5 -
Satin Flycatcher w 0 4 0 2 1 1 0 0 0 <5 -
Rufous Fantail w 2 0 11 5 4 4 0 0 <5 -
Grey Fantail 51 44 58 38 36 60 16 2 1 13 >0.05
Black-faced Cuckoo-shrike 9 4 7 4 2 10 4 0 0 <5 -
Olive-backed Oriole 1 5 0 2 2 2 0 0 0 <5 -
Dusky Woodswallow 0 2 15 0 0 3 5 5 4 <5 -
Grey Butcherbird 1 2 0 1 2 0 0 0 0 <5 -
Australian Magpie 3 0 0 0 0 3 0 0 0 <5 -
Pied Currawong 7 19 10 14 10 12 0 0 0 <5 -
Grey Currawong 2 0 0 0 1 1 0 0 0 <5 -
Australian Raven 1 20 0 10 1 5 0 2 3 <5 -
Satin Bowerbird w 4 19 10 9 16 5 3 0 0 <5 -
Red-browed Finch 0 38 10 2 4 15 16 2 9 <5 -
Beautiful Firetail 21 14 9 2 13 6 13 5 5 <5 -
Mistletoebird w 2 2 6 3 2 5 0 0 0 <5 -
Welcome Swallow 0 36 11 0 0 0 6 24 17 8.5 -
Fairy Martin 5 0 0 0 0 0 0 2 3 <5 -
Silvereye 34 182 12 31 53 81 45 5 13 13 >0.05
Common Blackbird 0 0 2 0 2 0 0 0 <5 -

Total numbers of species 56 62 58 61 58 65 37 33 36 86 69 68 40 77 48

The \(\chi^2\) test used the mean densities at the plots, ie the number of records divided by 8 visits. For \(\chi^2 > 9.24\) the values are shown in bold \(P < 0.10\). ANOVA results are shown as probability \(P\) levels of the significance of differences among the mean distances (plots) for each species that was tested.

![Graph](image)

Figure 4.5 Possible habitat generalist - ecotone ignorer. Figures 4.5-4.12 show the mean (± standard error) density for each species at each distance (plot). The ANOVA results (summarized) are shown for differences among the means at significance levels of \(P < 0.05\), \(P < 0.01\) and \(P < 0.001\). From the Tukey HSD test, unambiguously different means at plots are shown by separate levels of underlining.
Figure 4.6 Wood specialist - ecotone ignorer. Figures 4.5-4.12 show the mean (± standard error) density for each species at each distance (plot). The ANOVA results (summarized) are shown for differences among the means at significance levels of $P < 0.05^*$, $P < 0.01^{**}$ and $P < 0.001^{***}$. From the Tukey HSD test, unambiguously different means at plots are shown by separate levels of underlining.
Figures 4.5-4.12 show the mean (± standard error) density for each species at each distance (plot). The ANOVA results (summarized) are shown for differences among the means at significance levels of $P < 0.05^*$, $P < 0.01^{**}$ and $P < 0.001^{***}$. From the Tukey HSD test, unambiguously different means at plots are shown by separate levels of underlining.
Figures 4.5-4.12 show the mean (± standard error) density for each species at each distance (plot). The ANOVA results (summarized) are shown for differences among the means at significance levels of $P < 0.05\ast$, $P < 0.01\ast\ast$ and $P < 0.001\ast\ast\ast$. From the Tukey HSD test, unambiguously different means at plots are shown by separate levels of underlining.
Ecotonal species

This study set out to identify ecotonal bird species. Nine species were identified as potentially ecotonal. Seven species, including the eastern bristlebird, were like the ecotone exploiter models (Figures 4.6 and 4.9). However, without exception, these species were found at the wood and/or the heath and hence, they were certainly not entirely ecotonal.

Two species, the white-eared and white-naped honeyeaters, had histograms most like the ecotonal species model (Figure 4.12). However, both of these two potentially ecotonal honeyeaters were recorded outside the ecotone. There were 67 records for the white-eared honeyeater which occurred only at the four Barren Grounds-Budderoo sites. At two sites there were many records at the ecotone (13 and 28) whereas at the other two sites there were few records at the ecotone (2 and 4). The white-naped honeyeater occurred at seven sites. The ecotones at two sites accounted for most (33% and 32%) of the 125 records, whereas the ecotones at the remaining five sites accounted for a total of only 27 records (22%). With such high variability among sites, it is likely that the histograms are poor indicators of the white-eared and white-naped honeyeaters' density responses across heath ecotones. Neither species was considered to be an entirely ecotonal species.
Overall, for the eastern bristlebird, 65% of the records were at the ecotone, 24% were at the heath and 11% were at the wood. At each location, eastern bristlebirds were located at the heath or the wood or both, although, among locations, there was variation in density on either side of the edge (Figure 4.13). This density pattern is not consistent with the model for an ecotonal species.

Figure 4.13 Eastern bristlebird mean (± se) density at each distance (plot) at each location.
Discussion

The bird populations at Barren Grounds-Budderoo, Jervis Bay and Nadgee showed strong affinities with the vegetation types on either side of heath-wood edges. Odum (1958) suggested, that in terrestrial communities, the concept of edge effect was especially applicable to bird populations. However, in the present study, there was only limited evidence for the traditionally held concept of an edge effect of increased diversity. There was some quantitative support for the response models of ecotone ignorers, exploiters and avoiders. There were no entirely ecotonal species.

Edge effects

When the ecotone was taken as a 50 m wide zone spanning both sides of the heath-wood edge, there was no evidence for greater bird abundance or species richness at the ecotone. Rather, the general pattern was that the ecotone and the wood were similar and they had double the abundance and richness of the heath.

When the ecotone was divided into two 25 m wide zones either side of the edge, there was some evidence for an edge effect. Taking the six plots across the edge, there was an underlying pattern that the abundance and richness for the wood side of the edge were greatest at the ecotone plot and, similarly, the values for the heath side were greatest at the ecotone. This pattern was statistically significant in only one case; bird abundance at the wood side of the ecotone was approximately 67% greater than at the wood plots. This was the strongest piece of evidence in the present study for the traditional dogma of edge effect. The evidence was strengthened by the fact that bird abundance was greater at the wood side of the ecotone than at the other five plots across all of the sites. Abundance at the heath side of the ecotone was approximately 47% greater than at the heath plots but this difference was not statistically significant and the pattern was not consistent across all sites.

This evidence of an edge effect is similar to that reported by Baker et al. (1998) for forest edges adjacent to powerline easements in south-eastern NSW and the possible explanations are the same. (i) At the edge there is greater visibility than in the adjacent woodland and the birds may be easier to detect or they may be attracted to an observer more readily. This explanation could be tested by replacing the observer with a remote sensing technique such as paired, audio or audio-visual recorders. (ii) The wood side of the ecotone may only provide a brief resting place for birds moving between habitats or through the district. For example, in the present study, the New Holland honeyeater was frequently recorded in feeding sallies and aggressive displays which began and ended in
trees at the wood side of the ecotone and the mostly migratory yellow-faced and white-naped honeyeaters were recorded flocking along the heath-wood edges and perching in the trees at the wood side of the ecotone. Also, a feeding pattern noted for some species (e.g., white-throated treecreeper and spotted pardalote) was to move from the wood to the wood side of the ecotone, then along the ecotone and back into the wood again. These are instances of what Soule and Gilpin (1991) described as the "sticky" nature of edges.

(iii) The wood side of the ecotone may really provide habitat for significantly more birds than the wood which is away from the edge. Explanations (ii) and (iii) could be tested by using bird activity budgets to compare the relative value of the wood side of the ecotone to wood habitat away from the edge.

Some useful comparisons can be made to other studies which involved anthropogenic forest edges. At forest-pastoral land edges in KwaZulu-Natal, South Africa, Kruger and Lawes (1997) found no significant difference in bird species richness or diversity between the forest interior and the forest edge, although their raw data showed a modest increase (21%) in bird abundance at the edge. At forest-agricultural land edges in Illinois, central USA, Marini et al. (1995) found no difference in bird species richness and a modest non-significant increase (44%) in abundance at the forest edge compared to the interior. These increases in abundance towards the edge of forests are similar to the 67% increase from the wood to the wood ecotone and the 47% increase from the heath to the heath ecotone in the present study and are evidence of greater "turnover" at the edge (Kruger and Lawes 1997).

Other studies, in which low vegetation analogous to heath meets anthropogenic edges, made poor comparisons with the present study. At moorlands in Scotland, Avery (1989) had adequate data for four species of moorland nesting birds to test the effect of distance from forest plantation edges on bird numbers. The study found no effect of distance for eight distance categories spaced 100-1 500 m from the forest edges which were at least 4 km long. Hence, the study of Avery (1989) was conducted at a scale which was an order of magnitude greater than the present study and the results of the two are not comparable. At central USA cornfields, Best et al. (1990) compared bird diversity within field perimeters to field centres at a similar scale to the present study. They found a huge edge effect with the number of species doubling at the edge and the number of individual birds increasing five-fold over the centre of the cornfield. In the centre of the cornfields there was approximately 10 birds per 100 ha. This low density was very different to the present study in which the heath, although depauperate by comparison with the wood, had approximately 7 birds per ha, which is 70 times the density of the cornfields. This suggests that the processes determining the density of birds in the heath and the cornfields
and at the edges of these different vegetation types is different and that the study of Best et al. (1990) is not comparable with the present study.

Responses of species across heath-wood edges

The models of avian response to ecotones proposed earlier in this chapter were apt to describe the localized distribution patterns of some species in the present study. However, the statistical evidence for associating species with particular models was, in all but five cases, limited to an appraisal of mean densities and variances at six plots. For some of the species, their similarity to any model was limited and their patterns of means and variances suggested that grouping with a particular model was speculative.

Eleven wood specialists were identified. They obviously avoided the heath habitat and overall they showed little evidence of a response to the ecotone as a whole. Most of the wood specialists (8) fitted the model for ecotone ignorer. The one ecotone avoider was found at the ecotone, albeit at a relatively low density. The two ecotone exploiters showed relatively high density only at the wood side of the ecotone and might be better described as exploiters of the wood side of the ecotone. This was best exemplified by the grey fantail (Figure 4.9). Five habitat generalist - ecotone exploiters were identified. Four of these, the variegated fairy-wren, yellow-faced and New Holland honeyeaters and the grey shrike-thrush, similarly would be better described as exploiters of the wood side of the ecotone.

Four heath specialists were identified and all were very clear in their choice of heath habitat. Three showed a response to the ecotone and these were very clearly ecotone avoiders. There were no ecotone exploiters among the heath specialists. Hence, the heath specialists contributed little to avian diversity at the ecotone.

Results from the present study were comparable to those of Sisk and Margules (1993). In both studies, there were considerable proportions of species which ignored or exploited the ecotone, fewer species which avoided the ecotone and some species which were omitted from the categorization (Table 4.3).

Studies of edge effects can also provide examples of bird species which can be categorized by the models of responses across edges. In their analysis of the avifauna at the wet sclerophyll-rainforest ecotone in north-eastern Queensland, Chapman and Harrington (1997) chose some species to show the effect on bird density of encroachment by rainforest. Their results also demonstrated the responses of the species across the ecotone between the two habitat types. The mountain thornbill was a habitat generalist - ecotone ignorer, the golden whistler was a habitat generalist - ecotone exploiter, the eastern yellow robin was a wet sclerophyll specialist - ecotone ignorer and the chowchilla
was a rainforest specialist - edge avoider. For the above-mentioned study of birds on Scottish moors (Avery 1989), four species could be considered moorland specialist - ecotone ignorer.

**Table 4.3** Summary of results compared to Sisk and Margules (1993)

<table>
<thead>
<tr>
<th>Study</th>
<th>Species categorized by their response across an edge</th>
<th>Species categorized/studied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>ecotone ignorer 45%</td>
<td>20/86</td>
</tr>
<tr>
<td></td>
<td>ecotone exploiter 35%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ecotone avoider 20%</td>
<td></td>
</tr>
<tr>
<td>(Sisk and Margules</td>
<td>no response 35%</td>
<td>26/38</td>
</tr>
<tr>
<td>1993)</td>
<td>edge exploiter 54%</td>
<td></td>
</tr>
<tr>
<td>(hard edge)</td>
<td>edge avoider 12%</td>
<td></td>
</tr>
<tr>
<td>(soft edge)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Habitat specialization**

For the populations studied at Barren Grounds-Budderoo, Jervis Bay and Nadgee, the pattern of avifauna on either side of the heath-wood edge was more pronounced than the pattern of response to the ecotone. The diversity of avifauna at the wood was double that of the heath (Table 4.4). This result confirms self-evident observations and is supported by the literature. For example, Whelan and Goldingay (1986) commented that visits by honeyeaters to *Banksia* plants were few in heathland compared to woodland. The average density of 14.2 birds/ha recorded for wood habitats across all sites in the present study was similar to forest bird densities elsewhere in south-eastern NSW. Recher *et al.* (1991) recorded densities of 12 birds/ha at Eden and 18 birds/ha at Bega and Marchant (1992) recorded 13-14 birds/ha at Moruya.

**Table 4.4** Bird diversity: wood compared to heath

<table>
<thead>
<tr>
<th>Diversity measure</th>
<th>wood</th>
<th>heath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance - birds/ha</td>
<td>14.2</td>
<td>7.6</td>
</tr>
<tr>
<td>Richness - average species/ha</td>
<td>7.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Richness - cumulative species /ha</td>
<td>23.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Richness - total species</td>
<td>69</td>
<td>40</td>
</tr>
<tr>
<td>Species recorded at only one habitat</td>
<td>33</td>
<td>11</td>
</tr>
<tr>
<td>Species which are habitat specialist</td>
<td>20</td>
<td>7</td>
</tr>
</tbody>
</table>

In the present study, 20 species were considered to be wood specialists. At the heath habitat, including the heath side of the ecotone, the present study recorded 48 species. Of these, 11 species were detected only at the heath and only seven were considered heath specialists. These results are comparable with sub-tropical heath in south-eastern Queensland where McFarland (1988) recorded a total of 54 species with 15 "consistent"
users. McFarland (1988) considered that, for south-eastern Australia, there was a core of only 6-10 species restricted to the heath. The pattern of these results is in line with the prediction of MacArthur and MacArthur (1961). The wood has more vegetation storeys and a more diverse avifauna than the heath.

**Eastern bristlebird: ecotonal species? No**

Ecotonal species are by definition confined to the ecotone. At heath-wood edges in the present study, the eastern bristlebird was a habitat generalist-ecotone exploiter with twice as many records in the 50 m wide ecotone as in the adjacent wood plus heath. However, the eastern bristlebird was not an entirely ecotonal species. The distinction is important: it broadens the otherwise narrow focus of attention on ecotones and it fits well with other recent impressions of the species' habitat. At Barren Grounds, Bramwell et al. (1992) made 52% of 132 detections in a 40 m wide ecotone with the remaining 48% of detections in the adjacent woodland and heathland. In their study at Jervis Bay, Pyke et al. (1995) did not distinguish ecotone as a habitat but did count eastern bristlebirds in vegetation types ranging through forest, woodland, mallee heath and heath in the ratio 0.3 : 2.1 : 9.7 : 8.9. At Nadgee, Recher (1981) located three eastern bristlebirds in forests, two in near heathland edges.

**Any ecotonal species? None**

None of the potentially ecotonal species investigated at Barren Grounds-Budderoo, Jervis Bay and Nadgee showed strong evidence for being so. The eastern bristlebird has already been discredited as a possible ecotonal species. For eight others, their density patterns across the heath-wood edge are best described by the ecotonal exploiter models. The two honeyeaters, for which there were few records other than at the ecotone, were not ecotonal species. Their distribution patterns were artefacts of small sample sizes or skewing due to large numbers at just a few sites. The habitat descriptions given by Pizzey and Doyle (1980) and Blakers et al. (1984) confirm that both species are associated with a wide range of habitats including wet and dry forests, woodlands and coastal scrubs. Honeyeaters can cause sampling problems (eg Taylor et al. 1997) and the need for sampling adequate to provide a "good picture" has been reviewed by Mac Nally (1997). There are several possible explanations for this contrary result. (i) Ecotonal species occurred but were not detected. This explanation is rejected. Scrutiny of the 50 species recorded but not described or analysed in detail in the present study (Table 4.2) and scrutiny of the extensive species lists for Barren Grounds-Budderoo (Jordan 1987c), Jervis Bay (Anon 1986) and Nadgee (Gosper and Baker 1997) revealed no species likely to occur only at heath-wood ecotones. (ii) The 50 m wide ecotone zone was too narrow.
and 100 m either side of the edge was too close to distinguish ecotonal species. This is theoretically possible. Scale needs to be biologically significant (Paton 1994) and ecotones defined at a fraction of bird territory widths may be problematic (Terborgh 1985). However, to conduct the comparison at a larger scale is difficult at Nadgee and impossible at Barren Grounds-Budderoo and Jervis Bay, because of the natural heterogeneity of the landscape and vegetation. (iii) The 50 m wide ecotone zone was too wide. This explanation is rejected because having a narrower ecotone zone would not promote the detection of any further species nor would it prevent edge exploiting species being detected away from the ecotone. (iv) There are no heath-wood ecotonal species in the bird populations at Barren Grounds-Budderoo, Jervis Bay and Nadgee. This explanation is the most likely.

The failure of the present study to detect any ecotonal species was not surprising. Other studies have failed similarly. McFarland (1988) reported that no species were restricted to the ecotone between wet and dry heathland in south-eastern Queensland. Knopf et al. (1990) vaguely asserted that in western USA, green-tailed towhees showed a "tendency to use vegetative ecotones". Kruger and Lawes (1997) were dismissive of the eight species they found only at the forest edge. Two species were "invasives" from the adjacent grassland, two were forest species, one was a woodland savannah species, one was "typical edge species" but it was also regarded as a forest species and for the remaining two, the pygmy kingfisher and collared sunbird, the authors gave no further details and presumably these species were not ecotonal. For 88 bird species at montane rain forest-cloud forest ecotones in the Andes, Terborgh (1985) found that ecotones limited the distribution of some bird species but the study gave no evidence of any ecotonal species. In north-eastern United States, Able and Noon (1976) found that of approximately 40 bird species, half had their altitudinal limit coinciding with three ecotones, beech/maple-birch/spruce, birch/spruce-balsam fir and the tree line, but they noted no ecotonal species. Laudenslayer and Balda (1976), who tested specifically for ecotonal species (Chapter 1), found none.

In a study of the northern NSW tablelands bird community, Chan (1995) found no ecotonal birds at the riverine-woodland ecotone. Chan (1995) and Ford (1989) used the noisy scrub-bird as an example of ecotonal species, citing the work of G Smith (1985). However, G Smith (1985), while reporting that records of the species were mostly from the ecotone between forest and swamp vegetation, expanded considerably on this description of noisy scrub-bird habitat. The swamp vegetation provides reed and shrub cover for breeding, although this may be narrow (2-5 m) creekbeds or drier drainage lines. The forest, together with heath and thicket vegetation, provide suitable feeding areas. Furthermore, as the noisy scrub-bird population has expanded, the species has
occupied a wider range of habitats (Danks 1998). Hence, the noisy scrub-bird is not an ecotonal species.

