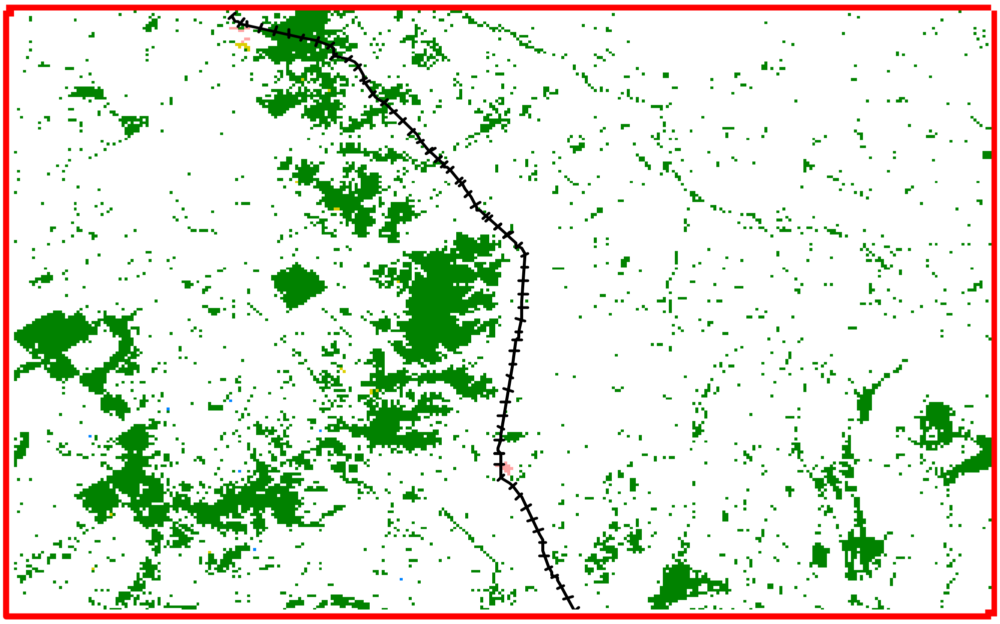
THREATENED AND DECLINING BIRDS IN THE NEW SOUTH WALES SHEEP-WHEAT BELT:

II. LANDSCAPE RELATIONSHIPS – MODELLING BIRD ATLAS DATA AGAINST VEGETATION COVER



Patchy but non-random distribution of remnant vegetation in the South West Slopes, NSW

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NOVEMBER 2000

A consultancy report prepared for the New South Wales National Parks and Wildlife Service with Threatened Species Unit (now Biodiversity Management Unit) funding.

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Citation:

Reid, J.R.W. 2000. *Threatened and declining birds in the New South Wales Sheep-Wheat Belt: II. Landscape relationships – modelling bird atlas data against vegetation cover.*

Consultancy report to NSW National Parks and Wildlife Service. CSIRO Sustainable Ecosystems, Canberra.

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Acknowledgments

This report completes Phase 2 of a continuing research program that is examining the status, threats, habitat, life-history characteristics and other management needs of threatened and declining bird species in the Sheep-Wheat Belt of New South Wales. I owe my chief debt of gratitude to the Project Manager, Sue Briggs (NSW National Parks and Wildlife Service), for initiating the research and for subsequent direction and collaboration; her colleagues, J. Seddon and S. Doyle, have also been unstinting in their help – for access to their preliminary results from unpublished data sets, thanks to all three. For his far sightedness in arranging funding for this project I thank Graham Wilson in NSW NPWS.

To colleagues here at CSIRO Sustainable Ecosystems (CSE), particularly M. Austin, G. Barnett, J. Baxter, D. Freudenberger, D. Saunders, N. Nicholls, D. Spratt and S. Morton, I owe a special debt of gratitude. Colleagues R. Allen, D. Baker-Gabb, G. Barrett, A. Bennett, M. Clayton, A. Fisher, S. Garnett, H. Ford, C. Kinross, R. Mac Nally, R. Major, D. Oliver, A. Overs, D. Paton, H. Recher, D. Robinson, N. Schrader, B. Traill and A. Wilson have also been liberal with their expertise and encouragement.

I thank colleagues in Environment Australia, Simon Bennett, Karl Bossard and Arthur Chapman, for assistance with cleaning the Bird Atlas data set, and to Dr Michele Barson and Dr Lucy Randall in Bureau of Rural Sciences for providing the remnant woody vegetation data set. Birds Australia is thanked for providing the Bird Atlas data to CSIRO.

Julian Reid, 2 November 2000

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Julian R.W. Reid November 2000

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Extended Summary

Aims, Methods and Results

Many recent studies have revealed that once common birds of open forest, woodland and mallee formations are undergoing serious population declines in the extensively modified agricultural landscapes across southern temperate Australia. The root cause is the loss of habitat with over 80% of the original vegetation having been cleared in most regions. It cannot be predicted at what point the process of decline will halt, we cannot tell how many species might be lost from these landscapes before the process of faunal relaxation has run its course. Faunal relaxation, also sometimes known as the extinction debt, is the extended process of species loss following habitat destruction. There is a precautionary imperative, therefore, to take comprehensive restoration action urgently. Further vegetation clearance should be curtailed and the remaining natural vegetation managed to balance the needs of biodiversity conservation and sustainable economic production.

Across the New South Wales Sheep-Wheat Belt most vegetation remnants are small and most small remnants are degraded. The deterioration in habitat quality of remnant vegetation, particularly of these smaller remnants, continues and is probably a major factor in the continuing loss of species. Previous workers have attempted to differentiate between species extinctions caused by habitat loss per se *and those caused by fragmentation. However, as habitat loss on the massive scales witnessed in these regions almost invariably sets in train a process of habitat degradation which, in turn, may contribute to observed fragmentation effects, I argue it is simplistic to attempt to differentiate among the many proximate causes of decline. Rather, the general imperative for restoration action must be to enhance both the size and quality of existing remnants, and a broad range of bush-dependent bird species should benefit. Individual species recovery will require actions tailored to*

combat the identified threatening processes that may be specific to a single species or to an ecologically similar suite of species.

Without being restricted to these activities, landscape reconstruction will undoubtedly revolve around revegetation and natural regeneration initiatives. However, one of the significant issues to be addressed is to find the most appropriate spatial scales at which the planning and the implementation of rehabilitation programs should be pitched in order to maximise biodiversity and socio-economic outcomes. Landscape-scaled processes and factors are believed to influence significantly the persistence of species and therefore the composition and dynamics of ecological communities. Planning ought to match these scales. First, however, we need to be more certain that landscape effects are important and we need to determine what is an appropriate scale or extent for landscapes and ecological processes in this context. That is, at what scale(s) do threatening and other important ecological processes occur or act with maximum effect, and at what scale(s) should we manage them.

Many bird observations were gathered in the period 1977-81 (ie 20 years ago) in the form of bird lists (presence/absence data) by numerous bird-watching enthusiasts as part of the Australian Bird Atlas project managed by Birds Australia. Data from this project were collected at the spatial scale of 10-minute squares of latitude and longitude (285 km^2). For this project they were extracted for 198 species of landbirds from the heart of the southern New South Wales Sheep-Wheat Belt (a region bounded by 32° and 35° S, 147° and 149° E; sources: Birds Australia and Environment Australia). Landbirds were the remaining species after removing seabirds, waterbirds, shorebirds and swallows from the data set. Landbird data were analysed in this study to determine if the species richness of woodland-dependent birds was positively correlated with percentage cover of remnant vegetation at the landscape scale, as a recent study in the northern box-ironbark plains of Victoria had found. If other factors could not be found to account for variation in species richness with vegetation cover, this would imply that local declines and extinctions of woodland bird species at the landscape scale had occurred as a result of vegetation clearance. A relatively small portion (six contiguous 1° squares) of the Sheep-Wheat Belt was selected for analysis in an attempt to minimise the potentially confounding effects of biogeography on avian distribution patterns.