Summary

At the heath-wood edges at Barren Grounds-Budderoo, Jervis Bay and Nadgee, the avian diversity of the wood habitat was double that of the heath habitat and there was a strong affinity of species with these habitat types. The heath provided habitat for a number of habitat specialists, including the threatened ground parrot and striated fieldwren and also provided habitat for the eastern bristlebird. There was little evidence for increased avian diversity at the ecotone. Species richness did not increase at the ecotone. At the wood side of the ecotone, there was a moderate but significantly higher abundance of birds and there were six ecotone exploiters species which appeared to be more abundant only at the wood side of the ecotone. The eastern bristlebird appeared to exploit both sides of the ecotone. Almost half of the 22 species analysed were ecotone ignorers. There were three heath specialist - ecotone avoiders and one wood specialist ecotone avoider identified. No heath specialists exploited the ecotone and heath specialists contributed little to diversity at the ecotone. There were no entirely ecotonal species.
## Appendix 4.1

### Study site descriptions

<table>
<thead>
<tr>
<th>Location and site</th>
<th>Vegetation</th>
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</thead>
<tbody>
<tr>
<td>Barren Grounds-Budderoo</td>
<td>Wood: Open forest of <em>Eucalyptus obliqua</em>, <em>E. gummifera</em>, <em>E. cypellocarpa</em> and <em>E. fastigata</em> to 35 m. Understorey 1.6 m (0-4.5 m) of shrubs <em>Acacia longifolia</em>, <em>A. obtusifolia</em>, <em>Goodenia ovata</em> and <em>Banksia spinulosa</em>; ferns <em>Calochaena dubia</em>, <em>Pteridium esculentum</em> and <em>Cyathea australis</em> and <em>Gahnia</em>. Ground cover 0.4 m (0-1.2 m) of litter, ferns and <em>Lomandra longifolia</em>.</td>
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<tr>
<td>AMG: 886 625</td>
<td>Edge: Understorey/taller shrub cover 2.1 m (0.6-4.2 m) of <em>Melaleuca squarrosa</em>, <em>Leptospermum juniperinum</em>, <em>L. lanigerum</em>, <em>Acacia longifolia</em>, <em>A. obtusifolia</em> and <em>Banksia spinulosa</em>. Ground cover 1.0 m (0.1-2.0) of <em>M. squarrosa</em>, <em>L. juniperinum</em>, <em>Gleichenia</em>, <em>Gahnia</em>, <em>Lomandra longifolia</em>, <em>Calochaena dubia</em>, herbs and litter.</td>
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<tr>
<td>Altitude: 590 m</td>
<td>Heath: Closed heathland. Ground cover 0.7 m (0.6-1.8 m) of <em>Gymnoschoenus sphaerocephalus</em>, overgrown masses of herbs eg <em>Leptocarpus tenax</em> and <em>Chorizandra sphaerocephala</em>, and shrubs and the fern <em>Gleichenia</em>. Taller shrub clumps 1.1 m (0.6-1.8 m) of <em>Hakea teretifolia</em>, <em>Baeckea linifolia</em>, <em>B. imbricata</em> and <em>Banksia paludosa</em>.</td>
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</tr>
<tr>
<td>Wood to heath edge aspect: N</td>
<td>Fire-age: 12 years</td>
<td></td>
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<tr>
<td>Site 1</td>
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<tr>
<td>AMG: 895 599</td>
<td>Wood: Woodland and open woodland of <em>Eucalyptus sieberi</em>, and <em>E. gummifera</em> 10-20 m. Understorey 2.6 m (0.3-5 m) of shrubs <em>Acacia terminalis</em>, <em>Leptospermum lanigerum</em>, <em>L. polygalifolium</em>, <em>Hakea teretifolia</em>, <em>Persoonia mollis</em> and <em>Bossiaea kiamensis</em>. Ground cover 0.9 m (0-2.0 m) of shrubs, litter, <em>Gahnia</em>, <em>Gleichenia</em>, herbs and &lt; 5% bare rock.</td>
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<tr>
<td>Altitude: 610 m</td>
<td>Edge: Understorey/taller shrub cover 1.9 m (0.9-4.5 m) of <em>Leptospermum lanigerum</em>, <em>L. polygalifolium</em>, <em>L. squarrosum</em>, <em>Melaleuca squarrosa</em>, <em>Hakea teretifolia</em>, <em>Baeckea linifolia</em>, <em>Banksia paludosa</em>, <em>Gahnia</em>, <em>Sprengelia incarnata</em> and <em>Epacris obtusifolia</em>. Ground cover 1.1 m (0.2-2.0 m) with masses of herbs and shrubs, <em>B. paludosa</em>, <em>Gahnia</em>, <em>Bauera rubioides</em> and <em>L. lanigerum</em>.</td>
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<tr>
<td>Edge aspect: NE</td>
<td>Heath: Closed heathland and sedgeland. Ground cover 0.8 m (0.3-1.4 m) of <em>Gleichenia</em>, <em>Gymnoschoenus sphaerocephalus</em>, masses of herbs and small shrubs particularly monocots, <em>Epacris</em> and <em>Bauera rubioides</em>. Taller shrub clumps 1.4 m (1.0-2.1 m) of <em>Baeckea linifolia</em>, <em>Leptospermum juniperinum</em> and <em>L. lanigerum</em>.</td>
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<tr>
<td>Site 2</td>
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<tr>
<td>AMG: 883 621</td>
<td>Wood: Woodland to open forest 15-35 m with <em>Eucalyptus cypellocarpa</em>, <em>E. obliqua</em>, and <em>E. piperita</em>. Understorey 1.7 m (0-4.5 m) of shrubs <em>Acacia longifolia</em>, Goodenia ovata, <em>Banksia spinulosa</em> and <em>Leptospermum polygalifolium</em> ferns <em>Calochaena dubia</em>, <em>Pteridium esculentum</em> and <em>Cyathea australis</em> and <em>Gahnia</em>. Ground cover 0.6 m (0-2.0 m) of <em>Gleichenia</em>, shrubs, herbs and litter, <em>Gahnia</em>, <em>M. squarrosa</em>, <em>B. paludosa</em> and <em>Gymnoschoenus sphaerocephalus</em>.</td>
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<tr>
<td>Altitude: 580 m</td>
<td>Edge: Understorey/taller shrub cover 1.5 m (0.3-3.6 m) <em>Leptospermum polygalifolium</em>, <em>Baeckea linifolia</em>, <em>Acacia terminalis</em>, <em>A. longifolia</em>, <em>Melaleuca squarrosa</em>, <em>Banksia paludosa</em>, <em>Eucalyptus dendromorpha</em> mallee, <em>Allocasuarina paludosa</em> and <em>Gleichenia</em>. Ground cover 0.6 m (0-2.0 m) of <em>Gleichenia</em>, shrubs, herbs and litter, <em>Gahnia</em>, <em>M. squarrosa</em>, <em>B. paludosa</em> and <em>Gymnoschoenus sphaerocephalus</em>.</td>
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<tr>
<td>Edge aspect: SE</td>
<td>Heath: Closed heathland and sedgeland. Ground cover 0.5 m (0.1-1.2 m) of <em>Gymnoschoenus sphaerocephalus</em>, overgrown masses of herbs eg <em>Lepidosperma laterale</em> and <em>Chorizandra sphaerocephala</em>, and shrubs and the fern <em>Gleichenia</em>. Taller shrub clumps 1.0 m (0.2-2.0 m) of <em>Baeckea linifolia</em>, <em>Leptospermum juniperinum</em>, <em>Allocasuarina paludosa</em> and <em>Banksia paludosa</em>.</td>
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<tr>
<td>Fire-age: 12 years</td>
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</table>
Chapter 4 Birds across heath-wood edges

Site 4
AMG: 878 626
Altitude: 590 m
Edge aspect: N
Fire-age: 12 years

Wood: Woodland and open woodland of *Eucalyptus gummifera*, and *E. sieberi* to 20 m. Understorey 1.3 m (0.3-2.3 m) of shrubs *Leptospermum lanigerum*, *Hakea dactyloides*, *H. teretifolia*, *Baeckea linifolia*, *Banksia paludosa* and *Acacia obtusifolia*. Ground cover 0.6 m (0.1-1.3 m) of shrubs, *Gleichenia*, litter, herbs and club moss *Selaginella uliginosa*.

Edge: Understorey/taller shrub cover 1.6 m (0.3-4.5 m) of *Allocasuarina paludosa*, *Leptospermum lanigerum*, *Hakea dactyloides*, *Eucalyptus gummifera* and *E. sieberi* saplings, *Acacia obtusifolia* and *Banksia paludosa*. Ground cover 0.7 m (0.1-1.5 m) of herbs and shrubs, *B. paludosa*, *A. paludosa*, *Gleichenia*, *H. dactyloides*, *Leptospermum lanigerum* and *Baeckea imbricata*.

Heath: Closed heathland. Ground cover 0.5 m (0.3-0.8 m) of small shrubs, *Gleichenia* and herbs. Taller shrub clumps 0.9 m (0.4-1.5 m) of *Allocasuarina paludosa*, *Baeckea imbricata*, *B. linifolia*, *Banksia paludosa*, *Hakea dactyloides* and *H. teretifolia*.

Jervis Bay
150°42′, 35°11′
Map: Sussex Inlet 9027-4-S

Site 1
AMG: 950 084
Altitude: 40 m
Wood to heath edge aspect: SE
Fire-age: heath patchy 3 and 9 years and wood 12 years

Wood: Woodland of *Eucalyptus sclerophylla*, *E. gummifera* to 15 m. Understorey 2.3 m (0.7-5.5 m) *Banksia ericifolia*, *B. serrata*, *Leptomeria acida*, *Woolssia pungens*, *Leptospermum* and *Acacia*. Ground cover 0.7 m (0.1-1.3 m) *W. pungens*, litter, shrubs, herbs and *Pteridium esculentum*.

Edge: Understorey/taller shrub cover 2.7 m (0.3-6.0 m) of *Eucalyptus sclerophylla*, *E. gummifera*, *Hakea teretifolia*, *Allocasuarina distyla*, *Banksia ericifolia*, *Darwinia leptantha* and *Leptospermum trinervium*. Ground cover 0.8 m (0.1-2.5 m) of shrubs, herbs and litter with *H. teretifolia*, *B. ericifolia* and *D. leptantha*.

Heath: Closed *Banksia ericifolia* heathland, heathland and *Eucalyptus gummifera* mallee. Ground cover 0.6 m (0.1-1.7 m) of sticks, shrubs and herbs including *Xanthorrhoea*, *Sprengelia incarnata*, *Darwinia leptantha* and *Empodisma minus*. Taller shrub clumps 1.4 m (0.3-4.8 m) *B. ericifolia*, *Allocasuarina distyla*, *Leptospermum trinervium*, *L. juniperinum*, *E. gummifera* and *Hakea teretifolia*.

Site 2
AMG: 931 085
Altitude: 40 m
Edge aspect: NW
Fire-age: 16 years

Wood: Forest of *Eucalyptus gummifera*, *E. pilularis* and *E. botryoides* 25-30 m. Understorey 2.7 m (0.7-6.0 m) *Banksia serrata*, *Pteridium esculentum*, *Leptomeria acida* and *Persoonia*. Ground cover 0.3 m (0.1-1.2 m) litter, shrubs herbs including the grass *Imperata cylindrica* and *Xanthorrhoea*.

Edge: Understorey/taller shrub cover 2.0 m (0.1-6.0 m) *Banksia serrata*, *B. ericifolia*, *Leptospermum juniperinum*, *Acacia suaveolens*, *Epacris obtusifolia*, *Woolssia pungens* and *Sprengelia incarnata*. Ground cover 0.6 m (0.1-1.2 m) *Gleichenia*, litter and herbs, *W. pungens*, *Leptomeria acida*, *B. ericifolia* and *Xanthorrhoea*.

Heath: Closed wet heathland and sedgeland. Ground cover 0.8 m (0.3-1.3 m) *Gymnoschoenus sphaerocephalus*, *Gleichenia*, *Sprengelia incarnata*, *Gahnia* and overgrown with herbs. Taller shrub clumps 1.4 m (0.8-2.4 m) *Leptospermum juniperinum*, *Banksia ericifolia*, *Baeckea linifolia* and *Callistemon citrinus*.
Chapter 4 Birds across heath-wood edges

Site 3
AMG: 897 106
Altitude: 10 m
Edge aspect: E
Fire age: ≥ 15 years and some ≥ 24 years

Wood: Forest of *Eucalyptus pilularis* and *E. gummifera* to 35 m. Understorey 2.5 m (0.3-6.0 m) *Banksia serrata*, *Zieria arborescens*, *Acacia suaveolens*, *Persoonia linearis* small trees, eg *Ceratopetalum gummiferum* and *Elaeocarpus reticulatus* and *Pteridium esculentum*. Ground cover 0.4 m (0-1.1 m) of litter, shrubs, *Podocarpus elatus*, *Lomandra longifolia*, herbs and *Cissus hypoglauca*.

Edge: Understorey/taller shrub cover 2.3 m (0.6-6.0 m) of *Banksia ericifolia*, *B. serrata*, *Melaleuca squarrosa*, *Acacia suaveolens* and *Leptospermum truncatum*. Ground cover 0.8 m (0.1-1.2 m) of *Gleichenia*, *Restio tetraphyllum*, litter and shrubs, *Gymnoschoenus sphaerocephalus*, *Gahnia* and *Goodenia heterophylla*.

Heath: Closed sedgeland and wet heathland. Ground cover 0.7 m (0.2-1.9 m) overgrown mass of herbs, eg *Empodisma minus*, *Gymnoschoenus sphaerocephalus*, *Lepidosperma forsythii*, *Chorizandra sphaerocephala* and *Gahnia*, shrubs and *Gleichenia*. Taller shrub clumps 1.2 m (0.6-2.3 m) *Sprengelia incarnata*, *Banksia ericifolia*, *Leptospermum juniperinum*, *Callistemon citrinus* and *Hakea teretifolia*.

Site 4
AMG: 916 075
Altitude: 70 m
Edge aspect: NW
Fire age: heath mostly 7 years, wood ≥ 24 years

Wood: Open forest of *Eucalyptus pilularis*, *Syncarpia glomulifera* and *E. gummifera* to 25 m. Understorey 2.2 m (0.4-6.0 m) of *Banksia serrata*, *Acacia longifolia*, *Ceratopetalum gummiferum*, *Pteridium esculentum*, *Calochaena dubia* and scattered shrubs, eg *Leucopogon lanceolatus*. Ground cover 0.4 m (0.1-2.0 m) of litter and herbs, eg *Imperata cylindrica*, and in wetter parts, *Gahnia* and *Causcis flexuosa*.

Edge: Understorey/taller shrub cover 2.0 m (0.8-6.0 m) of *Hakea teretifolia*, *Banksia ericifolia*, *Eucalyptus sclerophylla*, *E. gummifera*, *Darwinia leptantha* and *Sprengelia incarnata*. Ground cover 1.2 m (0.3-2.1 m) of *B. ericifolia*, *S. incarnata*, *H. teretifolia*, *Gahnia*, *Lepidosperma forsythii*, *Restio fastigiatus*, *Xanthorrhoea* and *Gleichenia*.

Heath: Closed heathland with patches of heathland and *Eucalyptus gummifera* mallee. Ground cover 0.6 m (0.2-1.2 m) *Banksia ericifolia*, *Xanthorrhoea* and *Sprengelia incarnata*. Taller shrub clumps 1.0 m (0.6-2.5 m) *B. ericifolia*, *Hakea teretifolia*, *Darwinia leptantha*, *E. gummifera* and *Sprengelia incarnata*.

Nadgee
149°57', 37°26'
Map: Nadgee 8823-2-S

Site 1
AMG: 610 540
Altitude: 40 m
Wood to heath edge aspect: E
Fire age: 16 years

Wood: Open forest of *Eucalyptus sieberi*, *E. gummifera*, *Angophora floribunda* and *E. baxteri* 5-20 m. Understorey 3.0 m (0.2-6.0 m) *Banksia serrata*, *B. integrifolia*, *Pteridium esculentum* and *Acacia terminalis*. Ground cover 0.3 m (0.1-1.8 m) herbs, eg *Causcis flexuosa*, litter and shrubs, eg *Pultenaea scabra*, *Platylobium formosum* and *Correa reflexa*.

Edge: Understorey/taller shrub cover 1.3 m (0.3-4.0 m) of *Allocasuarina paludosa*, *Leptospermum attenuatum*, *L. juniperinum*, *Banksia serrata*, *Hakea ulicina*, *Correa reflexa* and *Pultenaea daphnoides*. Ground cover 0.6 m (0.1-1.2 m) of *A. paludosa*, herbs, shrubs and *Pteridium esculentum*.

Heath: Closed heathland. Ground cover 0.5 m (0.1-1.0 m) *Allocasuarina paludosa*, *Hakea ulicina*, *Banksia serrata*, *Darwinia campylostylis* and herbs. Taller shrub clumps 0.7 m (0.2-1.2 m) *Allocasuarina paludosa*, *Hakea ulicina* and *Banksia serrata*.
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<th>AMG: 620 512</th>
<th>Altitude: 30 m</th>
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<td>Wood:</td>
<td>Open forest of <em>Eucalyptus sieberi</em>, <em>E. gummifera</em> and <em>Angophora floribunda</em> 20 m. Understorey 2.2 m (0-6.0 m) <em>Hakea sericea</em>, <em>Allocasuarina littoralis</em>, <em>Banksia integrifolia</em>, <em>Pteridium esculentum</em> and <em>Acacia longifolia</em>. Ground cover 0.1 m (0-0.3 m) herbs, litter and shrubs, eg <em>Platyllobium formosum</em>.</td>
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<td>Edge:</td>
<td>Understorey/taller shrub cover 2.4 m (0-6.0 m) of <em>Hakea sericea</em>, <em>H. ulicina</em>, <em>Allocasuarina littoralis</em>, <em>Leptospermum attenuatum</em> and <em>Banksia cunninghamii</em>. Ground cover 0.3 m (0-0.7 m) of herbs, litter, <em>H. ulicina</em>, <em>Allocasuarina paludosa</em> and <em>Epacris impressa</em>.</td>
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<td>Heath:</td>
<td>Closed heathland. Ground cover 0.4 m (0.1-0.8 m) <em>Allocasuarina paludosa</em>, <em>Hakea ulicina</em>, <em>H. teretifolia</em> other small shrubs and herbs. Taller shrub clumps 0.7 m (0.4-2.0 m) <em>Hakea ulicina</em>, <em>Allocasuarina paludosa</em> and <em>Leptospermum juniperinum</em>.</td>
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<th>Edge aspect: NE</th>
<th>Fire-age: parts 16 years and ≥ 24 years</th>
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<td>Wood:</td>
<td>Open forest of <em>Eucalyptus sieberi</em>, <em>E. gummifera</em>, and <em>Angophora floribunda</em> 10-20 m. Understorey 1.6 m (0-6.0 m) <em>Platyllobium formosum</em>, <em>Pomaderris</em>, <em>Banksia cunninghamii</em>, <em>Hakea sericea</em> and <em>Acacia terminalis</em>. Ground cover 0.2 m (0-0.8 m) herbs, litter and <em>Pteridium esculentum</em>.</td>
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<td>Edge:</td>
<td>Understorey/taller shrub cover 1.1 m (0-3.0 m) of <em>Hakea ulicina</em>, <em>H. sericea</em>, <em>Allocasuarina paludosa</em>, <em>Leptospermum attenuatum</em> and <em>Spyridium parvifolium</em>. Ground cover 0.3 m (0-1.5 m) herbs, <em>H. sericea</em>, <em>H. ulicina</em>, <em>L. attenuatum</em> and <em>Pteridium esculentum</em>.</td>
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<td>Heath:</td>
<td>Closed heathland. Ground cover 0.4 m (0.1-0.8 m) <em>Allocasuarina paludosa</em>, <em>Boronia muelleri</em>, <em>Hakea ulicina</em>, <em>H. teretifolia</em> other small shrubs and herbs. Taller shrub clumps 0.6 m (0.3-1.2 m) <em>Allocasuarina paludosa</em>, <em>Hakea ulicina</em>, <em>H. teretifolia</em> and <em>B. muelleri</em>.</td>
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</table>
Chapter 5

Eastern bristlebird habitat and vegetation structure across heath-wood edges

plant community ecologists attempt to find order in the apparent chaos of the vegetable world (Fox and Recher 1986)

Introduction

Plants occupy a basic position in terrestrial ecosystems as producers and because they provide a covering over much of the land. Hence, it is natural to define terrestrial habitats using vegetation characteristics (Kikkawa 1968). However, the extent to which vegetation communities determine the pattern of bird community structure is a matter of debate (Keast 1985). The theory of spatial heterogeneity predicts that more complex plant community structure gives a greater diversity of animals (Recher 1971) and supports the view that bird communities are tightly structured (Keast 1985) with vegetation structural components (eg canopy or forest floor) attracting particular guilds of bird species. The alternative view is that populations of individual bird species occur where they can and that bird communities are not tightly structured (Kikkawa 1982; Keast 1985).

Part of the plant-bird community debate is the question of the relative importance of vegetation structure versus floristics, in determining bird community structure. Vegetation structural diversity occurs in the vertical as well as the horizontal planes and bird diversity is likely to be partly determined by the amount of sharing and resource partitioning in both planes. MacArthur and MacArthur (1961) concluded that the bird community of a deciduous forest could be predicted by the foliage height profile of the vegetation. This has often been broadly interpreted to mean that the structural diversity of a plant community is the determinant of its bird diversity and this interpretation is supported by numerous studies (eg MacArthur et al. 1966; Breedy 1981; James and Warner 1982). Generally, however, support for this interpretation has been qualified, with many studies (eg Robinson and Holmes 1984; Shields et al. 1985; Holmes and Recher 1986; Arnold 1988) recognizing that bird diversity is influenced by both structural and floristic parameters.

Interpretation of plant-bird community studies may be complicated by scale or by sampling techniques. For instance, Wiens and Rotenberry (1981) found that the occurrence of shrubsteppe bird species was strongly correlated with vegetation structure at a continental scale and with floristics at a regional scale. Taylor et al. (1984) found that, at a local scale, variation in fauna (including birds) was best explained by vegetation structure if sampling was random-stratified and by floristics if sampling was systematic.
The need to understand individual species is fundamental to ecology (Andrewartha and Birch 1954; Southwood 1977) and, like whole bird communities, the constituent species are likely to be influenced by the vegetation structure and floristics of their habitat. For example, Bell (1985) found that three sympatric thornbills showed vertical resource partitioning by feeding on the ground, in shrub foliage and in tree foliage. Wyndham and Cannon (1985) reported that, where rosellas and lorikeets co-exist, resource partitioning was partially achieved by utilizing different layers of vegetation.

Understanding pattern and process in heterogeneous landscapes requires detailed knowledge of the populations and individuals (Wiens et al. 1985). For threatened terrestrial bird populations, conservation of particular structural and floristic elements of the vegetation is likely to be of critical importance. For example, the regent honeyeater has a strong preference for feeding at the nectaries of a limited number of eucalypt species, particularly box-ironbark, and several species of mistletoe (Christie 1997). Masked owls require old, hollow trees for nesting and roosting (Kavanagh 1996). For the western whipbird, the preferred habitat is a two layered thicket of vegetation 2-3 m high with low dense heath for nesting (Smith 1991). The vegetation characteristics of habitats that are occupied by the eastern bristlebird have not been described in detail except for the few, small northern populations which were described by Holmes (1989) and Lamb et al. (1993). A purpose of the present study was to redress this paucity of habitat information because of its importance to management decisions which affect the conservation of the species.

Adequate "cover" is often cited as an important habitat factor for terrestrial birds. Cover-dependent understorey species are likely to be adversely affected by forest fragmentation because of direct loss of habitat and through edge effects (Newmark 1991; Baker et al. 1998). In farming landscapes, well-developed shrub understoreys provide cover for small passerines in fragments of native vegetation (Ford and Bell 1982) and corridors (Lynch and Saunders 1991). Cover is particularly important for terrestrial birds of cursorial habit. There are numerous examples from Australia: the rufous scrub-bird (Ferrier 1985), western whipbird (Smith 1991) and ground parrot (Bryant 1994); and elsewhere: sage grouse (Musil and Reese 1994), ring-necked pheasant (Riley et al. 1994), California black rail (Flores and Eddleman 1995) and the gray partridge (Carroll et al. 1995).

All three bristlebird species are associated with dense vegetation (Smith 1977; Pizzey and Doyle 1980). This and the furtive behaviour of the eastern bristlebird at Barren Grounds suggested to me that layers of vegetation cover were an important habitat feature for the species. Another purpose of the present study was to test this hypothesis.
Ecotones were introduced in detail in Chapter 1 and the influence of heath-wood ecotones on bird diversity was investigated in Chapter 4. Briefly, an ecotone is a zone of transition between adjacent ecological systems which is typically distinguished by its vegetation patterns (Risser 1993). In theory, ecotones occur at the levels of the individual plant, plant population, patch, landscape and biome (Gosz 1993). Ecotones have some of the structural characteristics of both adjacent habitats as well as distinctive microhabitats found only in the ecotonal zone (Risser 1995). The present chapter is concerned with ecotones at the local level of plant populations and microhabitats.

The review of ecotones by Murcia (1995) indicated a trend of reduced tree canopy cover and increased understorey cover at forest ecotones. However, the findings for understorey cover are equivocal. In Panamanian tropical wet forest where small (5-20 ha) clearings were used for agriculture and grazing, Williams-Linera (1990) found that there was no significant difference in the percentage cover of low plants (< 2 m) with distance into the forest from the edge. In Pennsylvania-Delaware, USA, at edges between anthropogenic clearing and oak-chestnut forest, Matlack (1993) found that the edge effect of increased shrub cover, ≤ 40 m into the forest, was significant at only four out of six sites where clearing occurred < 5 years previously and at none of the four sites where clearing occurred ≥ 14 years previously.

The heath-wood ecotones at Barren Grounds-Budderoo and Jervis Bay are examples of what Gosz (1991) called the "traditional view" of ecotones because there is a relatively abrupt change between the two vegetation communities. The results presented in Chapter 4 indicate that the eastern bristlebird fits the model for a species which exploits the heath-wood ecotone. The question arises: Is there something special about the vegetation structure at the heath-wood ecotone which the eastern bristlebird is exploiting?

**Aims**

The aims of this chapter are (i) to describe the vegetation community characteristics of eastern bristlebird habitat, (ii) to characterize the layers of vegetation cover in eastern bristlebird habitat at Barren Grounds and (iii) to investigate the structure of eastern bristlebird habitat across heath-wood edges at Barren Grounds-Budderoo and Jervis Bay.
Chapter 5 Eastern bristlebird habitat and vegetation structure across heath-wood edges

Methods

(i) Vegetation community characteristics of eastern bristlebird habitat

All three regions where the eastern bristlebird occurs, south-eastern Queensland/north-eastern NSW, Illawarra-Shoalhaven and south-eastern NSW/north-eastern Victoria (Chapter 2), were visited at various times during 1992-7. Where eastern bristlebirds were located, the vegetation communities within approximately 50 m of the site were noted. These notes were supplemented by reference to the historic and recent literature. Details of the location and the vegetation microhabitat of eastern bristlebird nest sites were also summarized from the literature.

At Barren Grounds, a detailed study of the vegetation formation and floristics of eastern bristlebird habitat was undertaken during spring 1994. Fifty (50) survey sites along approximately 20 km of trails (as shown in Figure 3.2), were chosen as follows. During January-April 1992 and January-February 1994 the locations of all eastern bristlebird detections within 100 m of trails were mapped at a scale of 1 : 10 000. Fifty metre circles, as many as possible, were manually drawn to include at least two of the mapped eastern bristlebird locations. Eighty-four of the circles were not crossed by a trail and were separated by at least 100 m. Fifty of these were chosen at random as the survey sites. The vegetation structural formations occurring at each site were noted using the system of Walker and Hopkins (1984) simplified to include growth forms of tree, mallee, shrub (≥ 2 m) and heath (shrubs < 2 m and herbaceous vegetation) and crown separations of closed, mid-dense, sparse and isolated clumps. The floristics at each site were sampled along a 50 m transect located alternately north-south and east-west. At ten points, spaced at 5 m intervals along the transect, a vertical 16 mm diameter stick was used to record all plant species touching at height classes of ground cover (≤ 0.25 m), low cover (0.25-1.0 m) and tall shrub cover (≥ 1 m). Although the categorization of heights of the vegetation layers is a construct of the observer (MacArthur and MacArthur 1961), the height classes chosen for the present study were considered to be appropriate for the vegetation and the behaviour of the eastern bristlebird. All fine dead material and unidentifiable herbaceous stems were scored as "litter". Eastern bristlebird habitat was described by the abundance of individual plant species (% occurrence at the 50 sites) and the cover contributed by individual plant species (% occurrence at the 500 sample points).

The methods of measuring vegetation structure and plant species abundance and cover in the present study were adapted from the point-frequency intercept method often used in grassland and other low herbaceous vegetation (Smith 1990). The use of a "stick" rather
than a "pin" was more practicable in the dense eastern bristlebird habitat at Barren Grounds, where a pin would be difficult to see without disturbing the vegetation. The stick method has been used successfully to quantify vegetation structure of coastal heath in Victoria (Braithwaite and Gullan 1978). The stick-frequency intercept method also has the advantage of being objective and systematic without the complications and constraints associated with using a light meter (eg Fox 1979; Keith and Myerscough 1993).

(ii) Cover in eastern bristlebird habitat at Barren Grounds

During January-April 1992, all parts of approximately 20 km of trails at Barren Grounds were walked at least four times. The exact (± 1 m) locations (n = 130) of eastern bristlebirds were detected either by direct sightings or from their persistent calling. These locations were called "birded" sites. Birds seen on the trails were not counted, birded sites were ≥ 25 m apart and within 100 m of the trail. The distance of birded sites from the trail was estimated. All eastern bristlebird detections, including birded sites, were mapped at a scale of 1 : 10 000 and the lengths of trail which were bird-free for more than 100 m were highlighted. "Non-birded" sites were placed at 50 m intervals, alternately to the left and right of the trail in the bird-free areas (Figure 5.1a). The distance of each non-birded site from the trail was determined by a randomly allocated birded site distance. Some of the bird-free parts were revised and some non-birded sites were deleted because eastern bristlebirds were detected when the vegetation was being measured at non-birded sites. This gave 130 non-birded sites, after one was deleted at random for the convenience of statistical analysis.

At each of the birded and non-birded sites, the vegetation cover was scored (after Walker and Hopkins 1984) at nine, 1 m² quadrats. The quadrats were at the centre of the site and 2 m and 4 m to the north, east, south and west (Figure 5.1b). Each quadrat was scored for the presence (1) or absence (0) of vegetation at the three height-classes of ground cover, low cover and tall shrub cover (Table 5.1). Woody stems can contribute more cover than typical ericoid leaves (Fox 1979), hence their presence was also scored. Patchiness, caused by interactions between drainage, soil and bedrock, is a feature of the vegetation at Barren Grounds (Burrough et al. 1977) and hence the vegetation cover was not expected to be uniform at each site.

For each site, the number of quadrats (out of 9) with all three layers of cover was calculated. The proportion of birded and non-birded sites for which most of the site (defined as 7 or more quadrats) had all three layers, was calculated. The large sample sizes of 130 made it safe to assume that these sample proportions were close to the true proportions and that they were approximately normally distributed (K Russell pers.)
The true proportion of birded sites for which most of the site had all three layers of cover was called $p_B$ and the proportion of non-birded sites with this characteristic was called $p_N$. Using the standard test for the equality of two proportions (Zar 1984), the null hypothesis $H_0: p_B = p_N$ was tested against the one-sided alternative hypothesis $H_1: p_B > p_N$. Using the sample proportions of the birded sites with the characteristic layers of cover, 99% confidence intervals for the true proportions of birded sites with that characteristic were calculated using the conservative method described in Conover (1980).

(a) Survey trail

(b) Survey quadrats

Figure 5.1 (a) Part of the survey trail showing birded sites ⋆, other eastern bristlebird locations ★ and non-birded sites ■. (b) Arrangement of 1 m² quadrats for scoring vegetation cover at birded and non-birded sites.

Table 5.1 Vegetation height classes in eastern bristlebird habitat

<table>
<thead>
<tr>
<th>Class</th>
<th>Height (m)</th>
<th>Vegetation classification of Walker and Hopkins (1984)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>fern/herb</td>
</tr>
<tr>
<td>1</td>
<td>0-0.25</td>
<td>low</td>
</tr>
<tr>
<td>2</td>
<td>0.26-0.5</td>
<td>mid-high</td>
</tr>
<tr>
<td>3</td>
<td>0.5-1.0</td>
<td>tall</td>
</tr>
<tr>
<td>4</td>
<td>1.01-3</td>
<td>very tall</td>
</tr>
<tr>
<td>5</td>
<td>3.01-6</td>
<td>extremely tall</td>
</tr>
</tbody>
</table>
(iii) Vegetation structure across heath-wood edges

Four sites at each of Barren Grounds-Budderoo and Jervis Bay were selected to investigate the structure of eastern bristlebird habitat across heath-wood edges. The sites were the same as those used to study birds across heath-wood edges in Chapter 4 and the site attributes are summarized in Appendix 4.1. The sites were chosen because they had distinct, relatively straight heath edges at least 600 m long dividing relatively large, homogenous areas of vegetation extending for at least 200 m each side of the edge and because of the presence of eastern bristlebirds.

Vegetation surveys were conducted between December 1997 and April 1998. At each site, four contiguous plots 25 m × 400 m were marked on each side of the edge (Figure 5.2a). At the ecotone, in each of the heath ecotone and wood ecotone plots, there were 30 randomly located 2 m × 2 m quadrats and in each of the remaining six plots, 10 random quadrats. At each quadrat, ten sample points were located systematically (Figure 5.2b). At each point, a vertical 16 mm diameter stick was used to record presence or absence of vegetation touching at 14 height classes (Table 5.2). At each quadrat, the cover value at each height class was taken as the sum of the ten sample points.

Figure 5.2 Survey design - vegetation structure across heath-wood edges (a) One site showing the eight 25 m × 400 m survey plots (b) Survey 2 m × 2 m quadrat showing systematic arrangement of ten sample points (○)
Chapter 5 Eastern bristlebird habitat and vegetation structure across heath-wood edges

Table 5.2 Vegetation structural height classes across heath-wood edges

<table>
<thead>
<tr>
<th>Class</th>
<th>Height</th>
<th>Class</th>
<th>Height</th>
<th>Class</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-0.1 m</td>
<td>6</td>
<td>0.501-0.6 m</td>
<td>11</td>
<td>1.001-1.5 m</td>
</tr>
<tr>
<td>2</td>
<td>0.101-0.2 m</td>
<td>7</td>
<td>0.601-0.7 m</td>
<td>12</td>
<td>1.501-2 m</td>
</tr>
<tr>
<td>3</td>
<td>0.201-0.3 m</td>
<td>8</td>
<td>0.701-0.8 m</td>
<td>13</td>
<td>2.001-3 m</td>
</tr>
<tr>
<td>4</td>
<td>0.301-0.4 m</td>
<td>9</td>
<td>0.801-0.9 m</td>
<td>14</td>
<td>&gt; 3 m</td>
</tr>
<tr>
<td>5</td>
<td>0.401-0.5 m</td>
<td>10</td>
<td>0.901-1.0 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Multivariate analysis allows objective simplification of a large number of entities of interest (objects) for which there is an array of information (attributes) (Clifford 1975; Boesch 1977). The raw data for the vegetation structure at each site were the cover values at each of the 14 height classes (attributes) for each of the 120 quadrats (objects). These data were analysed by multivariate techniques using the PRIMER (Carr 1996) software package. For each site, an association matrix was calculated using the Bray-Curtis (Bray and Curtis 1957) index of similarity with unstandardized, untransformed data. Cluster analysis using group averaging of the association matrix was performed to produce a dendrogram which showed clusters of similar quadrats. Ordination was performed using non-metric multidimensional scaling (MDS) (Kruskal and Wish 1978) in two dimensions. The clusters of similar quadrats from the dendrogram were superimposed on the ordination and the resulting pattern was considered.

The "average" vegetation structure value was compared across all sites using multivariate analysis. The attributes were again the 14 height classes. In this case, the 32 objects were the 4 distance categories (wood, wood ecotone, heath ecotone and heath) at each of the 8 sites. At each site the attributes of the wood were the average of the 30 quadrats in the 25-50 m, 50-75 m and 75-100 m plots; the attributes of the wood ecotone were the average of the 30 quadrats in the 25-0 m plot and so on for the heath ecotone and the heath. Cluster and ordination analyses were performed and displayed as described for each site and the resulting patterns were noted.

Hypotheses about the vegetation structure across heath-wood edges were tested using analysis of similarity (ANOSIM). ANOSIM is a non-parametric test which utilizes a permutation procedure (Monte Carlo) applied to the rank similarity matrix to calculate the sample statistic, called the "Global R". It is the multivariate analogue of the univariate F in an ANOVA (Clarke and Warwick 1994). A two-way crossed ANOSIM was used with factors of location (Barren Grounds-Budderoo and Jervis Bay) and distance relative to the edge (wood, wood ecotone, heath ecotone and heath) and using 1 000 permutations for the calculations of the Global R. Where pairwise tests were made, appropriate caution was exercised in interpreting the results because there is no ANOSIM analogue to the
multiple comparison tests of ANOVA which control for experimentwise error rates (Clarke and Warwick 1994).

The features of the vegetation structure which contributed most to the similarity within each distance group and the difference between each pair of distance groups was described by the SIMPER program. This program calculates the contribution of each attribute to the Bray-Curtis similarity coefficients for a group of objects and the contribution of each attribute to the dissimilarity measure between two groups (Carr 1996).

Results

Eastern bristlebird habitat - vegetation community characteristics

Eastern bristlebirds were recorded in many vegetation types ranging from rainforest to dry forest, woodland, mallee, scrub, riparian, swamp, heathland and sedgeland.

Early records of eastern bristlebird habitat were brief but instructive. They all (Gould 1865; North 1898; White 1915; Le Souef and Macpherson 1920; Favaloro 1931; Marshall 1939; McNamara 1946; Robertson 1946; Goddard 1948; Chaffer 1954) described dense low vegetation usually in wet locations using the following descriptors: scrub, reedbed, creek, swamp, gully, thicket, stunted tea-tree in marsh, creeper, matted fern, long grass, tussock, sword grass, button grass, grass-tree, stunted shrub and eucalypt, low shrub, tall shrub, mallee, timbered swamp, well timbered with dense undergrowth. Altogether, it was "rank vegetation" (Gould 1865) which was too luxuriantly overgrown for humans to negotiate comfortably.

The results of the present study and other recent studies, allow eastern bristlebird habitat to be categorized into a wide range of vegetation communities, all of which may have dense low vegetation (Table 5.3). The literature indicates that, spanning the northern, central and southern populations, nesting sites are characterized by tufts of low, dense, fine and/or blady herbaceous vegetation. Nests are hidden within a metre of the ground and woven from fine herbaceous material (Table 5.4). The nests described as utilizing "grass" probably included fine sedges such as the common species Leptocarpus tenax.

The detailed study of eastern bristlebird habitat at 50 sites at Barren Grounds showed that eleven vegetation formations were present (Table 5.5). The most common formations were closed heathland and closed shrubland, which were present at 74% of the sites.
Heterogeneity is a feature of the habitat with 82% of the sites having more than one structural type present. Most of the sites (94%) were associated with heath or shrub vegetation and many sites (68%) had trees either as mallee, isolated trees and/or a woodland. The overall ground cover was 91% consisting mostly of herbs, coral ferns and litter. The overall low cover was 92% and generally consisted of a tangle of herbs, coral ferns, litter and/or small shrubs. The overall tall shrub cover was 74% which generally consisted of larger shrubs but also included mallee and tree cover. At some points there was a clear distinction between the three vegetation layers and at other points the tangled mass of vegetation extended from the ground to above one or two metres.

The detailed study of the floristics of eastern bristlebird habitat at 50 sites at Barren Grounds identified 97 plant species from 29 Families (Appendix 5.1). The most abundant plants were the coral ferns *Gleichenia* spp.; the herbs *Empodisma minus*, *Leptocarpus tenax*, *Lepyrodia scariosa* and *Actinotus minor*; the finely branched shrubs of *Epacris* spp. and *Baeckea linifolia*; stout shrubs of *Banksia paludosa*, *B. ericifolia*, *Dillwynia floribunda* and *Leptospermum* spp.; *Eucalyptus dendromorpha* mallee and mostly low *E. sieberi* trees. The high species richness recorded in the present study was similar to the findings of Wall (1989), who recorded 83 heathland species in 47 quadrats each 4 m × 4 m at Barren Grounds, and Brewer (1995), who recorded 110 heathland and woodland species in 84 quadrats each 9.1 m × 0.9 m near Ku-ring-gai Chase (150 km north of Barren Grounds). Understandably, the richness was considerably less than the 171 species recorded in the very detailed heathland study of Keith and Myerscough (1993) in which 3 600 quadrats, each 0.5 m × 0.5 m, were sampled at Woronora Plateau (70 km north of Barren Grounds).
Table 5.3 Eastern bristlebird habitat - vegetation communities

<table>
<thead>
<tr>
<th>Northern populations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainforest(^1, 2)</td>
</tr>
<tr>
<td>Open forest with <em>Eucalyptus saligna</em>, <em>Allocasuarina torulosa</em>, <em>E. andrewsii</em>, <em>Xanthorrhoea glauca</em>, <em>Acacia melanoxylon</em> or <em>A. impexa</em> and understorey/ground cover of tussocks <em>Imperata cylindrica</em>, <em>Poa sieberiana</em>, <em>P. labillardieri</em>, <em>Themeda</em> spp., <em>Sorghum leiocladum</em> and also bracken <em>Pteridium esculentum</em>(^2); understorey may be dominated by the weeds <em>Lantana camara</em>, <em>Rubus</em> (blackberry) and <em>Ageratina</em> spp. (crofton and mist weeds), eg at Richmond Gap(^1, 3)</td>
</tr>
<tr>
<td>Mallee heath with <em>E. approximans</em>, shrubs, <em>Gleichenia</em> and <em>Gahnia</em> at Mt Barney(^2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Central populations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet forest/rainforest relic with <em>Eucalyptus botryoides</em> and <em>Acmena smithii</em>(^1)</td>
</tr>
<tr>
<td>Forest of <em>E. pilularis</em>, <em>E. gummifera</em> and <em>E. botryoides</em> to 35 m(^1, 4)</td>
</tr>
<tr>
<td>Open forest of <em>E. obliqua</em>, <em>E. gummifera</em>, <em>E. cyphellocarpa</em> and <em>E. fastigata</em> to 35 m(^1)</td>
</tr>
<tr>
<td>Open forest of <em>Eucalyptus pilularis</em>, <em>Syncarpia glomulifera</em> and <em>E. gummifera</em> to 25 m(^1)</td>
</tr>
<tr>
<td>Former pipe plantation now covered densely with <em>Pteridium esculentum</em>, logs and shrub regeneration(^1)</td>
</tr>
<tr>
<td>Woodland with <em>Eucalyptus sclerophylla</em>, <em>E. gummifera</em> and/or <em>E. piperita</em> to 15 m(^1, 4)</td>
</tr>
<tr>
<td>Woodland and open woodland of <em>E. sieberi</em> and <em>E. gummifera</em> 10-20 m(^1, 5)</td>
</tr>
<tr>
<td>Closed scrub of <em>Banksia ericifolia</em>, <em>Allocasuarina distyla</em> and/or <em>Hakea teretifolia</em>(^1, 4) and of <em>Melaleuca squarrosa</em>(^1)</td>
</tr>
<tr>
<td>Closed coastal scrub of <em>Leptospermum laevigatum</em>(^1, 4)</td>
</tr>
<tr>
<td>Closed shrub swamp(^6)</td>
</tr>
<tr>
<td>Mallee of <em>E. gummifera</em> or <em>E. dendromorpha</em>(^1, 4)</td>
</tr>
<tr>
<td>Closed low (&lt; 0.5 m) to tall (&gt; 2 m) heathland(^1, 4, 5)</td>
</tr>
<tr>
<td>Heathland(^1, 4)</td>
</tr>
<tr>
<td>Closed sedgeland(^1, 7)</td>
</tr>
<tr>
<td>Closed wet heathland(^1, 7)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Southern populations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm temperate rainforest(^8)</td>
</tr>
<tr>
<td>Limestone box forest(^8)</td>
</tr>
<tr>
<td>Open forest of <em>Eucalyptus sieberi</em>, <em>E. gummifera</em>, <em>Angophora floribunda</em> and/or <em>E. baxteri</em> 5-20 m(^1, 8, 9)</td>
</tr>
<tr>
<td>Woodland of <em>Banksia integrifolia</em>(^8)</td>
</tr>
<tr>
<td>Woodland and low woodland with <em>E. sieberi</em> and dense shrubs and herbs(^1)</td>
</tr>
<tr>
<td>Scrub: coastal dune and riparian(^8), coastal <em>Melaleuca armillaris</em> and <em>Leptospermum laevigatum</em>(^1)</td>
</tr>
<tr>
<td>Hind-dune swamp(^8) with <em>Melaleuca ericifolia</em> to 2 m in wetter areas and <em>M. armillaris</em> to 5 m, some <em>Leptospermum juniperinum</em> and dense herbs, eg <em>Leptocarpus tenax</em>, in dryer areas(^1)</td>
</tr>
<tr>
<td>Wet heathland(^8) similar to closed swamp with <em>Melaleuca squarrosa</em>, <em>M. ericifolia</em>, <em>Sprengelia incarnata</em>, <em>Gleichenia</em> and/or dense herbs, eg <em>Gymnoschoenus sphaerocephalus</em>, <em>Leptocarpus tenax</em>, <em>Lepidosperma forsythii</em> or <em>Xyris</em> spp.(^1)</td>
</tr>
<tr>
<td>Low to tall closed heathland and heathland including <em>Xanthorrhoea</em> plain(^1)</td>
</tr>
</tbody>
</table>

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### Table 5.4 Nesting microhabitat of the eastern bristlebird

<table>
<thead>
<tr>
<th>Location</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern populations generally</td>
<td>Usually in grass tussocks most commonly <em>Sorghum leiocladum</em>(^1).</td>
</tr>
<tr>
<td>Clarence River near Grafton</td>
<td>Nest of grasses and leaves built in a tuft of rushes near the river(^2).</td>
</tr>
<tr>
<td>Middle Harbour, Sydney</td>
<td>Nest made of grass, 0.5 m off the ground in a <em>Banksia robur</em> shrub(^2).</td>
</tr>
<tr>
<td>Unspecified</td>
<td>Nest of grasses and debris at the foot of bushy shrub(^3).</td>
</tr>
<tr>
<td>Barren Grounds</td>
<td>Five nests 0.15-0.45 m off ground, all in the sedge <em>Gymnoschoenus sphaerocephalus</em>(^4). Three nests in <em>Gahnia</em> clumps, one was 0.3 m above ground; four nests hidden in grasses; one in a clump of long grass; one nest woven with grasses and some papery (<em>Leptospermum</em>) bark, one 0.9 m above ground(^5). One nest 0.1 m above ground in dense sedge below 2 m high <em>Leptospermum</em>(^6).</td>
</tr>
<tr>
<td>Marlo, Victoria</td>
<td>A nest in a clump of <em>Gahnia</em> at the foot of a <em>Melaleuca</em> shrub(^7).</td>
</tr>
</tbody>
</table>

1 Holmes (1989); 2 Jackson (1907); 3 Ramsay (1882); 4 McNamara (1946); 5 Chaffer (1954); 6 Birds Australia nest record scheme; 7 Howe (1947).