There are 216 ten-minute Atlas squares in the study region; in each there had been at least one bird list recorded during the Bird Atlas project. Using multiple stepwise least-squares regression, species richness in 11 groups of birds – All, Threatened, Declining, At Risk, Increasing, Woodland, 'Bennett & Ford' Woodland, Other, Non-Vagrant Other, Mobile, *Sedentary – was regressed against survey effort, vegetation cover and location variables (latitude, longitude and their interaction term). Survey effort was simply the number of bird lists available per square and vegetation cover was the percentage of natural woody vegetation remaining in each 10′ square in 1995 (ie five years ago). The vegetation data, originally captured and classified at the resolution of 1 ha, were re-analysed and provided by the Bureau of Rural Sciences.*

Logarithmic transformation of the vegetation cover data improved this variable's predictive capabilities, and so the transformed variable was used in models presented here. Amount of remnant vegetation accounted for maximum explained variance in species richness for five groups of birds, namely two categories of Woodland birds, Declining birds, all At Risk birds and Sedentary birds. Species richness in these groups of birds decreased with decreasing vegetation cover. Survey effort also had high explanatory power, for these and all 11 groups of birds. Species richness in non-woodland birds ('Others') and in Increaser birds did not vary significantly with vegetation cover. Location terms significantly improved the fit for some categories, particularly Declining, Threatened (and all At Risk), and Sedentary birds. Modelled richness of Declining and Threatened species peaked in the south-west of the study region, while Sedentary species richness increased to the west.

It was not possible in this study to examine the effects of physiographic, topographic and climatic variation on the distribution of species richness in the region. For example, there might exist an environmental factor that correlates strongly with both vegetation cover and Woodland/Sedentary bird species richness. If such a factor were found it would cloud the interpretation of cause and effect – the issue might then become has richness declined in response to vegetation clearance or was it historically distributed in this manner? Parsimony (ie seeking the simplest explanation for an observed relationship) leads me to conclude that the results presented here do not represent an historical and natural artefact. There are two reasons for this conclusion. First, there is no evidence to suggest that species richness, at this landscape scale, was ever distributed unevenly across the study region. The second line of evidence lies in the different responses of Woodland and non-Woodland (Other) birds to changes in percent vegetation cover. Species were assigned to the Woodland categories on the basis of their known habitat requirements for natural (woody) vegetation. Their richness varied significantly and strongly with cover while Other birds' species richness did not. Therefore, it is safely concluded that the amount of woody vegetation cover in the landscape does exert considerable control over the distribution of Woodland birds' species richness.

There is much evidence in the community ecology literature for a hump-shaped distribution of species richness when graphed against productivity and/or disturbance gradients. Vegetation clearance can be considered as a landscape-scaled agent of disturbance, and so perhaps we might expect bird species richness to peak at some intermediate point along the range of remnant vegetation cover values. Little evidence was found in this study for a humped-shaped species richness response to decreasing vegetation cover. If there is a response of this type, the turning point appears to be at the upper extreme of vegetation cover. Therefore, in relation to setting vegetation (including revegetation) targets for landscape reconstruction in these extensively cleared landscapes, it is a non-issue; there is no maximum point or threshold for an acceptable level of vegetation – more is simply better! By comparison, the response of species richness to survey effort was often found to be hump-shaped. This result is clearly illogical, but we can interpret the turning point to represent the amount of survey effort at which the species cumulation curve flattens markedly. By including a term for survey effort of this magnitude in the regression equations, we can then isolate the relationship between species richness and percent vegetation cover.

For Declining birds, (all else being equal) maximum species richness was predicted to result from 25 Atlas surveys or submitted bird lists. This figure applies only to the model using all Atlas squares ('full data set'). To make the following predictions, I standardised the approach by using 20 Atlas surveys in all models. The full regression model for Declining bird species richness was applied to calculate targets of percentage vegetation cover for landscapes in the region. To retain/aim for 90% of Decliner richness, 36-42% of the landscape needs to be vegetated (ie, if we are prepared to sacrifice two species); for 80% and 70% species' retention, the vegetation targets are 13-17% and 5-7% respectively. Using the best model for All Landbird species richness in a similar way, in order to retain 90% of maximum species richness in any one landscape 17% vegetation cover is required, and in opting for such a target we accept the local extinction of 13 Landbird species. Commonly cited vegetation targets of 10% and 30% vegetation cover translate to the predicted loss, respectively, of 17 (19%) and nine (10%) Woodland bird species from these landscapes.

Target vegetation figures generated from regression models derived from bird data that are 20 years out of date are likely to be overly optimistic for three related reasons. First, the declining bird problem has only come to the fore in the past 10 to 12 years – rates of decline in many woodland-dependent species appear to have accelerated in recent years. Therefore, if the models were rerun using contemporary bird data to derive the richness *response coefficients, the decline curves would be expected to be much steeper than those presented here. Second, the models do not specifically address the temporal component of declines – loss of species richness with time is inadequately modelled by the static equations used in this exercise. Third, there is likely to be hysteresis in the manner in which at least some locally extinct birds recolonise reconstructed landscapes – the recovery pathway may not be the simple reverse of the extinction path. Given the median value of 6.5% vegetation cover in the study region, the future persistence of many woodland species is uncertain.*

The strength of the relationship between Woodland birds and remnant vegetation cover at the 10′ scale indicates that landscapes of this order of size (286 km^2) are an appropriate scale at which to plan the reconstruction of landscapes from a bird conservation perspective. More closely fitting relationships would almost certainly exist at other spatial scales, but as the 1977-1981 Bird Atlas data were only gathered at the 10′ scale, this issue cannot be explored further.

The potential role of sources and sinks and other neighbourhood effects (eg effects of proximity of large vegetation remnants on species richness in adjacent squares, 'rescue effect', or landscape connectivity) at the landscape scale was partially examined. Low-remnancy Atlas squares were defined as squares with less than 5% vegetation cover, high-remnancy squares those with greater than 25% cover. Residual species richness of Woodland and Declining birds, having accounted for survey effort and vegetation cover, was contrasted using t-*tests for two classes of low-remnancy squares, depending on whether they were adjacent to a high-remnancy square (17) or not (45). Were source-to-sink flows of birds particularly strong over distances of* ca *10-20 km, the expectation would be for low-remnancy squares adjacent to high-remnancy squares to have higher residual species richness. While in both cases richness was higher in the expected direction, neither result was significant (*$P > 0.14$*). This test had low power, and so it is recommended that in future analyses of this type using Atlas data, the use of spatial statistics (designed to account explicitly for spatial dependencies of this nature) ought to be pursued. This caution applies not just to the detection of landscape processes but to all the correlation and regression analyses reported here. Because of the spatial contiguity of the sample units, ie because the Atlas squares abut one another, responses measured in adjacent squares cannot be considered to be truly independent.*

The modelling of species richness has shown that at the landscape scale it is strongly dependent on the amount of vegetation cover. This applies to richness of All Landbirds, *Decliners and Woodland bird groups. It does not apply, however, to the non-Woodland (Others) group of birds, ie the significant response shown by all landbirds is driven by the Woodland birds' component. Given that the number of species classified as Woodland birds is nearly half of the total landbird fauna recorded in the region and 64% of the non-vagrant landbirds reported in more than 10 Atlas squares, the problem of declining bird species is far more extensive than I diagnosed in the previous report in this series. The 20 species identified as Decliners in that report account for only a small percentage of species losses in the extensively cleared landscapes within the study region. To find out whether a subset of Woodland birds was driving the local extinction process or if it was a more pervasive phenomenon, it was necessary to examine individual species' responses to changes in vegetation cover.*

Reporting rate for a species in an Atlas square was defined here to be the ratio of the number of bird lists containing that species to the total number of bird lists received for that square. Reporting rate thus corrects for sampling effort to a large extent. I restricted analyses of individual species' reporting rates across the region to: i) 142 squares for which at least six bird lists were collected, and ii) 149 species recorded in ten or more squares. Species richness varied only to a minor extent in relation to latitude and longitude, but many landbirds exhibited strong distributional gradients across the region. Because there was also systematic geographical variation in the distribution of remnant vegetation cover, the potential for spurious (non-causal) correlations between avian reporting rates and vegetation cover arose. Accordingly, this systematic geographical component was partialled out by regression, and the residuals were used in subsequent correlations. A linear rank correlation procedure was then used as a screening exercise to examine each species' response to changes in vegetation cover. This approach circumvented the need to find appropriate response functions for each species (although various generalised linear regression techniques (GLMs) were tested for a few species), and it allowed the strength of both simple linear and monotonically increasing or decreasing functions to be rated equally. Strong unimodal (hump-shaped) relationships would be overlooked by this approach, but quick plots and GLMs of reporting rate against vegetation cover undertaken for about 20 species uncovered only one significant unimodal relationship.