### Table 5.5 Vegetation formations of eastern bristlebird habitat at Barren Grounds

<table>
<thead>
<tr>
<th>Site</th>
<th>Heath</th>
<th>Shrub</th>
<th>Tree</th>
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<tbody>
<tr>
<td>9</td>
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</tr>
<tr>
<td>23</td>
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<td>s</td>
<td>m</td>
</tr>
<tr>
<td>3</td>
<td></td>
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<td>v</td>
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<tr>
<td>11</td>
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<td>m</td>
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<tr>
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<td>m</td>
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<tr>
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<td>s</td>
<td>m</td>
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<td>7</td>
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<td>i</td>
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<tr>
<td>12</td>
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<td>s</td>
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<table>
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<th>Tree</th>
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<td>43</td>
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<td>v</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>hhh</td>
<td>i</td>
<td></td>
</tr>
<tr>
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<td>s</td>
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</tr>
<tr>
<td>13</td>
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<td>ss</td>
<td></td>
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</table>

\(h =\) open heathland; 
\(hh =\) heathland; 
\(hhh =\) closed heathland; 
\(s =\) open shrubland; 
\(ss =\) shrubland; \(sss =\) closed shrubland; \(m =\) mallee; 
\(i =\) isolated trees; \(v =\) low open woodland; \(w =\) low woodland; 
\(W =\) open woodland.
Eastern bristlebird habitat - vegetation cover

The vegetation cover at sites of eastern bristlebird habitat at Barren Grounds was compared to the cover at nearby sites where the birds were not detected. The proportion of sites where most of the site (defined as 7 or more out of 9 quadrats) had ground cover, low cover and tall shrub cover was high (96%) for birded sites and low (27%) for non-birded sites. The proportion of birded sites with all three layers of cover at most of the site was significantly greater than the proportion of non-birded sites with that characteristic ($z = 11.5, P < 0.0001$). The 99% confidence interval for the true proportion of birded sites with the characteristic layers of cover at most of the site was (0.88, 1.00]. This means that most of the eastern bristlebirds at Barren Grounds occurred in habitat with the characteristic layers of ground cover, low cover and tall shrub cover.

Vegetation structure across heath-wood edges: each site

For each site, the two dimensional ordinations had low stress values (0.08-0.13) which were considered to give good representations of spread of objects, particularly when viewed together with clustering (Clarke and Warwick 1994). Within sites, there was high similarity among most quadrats with the dendrograms showing > 96% of quadrats at each site clustering within the Bray-Curtis similarity coefficient of 50%.

When the cluster and ordination analyses were considered together for the 8 sites, the following patterns were evident.

(i) For all sites, on the wood side of the edge, the quadrats in the 25-50 m, 50-75 m and 75-100 m plots were mixed together with no grouping within plots. For the heath side of the edge, the quadrats showed the same pattern. These patterns are illustrated by Barren Grounds-Budderoo site 1 (Figure 5.3).

(ii) At six sites, there was a gradation of similarity from tightly grouped heath quadrats through heath ecotone and wood ecotone to least similarity among the wood quadrats. This trend was well illustrated at Jervis Bay site 4 (Figure 5.4).

(iii) At the remaining two of the eight sites, there was a tight grouping of heath and heath ecotone quadrats and a widely spread group of wood and wood ecotone quadrats with little evidence of a gradation between the two groups (Figure 5.5).

(iv) Subordinate to these patterns, there was some evidence for a grouping of ecotone quadrats at two sites. At Barren Grounds-Budderoo site 1, 10 wood ecotone and 5 heath ecotone quadrats (together with a wood and a heath quadrat) with 86% similarity,
clustered away from the general pattern of gradation from heath to wood (Figure 5.3). At Barren Grounds-Budderoo site 2, 18 heath ecotone quadrats (together with 3 heath and a wood ecotone quadrat) with 86% similarity, clustered away from the remainder of the heath ecotone and heath quadrats (Figure 5.5).

Figure 5.3 Barren Grounds-Budderoo site 1. Cluster and ordination analyses showing that the heath quadrats are mixed together with no pattern of grouping within the heath plots at 100-75 m ■, 75-50 m ▼ or 50-25 m ▴ and that the wood quadrats are mixed together with no pattern of grouping within the wood plots at 25-50 m ▲, 50-75 m ◊ or 75-100 m ▲. Clustering at the 80% similarity level is indicated, particularly group A in which there are ten wood ecotone quadrats □ and five heath ecotone quadrats ○. At this level of similarity, many of the wood quadrats and a few of the other quadrats are ungrouped or clustered in small groups.
Figure 5.4 Jervis Bay site 4. Cluster and ordination analyses showing the gradation of vegetation structure across the heath-wood edge with high similarity among heath • and heath ecotone ○ quadrats grading to the wood ecotone □ and wood ■ quadrats which are more widely spread. At the 83% level of similarity, most of the heath and heath ecotone quadrats cluster and the remainder of the quadrats are ungrouped or clustered in small groups.
Chapter 5 Eastern bristlebird habitat and vegetation structure across heath-wood edges

Figure 5.5 Barren Grounds-Budderoo site 2. Cluster and ordination analyses showing high similarity among heath • and heath ecotone ○ quadrats separating from the wood ecotone □ and wood ■ quadrats which are more widely spread. Groups A and B form separate clusters at 86% similarity. At this level of similarity, the remainder of the quadrats are ungrouped or clustered in small groups.

Vegetation structure across heath-wood edges: all sites combined

For all sites combined, the two dimensional ordination had a low stress value (0.03). The dendrogram showed high similarity with all quadrats clustering within a Bray-Curtis similarity coefficient of 73%. When the cluster and ordination analyses were considered together, four patterns were evident. (i) There was a strong separation of heath and heath ecotone from the wood and wood ecotone. (ii) The heath and heath ecotone were more tightly grouped than the wood and wood ecotone. (iii) Groups with quadrats from all of
the four distances clustered before the heath/heath ecotone or wood/wood ecotone pairs of distances were completely clustered.

These patterns were further explored using a square root transformation of the attribute data (Figure 5.6). The stress value for the ordination was low (0.05), which gives an excellent representation of the objects (Clarke and Warwick 1994), and all quadrats clustering within a Bray-Curtis similarity coefficient of 83%. Transforming the data had the effect of emphasising low cover values (0-22% transformed to cover scores of 0-1.49) relative to high cover value (23-100% transformed to cover scores of 1.5-3.1) and accentuating the separation of heath and heath ecotone from wood and wood ecotone. The schematic representation (height-cover profile) of the cover scores plotted against the four distances at each site used four classes: dense (3), mid-dense (2), sparse (1) and absent (0). For the transformed data, once again, neither the clustering nor the ordination distinguished a pattern of ecotone quadrats which grouped (Figure 5.6).

Across all sites, the two-way crossed ANOSIM revealed no significant difference between the vegetation structure at the two locations, Barren Grounds-Budderoo and Jervis Bay (raw data: Global $R = -0.007$, $P = 0.464$; transformed data: Global $R = -0.034$, $P = 0.552$). Among the distances, vegetation structure was highly significantly different (raw data: Global $R = 0.273$, $P = 0.006$; transformed data: Global $R = 0.346$; $P = 0.001$). The pairwise tests (Table 5.6) showed that the wood was significantly different to the heath and heath ecotone and the wood ecotone was significantly different to the heath (all $\alpha < 0.05$). The tests also showed that the wood and wood ecotone were very similar and the heath and heath ecotone were very similar. Considering the patterns shown in the ordination and clustering analyses (Figure 5.6), these results were expected.
(a) Height-cover profile and dendrogram (transformed data)

(b) Ordination (transformed data) showing the clusters at 92% similarity

Figure 5.6 Patterns of vegetation structure for all sites combined. The numbers 1-4, 5-8, 9-12, 13-16, 17-20, 21-24, 25-28 and 29-32 refer to the wood (■), wood ecotone (□), heath ecotone (○) and heath (●) quadrats at each of the four Barren Grounds-Budderoo (1-16) and Jervis Bay (17-32) sites respectively. The vegetation structure in the height-cover profile is shown as dense (●), mid dense (○), sparse (○) or absent. Groups A-F are the clusters at the 92% similarity level.
The null hypothesis that the vegetation structure at the heath ecotone and the wood ecotone are equivalent is of particular interest. If the vegetation structure is very similar, there would be support for the notion that the ecotone is a single habitat zone. If the null hypothesis is rejected, then, given the other pairwise test results, I would conclude that for the vegetation structure there is no heath-wood ecotone but rather an abrupt edge and a clear division between the heath zone and the wood zone. The pairwise tests (Table 5.6) showed equivocal results ($P > 0.05$ for the raw data and $P < 0.05$ for the transformed data) and, because there is no control for experimentwise error rates in the ANOSIM, the probability of committing a Type I error is greater than these test results indicated. Thus, although there was little support for the null hypothesis, it was not rejected. This result reflects the pattern shown in the cluster analysis of the transformed data (Figure 5.6), where the heath ecotone and wood ecotone distance groups are separate at a Bray-Curtis similarity of 92% but clustered into two groups (B + C and D + E + F) at a Bray-Curtis similarity of 89%.

Table 5.6 Pairwise tests of vegetation structure across the heath-wood edge

<table>
<thead>
<tr>
<th>Pairwise test comparisons</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>raw data</td>
</tr>
<tr>
<td>Wood v/s wood ecotone</td>
<td>0.797</td>
</tr>
<tr>
<td>Wood v/s heath ecotone</td>
<td>0.003</td>
</tr>
<tr>
<td>Wood v/s heath</td>
<td>0.002</td>
</tr>
<tr>
<td>Heath ecotone v/s wood ecotone</td>
<td>0.086</td>
</tr>
<tr>
<td>Heath v/s wood ecotone</td>
<td>0.013</td>
</tr>
<tr>
<td>Heath v/s heath ecotone</td>
<td>0.848</td>
</tr>
</tbody>
</table>

The SIMPER analysis was conducted on the raw data. It showed that for all sites combined, the similarity within each distance group was high, with a slight decline from heath through heath ecotone and wood ecotone to wood (Table 5.7). For each of the distance groups, the pattern of the contribution of the attributes to the Bray-Curtis similarity coefficients was closely alike. In each case, the height classes 1-7 (0-0.7 m) contributed most (79-88%) of the similarity and in each case the similarity was greatest for height class 1 (17-24%), decreasing steadily through classes 2, 3, etc to class 7 which contributed 5-6% of the similarity. The similarity between each pair of groups was also high (Table 5.7). That is, the pattern of vegetation structure was similar among all distance groups.
The SIMPER analysis showed clear patterns of differences among the distance groups. The attributes which contributed most (60-70%) of the dissimilarity between the heath/heath ecotone and the wood/wood ecotone were the height classes 2-7 (0.1-0.7 m). The difference was that in these height classes the heath/heath ecotone cover values were high (4.5-9.5) compared to cover values in the wood/wood ecotone (2.8-7.3). The tallest height class (> 3 m) had a cover value of 1.5-1.9 in the wood/wood ecotone and 0-0.2 in the heath/heath ecotone but this difference contributed only 6-7% of the dissimilarity among the groups.

**Table 5.7** Similarity (%) within and between distance groups

<table>
<thead>
<tr>
<th></th>
<th>Wood</th>
<th>Wood ecotone</th>
<th>Heath ecotone</th>
<th>Heath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood ecotone</td>
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<td>83</td>
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**Discussion**

Eastern bristlebirds inhabit a broad range of vegetation types including forests, woodlands, shrublands and heathlands. The species has often been associated with heathy vegetation, however, its habitat specialization appears to be dense low vegetation. Dense low cover was characteristic of all historic and recent eastern bristlebird habitat descriptions. Floristics are important only in as much as they provide the characteristic cover required by this cover-dependent species. There was little evidence for heath-wood ecotones with a unique vegetation structure and no evidence to suggest that the pattern of vegetation structure might explain the pattern of eastern bristlebird occurrence across heath-wood edges.

**Vegetation communities**

The present study found that the eastern bristlebird was associated with most major vegetation communities in wetter parts of south-eastern Australia. Hence, the general accounts (eg Cayley 1959; Macdonald 1973; Lindsay 1992) which described the eastern bristlebird as a heathland species are too narrow. Keast (1957) described the habitat specialization as "coastal undergrowth". Smith (1977) considered that the species preferred dense habitat but was a relict in heath which was probably of marginal habitat value, particularly where it was frequently burned. There needs to be a clear distinction...
Chapter 5 Eastern bristlebird habitat and vegetation structure across heath-wood edges

between the vegetation community where eastern bristlebirds are generally found and the potential area of habitat that a population could inhabit, given favourable conditions. The species is often associated with heathland or heathy vegetation, however, its habitat specialization is not heath, but dense low vegetation.

Eastern bristlebirds inhabit a broad range of vegetation types in which there is a wide variety of dominant plant species. Across their range, there is no plant or suite of plant species commonly associated with their habitat (Appendix 4.1, Table 5.3). They inhabit areas dominated by the introduced plants lantana, blackberry and crofton weed. This evidence suggests that in eastern bristlebird habitat, the floristics are important only in as much as they provide the characteristic cover required by the species.

**Cover**

Dense low cover was characteristic of all historic and recent eastern bristlebird habitat descriptions, including the field observations in the present study. This factor is common throughout the species' range and the various vegetation communities it inhabits. At Barren Grounds, layers of ground cover, low cover and tall shrub cover were shown to be important features which distinguished eastern bristlebird habitat from areas where bristlebirds were not detected. These results support the claim that the eastern bristlebird is a cover-dependent species.

Dense low cover is also characteristic of the habitat of the rufous bristlebird and the western bristlebird (Slater 1978; Garnett 1992). Rufous bristlebirds are found in a wide range of vegetation communities including temperate rainforest, coastal scrub and heath and even suburban gardens, but in all situations there is dense ground cover provided by native plants (Reilly 1991; Belcher 1992; Garnett 1992; Smith and Baker-Gabb 1993). The western bristlebird is restricted to coastal heaths of variable height which are generally dense and closed (McNee 1986; Smith 1987).

Other small semi-flightless cursorial Australian passerines have also shown a preference for habitats with low dense cover. Ferrier (1985) measured 70 habitat variables at 124 plots where rufous scrub-birds were located. He found that the most critical factors determining habitat suitability were cover 2-50 cm above the ground, cover 50-100 cm above the ground and leaf litter volume. For the noisy scrub-bird, habitat is characterized by a thick layer of leaf litter and dense layers of sedges and shrubs (Danks et al. 1996). Pilotbirds are usually associated with dense understoreys of ferns, sedges and shrubs (Howe 1915; Taylor 1992).
Heath-wood ecotones

The present study showed little evidence for heath-wood ecotones with a unique vegetation structure. Eastern bristlebird habitat was studied at Barren Grounds-Budderoo and Jervis Bay, where the two largest populations of the eastern bristlebird exist. At Barren Grounds-Budderoo, sites 1 and 2 had small groups (25% and 32%) of ecotone quadrats with vegetation structure slightly different to the rest of the site. However, there was no evidence for an overall pattern or even a single site where there was a substantial grouping of heath ecotone and wood ecotone which had a unique vegetation structure different to that of the heath or the wood. The most usual pattern of vegetation structure measured at the ecotone was a simple grading from a highly uniform heath to a less uniform wood. At each site and especially taking the average across all sites, heath ecotone grouped most closely with heath and wood ecotone grouped most closely with wood. Therefore, it is concluded that the vegetation structural characteristics thought to be relevant to the eastern bristlebird were not unique to the heath-wood ecotone.

The eastern bristlebird has been described as an "ecotonal species" (Bramwell et al. 1992) and as an "ecotone exploiter" (Chapter 4). However, if there is nothing special about the vegetation structure at the heath-wood ecotone which could make it particularly suited to the eastern bristlebird, what factors might explain these patterns of occurrence?

Floristics, together with vegetation structural parameters, have been recognized as a determinant of bird distributions (Robinson and Holmes 1984; Shields et al. 1985; Holmes and Recher 1986; Arnold 1988). However, it seems unlikely that floristics alone would explain the eastern bristlebird's apparent ecotonal pattern of occurrence. Eastern bristlebirds are found over a wide range of vegetation communities with considerable variation in plant species, which led to my earlier conclusion that floristics are important only in as much as they provide the characteristic cover required by the species. Furthermore, for the population at Spicers Gap, Queensland, Lamb et al. (1993) found that the plant species composition of the ground cover was not a significant habitat factor.

Food, including quantity, quality and seasonal variation of food and foraging opportunities, may be more plentiful at the heath-wood ecotone than in the adjacent habitat. The diet of the eastern bristlebird is poorly understood (Chapter 1) and there is no information available to assess this possible explanation. Testing this hypothesis would be a useful addition to any eastern bristlebird dietary studies undertaken in the future.

For Chapters 4 and 5, the investigations into eastern bristlebird occurrence across heath-wood edges gave contradictory results. Considering that the structure of the low
vegetation was dense at the wood, the heath and the ecotone, the eastern bristlebird density might have been similar across these three zones but it was not. The pattern of differences in vegetation structure across the heath-wood edge was mainly a division between heath and wood. So, eastern bristlebirds might have shown a preference for one or the other side of the edge but they did not. The pattern of the eastern bristlebird density was not uniform across the heath-wood ecotone. It was high at the ecotone, on both sides of the edge, and low in the heath and the wood (Figure 4.8). The attributes of the vegetation structure measured across the heath-wood edge did not show a pattern which could explain the apparent occurrence of the eastern bristlebird.

Intrinsic behaviour of eastern bristlebirds may explain their apparent affinity for heath-wood ecotones. On the one hand, the ecotone may really be the preferred habitat of the eastern bristlebird. Perhaps there is no better reason than the "psychology" (Lack 1933) of the species which attracts it to heath-wood ecotones. Lack (1933) argued that intraspecific habitat selection may be based on instinctive selection of ancestral habitat rather than on environmental necessity. On the other hand, survey results may be biased by differential detectability of eastern bristlebirds if they call and show themselves more frequently at heath-wood ecotones than in the adjacent heath or wood. The question of the relative importance of the heath-wood ecotone to the eastern bristlebird was explored further using radio-tracking (Chapter 6).
## Appendix 5.1
Floristics of eastern bristlebird habitat at Barren Grounds

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<th>Plants</th>
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<th>% cover</th>
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<tr>
<td>Lycopodium deuterodensum</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Selaginella uliginosa</td>
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</tr>
<tr>
<td><strong>FERNS</strong></td>
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*a* For some species, field identification was limited to genus.

*b* For some herbs, identification to species level was not possible because only stem and leaf material was present.
Chapter 6

Radio-tracking eastern bristlebirds at Jervis Bay

beep beep beep went the feathered rat
to the outliers, out-and-outliers and statistics

Introduction

On the song of a bird

Management planning for threatened species should be based on valid scientific studies. Information about each population, particularly where the individuals live, is fundamental to ecology (Andrewartha and Birch 1954; Southwood 1977) and planning (Goldingay and Kavanagh 1993; North and Reynolds 1996). However, eastern bristlebirds are cryptic by nature. All of the past studies have relied on detecting individuals by their loud, distinctive calls and an occasional fleeting glimpse. A study of colour-banded eastern bristlebirds at Barren Grounds (J Baker unpubl. data) yielded few useful data about the population and its habitat utilization. Hence, there has been little opportunity to assess the validity of the previous eastern bristlebird studies.

Calls have been used to map the positions of individual eastern bristlebirds from which population densities have been calculated and population sizes estimated (Chapters 2 and 3). The species has been assumed to be highly sedentary and to maintain small territories of 50 yards radius (McNamara 1946) and 1-2 ha (Blakers et al. 1984; Holmes 1989). Based on its call, the species was found to be an ecotone exploiter (Chapter 4) and Bramwell et al. (1992) reported that eastern bristlebird detections were concentrated at edges between heathland and woodland. However, no particular characteristic of the vegetation structure at heath-wood ecotones could be identified to suggest that it was of special significance as eastern bristlebird habitat (Chapter 5). Furthermore, eastern bristlebirds have been located calling from a wide variety of vegetation types (Chapter 5). Hence, a number of important questions remain unanswered: Are the population density estimates for the eastern bristlebird valid? What area is required for an eastern bristlebird territory or home range? What is their pattern of habitat utilization and are ecotones important? Radio-tracking, although expensive and time-consuming, can answer otherwise unassailable questions (Macdonald and Amlaner 1980) and it seemed to be an appropriate method to "see" eastern bristlebirds in their habitat and to address these questions.

A radio-tracking project was planned for Jervis Bay. However, there was a paucity of recently published detailed methodologies and the effects that the radio-tags might have on the birds. Hence, there was a need to document this information for the benefit of
future research and management of bristlebirds and similar species. In particular, radio-tracking may be contemplated if translocation is used as a species recovery action.

Aims

The aims of this chapter are (i) to document the methods and success rates of trapping, processing, radio-tagging and radio-tracking the eastern bristlebird at Jervis Bay, (ii) to use radio-tracking data to check the validity of previous population density estimates, (iii) to record bird movements and assess the effects of the radio-tags on the birds, (iv) to determine the home range of the eastern bristlebird and (v) to study habitat utilization, particularly across heath-wood edges.

Problematic bristlebirds

Studying the eastern bristlebird is problematic because it is a small, brown, ground-dwelling inhabitant of very dense vegetation and it is shy and elusive. In considering a radio-tacking study of the eastern bristlebird, further problems arise. The species is difficult to trap and sensitive to disturbance, characteristics shared with the rufous (J Seymour pers. comm.) and the western (Murphy 1994) bristlebirds.

There was no apparent easy solution to the problem of catching eastern bristlebirds, so the present study was planned to include a considerable trapping effort. All three species of bristlebirds are recognized as being sensitive to disturbance during breeding (Chapter 1). This problem was overcome by planning the study in autumn, outside the breeding season. There are other examples of the sensitivity of bristlebirds to disturbance. For instance, at Barren Grounds, in the 12 years to the end of 1994, 42 eastern bristlebirds were trapped and there were four retraps. Two of these birds (one was a retrap) died suddenly and unexpectedly during processing. This rate of mortality is extremely high compared to all other species which are trapped and banded at Barren Grounds. At Two Peoples Bay, Western Australia, Murphy (1994) fitted radio-tags to three western bristlebirds. Two of the birds had no apparent difficulties and were tracked for six and 14 days respectively. The third bird was fitted with a radio-tag and released in the late afternoon, tracked successfully on the second day but found dead on the morning of the third day. Hence, in designing the radio-tracking study of eastern bristlebirds at Jervis Bay, extreme caution was planned for handling and tracking the birds.
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

Figure 6.1 Location of study sites at Bherwerre Peninsula, Jervis Bay

Study area

The study was undertaken at three sites (A, B and C) in Booderee and two sites (D and E) in NSW Jervis Bay National Park (JBNP) (Figure 6.1). Each site had trails suitable for the erection of lines of mist-nets and for the subsequent ease of radio-tracking and mapping, but the trails were away from areas of high public visitation. The sites were also known to support relatively high densities of eastern bristlebirds (Chapters 2 and 4).

Trapping

Methods

Trapping was conducted from 26 March to 20 May 1997. Combinations of 18, 12, 9, and 6 m mist-nets were used with up to 168 m of net used at once. The net size was 31
mm (stretched diagonal). Nets were either set in continuous walls, an en masse catching tactic, or placed individually near places of eastern bristlebird activity. All vegetation under the nets was clipped to ground level and the ground was raked to prevent snags. The bottom shelf-string was set at ground level and, where necessary, held down with small rocks. The second shelf-string was placed approximately 300 mm above the ground at the net-ends. Eastern bristlebirds were not expected to be caught above the second shelf because of their poor flying ability and tendency to run across tracks. Hence, the higher shelves were stretched fully opened which minimized the by-catch because most birds bounced away from the nets rather than becoming entangled in the pockets. The nets were used between sunrise and 15 minutes pre-sunset but were not used during excessively windy or hot periods or during rain. Two experienced mist-netters checked the nets continuously during trapping periods. Birds other than eastern bristlebirds were quickly released without being banded or measured. All nets were closed as soon as an eastern bristlebird was trapped and they remained closed while the bird was being processed.

Taped call replay was used in anticipation that it would attract eastern bristlebirds to the nets. The most commonly heard calls at Barren Grounds and Jervis Bay are variations of the A-call, "pretty birdie", and the strident "prist", B-call (see Chapter 1). The tape recordings were made at Barren Grounds and replayed on a one-minute loop tape using a portable tape player. The main recording used contained A-B duetting sequences from two different "pairs" of birds. The success of the call replay was difficult to assess. A second recording, a continuous squawking eastern bristlebird distress call, was tried but it did not seem to attract eastern bristlebirds.

Call replay was either a loud broadcast for one minute at approximately 30 minute intervals in the general vicinity of the nets or was more specific if a bird approached the nets. This latter technique, which was relatively successful, required one person hidden with the tape player in vegetation on the opposite side of the mist-nets to the bird. The tape was played at varying volumes using the A-B duetting sequences or the A or B parts of the sequences, depending on how the bird seemed to react. A second person hid near the track on the bird's side of the net and watched for the bird's movements. If the bird went into the net, this person was able to rush toward it, thereby discouraging it from doubling back and escaping if it was not tangled, and secure the bird in a net-pocket by lifting the net off the ground. An alternative strategy of moving noisily behind a bird which was within 10 m of a net, in the hope of flushing it into the net, failed on all ten attempts.
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

Results

Twenty-six eastern bristlebirds were trapped (including a retrap) during 29 days (145 hours) of mist-netting (Table 6.1). There were approximately 1000 captures of birds which were not eastern bristlebirds and all of these were released unharmed. For the 26 successful trappings, six were considered to be directly attributable to the tape because the birds called and/or were seen nearby within a few minutes, ten occurred in conjunction with tape playing, although the influence of the tape in these cases was not known, and the remaining ten occurred without the tape being played.

Table 6.1 Trapping results

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<td><strong>962</strong></td>
<td><strong>26</strong></td>
<td><strong>22</strong></td>
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</table>

\( a \) Number of mist-nets (based on a standard 18 m net) \( \times \) number of hours of netting

Processing

Methods

The processing of each bird was organized to minimize handling and holding time and maximize the chance of a successful radio-tag attachment. Birds were removed from the net and held in a calico bag while all of the nets were closed. Each bird was weighed in its bag, then removed and banded with a standard size 5 aluminium band issued by the Australian Bird Banding Scheme. The band number was used to name the bird. The bag was weighed and stored for later inspection. The bird was held over a work-sheet of blotting paper and care was taken to prevent it from touching its feet on anything because eastern bristlebirds have a tendency to jump if they can push off with their legs. Standard measurements of head-bill (HB), bill (BK) and tarsus with foot (TZ) lengths were taken (Low 1989). Eye colour was noted. In four cases, to hasten processing time, not all morphometric measurements were taken.
Radio-tagging studies of small to medium-sized birds generally invoke some modification of the methods of Raim (1978). The methods of the present study were sufficiently different to Raim (1978) to warrant the following detailed description. Preparation for radio-tagging required one person to hold the bird and a second person to perform the following tasks:

(i) The bird's head was enclosed in a hood which was a draw-string bag 80 mm × 100 mm made from black, open-weave cotton. Eastern bristlebirds are very wriggly when being handled and the hood had a noticeable calming effect on most of them.

(ii) The feathers in the interscapular area were trimmed to 1 mm over an area approximately 10 mm wide and 20 mm long using round-nosed scissors and an artist's size-4 pure bristle paint brush wet with 70% ethanol. This was the most time consuming part of the processing. Wet feathers were easier to snip than dry ones and the ethanol was intended to clean dirt and oil from the radio-tag attachment area. Because of the likelihood of the bird making a sudden movement, round-nosed scissors were considered less likely to accidentally damage the bird than pointed scissors. The birds were moulting and when the emerging pin feathers were trimmed they bled which may have hindered radio-tag attachment. Hence, wherever possible, the pin feathers were left unsnipped.

(iii) When the attachment area was clean and dry, a fresh smear of Supa Glue Gel (Selleys) was applied to the radio-tag which was then held firmly to the bird for 5 minutes, aligned with the bird's dorsal axis.

(iv) The behooded bird was then placed in a 100 mm × 200 mm × 300 mm holding box for 10 minutes to allow additional time for the adhesive to strengthen.

(v) When the bird was taken from the box, the hood was removed and the bird was released into thick vegetation close to the point of trapping.

The Supa Glue is a cyanoacrylate which Perry et al. (1981) found the most successful type of adhesive to use with birds and which Johnson et al. (1991) found to be safe for use with 128 birds from 4 passerine species. Acetone was kept handy as a solvent in case of accidental gluing with Supa Glue. Forthané, an anaesthetic, was kept handy for the euthanasia of injured birds, as specified by the Animal Ethics Approval.

From each bird, 2-6 pin feathers were removed with tweezers and stored in 70% ethanol for subsequent DNA analysis. The calico bag, work-sheet and holding box were checked for faecal samples which were collected and stored in 70% ethanol for subsequent dietary analysis. These data and the morphometric data were not analysed in the present study. However, collecting the data was quick and easy and did not hinder the processing of the birds. It is sensible to take such opportunities to collect data which may be valuable in future studies.
Chapter 6  Radio-tracking eastern bristlebirds at Jervis Bay

Results

Nineteen of the 26 birds were processed routinely, as described above, in an average time of 45 minutes, with holding time in the calico bag averaging 17 minutes (range 2-38 min) and processing time, including time in the holding box, averaging 28 minutes (range 23-34 min). The seven exceptions to the processing routine were as follows:

Bird #52 was recaptured 12 days after first capture and 9 days after its radio-tag became detached. It was assessed to be in good condition. In the interscapular area, there was no sign of glue or skin damage and approximately 20 new pin feathers had sprouted to a length of 8 mm. Morphometrics were taken and the bird was released.

Bird #57 was captured 35 minutes before sunset, held in a calico bag for 2 minutes then processed very quickly (20 minutes). However, the air temperature dropped suddenly and when the bird was released it was reluctant to move. It was cold to touch and presumably was hypothermic. It was immediately placed in a calico bag and warmed. It was kept warm and held overnight in the bag and released the following morning after a drink of warm, sugary water from an eye-dropper. The bird was then successfully tracked for 11 days before the radio-tag became detached and was retrieved.

A bird was captured as the nets were being closed, 15 minutes before sunset. It was released immediately without being measured, banded or radio-tagged because there was insufficient time pre-dusk for processing. Holding birds overnight was considered to be an emergency not a routine procedure.

Bird #60 was captured in the early morning. The weather was cool but the bird was warm and dry so it was held in a bag for one hour and then it was processed quickly (20 minutes) and released.

Bird #68 was captured accidentally in a partly furled net, as a line of nets were being erected on a warm afternoon in late April. The bird appeared to be normal and healthy, although it may have been trapped for up to 30 minutes, from 90 minutes pre-sunset. The bird was processed immediately and quickly. However, 13 minutes into the processing, after the radio-tag had been held in place for 3 minutes, the bird's heart gave several very strong beats and stopped. Attempts to revive the bird with artificial respiration and external cardiac massage failed. The body was frozen and held for later examination, after which it will be lodged with the Australian Museum, Sydney.

A bird was captured in the early morning as the nets were being opened. The bird was cold and wet from dew and so it was held and warmed in a bag for an hour until it was
dry. It was then photographed and, although it appeared to be normal and healthy, it was released without being measured, banded or radio-tagged because it was considered that the additional time required for processing could have been excessively stressful to the bird.

Bird #72 was held in a bag for only 10 minutes prior to processing. However, for no apparent reason it became droopy while the radio-tag was being held in position. It was given some sugary water with an eye-dropper and released without being placed in the holding box. When released it remained still for approximately 30 seconds then suddenly retreated into the cover of the vegetation. The bird was then successfully tracked for 5 days before the radio-tag became detached and was retrieved.

Of the 25 individuals captured during the present study at Jervis Bay, only one (trapped in late April) had a pale iris. This may be characteristic of a juvenile or immature bird (Chapter 1). However, a brief examination showed no particular pattern of plumage or soft parts which was noticeably different from the other birds and I was uncertain whether it was a young bird.

Radio-tags and tracking

Methods

The radio-tags were supplied by Titley Electronics at $145 each. They consisted of a single-stage, miniature transmitter (Model LTM), a 388 Varta 1.35 V mercury battery and a magnetically operated reed switch, all hermetically encapsulated in heat-shrunk plastic tubing with a whip style transmitting aerial attached. The mean dimensions of the radio-tags were 21 mm X 9.4 mm X 3.5 mm and each weighed approximately 1.6 g. The aerials were 250 mm long, nylon-covered multi-strand stainless steel fishing trace wire. The expected battery life was 6-8 weeks. The radio-transmitters pulsed at approximately 1 Hz and each had unique frequencies ± 2 kHz in the 151 MHz band. Signals were detected using hand-held three-element Yagi antennae and Telonics TR-2 and TR-4 portable receivers.

Before the radio-tags were used and again immediately prior to attachment, each was checked for transmitter signal frequency and strength. Prior to catching each bird, a piece of gauze (cotton T-shirt material approximately 0.5 mm thick) was attached to the radio-tag using Supa Glue Gel and trimmed to overlap the radio-tag by 1 mm. This was intended to enhance the adhesion of the radio-tag to the bird. Direct attachment of radio-
tags to birds without using the gauze was attempted thrice with attachment lasting 5 days, 9 hours and 6 hours respectively, after which this method was not used again.

A detached radio-tag was recognized by its constant signal strength, constant source location and occasionally by having a strong signal when the receiving antenna was held vertically. Detached radio-tags were generally easy to find. This was achieved by finding the approximate location to within a few square metres then folding away the elements of the Yagi antenna and using it as a probe every 250 mm and progressively reducing the receiver gain (volume).

Ten radio-tags were used. When retrieved, the radio-tags were cleaned and reused or returned to the supplier for new batteries which were fitted for a minimal cost.

Twenty-two birds were radio-tracked during 77 days between 26 March and 26 June. The initial intention to have an approximately even tracking effort across all sites was not achieved because few eastern bristlebirds were trapped at sites C, D and E (Table 6.1). During the first 50 days of the project, a median of 3 birds (range 1-5) were tracked simultaneously and for the remainder of the project, only one bird was tracked. Some birds were not tracked on every day that they were tagged.

**Results**

The radio-tags averaged 3.8% (range 3.3-4.7%) of the birds' weights (range 34-49 g). Once attached, the radio-tag fitted neatly between the bird's scapulae and was covered by body feathers with the aerial lying along the back and projecting approximately 120 mm beyond the tail. The transmitter axis was parallel to the bird's anterior-posterior axis.

When the radio-tags became detached from the birds, they were retrieved and they showed varying degrees of bending and scraping along the aerial, indicative of the birds' attempts to preen or remove the radio-tags.

The detached radio-tags had the stubs of the snipped feathers and up to 13 whole body feathers glued to the gauze. During search and retrieval of radio-tags, no indication of injury to the birds was found, except in one case, bird #69, which is noted below. This was taken to indicate that the birds were unaffected by the temporary attachment of the radio-tag.

The most serviceable radio-tags included one which was used on five different birds for a total of 19 days and another used on three birds for a total of 18 days then fitted with a new battery and used on another bird for 41 days.
In three cases there were problems with receiving signals. A radio-tag was fitted to bird #59 but the following day the signal could not be detected within a radius of approximately 1 km. Despite frequent checking, the signal was not detected again during the remaining 6 weeks of the study. A radio-tag was fitted to bird #64 and it transmitted without problems for two days. However, the signal became increasingly variable in strength and pulse rate with few data being obtained after the sixth day of tracking. No signal was detected for several days but the radio-tag was retrieved, detached from the bird, when it transmitted briefly on the fourteenth day.

A radio-tag was fitted to bird #69 and it transmitted without problems for four days. On the fifth day the signal became weak and ceased. On the ninth day, when a faint signal was detected, the radio-tag was found. It was punctured with several blunt tooth-like marks and was located with some eastern bristlebird feathers (approximately 20 body feathers and three wing primaries) but no other bird remains were found. Presumably, this bird was predated by a fox because within 50 m there were piles of feathers from a ground parrot and a crimson rosella and some chewed kangaroo bones; within 100 m, in thick scrub on the eighth day, a fox-sized mammal was flushed, although not sighted; and a fox had been seen 200 m from the location 5 months previously.

Generally, signal detection was easily achieved within 200 m of the radio-tagged birds. The maximum distance at which each transmitter signal was received averaged 330 m (n = 9; range 200-500 m). The median radio-tag attachment time was 5.5 days (or part thereof) and the mean was 8.4 days (Figure 6.2).
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

Mapping

Methods

The study of population density, bird movements, home range and habitat utilization involved tracking radio-tagged birds and mapping their location. The location fixes were mapped manually in the field at a scale of 1:5000 with an accuracy of ±5 m in known vegetation communities which were confirmed in the field, thus avoiding the problems associated with habitat misclassification (White and Garrott 1986; Samuel and Kenow 1992). This was possible because digitized maps were available which showed landscape features, trails and vegetation communities in MapInfo (ESRI 1995) for Booderee (Taws 1997) and E-RMS (NPWS 1992) for JBNP (Mills 1993). At each site, the relative positions of features such as trail intersection and vegetation boundaries were ground truthed and flagging tape was used to mark accurately identified map positions. The fixes for each bird were stored in a database as map co-ordinates. The data were manipulated interactively with the vegetation maps using the GIS program ArcView (ESRI 1996).

Generally, if an accurate fix is required when radio-tracking, it is desirable to follow the signal until the animal is sighted (Naef-Daenzer 1993). In other studies, this was possible with large mammals such as the swamp wallaby (Troy and Coulson 1993), with small nocturnal mammals such as the sugar glider which can be spotlighted (Quin et al. 1992), with noticeable birds such as the kiwi (McLennan et al. 1987) and with cryptic birds such as the ground parrot which can be flushed to confirm locations (Jordan 1988). However, eastern bristlebirds are both cryptic and sensitive to intrusion and hence, during tracking they were rarely seen or intentionally disturbed.

Tracking was conducted on foot and began on a trail by estimating the general location of the signal. Adequate trail access, flat terrain and short tracking distances facilitated the locating of birds and minimized the errors of the fixes. To pin-point the fix, 2-4 bearings were mapped and, if necessary, closer tracking was undertaken by moving off the trail and circling the location at a radius of approximately 25 m. Sometimes, when tracking a bird, its location could not be fixed because it was distant from a trail and/or moving across the landscape more quickly than the observer could obtain successive bearings.

Results

Radio-tagged birds were tracked opportunistically and an average of 5 fixes per day were obtained (range 1-14) (Table 6.3). The point of capture was not taken to be a fix, although the 19 birds that were tracked for more than a day were captured within or near (20-60 m outside) the area enscribed by their subsequent fixes (Table 6.3).
Population density

Methods

During radio-tracking, the positions of untagged eastern bristlebirds were noted in addition to birds which were radio-tagged. This facilitated the calculation of eastern bristlebird densities at sites A and B and allowed a comparison with earlier estimates (Chapter 2). For sites C, D and E a total of only two birds was tracked and there was noticeably less eastern bristlebird activity than at sites A and B. Consequently, although this pattern was similar to the pattern reported earlier (Chapter 2), there were insufficient data to make valid population density comparisons. The total area at each site was taken as the convex polygon to contain all of the tagged and untagged bird locations.

Results

At site A, 14 birds were radio-tagged and tracked over 34 days with no more than five tagged at any time. One additional bird was confirmed at the site and it seemed likely that others went undetected. This gave a density of at least 15 birds in 48 ha. At site B, including bird #68 which died, the seven trapped birds plus one additional bird were thought to be the only eastern bristlebirds present during the 19 days of tracking at the site. This gave a density of 8 birds in 19 ha. These estimates were 15-30% higher than the estimates of maximum density calculated for December 1994 to February 1996 (Table 6.2).