The vast majority of landbirds screened in the above manner showed a positive correlation between reporting rate and vegetation cover, after correcting for location. For the categories of Declining, Threatened, Woodland and Sedentary birds, the mean Spearman *correlation coefficient was greater than the critical 5% significance value (used only as an indication of relationship strength). Within the broader classification of Woodland birds adopted here, 11 of the 94 species yielded negative correlations. These few species were raptors, known Increasers or species with Eyrean (arid) or Torresian (tropical) biogeographic affinities. As an earlier study showed, sedentariness and insectivory proved to be significant risk factors. Both species with these characteristics and Bassian (temperate) species, with distributions restricted to high-rainfall parts of southern and eastern Australia and that reach the western limits of their range within the study region, proved to be highly susceptible to the impacts of extensive land clearance.*

The major finding from screening individual Woodland birds' responses to vegetation cover was that most Woodland bird species appear to be adversely affected by vegetation clearance at the landscape scale. Although rates of decline vary among species there does not appear to be a single, ecologically well-defined group (or a distinct subgroup of Woodland birds) driving the extinction process in these landscapes. Rather, most of the Woodland species appear to be dropping out of at least some heavily modified landscapes, and, perhaps fortuitously, the identity of the species that do fail varies from one location to the next.

What factors might be driving the individualistic and spatially-variable extinction process in Woodland birds? By their nature and definition, Woodland birds are heavily dependent on the presence of suitable habitat. Each species probably responds individually to particular features of habitat; this applies both within patches (eg microhabitat features) and between stands (eg type of vegetation community). At landscape scales these variables are under the strong control of geology, topography and climate, but peculiarities of site history (disturbance, adjacent land use) vary across locations and among patches, thereby contributing differently to habitat favourability among species. In addition, there is probably an independent role for the interaction between climate and bird species' physiological tolerances and preferences (ie over and above the climatic controls on habitat type and quality). Important relationships between climate and the abundance and activity cycles of invertebrates undoubtedly operate at several time and geographic scales, which in turn probably affect food availability for the majority of Woodland bird species. Add a strong stochastic element of variability to these processes and the outcomes generated (relationships between bird species and percent cover of vegetation) may seem to unfold haphazardly and individualistically.

The reporting rates of each Woodland species were correlated against a location-corrected measure of Noisy Miner's reporting rate in squares (141) where the miner occurred. Surprisingly, very few Woodland species correlated negatively with this measure. At this scale in this region using these data, therefore, there is no evidence for a negative impact of Noisy Miners on Woodland birds. If Noisy Miners were contributing significantly to the patch extinction rate of Woodland birds in the region 20 years ago, the results of this would probably scale up and be evident at the landscape level. They are not. Admittedly, the reporting rate measure is a very crude measure of abundance – were reporting rate at this landscape scale not significantly correlated with mean density across patches (within the same landscape) there would be grounds to dismiss these results as inconclusive. However, preliminary studies of the new Bird Atlas data have shown that the two measures are tightly correlated. Accordingly, caution is urged lest large amounts of scarce natural resource management funds get channelled down the route of Noisy Miner eradication and control schemes in the absence of scientific evidence for the severity and pervasiveness of their impacts.

Recommendations for Landscape Reconstruction

In landscapes where vegetation clearance for agricultural development continues, *reasoned if inevitably arbitrary stopping rules need to be advanced from the biodiversity conservation perspective. Here I propose a set of clearance guidelines from this perspective. They have been formulated from the broader biodiversity perspective than birds alone. While outside the scope of this report it has to be acknowledged that the potential for land degradation (eg salinity hazard assessment) should also inform policy development and implementation in this regard. Nor should it need stating that appropriate and sympathetic financial mechanisms will need to be developed to allow the effective implementation of clearance regulations. From the biodiversity perspective, I assume that landscapes or districts are of the order of 300 km^2, and that a prior vegetation survey has been conducted for the entire landscape so that all patches (down to 1 ha) have been mapped and classified into broad vegetation communities.*

Stopping Rule 1, Habitat Rarity Principle: *Defined vegetation communities should not be cleared below 1% of the total landscape area (eg 3 km^2); this applies whether the community is naturally rare locally or if it has become rare through past clearance.*

***Stopping Rule 2, Habitat Conservation and Ecosystem Function Principle**: Defined vegetation communities should not be cleared below 30% of their original extent in that landscape.*

***Stopping Rule 3, Landscape and Regional Conservation Principle**:* In toto*, all broad-acre clearance should cease if 50% or more of the landscape is cleared.*

***Landscape reconstruction in those landscapes where broad-acre land clearance is no longer an issue** should focus on the protection and enhancement of existing natural vegetation. The major imperative is to prevent the deterioration in habitat quality of existing remnants, particularly remnants in the small to medium size class (15-250 ha). Principal threats facing these types of patches are firewood harvesting, cleaning up the understorey, over-heavy and continuous grazing, and insufficient regeneration.*

In salinity prone districts the protection of existing remnants may involve extensive revegetation efforts targeted at recharge zones. However, in most cases where biodiversity enhancement is the principal aim, the benefits from revegetation are likely to be greater from increasing the size of existing small remnants rather than growing new patches. The benefits should be even greater if existing patches that provide linkages in extensively cleared landscapes are expanded. Existing roadside and riparian corridor remnants provide the logical focus for these revegetation activities. The principle for adding onto existing remnants rather than starting from scratch can be extended to 'remnants' consisting only of scattered indigenous trees – these big old warhorses provide habitat resources that young trees cannot.

The most cost-effective rehabilitation, patch enlargement and patch enhancement procedures will be those where direct revegetation activities, necessarily expensive, can be minimised or eliminated altogether. Fencing off, reducing grazing pressure and frequency, encouraging natural regeneration with disturbances are examples of measures that can be applied in areas where some of the original vegetation diversity and soil seed stocks remain. These landscapes, where grazing of unimproved and natural pastures is the predominant land use, comprise a minority of agricultural lands, but they provide the greatest potential for broad-acre, relatively cheap restoration, provided they are taken out of intensive and continuous livestock production.

In medium to medium-large sized remnants (eg 50-1000 ha), while management of grazing pressure remains an important issue, the opportunity exists to take a deliberate interventionist approach to management, and to enhance biodiversity through implementing *patchy habitat disturbances. The aim here is to present a greater range of habitat stages, structural types and niches for a wide range of organisms. There are many examples on private (and public) land of large patches of open forest and woodland of a uniform composition and stand structure, presumably arising from a past disturbance or clearance. If the trees are closely spaced there is often little undergrowth present. The creation of open patches within these stands would undoubtedly allow them to support a greater diversity of species.*

Large remnants are generally State-owned and managed for various uses, eg protection of water quality, timber production, conservation. Management for the continuation of natural disturbance regimes and broad-scale ecological processes should be encouraged in these reserves, particularly in the largest of them. Again, a mix of habitat types distributed across a range of successional states should be the driving biodiversity objective. These larger blocks of near-natural and semi-natural vegetation bear the major responsibility for the continued persistence of many, probably most, of the declining bird species in the Sheep-Wheat Belt in the immediate and medium-term future.

A problem remains – where precisely and to what formula should rehabilitation and revegetation efforts take priority and be targeted. Should restoration funds and effort be expended evenly throughout the Sheep-Wheat Belt, or should a greater proportion be given to the most beleaguered landscapes, or to those in best condition? The only practical advice that can be tendered on these questions flows from the belief that increasing the area of 'habitat of some indeterminate threshold of quality' is the single most important action society can take. Therefore, the investment of funds in protecting and enhancing the quality of existing remnants (eg fencing and grazing management) and in increasing the size of remnants through natural processes of regeneration where this is possible (again fencing, grazing management, with some site preparation as needed) might produce the biggest bang for the buck. In terms of social equity, however, an even expenditure across landscapes would be fairest. For practical reasons there are sound arguments for engaging, at the outset at least, with those rural communities which embrace the imperative for landscape reconstruction and demonstrate a high level commitment to achieving change.

Threatened and declining birds in the New South Wales Sheep-Wheat Belt: II. Landscape relationships – modelling bird atlas data against vegetation cover.

Introduction

Many species of landbirds dependent on natural woodland and open-forest habitat (‘Woodland birds’) are undergoing population declines across southern temperate Australia in response to habitat loss (‘vegetation clearance’), habitat fragmentation (the further consequences of clearance) and habitat degradation (Saunders 1989; Recher & Lim 1990; Robinson 1991, 1993, 1994; Barrett et al. 1994; Ford et al. 1995a&b; Robinson & Traill 1996; Reid 1999; Recher 1999).