Table 6.2 Eastern bristlebird densities

<table>
<thead>
<tr>
<th>Site</th>
<th>Birds detected</th>
<th>Area (ha)</th>
<th>Density</th>
<th>Density extrapolated: birds/100 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Autumn 1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dec 94 - Feb 96</td>
</tr>
<tr>
<td>A</td>
<td>≥ 15</td>
<td>48</td>
<td>≥ 15/48 ha</td>
<td>≥ 31</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>19</td>
<td>8/19 ha</td>
<td>42</td>
</tr>
</tbody>
</table>

Bird movements and the effects of radio-tagging

Radio-tags must be small, relative to the animals being studied. From 5 886 retrapped birds (6-80 g) of 40 species, Naef-Daenzer (1993) calculated that within 8 days, 49% changed weight by ≥ 5% and 18% changed weight by ≥ 10% and he considered that all of these species were capable of carrying tags which were 5-7% of their body weight.
From flight aerodynamics calculations, Caccamise and Hedin (1985) considered that radio-tag loads of 5% of a bird's weight were generally acceptable, although this is probably conservative for the eastern bristlebird because it is semi-flightless. Generally, my review of radio-tagging studies (Appendix 6.1) suggested that for small to medium-sized birds, small radio-tags have minimal effect and the acclimation period is less than a day.

Methods

The average weight of the radio-tags was compared to the weight of the birds trapped during the study (n = 26 including a retrap).

Tracking of birds was commenced from the day of radio-tagging and their movements and behaviour were studied for any indications of acclimation, exceptional movements or dispersal.

The initial activity of the radio-tagged eastern bristlebirds was compared to their activity on subsequent days. A trend of increasing movement over time would indicate that radio-tagging initially inhibited birds and a trend of decreasing movement over time would indicate that radio-tagging initially aggravated birds. The greatest distance between any two locations of a bird during a day was taken as an index of activity and the first full day of tracking was compared to the mean of the subsequent two days using the Wilcoxon paired-sample test (Zar 1984).

Results

The only retrapped bird had a weight change of 10% (+4 g) in a period of 12 days. The 1.6 g radio-tags averaged 3.8% (range 3.3-4.7%) of the eastern bristlebirds' weights (range 34-49 g).

When radio-tagged birds were released, they quickly disappeared into thick vegetation. However, often their movements seemed to be conservative in the first few hours after release. Movements of ≤ 60 m from the point of release were recorded for 16 birds in their first 20-220 minutes of tracking, including four birds released late in the afternoon which did not move beyond 60 m until the following morning. In nine cases of longer movements, including five of the birds which were initially conservative in their movement, birds moved 70-260 m in their first 80-225 minutes of tracking. For example, bird #55 was released late in the afternoon and moved only 25 m in 20 minutes before roosting for the night but then it moved at least 300 m in the first hour of light the next morning.
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

There was no difference between the index of activity on the first full day of tracking (mean distance 145 m; range 75-230 m) and the subsequent two days (170 m; 100-325 m) \( (T_{0.05}, (2), 16 = 29; T = 54.5, P = 0.5) \).

The above results are taken to indicate that radio-tagged eastern bristlebirds may take a few hours before they begin to move about normally but they recover within the first day of tagging.

Occasionally, radio-tagged birds seemed to react when they were approached to within 25 m by an observer. On 28 occasions, birds (14 different individuals) evaded by moving perpendicularly to the direction of the approaching observer. On 10 occasions, birds (9) retreated rapidly in the direction opposite to the approaching observer. On three occasions, birds (2) approached to within 2 m of the observer. On three occasions, birds (2) remained still, silent and hidden, even when the observer approached to within one metre. Two radio-tagged birds were flushed from cover and seen flying approximately 20 m and 10 m respectively. Rapid movements of 35-80 m within 10 seconds were recorded for 13 individuals moving through thick vegetation.

Radio-locations were sometimes taken after sunset and before sunrise. Birds were active at dawn, as early as 15 minutes before sunrise, and at dusk, up to 15 minutes after sunrise. No activity was detected from 20 minutes after sunset until 20 minutes before sunrise (41 fixes from 17 birds). Sometimes, birds (n = 11) roosted within a small area (50 X 50 m) on consecutive nights or over longer periods. Bird #55 roosted within approximately 1 ha of its 11.6 ha home range for at least 12 nights during the 21 nights it was tagged. For the remaining birds, there were insufficient data to show regular roosting locations. Some birds showed large differences in roost locations. For example, on two consecutive nights, the roosts of bird #67 were 215 m apart in a home range with a width of 390 m.

There were a number of notable movements by radio-tagged birds. After it was radio-tagged, bird #51 accidentally escaped 295 m from the point of trapping. It moved 20-50 m into thick vegetation and remained there for at least 30 minutes. Three and a half hours after release, it had returned to within 90 m of the point of trapping. Rapid movements by five radio-tagged individuals were: 110 m in one minute, 140 m in one minute, 165 m in < 20 minutes, 190 m in < 10 minutes, 320 m in < 20 minutes and 330 m in < 60 minutes. The furthest daily movement between two fixes was 525 m by bird #55. Bird #73 was the most intensively tracked bird and during 5 days, for 8-11 hours/day and 9-18 fixes/day, it moved 830-1540 m/day at an average of 115 m/hour.
Dispersal was not apparent with any of the birds during the present study, since none of the birds appeared to move their home range area. Bird #59 was not detected subsequent to the day it was radio-tagged but this was considered to be due to transmitter failure not dispersal. Bird #52 was recaptured 9 days after losing its radio-tag, only 30 m away from where it had been previously been tracked. The two birds tracked for the longest period did not increase their home range after 13 and 14 days in a total of 21 and 28 days of tracking.

Home range

Home range measurement gives a convenient index of the area over which an individual animal normally travels in a given period (Burt 1943). What constitutes normal travel and an appropriate time period for individuals or for a species, is open to interpretation (Burt 1943; White and Garrott 1990). With the advent of radio-tracking, home range studies became common and the most usual home range index was the minimum convex polygon (MCP) (Harris et al. 1990). This index is often credited to Mohr (1947), although it is intuitive and simply the convex polygon enscribed by the outermost locations noted for an animal in a specified period (Figure 6.3). Recently, numerous computer programs have become available which calculate home range utilizing a number of different procedures.

Using a MCP area to calculate home range has the advantages of being simple and comparable among studies. The main disadvantages are that the home range is underestimated if an animal's normal behaviour is undersampled and overestimated if the animal normally doesn't use parts of the MCP area. The latter situation can arise if the animal makes long-distance sallies outside its normal range, as illustrated by bird #57 (Figure 6.3).

The problem of outliers can be overcome by using an elliptic area (Jennrich and Turner 1969). However, this was inappropriate for the present study because the model assumes that home ranges are bivariate normal around a single centre of activity and requires a large number of fixes (Jennrich and Turner 1969; White and Garrott 1990). Nonparametric methods of estimating home range are available and it is now recommended that the earlier method of harmonic means (Dixon and Chapman 1980) be replaced by more flexible, reliable methods such as the kernel method (Worton 1987; Kie et al. 1994) based on the utilization distribution (UD) of fixes. By specifying varying utilization levels, outliers can be omitted progressively (eg 90% UD, 75% UD) and areas of intense home range usage can be identified (eg 50% UD). This is illustrated in Figure 6.3.
Ideally, regardless of the method of measurement, the home range area should approach an asymptote within the period of collecting fixes. The minimum number of fixes required to estimate this asymptote may be calculated by the resampling technique proposed by Jaremovic and Croft (1987).

The pattern of overlap of home ranges across a landscape can give some clues about a population's resource utilization and social behaviour. For instance, if a number of home ranges converge on a small area, that may indicate an important food resource or roost site. If there are mutually exclusive home ranges, I would hypothesize that strongly defended territories are a feature of the species' social structure.

**Methods**

For the present study, the software package CALHOME (Kie *et al.* 1994) was used to calculate and draw MCP and 90%, 75% and 50% UD home range areas.

Generally, to ensure independence, 20 minutes was allowed between fixes (n = 747), although fixes (n = 33) taken within 20 minutes were considered independent where they were ≥ 25 m apart. Other fixes were considered to be autocorrelated and they were discarded. These decision rules for the independence of fixes were based on the time being sufficient to traverse a home range and the distance being relative to the scale of interest in the study. A 10 ha circle has a diameter of 360 m and there was an instance of a bird being tracked over 320 m in less than 20 minutes, although eastern bristlebirds are probably able to traverse such distances more quickly. The study of habitat zones described below was based on the heath-wood ecotone being 25 m either side of the edge.

For each bird, the cumulative home range area was calculated for each successive day of tracking. To determine the number of fixes per bird required to approach an asymptote of home range area, the total cumulative home range area for each bird was plotted against its total number of fixes. To determine the number of days of tracking data required to approach an asymptote of home range, the mean of all of the birds' cumulative home range areas was plotted against the number of days of tracking. For individual birds which were tracked for more than 6 days, to determine the number of days of tracking data required to approach an asymptote of home range, the bird's cumulative home range areas were plotted against the number of days of tracking.

The patterns of overlap of individual home ranges were illustrated by drawing the MCP areas of the birds tracked at sites A and B. The overlap patterns were quantified using the index proposed by Horsup (1994), expressed as a percentage:

\[
\text{Percentage mean overlap of areas } X \text{ and } Y = 100\left\{\frac{X \cap Y}{X} + \frac{X \cap Y}{Y}\right\}/2.
\]
Results

The home ranges of the eastern bristlebirds in the present study were best described as having MCP areas averaging 4 ha (range 1.5-6.6 ha) for one week and ≥ 10 ha for 2-6 weeks. The MCP areas ranged from 1.2-11.6 ha, the 90% UD range was 2.0-7.4 ha and the 50% UD range was 0.23-2.2 ha (Table 6.3). Bird #57 and bird #73 are given as examples to show the different methods of illustrating and calculating home range area (Figure 6.3).

For the present study, no asymptote of home range area could be deduced from the data. The home range MCP area was roughly proportional to the number of fixes (Figure 6.4) and similar patterns were observed for the 50, 75 and 90% UD areas. With the exceptions of birds #55 and #73, the home ranges of the eastern bristlebirds were undersampled. This is illustrated by the lack of asymptotes in the cumulative home range areas of individual birds (Figure 6.5) and in the mean home range of all the birds (Figure 6.6). This does not diminish the utility of the estimates but does emphasize what Spencer et al. (1990) called the temporal dependence of operationally defined home range.

Table 6.3 Radio-tracking data collection and home range areas

<table>
<thead>
<tr>
<th>Bird</th>
<th>Tracking days of data</th>
<th>Fixes</th>
<th>Home range area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>total; max/day</td>
<td>d&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>#51</td>
<td>6</td>
<td>33 9</td>
<td>2.6</td>
</tr>
<tr>
<td>#52</td>
<td>3</td>
<td>15 7</td>
<td>4.6</td>
</tr>
<tr>
<td>#53</td>
<td>5</td>
<td>25 9 (20 m)</td>
<td>5.8</td>
</tr>
<tr>
<td>#54</td>
<td>3</td>
<td>17 8</td>
<td>2.4</td>
</tr>
<tr>
<td>#55</td>
<td>21</td>
<td>107 11</td>
<td>11.6</td>
</tr>
<tr>
<td>#56</td>
<td>3</td>
<td>16 9 (45 m)</td>
<td>1.2</td>
</tr>
<tr>
<td>#57</td>
<td>11</td>
<td>59 13</td>
<td>2.8</td>
</tr>
<tr>
<td>#58</td>
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<td>17 7 (60 m)</td>
<td>1.8</td>
</tr>
<tr>
<td>#59</td>
<td>1</td>
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</tr>
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<td>10</td>
<td>56 9 (20 m)</td>
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<td>5</td>
<td>26 8</td>
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</tr>
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</tr>
<tr>
<td>#73</td>
<td>28</td>
<td>111 18</td>
<td>9.6</td>
</tr>
</tbody>
</table>

<sup>a</sup> d is the distance of the trapping point to the MCP when it was not within the home range MCP area
<sup>b</sup> MCP is the minimum convex polygon
<sup>c</sup> UD is the utilization distribution
Figure 6.3 Home range areas of bird #57 and bird #73. The home range areas show the location of fixes (+) and the minimum convex polygon (MCP) and the 90%, 75% and 50% utilization distribution (UD) for bird #73 and bird #57.
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

Figure 6.4 The effect of sample size on home range MCP area. Sample sizes range from 3 fixes for bird #61 to 111 fixes for bird #73.

Figure 6.5 Daily cumulative home range MCP areas of the 7 birds for which there was > 6 days of radio-tracking data.
The patterns of overlap of the individual MCP home ranges of the birds tracked at sites A and B are shown in Figures 6.7 and 6.8. The pattern is incomplete because the tracking was discontinuous and the period of tracking was brief for most birds and sometimes asynchronous. Generally, neighbours were irregularly spaced with one home range overlapping several others (bird #55 overlaps six others) and overlap varying from 80% to nil (Table 6.4).

Table 6.4 Percentage overlap of neighbour home range MCP areas

<table>
<thead>
<tr>
<th>#52</th>
<th>#53</th>
<th>#54</th>
<th>#55</th>
<th>#56</th>
<th>#57</th>
<th>#58</th>
<th>#61</th>
<th>#62</th>
<th>#63</th>
<th>#64</th>
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<tr>
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<td></td>
<td></td>
<td></td>
<td>#55</td>
</tr>
<tr>
<td>#67</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Site A</td>
</tr>
<tr>
<td>#69</td>
<td>0</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#70</td>
<td>10%</td>
<td>40%</td>
<td>60%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#71</td>
<td>0</td>
<td>0</td>
<td>20%</td>
<td>20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>#61</td>
</tr>
<tr>
<td>#72</td>
<td>0</td>
<td>20%</td>
<td>70%</td>
<td>80%</td>
<td>30%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>#62</td>
</tr>
<tr>
<td></td>
<td>#66</td>
<td>#67</td>
<td>#69</td>
<td>#70</td>
<td>#71</td>
<td>#66</td>
<td>#67</td>
<td>#69</td>
<td>#70</td>
<td>#71</td>
<td>#63</td>
</tr>
</tbody>
</table>
Habitat utilization

Studies of wildlife habitat utilization may be descriptive (eg Kavanagh and Murray 1996) or restricted to analysis of a few broad vegetation types to distinguish different habitats (eg Coleman et al. 1983; Evans 1996; Handasyde and Martin 1996). Fine resolution of habitat types is sometimes attempted (eg Moysey 1997), although it may be complicated by heterogeneity of landscapes and variability in animal behaviour patterns. At Jervis Bay, there is a mosaic of fire histories superimposed upon a mosaic of vegetation types (Taws 1997; BNP-database 1998) and fire-age of vegetation may affect habitat utilization by eastern bristlebirds (Chapter 3).

In the present study, eastern bristlebird habitat utilization is investigated by: (i) broadly describing the vegetation community and fire history, (ii) a study of habitat selection across heath-wood edges and (iii) a study of edge affinity.

Methods

(i) Description
The vegetation community and fire history of all eastern bristlebird radio-tracking locations were noted.

(ii) Habitat selection
Habitat utilization was studied using simple habitat zones with combinations of fire histories and vegetation types related to heath-wood edges at sites A and B. These are the Jervis Bay sites 1 and 4 studied in Chapters 4 and 5 and described in Appendix 4.1. These sites were chosen because they had relatively high eastern bristlebird densities and relatively long, distinct heathland edges dividing relatively large, homogenous areas of vegetation. Birds #51-56 at site A and birds #66, 67 and 69-72 at site B were used because the birds were trapped near the edges, at a mean distance of 23 m from the edge, 10-85 m at site A and 5-30 m at site B. The home range MCP areas were used because they were considered to be representative of the birds' spatial utilization even though most birds were undersampled. Data manipulations were performed using ArcView (ESRI 1996).

For each site, the heath-wood edge was drawn on the vegetation map. The ecotone habitat zone was delimited by lines 25 m each side of the edge and the areas outside the ecotone habitat were denoted wood habitat and heath habitat (Figures 6.7, 6.8 and 6.9). The width of the ecotone habitat zone was chosen by the apparent average extent of the intergrading of heathland with taller woody vegetation and corresponds to the width of the ecotone studied in Chapters 4 and 5. At both sites, the edge line approximated a recent
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

heath-fire boundary and the heath habitat was mostly *Sprengelia incarnata* heath (HiSi) with small patches of low eucalypt woodland and mallee (WdEscEg and MdEsEg). In the heath habitat there was evidence at site A of patchy burns 3 years and approximately 10 years previous to the study and at site B, of a thorough burn 7 years previously. The wood habitat appeared to be long-unburnt and at site A it was mostly *Eucalyptus sclerophylla* - *E. gummifera* woodland (WdEscEg) with some woodland regenerating on former pine plantation (PeP) and at site B it was mostly *E. pilularis* forest (FdEp). The edge habitat at each site was a mix of the wood and heath habitats with substantial patches of tall closed shrubland (HiBe) on the wood side of the edge. For site B, to expedite mapping, the southern end of the edge line forced a small patch of heathland onto the wood habitat side. On the ground, this patch is smaller than the area mapped and was considered analogous to the small patches of woodland which were included in the heath habitat.

Definition of the study area is of critical importance to $\chi^2$ calculations because it determines the areas of the available (expected) habitat. In their study of the American woodcock, Krementz and Pendleton (1994) used arbitrary boundaries whereas, in a study of the California black rail, Flores and Eddleman (1995) had a clearly defined 15.4 ha wetland study area. Habitat analysis using arbitrary boundaries may give spurious results (Johnson 1980; Porter and Church 1987) but the present study lacked clearly defined natural boundaries. Hence, it was decided to define the study area at each site as the union of the home range MCP areas of the six birds being studied. The available habitat areas were calculated from the proportion of each habitat in the study area at each of the two study sites (Table 6.6). This is illustrated in Figure 6.9 by the total of the coloured areas less the area not included in the home range MCP areas for the individual birds at each site.

In the study of habitat selection, to compare habitat utilization (observed) to habitat availability (expected), Neu *et al.* (1974) used a $\chi^2$ goodness of fit test. The method has low rates of Type I and II errors for a small number of habitats (4) and small numbers of animals (10) with small numbers of fixes (50) (Alldredge and Ratti 1986). It is a standard procedure used to study habitat selection which was considered suitable for the present study of the eastern bristlebird. In studies where individual animals differ in their use of the available habitats, pooling data across animals would tend to cancel out the evidence for habitat selection among animals. To avoid this problem, the $\chi^2$ for individuals may be summed to test the null hypothesis that there is no habitat selection among all animals (White and Garrott 1990; Aebischer *et al.* 1993; K Russell pers. comm.). This procedure was used in the present study and analysis followed the stepwise guide provided by White and Garrott (1990). The habitats in the present study were wood, ecotone and

120
heath. Habitat utilization was taken to be the number of fixes per habitat. The Bonferroni $z$ statistic (Miller 1966) ($\alpha = 0.05; k = 3$ habitat types) was used to determine habitat selection, either preference or avoidance.

For $\chi^2$ goodness of fit calculations, the suggested rule that no more than 20% of the expected frequencies should be less than five (Zar 1984) may be relaxed (Conover 1980; K Russell pers. comm.). The procedure of Yarnold (1970, given in Conover 1980) was applied to the present study and the minimum allowable expected frequency for three habitat classes, where one habitat has an expected frequency less than five, was calculated to be 1.67. The expected frequencies for the 12 birds in each of the three habitats was greater than this minimum value.

(iii) Edge affinity

To measure edge affinity, Tufto et al. (1996) modified the procedure of Kremsater and Bunnell (1992) by considering individual animals as the sample unit to overcome the problem of pooling data across animals. The method compares the distribution of actual fixes with a uniform distribution of points within each animal's home range MCP area and it was considered suitable for the present study of the eastern bristlebird.

The study sites and animals were the same as for the study of habitat selection. The uniform distribution of points was created by points at 2 m intervals along a set of lines spaced at 2 m and parallel to the edge line. In the present study this generated 2 500 uniformly distributed points per ha which is approximately 200 times the density of actual fixes and overcomes the quandary of how many random points are needed to compare with actual points (Kremsater and Bunnell 1992).

At each site, the edge line divided the home range MCP areas of each individual into two part "polygons". This is illustrated in Figure 6.9 by the green versus the pink areas. For each part polygon, an edge index was calculated using the mean distance to the edge line of the fixes divided by the mean distance to the edge line of the uniformly distributed points. Then, for each home range, each bird's edge affinity index was calculated using the mean of the edge indices for the two part polygons weighted by the number of fixes in each part. The set of the 12 birds' edge affinity indices was tested for normality using the Shapiro-Wilk test and their mean was tested against one (1), the hypothetical index for no edge affinity, using a two-tailed t test (Zar 1984).
Chapter 6  Radio-tracking eastern bristlebirds at Jervis Bay

Results

(i) Description
The radio-tagged birds were tracked in a wide variety of habitats. There were nine different vegetation communities ranging through dry forest, woodland, shrubland, heathland and sedgeland. These have various fire histories including areas with eight different fire-ages 3 to ≥ 24 years, burnt at various times of the year with a range of intensities (Table 6.5; Figures 6.7 and 6.8).