While various characteristics of individual remnants can account for the presence and absence of species – eg patch size and shape, amount of understorey and litter, number of hollows – there is growing appreciation of the strong, sometimes overriding, role that the surrounding matrix (country between remnants) plays in determining species composition. In fact some studies have revealed that these landscape scale (extrinsic) factors explain more of the variability of bird community composition than intrinsic variables within patches (Saab 1999). Therefore, in our attempts to understand the reasons for the decline of birds in southern Australian woodland landscapes we need to investigate the spatial context of these landscapes. Restoration activities require a multi-scaled perspective.

One, if not the most, pervasive landscape factor affecting the prospects of woodland birds is the amount of remnant native vegetation in the surrounding district, ie the amount of habitat, p, in the parlance of metapopulation theory. Although there are many indices relating to connectivity, patch size and degree of habitat fragmentation that have been developed by landscape ecologists, a recent review concluded that p itself was of primary importance (Hargis et al. 1998) - many of the other indices were strongly correlated with p and among themselves. Indeed it is difficult to disentangle the effects of habitat loss from fragmentation, both conceptually and analytically (eg Fahrig 1997). There may be no clear or useful distinction. In the context of wholesale conversion of regional landscapes from primarily forested/wooded to primarily agricultural, fragmentation effects clearly flow from the habitat loss (eg Mac Nally 1999). This topic is revisited in the Discussion. It would however be wrong to conclude that the landscape context, ie factors other than overall amount of habitat, is unimportant. Various factors, such as connectivity, selective clearance of particular vegetation types and grazing pressure, are at play in determining the persistence of some and perhaps of many bird species in extensively cleared landscapes (Lambeck 1997; Brooker et al. 1999).

Here I investigate relationships between the presence/absence of bird species and amount of remnant woody vegetation in the Sheep-Wheat Belt of New South Wales. Presence/absence data on bird species were derived from a large historical data set (the RAOU Bird Atlas: Blakers et al. 1984), with observations gathered at the spatial scale of 10 minutes of latitude and longitude ("10′ Atlas squares", of size 15.4 by 18.5 km, or 285 km^2 in the southern NSW Sheep-Wheat Belt). The investigation is similar to that conducted by Bennett & Ford (1997) in the northern Victorian box-ironbark ecosystem. Bennett & Ford (1997) contrasted the patterns in distribution of species richness in two categories of birds, 'Woodland' and 'Other', against the percentage of remnant woody vegetation. They found that woodland bird species richness decreased as a monotonic, logarithmic function as area of vegetation cover decreased. This result clearly indicated that many species of woodland dependent birds had dropped out of extensively cleared landscapes. By contrast, species richness of their 'Other' category did not vary systematically with vegetation cover.

As Bennett & Ford's (1997) study is the only published material on this topic in Australia it is important to determine if their results apply to a different region, ie the NSW Sheep-Wheat Belt. The study region used here is similar to that of the northern Victorian region in that agriculture is the dominant land use, and box-ironbark woodlands are dominant components of the original native vegetation. The expectation is that broadly similar results should obtain. Landbird species richness might be expected to vary in response to a host of factors other than vegetation cover (eg climate, topographic features: Bennett & Ford 1997). The null hypothesis for this study is that species richness does not vary systematically with the amount of remnant vegetation. Should the null hypothesis be rejected, we can conclude that local extinctions of woodland birds increase with decreasing vegetation cover or the amount of historical clearance. A cause-effect relationship can never be proven with observational data, but the results would be consistent with this explanation. It would rest on the assumption that species richness was not naturally distributed in this manner prior to extensive clearance for agriculture. This assumption cannot be directly examined as high-quality historical avian data sets do not exist, but it behoves the investigator to search for other factors that could account for the distribution pattern. Bennett & Ford (1997) compiled data on a range of topographic and other landscape variables that could have accounted for variation in Woodland birds' species richness, but the remnant vegetation variable accounted for more variance than any other variable in their study.

A second expectation can be stated and formally tested based on the conclusions of my earlier study (Reid 1999). This hypothesis states that the group of 20 Declining species of woodland birds formally diagnosed in that report exhibit stronger positive relationships with woody vegetation cover than other woodland birds do. Indeed, an obvious threshold effect could be anticipated, that the Decliners tend to 'drop out' of landscapes altogether when some threshold of percentage woody vegetation cover ('remnancy threshold') is crossed. One rider needs to be stressed – the bird Atlas data on which this study is based were gathered 20 years ago, and the marked decline in abundance and patch occupancy of this group of species has only become obvious in the last 10 years or so. Therefore, it will be highly desirable to repeat these analyses with more contemporary data sets; this ought to be possible soon as Birds Australia (formerly RAOU) is conducting a second Australian Bird Atlas currently.

The results presented here are provisional and have been subject only to informal peer review; accordingly interpretation of the results is brief and cautious, pending formal review. It is anticipated that including climatic and topographic variables, as predictors of bird species diversity, will extend the analyses commenced here. Conclusions and detailed management recommendations will follow from the interpretation of these analyses and others based on field data.

One logical extension of Bennett & Ford's (1997) study is pursued here, and that is to study the response of individual species to differences in percentage woody vegetation cover across these landscapes. In this way it was hoped to identify or even rank those species of woodland birds that seemed most susceptible to changes in natural vegetation cover.

Brief recommendations on landscape management and restoration are presented on the basis of the results, analyses and interpretations contained in the report. More detailed results are presented in Appendices 1-4.

Corrected Figure 1 Map, DDII

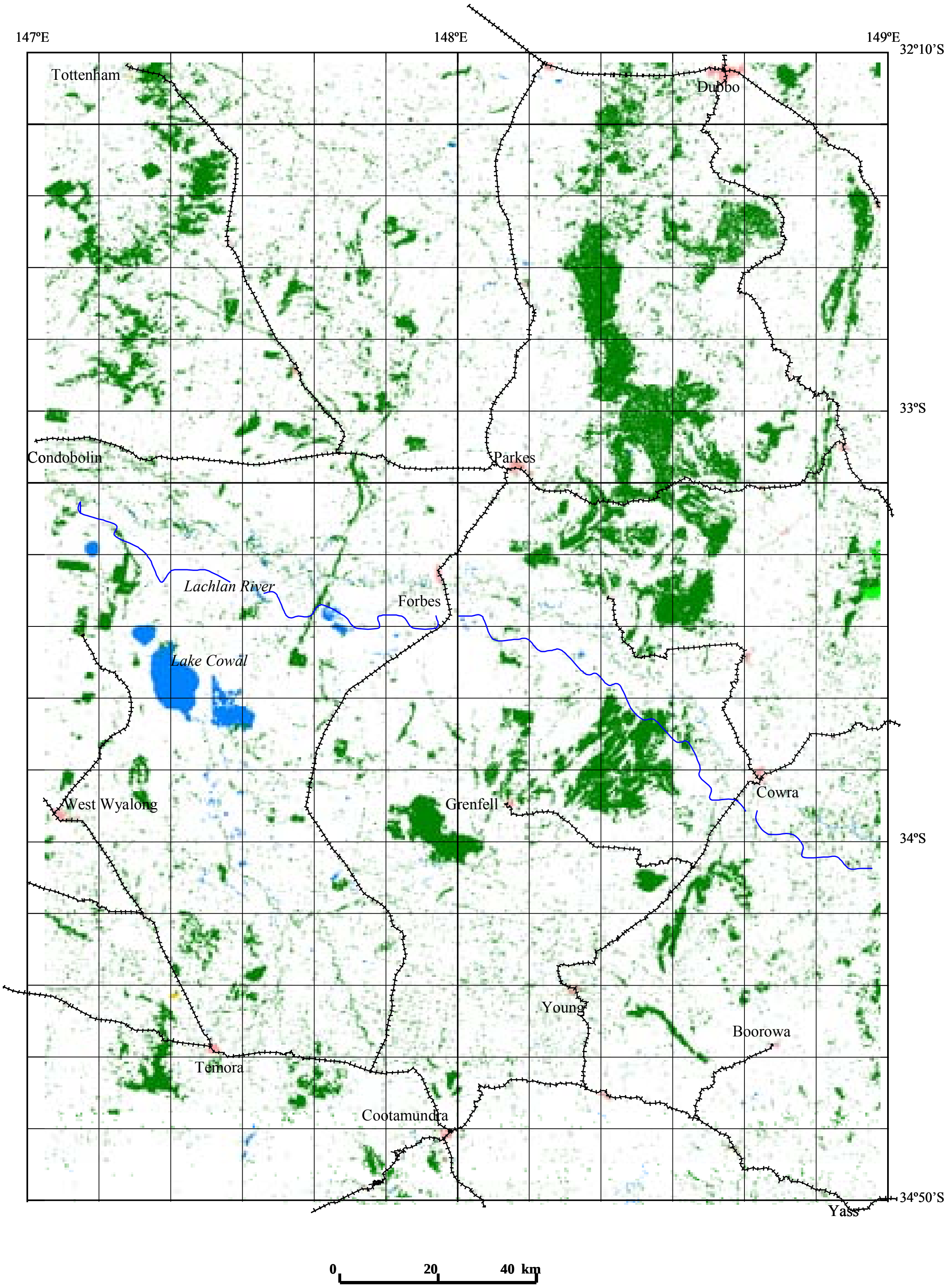


Figure 1. Map of most of study region showing remnant vegetation, major towns and railway lines (source BRS: Land Cover Change project; Dr L. Randall, BRS).

Methods

Study Region

The study region was selected in consultation with NPWS staff (S. Briggs, J. Seddon) to include study areas of various parallel investigations examining the distribution and conservation requirements of birds in the southern NSW Sheep-Wheat Belt (eg Schrader 1987, unpubl.; Major et al. 1998; Seddon et al. 2000). It is defined to lie between 32˚ and 35˚ S and between 147˚ and 149˚ E. Geographically, the region is approximately defined by Yass in the south-east, Temora in the south-west, Dubbo in the north-east, and Tottenham in the north-west. Major townships include Parkes, Forbes, Cowra, Young, Condobolin and West Wyalong (Fig. 1). At this latitude, 10' squares comprise 285 km^2, slightly greater than the 277 km^2 area in Bennett & Ford's (1997) study.

Physiographically, most of the region lies immediately to the west of the Central Tablelands on the western slopes of the Great Dividing Range and includes the adjacent plains. Maximum elevation reaches 1400 m near Orange with most land in the 200-600 m range falling east to west. The Weddin Mountains comprise a fairly isolated, small but significant range west of Grenfell. The Lachlan River is the major watercourse in the region. Rainfall varies from 600 mm along the eastern margins falling to 450 mm in the west, being lowest in the north-west corner of the region. A temperature gradient exists increasing from the east-south-east (Yass: mean annual maximum, 20.7°) to the north and north-west (25°). Livestock grazing and cropping are the predominant agricultural land uses with wheat and canola cropping becoming more prevalent to the west.

Open forests and woodlands comprise the dominant natural vegetation structure in the region. Isolated patches of wet forest occur in the extreme north-east, and mallee becomes prevalent only in the north-west. The distribution of the major vegetation formations strongly influences avian distribution patterns (eg Blakers et al. 1984), and so relatively strong biogeographic effects within the region are expected. The changes in vegetation across the region reflect and are largely controlled by the underlying climatic and topographic gradients briefly described above. Together they shape the historical or 'natural' distribution patterns of birds. It is important to differentiate modern, anthropogenic-driven changes in patterns of bird distribution and abundance from historical patterns. This is not a straightforward task as the nature and extent of vegetation clearance have historically varied according to terrain, climate, vegetation formation and intended agricultural land use.

Landscape Data

Without access to climatic, topographic and original vegetation data sets, the biophysical data required to model the effects of these factors on bird species and community responses, I have used geographic coordinates as a substitute or surrogate for some of these influences. The substitution is considered reasonable in the study area as pervasive climatic and topographic gradients exist, such that gradational rather than patchy or checkerboard distributional responses are likely. The latitude, longitude and the interaction term (their product) at the centre of each 10' square were used to model these influences.

Bird Data

The RAOU's (Birds Australia) original Field Atlas consists of presence/absence data based on birdlists collected mainly by amateur ornithologists over the period 1977-1981. Birdlists were gathered at two spatial resolutions: one-degree squares of latitude and longitude, and 10-minute squares. There was no attempt made to standardise observer effort (or ability), and so the quality of the data set is coarse. The data set has previously been found to contain numerous errors (M. Clayton, *personal communication*; the author's personal experience). For example, composite lists derived from all Atlas data at the 1˚ scale frequently contain several species outside their accepted range. Consequently, I spent two weeks with ERIN staff (S. Bennett & K. Bossard, Environment Australia) compiling a relatively clean data set from their copy of the Atlas data base, which had been previously cleared of many errors (S. Bennett, *personal communication*). I adopted the published maps in Blakers *et al.* (1984) as the authority for whether records in the data base needed to be omitted or added, and I completed this task for all 1˚ squares in Australia.

Birdlists from the study region in the years 1977-81 were extracted from the RAOU Atlas. Lists gathered at the 1˚ scale were excluded, leaving 2070 birdlists gathered at the 10' scale in the region. At least one birdlist existed for all 216 ten-minute squares, although coverage varied widely (Table 1). The majority of squares had 5-15 sheets of effort (range 1 - 80, mean 9.7, median 8). One square, centered on 32° 15′ S, 148° 35′ E (Dubbo), had over double the sampling effort of any other square (Table 1). Seabirds, shorebirds, waterbirds and swallows were removed from the birdlists leaving records of 198 'Landbird' species. These Landbirds are the subject of this report.

Table 1. Frequency of sampling effort across study region measured by number of individual data sheets in 10' Atlas squares.

No. Sheets	1	2	3	4	5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	80
No. Squares	9	4	19	19	23	70	40	13	9	4	3	2	1

Remnant Vegetation Data

Remnant woody vegetation cover has been mapped at a fine scale (0.25 ha resolution) across the region as part of the ‘Land Cover Change Project’ of the Bureau of Rural Sciences (see Kitchin & Barson 1998; Barson et al. 2000). A GIS coverage of these data (Fig. 1) and summary statistics for each 10' square were made available for the study by BRS. For this study, analyses are confined to the summary statistics for percentage remnant woody vegetation in each 10' square. The distribution of percentage vegetation cover is strongly positively skewed (percentages: range 0.18 - 78.37, mean 10.76, median 6.54; Table 2). Consequently, a $\log_e$ transformation of the percent vegetation cover variable was used for modelling and some graphical display purposes.

Table 2. Frequency of percentage cover of native vegetation across the study region by 10' Atlas squares (source: BRS).

Woody Veg Cover (%)	0-4.9	5-9.9	10-14.9	15-19.9	20-24.9	25-29.9	30-34.9	35-39.9	40-49.9	50-59.9	60-69.9	70-79.9
No. Squares	88	50	31	14	12	7	5	3	2	1	2	1

An informal ground truthing exercise was performed in the Boorowa-Binalong region to gauge how well the mapped data depicted the percentage and location of remnant vegetation within the landscape. The coverage proved to be highly realistic.

Analysis

Bird Groupings

Ten groups of birds were used for regressions analysis, and the groupings were adapted from Reid (1999) and from Bennett & Ford (1997). The number of species within a group recorded in each 10 Atlas square became the response variable in subsequent regressions. The names of the response (or dependent) variables – these 10 groups of landbirds – are presented below. Two sets of total species numbers within groups occurring in the study region are given in brackets: the first is for the full data set (no species removed); the second is for a reduced data set which records the number of species remaining in each group having removed species recorded in less than 10 squares. Analyses were performed with either or both data sets, as outlined below.

CRICH – All landbird species (198, 149);
CUMDP – Declining landbird species (21, 21);
CUMTP – Threatened landbird species (14, 5);
CUMAP – At Risk landbird species (35, 26);
CUMIP – Increaser landbird species (36, 31);
CUMWP – (the author's) Woodland landbird species (99, 94);
CUMOP – Others or non-Woodland landbird species (99, 55);
CUMBWP –Bennett & Ford (1997) Woodland landbird species (76, 69);
CUMMMP – Mobile landbird species (98, 72);
CUMNMP – Sedentary or non-Mobile landbird species (100, 77).

Reid (1999) diagnosed 20 species of Declining woodland birds in the NSW Sheep-Wheat Belt. There are 38 landbird species classified as Threatened (Endangered and Vulnerable) under State and Federal legislation that are known to occur regularly (historically at least) in the Sheep-Wheat Belt of New South Wales. On other grounds Reid (1999) added two species – Black-chinned Honeyeater and White-browed Treecreeper – to the list of Declining or otherwise 'At Risk' species. Collectively, these 60 species are hereafter referred to as 'At Risk' species, but not all of the Threatened species found in the New South Wales Sheep-Wheat Belt occur in the current study region. Reid (1999) also identified 29 native and seven introduced species as Increasers. Whistling Kite was added to the list of Decliners acting upon advice from Dr D. Baker-Gabb (Birds Australia, *personal communication*). On the above basis I formed the first five groups of birds shown above, namely All landbirds, Decliners, Threatened, At Risk, and Increasers.