Table 6.5 Habitat of eastern bristlebird radio-tracking locations

<table>
<thead>
<tr>
<th>Vegetation code&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Vegetation community&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Fire history to January 1997&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>FdEp</td>
<td>Eucalyptus pilularis dry forest</td>
<td>Appeared to be long-unburnt (≥ 24 years). Last fire probably a wildfire in 1972.</td>
</tr>
<tr>
<td>WdEscEg</td>
<td>E. sclerophylla - E. gummifera dry woodland</td>
<td>Patchy to thorough management burns in parts with fire-ages 3, 7, 12, 14 and 18 years.</td>
</tr>
<tr>
<td>MdEsEg</td>
<td>E. sieberi - E. gummifera dry mallee</td>
<td>Very patchy management burn 3 years previous. Probably burnt 18 years previous.</td>
</tr>
<tr>
<td>HiBe</td>
<td>Banksia ericifolia intermediate heath (mostly closed shrubland ≥ 3 m)</td>
<td>Some long-unburnt (≥ 24 years) and some very patchy to patchy management burns 3 and probably 15 years previous.</td>
</tr>
<tr>
<td>HiSi</td>
<td>Sprengelia incarnata intermediate heath</td>
<td>Patchy to thorough management burns in parts with fire-ages 3, 7 and 10 years.</td>
</tr>
<tr>
<td>HwLj</td>
<td>Wet heath (with Leptospermum juniperinum and B. ericifolia)</td>
<td>Probably unburnt for ≥ 15 years in some parts and ≥ 24 years in some parts.</td>
</tr>
<tr>
<td>HkAd</td>
<td>Allocasuarina distyla rocky heath (mostly closed shrubland ≥ 3 m)</td>
<td>Long-unburnt (≥ 24 years).</td>
</tr>
<tr>
<td>VfGc</td>
<td>Gahnia clarkei fern sedgeland</td>
<td>Probably unburnt for ≥ 15 years.</td>
</tr>
<tr>
<td>PeP</td>
<td>Former pine plantation</td>
<td>Parts probably burnt 12 or 18 years previous (woodland with dense bracken ground cover)</td>
</tr>
</tbody>
</table>

<sup>a</sup> from Taws (1997); <sup>b</sup> from BNP-database (1998) and J Baker (pers. obs.)

(ii) Habitat selection
Generally, the eastern bristlebirds in this study selected among the habitats of wood, ecotone and heath. At both sites combined, among all birds, there was significant habitat selection ($\chi^2 = 129.7$, $P < 0.001$). There was significant habitat selection for the birds at site A ($\chi^2 = 103.9$, $P < 0.001$) and at site B ($\chi^2 = 25.85$, $P < 0.02$) (Table 6.6).

However, overall there was not a strong pattern of birds preferring or avoiding particular habitats. Instead, eight birds preferred or avoided one or more of the habitats and four birds were detected at the three habitats as often as expected considering the proportion of
each habitat that was available. In particular, there was little evidence that the ecotone was the preferred habitat of the eastern bristlebird. Two birds preferred ecotone habitat, one avoided it and the remaining nine were detected in the ecotone habitat zone as often as expected (Table 6.6).

**Table 6.6** Habitat selection by 12 radio-tracked eastern bristlebirds

<table>
<thead>
<tr>
<th>Bird</th>
<th>$\chi^2$</th>
<th>$v$</th>
<th>Site A (p)</th>
<th>Habitat and n(fixes)</th>
<th>Total fixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>#51</td>
<td>9.12</td>
<td>2</td>
<td>Wood (0.371)</td>
<td>Avoid (6) - (12) Avoid (0) - (15)</td>
<td>33</td>
</tr>
<tr>
<td>#52</td>
<td>8.13</td>
<td>2</td>
<td>Ecotone (0.183)</td>
<td>Avoid (0) - (12) Prefer (12)</td>
<td>15</td>
</tr>
<tr>
<td>#53</td>
<td>12.4</td>
<td>2</td>
<td>Heath (0.446)</td>
<td>Prefer (17) - (5) Avoid (3)</td>
<td>25</td>
</tr>
<tr>
<td>#54</td>
<td>7.17</td>
<td>2</td>
<td></td>
<td>Avoid (1) - (5) - (11)</td>
<td>17</td>
</tr>
<tr>
<td>#55</td>
<td>32.5</td>
<td>2</td>
<td></td>
<td>- (34) Prefer (42) Avoid (31)</td>
<td>107</td>
</tr>
<tr>
<td>#56</td>
<td>34.5</td>
<td>2</td>
<td></td>
<td>Avoid (2) Prefer (12) Avoid (2)</td>
<td>16</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>103.9</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site B (p)</th>
<th>Wood (0.243)</th>
<th>Ecotone (0.216)</th>
<th>Heath (0.541)</th>
<th>Total fixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>#66</td>
<td>10.6</td>
<td>2</td>
<td>Avoid (0) - (4) Prefer (21)</td>
<td>25</td>
</tr>
<tr>
<td>#67</td>
<td>1.46</td>
<td>2</td>
<td>- (12) - (7) - (29)</td>
<td>48</td>
</tr>
<tr>
<td>#69</td>
<td>7.06</td>
<td>2</td>
<td>Avoid (1) - (5) Prefer (20)</td>
<td>26</td>
</tr>
<tr>
<td>#70</td>
<td>0.0820</td>
<td>2</td>
<td>- (11) - (9) - (22)</td>
<td>42</td>
</tr>
<tr>
<td>#71</td>
<td>3.30</td>
<td>2</td>
<td>- (15) - (18) - (26)</td>
<td>59</td>
</tr>
<tr>
<td>#72</td>
<td>3.37</td>
<td>2</td>
<td>- (8) - (8) - (9)</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>25.85</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total all</strong></td>
<td>129.7</td>
<td>24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$v$ is the degrees of freedom for each $\chi^2$ test; $p$ is the proportion of available habitat at each site.

(iii) Edge affinity

The set of the 12 birds' edge affinity indices did not depart significantly from a normal distribution (Shapiro-Wilk test $W = 0.927$, $P = 0.331$). The mean ($\pm$ se) of the edge affinity indices $1.06 (\pm 0.062)$ was not significantly different from what would be expected for a uniform distribution of tracking points ($t_{0.05, (2)}, 11 = 2.201$; $t = 0.933$, $P > 0.342$). In other words, the eastern bristlebirds did not show an attraction to or avoidance of the edge.
Figure 6.7 Site A. Vegetation communities (codes as per Table 6.5) and home range MCP areas of the eastern bristlebirds tracked at site A. Tracks and roads are shown as dotted lines.
Figure 6.8 Site B. Vegetation communities (codes as per Table 6.5) and home range MCP areas of the eastern bristlebirds tracked at site B. Tracks and roads are shown as dotted lines.
Figure 6.9 Habitat zones across the heath-wood edge at Sites A and B.
Discussion

Trapping to tracking

The materials and procedures used to trap, process, radio-tag and track eastern bristlebirds in this project were generally considered to be quite satisfactory. Trapping took a large proportion of the field work time and this reduced the time available for tracking. In future, this situation could be overcome with additional field workers or by increasing the trapping success rate. Other studies have reported similar variable and short times of radio-tag attachment (Sykes et al. 1990; Johnson et al. 1991; Murphy 1994). Nevertheless, the short time of attachment in the present study was disappointing and it may have been exacerbated because the birds were undergoing their annual moult. Trapping in early spring would possibly increase the trapping rate if the birds were more responsive to taped call replay and should avoid the problems of moult of feathers and bleeds pin feathers. However, there is a strong risk of disrupting breeding if eastern bristlebirds are disturbed in spring (Chapter 1). Future similar radio-tracking projects will need to anticipate this dilemma.

Alternative, more secure methods of radio-tag attachment using a thread harness (Sykes et al. 1990), collar (Marcstrom et al. 1989) or leg band (Morris and Burness 1992) were considered unsuitable for the eastern bristlebird because of the possibility of becoming snagged in their dense habitat. Surgical implanting of radio-tags was also considered inappropriate because of the problematic nature of the eastern bristlebird and the numerous potential difficulties associated with the method (Perry et al. 1981). In the future, tail mounting could be attempted but I expect that eastern bristlebirds would quickly remove the radio-tags with or without their tail feathers.

The effects of the radio-tags on the birds

Processing was traumatic for the birds (and nerve-racking for the researchers). One bird died and two became temporarily stressed. When released, all of the birds disappeared quickly but then seemed to take a few hours before they began to move about normally. They appeared to recover within the first day and were then capable of rapid and extensive movements and typical short flights. When the detached radio-tags were found there was no sign of injury to the birds. The effects of trimming the feathers was temporary. Bird #52 had begun to regrow feathers 9 days after radio-tag detachment. Sykes et al. (1990) found that feather replacement in small passerines, independent of the moult cycle, occurred within 17-24 days. The radio-tags used in the present study were considered to be sufficiently small to cause minimal deleterious effects and minimal changes in behaviour to the birds being studied. Future studies would benefit from more
Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

rapid attachment techniques aimed at reducing the trauma of processing. Captive experimental animals (eg common starling) could be used to investigate rapid glues such as 10 second Supa Glue (Selleys) and refinement or omission of the feather-trimming process.

Evidence indicated that one radio-tagged bird was killed by a fox but this did not suggest a particularly vulnerable bird. There has been evidence of similar instances of untagged eastern bristlebirds being predated at Barren Grounds and Nadgee (Chapter 1).

Radio-tagging may be better tolerated by some species than others. Johnson et al. (1991) found that of four similarly small species, only one, a cardinal, displayed little tolerance for an interscapular radio-tag. The cardinals worked at the tag until they removed it. In the present study, the scraping and bending of the aerials and the generally short attachment times suggested that eastern bristlebirds may have little tolerance to wearing an interscapular radio-tag.

Population density estimate

The pattern and magnitude of the eastern bristlebird population density observed at Jervis Bay in the radio-tracking study were similar to the previous aural study (Chapter 2). The density appears to have increased by 15-30% between December 1994-February 1996 and autumn 1997. There are three plausible reasons: (i) The population may be unchanged but the earlier aural survey detected less birds than the 1997 radio-tracking study. A similar result was obtained by Novoa (1992) who detected 75% of his radio-tagged partridge by their call alone. (ii) The population may be stable overall with the apparent increase being the post-breeding influx of juveniles, many of which would not be expected to survive to the following spring. (iii) The population may have increased due to natural breeding success made possible by the relative lack of disturbance to eastern bristlebird habitat in the 1994-7 period.

Estimates of maximum eastern bristlebird density based on aural surveys have ranged from 6 birds per 100 ha at Nadgee to 32.5/100 ha at Jervis Bay and 52/100 at Barren Grounds (Chapters 2 and 3). The present radio-tracking study gave a very similar maximum density estimate of 42 birds per 100 ha. This result, together with the general pattern of movements and home range areas, makes me confident that the previous estimates were valid measures of the actual eastern bristlebird densities.

Home range

The average home range of an eastern bristlebird may be considered as a MCP area of approximately 10 ha. This is at the upper limit of home range size found for other
omnivorous-insectivorous passerines considering their weight and daily energy requirements (Schoener 1968; Mace and Harvey 1983) and also accommodates the records of two banded birds at Barren Grounds which moved 600 m in less than a year (unpubl. data). Home range has not been estimated for the eastern bristlebird previously, although it was inferred to be 1-2 ha (McNamara 1946; Blakers et al. 1984; Holmes 1989; Baker and French 1994). There is no published home range estimate for the rufous bristlebird. For the western bristlebird, which weighs 75% of the eastern bristlebird, Smith (1987) estimated from aural surveys that pairs occupied irregular amoeboid-shaped home ranges of 6-8 ha and Murphy (1994) radio-tracked two birds which had MCP areas of 6 and 21 ha.

Minimum convex polygon shape and area used to describe eastern bristlebird home range are conservative in terms of the species' ecology. Areas of intense home range usage such as the 50 % UD area (Table 6.3) or the core areas of 1-3 ha calculated for the western bristlebird (Smith 1987) omit infrequently used but nevertheless important parts of an animal's home range, eg a drinking point visited for only one minute each day (North and Reynolds 1996). For instance, bird #57 was tracked making brief (< 1 hour) sallies to the south-western end of its home range on three consecutive days and the fixes for these movements are excluded from the 90% UD (Figure 6.3). However, such sallies may be vital to population dispersal and gene flow (Koenig et al. 1996). Furthermore, the present study was confined to a brief period of radio-tracking within a single population and does not account for the likely differences among locations (Laidlaw and Wilson 1996) or the likely changes in ranging behaviour which may occur in different seasons (Spencer et al. 1990) and with different times in the breeding cycle (Grahn 1990; Spencer et al. 1990; Chandler et al. 1994; Montadert 1995).

**Habitat utilization**

The vegetation at Jervis Bay is heterogeneous and the radio-tagged eastern bristlebirds were caught and/or tracked in a wide variety of habitats similar to those where the species had been detected previously (Chapters 4 and 5). The vegetation map (Taws 1997) indicates that it is impossible to be more than 500 m from the edge of a vegetation community and the mosaic pattern of past fires has created edges within the vegetation communities map (Taws 1997; BNP-database 1998). Hence, it is very likely that most eastern bristlebirds would have some edge habitat within their home range. The 12 birds used in the detailed habitat study were trapped at an average of 23 m from a heathland edge and hence, were considered more likely to utilize ecotones than birds trapped hundreds of metres from an edge. However, no overall pattern of ecotone preference or edge affinity was detected.
The width chosen for the ecotone habitat zone (edge line ± 25 m) in the present study was similar to the ± 20 m chosen by Bramwell et al. (1992) in their study at Barren Grounds. They detected significantly more eastern bristlebirds within this 40 m zone than expected for the proportion of ecotone habitat available. In the present study, two eastern bristlebirds preferred edge habitat, one avoided the edge habitat and the remaining nine were detected in the edge habitat zone as often as expected. The edge affinity method of Tufto et al. (1996) removes any bias associated with specifying the width of an edge zone. This analysis showed that the 12 eastern bristlebirds had no edge attraction (or avoidance).

From this evidence it is concluded that heath-wood ecotones may provide suitable habitat for some eastern bristlebird at Jervis Bay but that heathland edges do not define the species’ preferred habitat. Similarly, although some individual birds chose heath or wood habitats, overall eastern bristlebirds utilized the heath and wood habitats approximately in proportion with the available area with the possible exception that the wood habitat was avoided by more individuals.
Appendix 6.1

Radio-tags on small to medium-sized birds: their relative size and effect.

Tags were glued to inter-scapular or *otherwise in one study.

The Table shows a total of 24 studies across 32 avian taxa weighing 7-180 g, carrying radio-tags 0.4-6.9 g which were 0.9-16% of their weight. Five of the studies did not mention the effect of the radio-tags. Ten studies reported no effects on the birds. Six of the studies reported generally minor effects associated with radio-tagging and tracking, mainly on the first day, although in two of these studies a bird died. In two studies, radio-tagging was implicated in reduced breeding success. In the remaining study, Hooge (1991) found that acorn woodpeckers reduced their amount of flying with radio-tags > 5% of their body weight but behaved normally with radio-tags weighing < 4%.

<table>
<thead>
<tr>
<th>Species</th>
<th>Bird weight (g)</th>
<th>Radio-tag weight (g)</th>
<th>Tag : Bird %</th>
<th>Effect of tag (source reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gouldian finch (4)</td>
<td>approx. 14</td>
<td>0.9-1.0</td>
<td>approx. 7</td>
<td>No effect reported (1).</td>
</tr>
<tr>
<td>Red-browed finch (3)</td>
<td>approx. 15</td>
<td>0.7</td>
<td>7</td>
<td>No effect reported (2).</td>
</tr>
<tr>
<td>Helmeted honeyeater (14)</td>
<td>approx. 17</td>
<td>1.7 and 2.3</td>
<td>4.5-8</td>
<td>Laboured flight for first few hours (3). Possible minor change in foraging strategy: less flying (4).</td>
</tr>
<tr>
<td>New Holland and white-cheeked honeyeaters (23)</td>
<td>20 (NHhe)</td>
<td>1.5-1.6</td>
<td>7.6-8.7</td>
<td>Initially, some pecking at tag but then no obvious affect on behaviour (5). One died within 40 hours of release. Two avoided observers when they were tracking close to the bird (6).</td>
</tr>
<tr>
<td>Western bristlebird (3)</td>
<td>approx. 30</td>
<td>2</td>
<td>approx. 7</td>
<td></td>
</tr>
<tr>
<td>Noisy scrub-bird (7)</td>
<td>f: (31.5-39.2); m: (47-57)</td>
<td>f and m 2; m 1.2</td>
<td>2-6.3</td>
<td>No effect reported (7).</td>
</tr>
<tr>
<td>Plains-wanderer</td>
<td>approx. 40-95</td>
<td>1.5</td>
<td>approx. 1.6-3.8</td>
<td>No discomfort or behaviour changes were discernible (8).</td>
</tr>
<tr>
<td>(captive bird trials + 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground parrot (4);</td>
<td>70-94;</td>
<td>4.8-5.6;</td>
<td>5-8;</td>
<td>Birds appeared unaffected (9); no effect reported (10);</td>
</tr>
<tr>
<td>(18);</td>
<td>mean 78;</td>
<td>4.7-5;</td>
<td>6-6.4;</td>
<td>birds flew away strongly (11).</td>
</tr>
<tr>
<td>(13)</td>
<td>84-108</td>
<td>4.5-5</td>
<td>4.2-6</td>
<td></td>
</tr>
</tbody>
</table>

Approximate weights are given where the given reference did not indicate bird weight

### Chapter 6 Radio-tracking eastern bristlebirds at Jervis Bay

#### Studies outside Australia

<table>
<thead>
<tr>
<th>Species (sample size)</th>
<th>Bird weight (g)</th>
<th>Radio-tag weight (g)</th>
<th>Tag : Bird %</th>
<th>Effect of tag (source reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common yellowthroat (8)</td>
<td>7.6-15.5</td>
<td>1.1</td>
<td>8.6</td>
<td>One died due to capture stress. Remaining seven had excellent physical health. No effect on the number of flights or weight (12).</td>
</tr>
<tr>
<td>Tits (46): blue, great, crested &amp; coal; Garden warbler (39)</td>
<td>9-18</td>
<td>0.4-0.9</td>
<td>4-5</td>
<td>Normal behaviour resumed within 0.5-24 hours. Possible adverse effects due to handling of 3/150 birds (13).</td>
</tr>
<tr>
<td>California black quail (36)</td>
<td>33</td>
<td>2</td>
<td>6</td>
<td>No effect reported (14).</td>
</tr>
<tr>
<td>Interior least tern &amp; Western snowy plover (38)</td>
<td>approx. 35</td>
<td>2-2.6</td>
<td>6-7</td>
<td>No adverse reaction. No effect on reproductive success rates (15).</td>
</tr>
<tr>
<td>Brown-headed cowbird (60)</td>
<td>approx. 44</td>
<td>1.7-1.8</td>
<td>3-5</td>
<td>30% ignored the tag. The rest pecked and preened it for up to several hours. Two birds persisted for many hours until they removed their tags. Otherwise, all behaviour was normal (16).</td>
</tr>
<tr>
<td>Blue jay; American robin; Brown thrasher; Northern cardinal</td>
<td>approx. 50</td>
<td>1.4</td>
<td>generally &lt;3</td>
<td>No apparently abnormal behaviour (17).</td>
</tr>
<tr>
<td>California least tern (7)</td>
<td>60</td>
<td>1.8</td>
<td>3</td>
<td>Affected breeding success (18).</td>
</tr>
<tr>
<td>Acorn woodpecker (25)</td>
<td>76-84</td>
<td>3</td>
<td>3.5-3.9</td>
<td>No effects.</td>
</tr>
<tr>
<td>Robin (1); House sparrow (1); Common starling (8); Common grackle (8)</td>
<td>76.6 (robin)</td>
<td>5.7</td>
<td>7.4</td>
<td>Reduced time in high energy activities (19).</td>
</tr>
<tr>
<td>Common starling (8)</td>
<td>95 (starling)</td>
<td>6.4</td>
<td>6.7</td>
<td>No effects (20).</td>
</tr>
<tr>
<td>Common grackle (100 (grackle))</td>
<td>4.7-6.9</td>
<td>4.7-6.9</td>
<td>3.4</td>
<td>Some birds slower on the first day. Otherwise, no effect (21).</td>
</tr>
<tr>
<td>Common tern (10)</td>
<td>approx. 120</td>
<td>1.1</td>
<td>0.9</td>
<td>*Tag glued to leg-band. No effect on brood attendance patterns or chick feeding rates (22).</td>
</tr>
<tr>
<td>American woodcock (8); (177)</td>
<td>approx. 120-170</td>
<td>3.5-5</td>
<td>3</td>
<td>Three hens abandoned broods (23)</td>
</tr>
<tr>
<td>Great snipe (52)</td>
<td>180 (female)</td>
<td>3.2</td>
<td>1.8</td>
<td>No effect reported (24).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species (sample size)</th>
<th>Bird weight (g)</th>
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<tr>
<td>American woodcock (8); (177)</td>
<td>approx. 120-170</td>
<td>3.5-5</td>
<td>3</td>
<td>No effect reported (24).</td>
</tr>
<tr>
<td>Great snipe (52)</td>
<td>180 (female)</td>
<td>3.2</td>
<td>1.8</td>
<td>A detailed study showing no differences for clutch size or volume, egg-fertilization, physical condition or territorial behaviour (25).</td>
</tr>
</tbody>
</table>

Chapter 7

General Discussion

It was a wearying and discouraging business, for tramping through the areas which form the habitat of this bird is a tiring pastime indeed, and, in addition, is often most unpleasant, especially in areas where the prickly Hakea bush grows. (McNamara 1946)

Synthesis of results

Status of the eastern bristlebird

The biological status of the eastern bristlebird was adequately documented by 1997. There were fewer than 2 000 individuals occupying less than 120 km². The 6-9 northern populations were on the brink of local extinction. There was one small widely spread southern population. The central populations were concentrated at Barren Grounds-Budderoo and Jervis Bay and they both exceeded 500 individuals. Population estimates were all based on density estimates derived from aural surveys. For the Jervis Bay population, the density estimates calculated using aural survey data were very similar to those calculated using radio-tracked birds. This result placed confidence in the validity of the aural surveys in all areas.