Bennett & Ford (1997) classified their 163 non-vagrant landbirds into 76 Woodland and 87 'Other' species, based on whether they regarded species to be obligate woodland and forest denizens ('Bennet & Ford Woodland') or not. Their classification cannot be directly transferred to the South-Western Slopes region of NSW, because some species of regular occurrence in one region do not occur regularly or at all in the other. For example, the Yellow Rosella is a Woodland species under Bennett & Ford's (1997) scheme, but is a rare vagrant in this part of NSW; the Apostlebird is a common species in the warmer portions of the NSW study region, but is absent from the Victorian region. In addition to this problem I was concerned with a few particular designations and with the fairly restrictive definition of Woodland birds used by Bennett & Ford (1997). Bennett & Ford stress their classification is subjective, being based on their own field experiences. I developed two classifications of 'Woodland' species. The first is based on Bennett & Ford's (1997) scheme. For the alternative scheme I made my own subjective assessment, but relaxed the definition so that regular users of large patches of woodland habitat in the NSW Sheep-Wheat Belt (eg Superb Fairy-wren, Scarlet Robin, Restless Flycatcher and Black-faced Cuckoo-shrike) were also included. The criterion I used was whether I would expect to see the species as frequently or more often in larger woodland remnants than in agricultural landscapes with scattered trees and small woodland patches only. I formed three groups of landbird species, namely 'Bennett & Ford' Woodland birds, Woodland birds (ie the author's), and Others (or non-Woodland birds, the complement of the Woodland group); these are the next three groups listed above.

Finally, another dichotomous grouping was used, based on mobility characteristics, to form the ninth and tenth groups. Strictly sedentary species (breeding adults establish and maintain permanent home ranges in a confined area) were separated from mobile species, whether semi-nomadic, nomadic or migratory. This classification was presented in Reid (1999). In addition to the complete list of species, birds were assigned to nine categories in all, some of which are mutually exclusive (Appendix 2). An eleventh category was investigated, that of non-Woodland species excluding vagrants (NVO – 'non-vagrant Others'), but in terms of how species richness responded to remnant vegetation cover this category proved to be indistinguishable from the 'Others' group. Summary statistics only are presented for the 'non-vagrant Others' group of birds.

The influence of biogeographic affinity was investigated by identifying those species that were largely confined to arid and semi-arid Australia (Eyrean), south-eastern Australia (Bassian), and the wet-dry tropical savannahs of northern and eastern Australia (Torresian). Most species in the study region have broader geographic distributions than this, and only about one third of species could be assigned to a biogeographic provenance in this manner. Species richness modelling was not attempted for bird groups derived from this biogeographic classification.

Statistical Methods

A variety of models were fitted to a large data set with almost 200 individual response variables (species and richness responses). Fitting in this context means accepting a predictor variable as having a significant fit at the 5% probability level. With this Type 1 error rate, some terms will have been fitted by chance alone. The response data are not strictly spatially independent, as the 10' squares are contiguous (see Bennett & Ford 1997). Although there are methods available to model such spatial autocorrelation (Lewis 1995; Pearson & Carroll 1998), the additional programming required to fit the autocorrelation term was beyond the scope of this exercise.

1. Models of Species Richness

Linear (least-squares) regression methods similar to those described by Bennett & Ford (1997) were used to model the response of species richness to sampling effort, geographic location and woody vegetation cover. Species richness was modelled as a normally distributed variate and, having fitted the models, the distribution of residual errors was plotted to check that they appeared normally distributed (formal tests not undertaken).

Species richness in all ten categories of birds was modelled using forward stepwise regression in Systat (Version 5: Wilkinson et al. 1992), with significance for input to, and output from, models set at $P <= 0.05$. Graphs of the response variable, ie the number of species recorded in Atlas squares in a particular bird group (or its residuals once terms had been fitted), against each predictor indicated that squared terms of sampling effort (number of observer sheets), and of percent woody vegetation cover needed to be included in the analyses. Logarithmic transformations of these two variables were also tested. Latitude, longitude and their interaction term were included following the methods of Chase et al. (2000). Bennett & Ford (1997) log-transformed their sampling effort and vegetation cover data to make the species richness response 'simple linear'. This method was adopted to allow comparisons across the two studies. The log transformation is acceptable only in cases where the response monotonically increases. There were indications in this study that richness could decline with increasing vegetation cover at high values. Therefore, it was considered prudent to model the variables untransformed as well. Backward stepwise regression was used in some cases to see if a better fit could be obtained.

A partial test of the hypothesis that large remnants might play an important role in structuring woodland bird communities was devised. Specifically, I expected that there would be more species of woodland dependent birds in squares with low vegetation cover if those squares were located next to squares with high cover values. Accordingly, I undertook the following analysis for the categories of Declining and Woodland birds. The residuals of species richness for these two groups were saved from the best-fit models (terms fitted at $P < 0.05$). I confined the analysis to the subset of squares that had vegetation cover less than 5%, and compared residual species richness in these 'low-cover' squares across two groups. Low cover squares that had at least one neighbouring square with > 25% remnant woody vegetation ('high cover') comprised one group ($n = 17$), while the second group comprised low-cover squares with no neighbouring squares having high cover ($n = 45$). A one-tailed *t*-test was performed to test whether the residual richness of squares adjacent to high-cover squares (> 25%) was greater than residual richness in the other group. The 56 Atlas squares that comprise the outermost portion of the study region could not be included in this analysis, due to the absence of information about vegetation cover in the neighbouring squares outside the study region.

2. Models of Individual Species' Reporting Rates

Only species recorded in ten or more squares were used in this analysis – 149 of the total 198 species. Only squares with six or more observer sheets were used to calculate the reporting rate for these species (142 squares out of the original 216). Reporting rate was defined as the number of sheets with records of the target species divided by total number of sheets submitted for that square, yielding a fraction in the range of 0-1. Reporting rate as a measure, therefore, should be independent of sampling effort. A variety of generalised linear techniques were trialled – least-squares regression, log-linear regression and logistic regression – to investigate the response of each species' reporting rate to the main predictor of interest, percent vegetation cover, having accounted for other variables. Multiple logistic regression was the preferred option, but was found to be frequently beyond the capabilities of the software contained in the standard Systat statistical package. The modelling of reporting rate against percent vegetation cover in isolation was fraught with problems of interpretation because, like individual species' distribution patterns, vegetation cover itself was not distributed randomly across the region. The term logistic regression here means the generalised linear modelling technique that fits predictor terms to a dichotomous response assuming binomial errors.

Logistic regression was employed to model the responses of individual species' reporting rates against the following variables individually: logarithmically transformed percentage vegetation cover data; latitude, longitude, and the interaction between latitude and longitude (location terms). Logistic regression constrains the modelled response to lie between 0 and 1 (of form $y = \exp(b_0 + b_1 x) / (1 + (\exp(b_0 + b_1 x)))$. For some frequently recorded species (few zeros) a log-linear fit (with no upper bound – of form $y = \exp(b_0 + b_1 x)$) proved to model the data better, and so these models were run on these species as well.

Because there were difficulties (eg high collinearity) experienced with building multiple logistic regression models of species' reporting rates in Systat, alternative approaches were developed. For species where a location variable could be fitted in a generalised linear model of logistic or log-linear form, the residuals were saved to form a new response variable: 'reporting rate corrected for location'. This new variable was correlated with percent vegetation cover using Spearman rank correlation. This technique proved tedious to perform for all 149 species, and so a speedier solution was devised. The $\log_e$-transformed percent vegetation cover data (LOGZW) proved to be normally distributed, and so a stepwise least-squares regression against the locational variables was performed, and the residuals were saved from the model to form a 'location-corrected' variable (ZWRS). This variable was then correlated with all 149 species' reporting rates (Spearman Rank), to examine the proposition that Decliner species are more strongly positively correlated with percent vegetation cover than general woodland-dependent species. This proposition was tested by performing a *t*-test on the rank correlation coefficients of passerine Declining species and Woodland passerine species (having first removed the Declining species). The White-browed Woodswallow, diagnosed by Reid (1999) as a Decliner, was omitted from this analysis because its distribution of reporting rate was negatively correlated with percent vegetation cover.