The legal status of the eastern bristlebird has been changed during the past decade from Vulnerable to the more appropriate category of Endangered. This has happened in all states where the species occurs (Queensland, NSW and Victoria) and nationally, in recognition of its historic decline and current biological status.

Fire and the habitat of the eastern bristlebird

Eastern bristlebirds are found in a wide variety of vegetation types, all of which are fire-prone. The species is cover-dependent and fire-sensitive. Fire is a major disturbance in eastern bristlebird habitat and a major threat to the species in all areas where it occurs. Individuals may be killed by fire, the dense low vegetation which characterizes eastern bristlebird habitat is removed by fire and repeated fire and/or extensive fire may suppress population growth and cause local populations to become extinct. Long-term fire exclusion would benefit the eastern bristlebird and this thesis has answered two questions which support this conclusion.

(i) Do eastern bristlebird populations rebuild quickly after fire? No. The results for Barren Grounds indicate that a population may plateau ten years after fire provided that only a relatively small proportion of the habitat is burned. The results for Nadgee indicate that populations may take much longer than ten years to rebuild after intense and widespread fire.
(ii) Can eastern bristlebirds persist and breed in long-unburnt habitat? Yes. The two largest populations have relatively high densities in the habitat with the oldest known local fire-age. At Barren Grounds, there was a density of 2.4 birds/5 ha in an area with a fire-age of 18.4 years and at Jervis Bay, the area of highest concentration of bristlebirds included areas unburnt for 24.3 years. At Nadgee, there was a confirmed breeding record for eastern bristlebirds in an area with fire-age exceeding 24 years.

Two further questions arise in regard to the ability of eastern bristlebird populations to recover if the disturbance of fire in their habitat is removed.

(i) Can existing populations grow through natural breeding success? Yes. At Barren Grounds, in the absence of fire during 1992-7, the population increased from 310 to 600 which is equivalent to an exponential growth rate of 13.2% per annum.

(ii) Can populations expand into surrounding habitat? Yes. Although semi-flightless, individuals can traverse relatively large distances (> 500 m) across the landscape in one day and daily movements around their habitat can amount to a substantial distance (> 1 500 m). Individuals can run across wide open spaces such as roads (> 50 m). At each of the three largest populations, there have been instances of isolated eastern bristlebirds recorded several kilometres away from the bulk of other records.

Other threatened bird species have begun to recover when they were protected from disturbance. In the case of the noisy scrub-bird, when fire was excluded and the threat of predators was reduced, the population grew and extended its range (Danks 1997). Populations of two threatened New Zealand birds, the takahe and the North Island saddleback, survived better when translocated to islands of habitat different to their source location which demonstrated that previous assumptions about their habitat requirements were too narrow (Craig 1997). Lack (1933) argued that when "typical" habitat was overcrowded, individual birds became less restrictive in their habitat selection.

Using modelling of species boundaries, Lennon et al. (1997) demonstrated that for species with a metapopulation structure, population stochasticity rather than unsuitable habitat may be the cause of failure to expand their range. This concurs with the theory that birds will occur where they can rather than as part of a tightly structured community (Kikkawa 1982; Keast 1985).

Hence, the results of this thesis, evidence from the practice of managing other threatened birds species and ecological theory all support the following conclusion. If the larger existing eastern bristlebird populations (Barren Grounds-Budderoo, Jervis Bay and
possibly Nadgee) were protected from disturbance, particularly fire, they could begin to recover through both population growth and by expanding their local area of occupancy.

The bird community across heath-wood edges

A study was undertaken to test for the presence of ecotonal bird species and for increased bird diversity across heath-wood edges. There was no evidence for any entirely ecotonal species. The only evidence for an edge effect occurred on the wood side of the edge where there was a modestly greater abundance of birds at the ecotone compared with 100 m into the wood. The outstanding avian community patterns were that bird diversity in the wood habitat was double that of the heath habitat and that the specialization of bird species for the habitat on either side of the edge was more pronounced than the pattern of response to the ecotone.

Similarly, a study of vegetation found little evidence for the presence of a unique vegetation structure at heath-wood ecotones. Overall, the vegetation structure across the heath-wood edge was similar. The underlying patterns were that the heath and heath ecotone had the most similar structure and were separated from the wood and wood ecotones which were similar to each other but showed more diversity of structure than the heath.

Taken together, the results of the bird and the vegetation studies provide strong circumstantial evidence to support the theory that avian diversity is proportional to plant structural diversity. The more structurally diverse plant community at the wood and wood ecotone had a higher bird diversity than the less structurally diverse heath and heath ecotone. Furthermore, the lack of a unique vegetation structure at the ecotone was concomitant with a lack of any entirely ecotonal bird species and little evidence for increased bird diversity at the edge.

The eastern bristlebird at heath-wood ecotones

Although the eastern bristlebird is not entirely ecotonal, the density pattern of the species across heath-wood edges fitted the model for a habitat generalist - ecotone exploiter (Figure 7.1a). This result relied upon aural survey data because of the cryptic nature of the species. The species is cover-dependent and so it was predicted that the pattern of cover at heath-wood ecotones would be unique and different to the adjacent heath and the wood. However, this was not the case. The vegetation structure was dense right across the heath-wood edge and showed an underlying pattern of heath ecotone being most similar to heath and wood ecotone being most similar to wood (Figure 7.1b). Hence, these two sets of results appear to be contradictory.
Twelve eastern bristlebirds were radio-tracked near heath-wood edges in the zones of heath, heath-wood ecotone and wood. Their habitat selection was that (i) three individuals showed preference for the heath, two preferred the ecotone and one preferred the wood and (ii) three individuals showed avoidance of the heath, one avoided the ecotone and five avoided the wood (Figure 7.1c). Furthermore, the distribution of radio-tracking fixes relative to the heath-wood edge was not different to a uniform distribution of points in each bird's home range which showed that, overall, there was neither attraction to edges nor avoidance of edges. The radio-tracking results are consistent with the pattern of the vegetation structure across the heath-wood edge but are inconsistent with the model for an ecotone exploiter. My preliminary conclusions are that (i) the results of the aural survey are biased by eastern bristlebirds being detected more frequently near heath-wood edges than in the adjacent heath or wood and (ii) the eastern bristlebird is more a habitat generalist than a heath-wood ecotone exploiter.
Chapter 7 General Discussion

(a)
Aural survey results showing that the eastern bristlebird fits the model of a habitat generalist - ecotone exploiter (taken from Figure 4.8).

(b)
Height cover profile of the vegetation. Pattern of vegetation cover averaged across all plots and all sites. Summarized from the transformed data of the height cover profile shown in Figure 5.6a. The vegetation structure is shown as dense (●), mid dense (O), sparse (○) or absent.

(c)
Radio-tracking results. The columns show the habitat selection of the same 12 birds at each of the three different habitats of wood, ecotone and heath. This graph is a summary of the information in Table 6.6.
Conservation and management

The eastern bristlebird is threatened with extinction and thereby deserving of and legally entitled to some conservation effort aimed at the recovery of the species. Fire has been identified as a major threat to the species and thus the management of fire in eastern bristlebird habitat is an important conservation issue. The expansion of local populations has been identified as one way to enhance species' recovery and thus home range requirements and movement of eastern bristlebirds are also important conservation issues. The case study of the eastern bristlebird has been a focus throughout this thesis although avian diversity has also been discussed, particularly in regard to heath-wood edges. The management of threatened species recovery and biodiversity generally could be considered at two levels: (i) the level of administrative bureaucracy which is concerned with "whole" species and biomes and (ii) the level of local management which deals with populations "on the ground".

Recovery planning for the eastern bristlebird

Both the Commonwealth Endangered Species Protection Act 1992 and the NSW Threatened Species Conservation Act 1995 require that any species listed as Endangered after their enactment, must have a Recovery Plan prepared within three years. Accordingly, NSW and national plans have been drafted for the eastern bristlebird. Generally, the long-term objective of Species Recovery Plans is to secure the biological status and to remove the species from Threatened Species Lists. For the eastern bristlebird, this requires an increase in the number of individuals and the rebuilding or re-establishment of populations outside Barren Grounds-Budderoo, Bherwerre Peninsula and Nadgee-Croajingolong. The NSW Draft Plan included a research based strategy to monitor populations and their habitat in order to facilitate site-specific, adaptive management.

Recovery planning for the eastern bristlebird has identified the need to increase the size of the established populations. To achieve this goal, future management of eastern bristlebird populations should focus on protecting and promoting the dense low cover of vegetation which characterizes the species' habitat. This may be planned for any vegetation community type where dense low cover can be achieved, regardless of the composition of the plant species and regardless of the extent of heath-wood ecotones.

The pattern of habitat utilization by eastern bristlebirds at Jervis Bay illustrates the importance of managing broad areas of all types of potential habitat as well as the particular locations where individuals are known to occur. Long-term conservation of the
species will be enhanced by larger populations in larger areas of habitat. At Jervis Bay, there are areas of apparently potential habitat with few or no eastern bristlebirds. The focus of future management of the eastern bristlebird at Jervis Bay should be to minimize disturbance of the species and to maximize the opportunities for the population to increase and expand throughout all potential habitat in the district.

Recovery planning has also identified the need to rebuild or re-establish populations outside Barren Grounds-Budderoo, Bherwerre Peninsula (Jervis Bay) and Nadgee-Croajingolong and to assess Ku-ring-gai, Woronora Plateau, Morton and Beecroft Peninsula as possible translocation sites. Potential translocation sites will need to be assessed for suitable habitat, particularly adequate cover, in a wide range of vegetation communities and need not be restricted to heathland vegetation or to heath-wood ecotones.

The distribution of the eastern bristlebird presents a management dilemma. The northern populations are declining to local extinction. The central populations are the largest and, with appropriate management, they appear to offer the best hope for the species to remain extant. The conundrum is how to apportion the limited management resources to achieve the best conservation outcome for the species. "Economic necessity" (Jensz 1996) would suggest that resources would be best invested in the central populations where they are likely to have greatest effect on the conservation of the species as a whole. However, the prospect of local extinctions, particularly the loss of the species from Queensland, could result in a politically motivated decision to allocate a disproportionate amount of resources to the northern populations, although even with intensive management, their long-term viability seems very doubtful.

At all eastern bristlebird strongholds, the ground parrot co-exists and has been a conservation icon and management priority for several decades. The comparative biological status and the Endangered legal status of the eastern bristlebird implies that it now has a higher conservation priority than the ground parrot.

**Fire and the eastern bristlebird**

The eastern bristlebird is fire-sensitive and its management is difficult. It is now limited to a small number of small populations which could be extirpated by fire. Where fires have affected a small proportion of a population's total habitat or where there has been long-term fire exclusion, eastern bristlebirds are relatively abundant. The most sensible way to manage eastern bristlebird habitat in the future would be to exclude fire unless site-specific population monitoring data demonstrate that this is detrimental.
Management plans need to identify areas of eastern bristlebird habitat and the strategies for protecting them from fire. Aerial water-bombing may be useful to control unplanned fire or to create patches of unburnt habitat where fires are out of control. Sources of appropriate fire-fighting water and appropriate types of fire retardants would need to be indicated in the management plans for each area where eastern bristlebirds occur.

Conservation of the eastern bristlebird is unlikely to be the sole management objective in areas where the species occurs. Prescription burns are often used to create fuel-reduction zones to assist with the protection of property against unplanned fire. Where eastern bristlebirds occur, strategic slashing should be tested as a means of reducing the dependence on frequent fuel-reduction burns. In some instances, prescription burns will be used in eastern bristlebird habitat. Prescribed fires are sometimes managed by finishing off with fire-fronts meeting from different directions (e.g., backburning). The use of this fire control measure is likely to block escape routes for eastern bristlebirds and cause a high mortality rate. Presumably, if a fire stops at some non-lethal barrier, some animals would escape ahead of the fire. Hence, where a burnt area is planned as a firebreak, if possible, it should be burned several days prior to the main prescribed burn.

**Eastern bristlebird home range and movements**

Area, length and overlap of eastern bristlebird home ranges are useful indices when considering the species' conservation. The results from the radio-tracking study at Jervis Bay indicate that even small-scale disturbances in eastern bristlebird habitat are likely to impact on numerous individuals. For instance, take a density of 40 eastern bristlebirds in a square of 100 ha of habitat with a 1 km line of road through the middle. If birds remain in exclusive 1 ha territories the road has the potential to impact upon 8 birds. However, with the overlapping 10 ha home ranges and 500 m daily sallies found at Jervis Bay, the road has the potential to impact upon all 40 birds. This may help to explain the high number of road-kills relative to the eastern bristlebird population size at Jervis Bay.

**Avian diversity at heath-wood ecotones**

Avian diversity conservation at Barren Grounds-Budderoo, Jervis Bay and Nadgee will not benefit greatly from a concentrated management of heath-wood ecotones. These ecotones are narrow, they contribute little to avian diversity and there are no bird species which are unique to the ecotone. Edge or ecotone avoiding species would be favoured by large areas of habitat rather than a heterogeneous mosaic of small habitat patches.
Chapter 7 General Discussion

Administrative bureaucracy: threatening process or conservation agency

Australia is a whole ecosystem (Recher and Lim 1990) and, generally, ecological and administrative boundaries do not coincide (Schonewald-Cox and Bayless 1986). Threatened species do not recognize administrative boundaries. For example, eastern bristlebird populations span three state/territory borders: Queensland-NSW, NSW-Jervis Bay Territory and NSW-Victoria. Hence, it makes good sense to have a single national administrative bureaucracy to oversee the conservation of "whole" species.

There is interspecific competition for the limited conservation resources available nationwide. Hence, national priorities for the allocation of resources need to be set and should take precedence over local priorities. For example, at Booderee, the threatened ground parrot is less abundant than the eastern bristlebird. However, nationally, ground parrot numbers are two orders of magnitude greater than the eastern bristlebird and therefore, at Booderee, the bristlebird should have a much higher conservation priority than the parrot. Intraspecific competition for conservation resources is also exemplified by the eastern bristlebird with the declining small northern populations attracting higher levels of conservation funding than the larger central and southern populations. In this case, a cost benefit analysis is needed to guide the allocation of resources. A nation-wide perspective could also facilitate cost-efficient linking of related conservation projects across a broad range of species and threatening processes and across a broad geographic range.

Mediocre government agencies can be a bane to conservation (Craig 1997). Time consuming and wasteful duplication occurs with the present federal-state arrangements for the administration of threatened species in Australia. In the case of the eastern bristlebird, despite the good sense and cost effectiveness of preparing one Recovery Plan, separate plans were drafted for the Commonwealth (to include Queensland) (Holmes 1997b), NSW (Baker 1997a) and Victoria (Bramwell 1997). Lim (1997) commented that there may be some resistance to delisting threatened species which had "recovered". However, my experience with the eastern bristlebird was quite the opposite. There was considerable bureaucratic resistance to the revision of the species from Vulnerable to Endangered in NSW and, as if the "10 Lords of the Universe" (Lim 1997) were not sufficient authority, the species was then re-assessed by a different committee at the national level for consideration of its national legal status.

An Australia-wide system of administration for threatened species conservation is a sensible plan. Time-consuming and money-wasting practices should be eliminated and the conservation effort needs to be concentrated at the "ground level". A high standard of
accountability is needed and the assessment criteria need to be measured, as Adam et al. (1998) suggested, by the improvements in conservation.

Local management: prescriptive or adaptive

Prescriptive management involves repeatedly applying the same set of management actions according to a fixed set of rules. This may be easy from the point of view of local operation management, however, there may be substantial drawbacks. Prescriptions which are applicable to a particular species in one region on one occasion may not be "portable" (Williams et al. 1994) to other times, places, species or situations with other histories. Worse, once established, prescriptions may reinforce unfounded dogma (Saunders and Burbidge 1988). Even worse, prescriptions can overshadow the need to monitor threatened species populations which is arguably the simplest and most important conservation management tool available.

Adaptive management involves the constant review and updating of procedures, plans and policies based on the findings of current research, particularly monitoring (modified from Underwood 1988). It is a sensible alternative to prescription management and encompasses the need expressed by Naiman and DeCamps (1991) to shift from pro-stability management to management for uncertainty. For instance, the ground parrot continues to be regarded as a species which requires frequent fire to maintain suitable habitat (eg Baird et al. 1994; Possingham and Tuck 1998). However, the long-term monitoring programme at Barren Grounds has shown that the parrots have persisted at a high density for more than 14 years (see Figure 3.1) and that the 8 year fire frequency suggested to maintain ground parrot habitat (NPWS 1986) was inappropriate in this case. The key to adaptive management is communication between researchers and managers and within the levels of management (Underwood 1988; and the workshop summaries in Saunders and Burbidge 1988).

Future research

Many research questions have arisen during the course of my studies. These questions are listed below together with some explanations of their ecological, conservation and/or management significance. The answers to many of these questions could be useful in directing the recovery of the endangered eastern bristlebird, although research planning may require consultation with local managers. Saunders et al. (1991) cautioned that research into fragmented ecosystems had provided little of practical value to managers.
Ecotones

At heath-wood edges, are there populations of any species which are entirely ecotonal? Are there any groups of species which are more diverse at the ecotone? A considerable array of questions such as these arise because there are few population studies which have tested for edge effects at naturally occurring ecotones and there is little evidence for an edge effect of increased diversity or any entirely ecotonal species. These questions could be investigated for plant species, invertebrates and the vertebrate groups other than birds. Investigations could be at different scales. For instance, intraspecific response at ecotones could be tested for seasonal variation and using intensive studies of the behaviour of individual animals. The radio-tracking study conducted on eastern bristlebirds at Jervis Bay could be replicated at Barren Grounds to test the generality of the conclusion that the species is a habitat generalist.

Methodological questions arise about the detectability of birds at edges. For instance: Does observer bias affect avian studies at edges? Is there differential detectability of bird species at edges? Could audio and/or audio-visual recording techniques be used to validate the findings of studies which have used a human observer?

Fire

What are the effects of fire on local populations of eastern bristlebirds? Will long-unburnt habitat continue to be utilized by eastern bristlebirds? The results of the study in Chapter 3 showed the post-fire recovery of the species at Barren Grounds during 1992-8. The generality of these results could be tested. For instance, at Jervis Bay, fire is prescribed for reasons other than the conservation of the eastern bristlebird. Hence, there is an opportunity to establish a set of replicated plots with controls to test hypotheses about the effects of fire upon eastern bristlebirds.

Population viability analysis (PVA)

What is the long-term viability of the northern populations of the eastern bristlebird? What management options are most likely to be cost-beneficial in the management of the northern populations and the whole species? What would be the minimum size required for a founder group if eastern bristlebird translocation were to be undertaken? These are theoretical questions with very practical applications. The northern populations have been in decline for at least a century and local extinctions are continuing. Recovery actions may need to be site-specific but perhaps no amount of effort will halt the decline. Modelling of management options (Possingham 1997) and PVA (Shaffer 1990) may provide a decision-making framework which minimises the risk of wasting resources on recovery
efforts for the eastern bristlebird, a problem which has occurred previously with other threatened species (Dickman 1996; Craig 1997). Information about eastern bristlebird genetics may be particularly important to PVA.

Genetics of eastern bristlebird populations

What is the extent of genetic variability within and among eastern bristlebird populations? This is an important question in relation to the long-term viability and recovery of threatened species (as summarized in Armstrong et al. 1994). The lack of genetic variability within small populations may lead to inbreeding depression and a subsequent loss of long-term population viability. If translocations are undertaken as a recovery action, the genetic composition of the founder groups may need to be considered. Mixing genetically distant individuals may lead to hybridization of previously separate genetic lines or to outbreeding depression and a subsequent loss of long-term population viability.

Previous studies (Keast 1957; Smith 1977) have speculated about the climatic and anthropogenic processes underlying the fragmentation of eastern bristlebird populations. Future conservation genetic studies may provide further evidence, particularly about the temporal scale of the fragmentation, which adds to the general knowledge about these processes.

Road-kills

Does vehicular traffic impact significantly upon eastern bristlebird populations? Roads occur through many areas of eastern bristlebird habitat. Road-kills occur at Jervis Bay but the extent of this impact is unknown. Research at Jervis Bay into this question may provide insights which assist eastern bristlebird conservation locally and which generalize to other populations and species.

Bristlebird gender

Can reliable methods be developed to sex an eastern bristlebird? Reliable sexing of eastern bristlebirds based on their call would make the results of aural surveys more useful in demographic studies. Reliable sexing of birds in the hand, based on morphology or a blood test, would be useful for establishing an appropriate sex ratio in the founder group of any translocation programme.

Diet of the eastern bristlebird

What is the diet of the eastern bristlebird? Is diet specialization a limiting factor affecting the success of extant populations? Is diet variable with season? Do heath-wood ecotones
provide greater diversity of dietary items? In addition to the intrinsic value of the answers to these questions, their applied value would be in assessing the suitability of habitat, particularly at any proposed translocation site.

**Monitoring**

What are the spatial and temporal patterns of eastern bristlebird populations? The answers to this question are fundamental to the management of the species. Adaptive management is based on current species monitoring information. The success of recovery actions, translocations and changes to management practices should be assessed in terms of population growth and range expansion. Temporal changes in habitat, particularly in relation to fire-age, need to be assessed against habitat utilization.

And, then there is the best reason to monitor our threatened species. The managers and researchers in whose care threatened species conservation is entrusted, need to go outdoors and to keep in touch with the wildlife that is so precious.

*And is he not immortal, where I found him, in love and hope, along his careful pages?*
*the poet vanished, in the vanished forest, among his brightly tinted extinct birds?*

Judith Wright
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