Finally, the reporting rate of Noisy Miner was correlated with reporting rates of 53 widespread Woodland bird species to examine the proposition that this species negatively impacts upon species of small Woodland birds in these landscapes (Ford et al. 1995a; Grey et al. 1997). Because the Noisy Miner is not distributed uniformly across the study region, I used its residual reporting rate having accounted for any significant location terms as well as the raw reporting rate. I also investigated the relationships between Noisy Miner reporting rates and species richness in two bird groups, namely All Landbirds and (the author's) Woodland birds. One square with no records of Noisy Miner was removed from the data set, leaving 141 Atlas squares for analysis. Because of the uncertainty surrounding the expected direction (sign) of these numerous correlations, two-tailed levels of significance were applied. Further details of the procedures followed are presented with the results.

3. Predictor Variables

The names of predictor variables used in models and correlations are:

ZWOODY – % remnant woody vegetation cover per square;
LOGZW – natural logarithm of % remnant woody vegetation;
ZWRS – ‘location-corrected’ form of LOGZW (see above);
LONGI – midpoint of longitude of each 10' square;
LATI – midpoint of latitude of each 10' square;
DSHEET – number of observer sheets per square;
L10DSH – logarithm of DSHEET (base 10).

Results

The RAOU Bird Atlas data base contains 51, 962 records of 198 landbird species at the 10' scale in the study region. These records are contained in 2100 observer sheets, and there is at least one sheet in every square. Cumulative landbird species richness varies from 31 to 131 (mean 70, median 67), and so its distribution is slightly right-skewed. Summary data for 11 categories of birds (including 'non-vagrant Others') are presented in Table 3. The same summary data for each species are presented in Appendix 1. The frequency distribution of the occupancy of Atlas squares by all species and of all records for each species is given in Fig. 2. There were 16 vagrant species for which there was one record, and one other species was confined to one square (Appendix 1). The most frequently recorded species was the Galah (1585 records); Galah, Willie Wagtail, Magpie-lark and Australian Magpie were recorded in every square, while there were 14 species with in excess of 1000 records. These most frequently recorded and widespread species were outnumbered by rare species, giving rise to the familiar shaped graphs depicted in Fig. 2 (eg Hanski 1982; Ford 1990).

Table 3. Summary data on number of species (*n*) per Atlas square for 11 categories of birds. T: Threatened; D: Declining; AR: At Risk (T+D); I: Increasing; BW: Bennett & Ford's (1997) 'Woodland-dependent species'; W: the author's Woodland birds; O: Others (All-W); NVO: non-vagrant Others; M: Mobile; S: Sedentary (resident, non-mobile).

	All	**T**	**D**	**AR**	**I**	**BW**	**W**	**O**	**NVO**	**M**	**S**
n	198	14	21	35	36	76	99	99	70	98	100
min	31	0	2	2	15	4	16	11	11	7	19
max	131	7	20	26	33	63	85	47	47	68	66
median	70	1	13	13	25	30	44	22	22	28	40
mean	69.57	0.84	11.82	12.66	24.84	30.15	46.21	23.36	23.08	30.09	39.48
s.d.	20.54	1.12	4.36	4.88	3.27	12.46	15.22	6.94	6.68	11.72	10.23
CV (%)	29.52	133.33	36.89	38.55	13.16	41.33	32.94	29.71	28.94	38.95	25.91

Least frequently recorded species have low 'sheets' to 'squares' ratios (eg < 2), ie low reporting rates, while widespread and abundant species have much higher ratios (eg > 5) (Appendix 1). However, there were exceptions to this trend. For species with very localised distributions but high reporting rates (larger ratios than expected), the two most extreme examples are provided by two introduced species, Eurasian Tree Sparrow (6 squares, ratio 5.33) and Common Blackbird (25, 4.96). Two native species, Yellow-tufted Honeyeater (42, 4.40) and Gilbert's Whistler (11, 4.27), showed a similar pattern – patchily distributed and

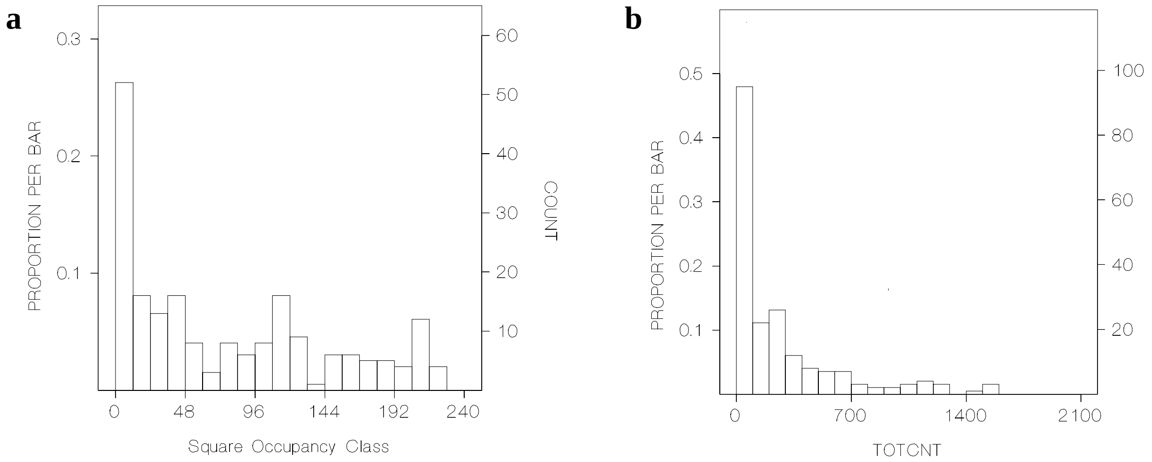


Figure 2. Frequency histograms of a) square occupancy rate, and b) total number of records (TOTCNT), for all 198 landbird species in study region.

presumably habitat specific with a high degree of site fidelity. In exotic species these are desirable traits – at least in this region they are unlikely to spread far – but for native species they are the hallmarks of rare species (Rey Benayas et al. 1999) and perhaps indicate species with special conservation requirements. Gilbert's Whistler is listed as Vulnerable in New South Wales for instance. At the other extreme, there are a few species with wider ranges but with generally only one record per square – Budgerigar (41, 1.34), Little Raven (122, 1.67) and Plum-headed Finch (37, 1.27) typify this pattern. These three species are highly nomadic. In general, mobile species are expected to be recorded less frequently but over a broader area than sedentary birds. Such birds are not habitat specific in the usual sense or, if defined by food resources, then their preferred habitat varies widely in space and time. These exceptions to the general trend of correlated reporting rates and breadth of distribution would provide interesting subjects for further research.

Of the 251 species considered by Reid (1999) to be true NSW Sheep-Wheat Belt native landbird species, 188 are included in the data set. The balance from 198 is made up by exotic and a few vagrant species. The assemblage is very similar to that described by Bennett & Ford (1997).

Species Richness Modelling

Survey Effort

Species richness was generally highly dependent on observer effort (Fig. 3). One Atlas square, centered on the township of Dubbo received twice as much survey effort as any other square, yet had relatively low richness, and so this data point was removed (undue leverage). This was justified on the basis that species richness should only accumulate with increasing survey effort, and so the appropriate response form should accord with a monotonically increasing function (Palmer 1990). Comparisons of the results between the full data set (minus this one observation) and the subset of 142 squares for which six or more sheets were recorded revealed that the variance explained by sampling effort was much higher in the full data set than in the subset (Table 4).

Species richness in all bird groups was significantly dependent on survey effort, although the amount of variance explained varied considerably, eg R^2 = 15.2% for Decliners to R^2 = 66.0% for mobile birds (full data set). These figures dropped to 4.6% and 52.8% respectively for the subset of squares (Table 4).

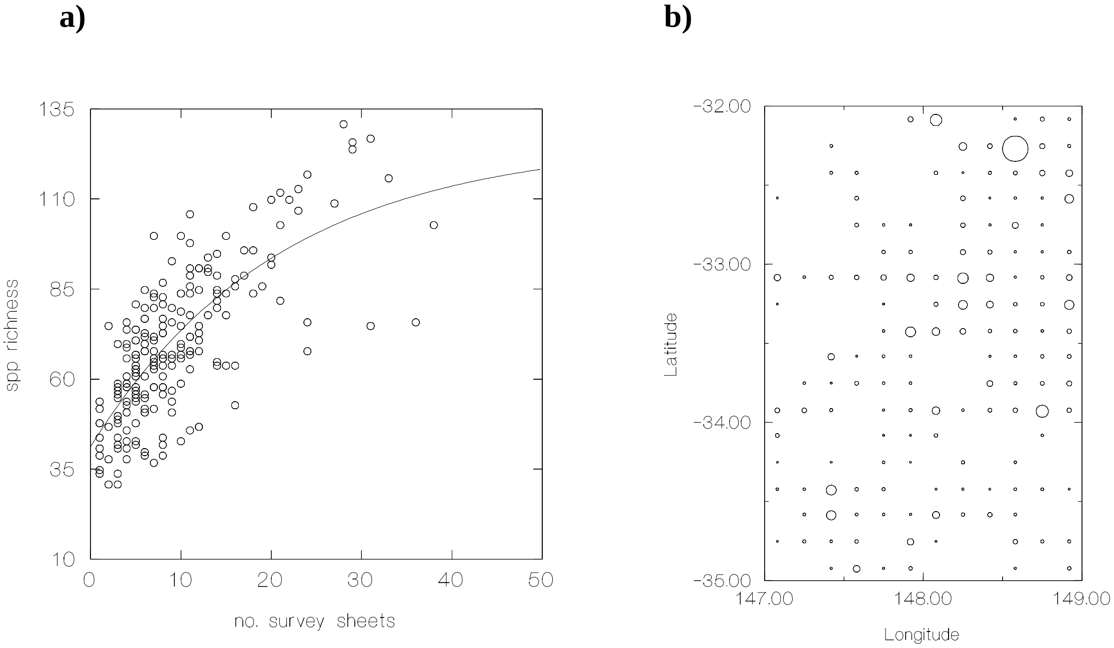


Figure 3. a) The species accumulation curve across Atlas squares and fitted quadratic curve that explained 55% of variance in species richness of All landbird species. **b)** Map of relative observer effort across study region, with Dubbo square prominent in north-east.

Vegetation Cover

Species richness in two categories of birds, namely Increasers and 'Others' (non-Woodland), was not significantly correlated with percent vegetation cover, either in isolation or in combination with survey effort (Table 4). Richness in four groups of birds – Decliner, At Risk, 'Bennett & Ford's' Woodland, and non-mobile birds – showed a stronger correlation with vegetation cover than with survey effort. The At Risk category mimics the response shown by the Decliners because the two groups are similar and highly correlated, with Decliners comprising most At Risk species in any one square. It is more interesting to note that Threatened species do not follow this pattern, confirming earlier conclusions that Declining and Threatened species are ecologically dissimilar suites of birds (Reid 1999).

The untransformed vegetation cover variable (ZWOODY: % vegetation cover) was outperformed by its derivative variable (LOGZW: natural logarithm of % vegetation cover) in terms of additional variance explained in multiple regression for most categories (Table 4; Fig. 4). In those few cases (four in 17) where the reverse applied, the additional performance gained was slight, a maximum of 1.6%. This result indicates that a hump-shaped community-wide response to increasing vegetation cover is not an obvious feature of the bird fauna in

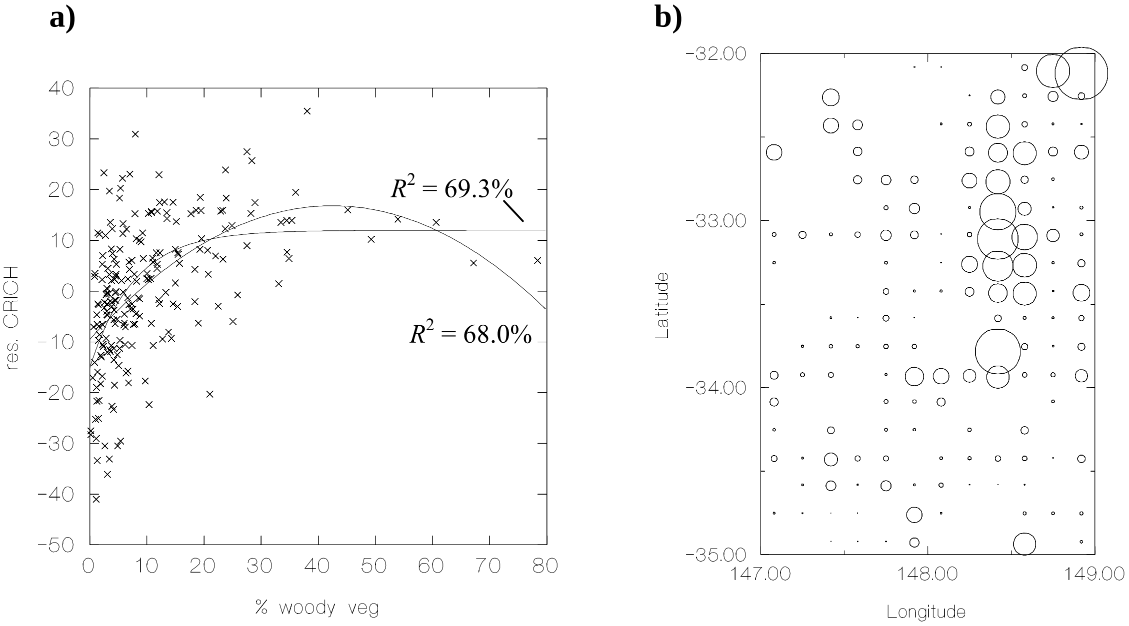


Figure 4. a) Residuals from regression of sampling effort on species richness (res CRICH, all birds, $n = 215$ squares) as a function of percent woody vegetation cover. The logarithmic function explained more of the residual variance (R^2) than the quadratic curve shown, but note the impression of declining richness at higher percent cover values. R^2 values are for combined models (survey effort + % vegetation cover)
b) Graphical representation of vegetation cover across study region.

Table 4. Percent variance explained by addition of terms a) – d) in modelled species richness for 10 categories of birds: T: Threatened; D: Declining; AR: At Risk (T+D); I: Increasing; BW: Bennett & Ford's (1997) 'Woodland-dependent species'; W: the author's Woodland birds; O: Others (All-W); M: Mobile; S: Sedentary (resident, non-mobile); [NVO returned similar results to O.]
$\%R^2$ shown for 'all' (n = 215) squares, and n = 141 squares with >= 6 sheets.
a) survey effort and its square fitted - [1] indicates linear term alone significant.
b) increased fit over a) by adding log of vegetation cover term (linear term only, LOGZW).
c) increased fit over a) by adding percent vegetation cover term (ZWOODY) and its square
d) increased fit over best model in a-c) by adding location terms (LATI, LONGI and/or their interaction term). Best fit for each category of birds highlighted with bold type*.

	All	**T**	**D**	**AR**	**I**	**BW**	**W**	**O**	**M**	**S**
# spp	198	14	21	35	36	76	99	99	98	100
a) (DSHEET)										
all squares	55.4	21.7	15.2	18.9	58.2	34.6	41.6	62.6	66.0	31.7
>= 6 sheets	42.1	19.0	4.6[1]	9.0[1]	44.0	17.6[1]	26.6	54.3[1]	52.8	21.8
b) (LOGZW)										
all squares	**69.3**	24.8	42.9	45.1	*ns*	**65.3**	**66.5**	*ns*	69.9	58.6
>= 6 sheets	60.3	23.1	39.7	41.3	*ns*	58.6	58.5	*ns*	58.2	55.5
c) (ZWOODY)										
all squares	68.0	24.2	35.9	38.2	**59.5**	61.1	63.3	*ns*	**70.6**	52.8
>= 6 sheets	57.9	23.1	41.3	31.4	*ns*	52.9	54.4	*ns*	59.1	46.5
d) (LATI, LONGI)										
all squares	*ns*	30.7	**50.3**	**52.3**	*ns*	*ns*	*ns*	**66.3**	*ns*	**61.7**
>= 6 sheets	*ns*	**34.7**	47.4	50.4	*ns*	*ns*	*ns*	59.1	60.1	58.0

*Model terms and coefficients given in Appendix 4

these landscapes. This conclusion is tempered by the fact that the data are sparse at this end of the gradient (few squares with large amounts of vegetation) - the possibility of a hump-shaped response between species richness and vegetation cover should not be rejected altogether.

In Figure 5, the contrasting responses of mobile birds and Woodland birds are graphed, holding survey effort constant at 20 sheets. Note the much steeper rising limb at low percent cover scores for mobile birds in Figure 5a. This result indicates that mobile bird species as a group can utilise low-cover landscapes much better than the more sedentary woodland-dependent birds. In fact the introduction of a cubic term for ZWOODY significantly, if marginally (*ca* 1%), improves the fit of the models for both these categories, allowing asymmetry in the curves so that the right- hand decreasing limb can tail off more gently than in the symmetric quadratic function.

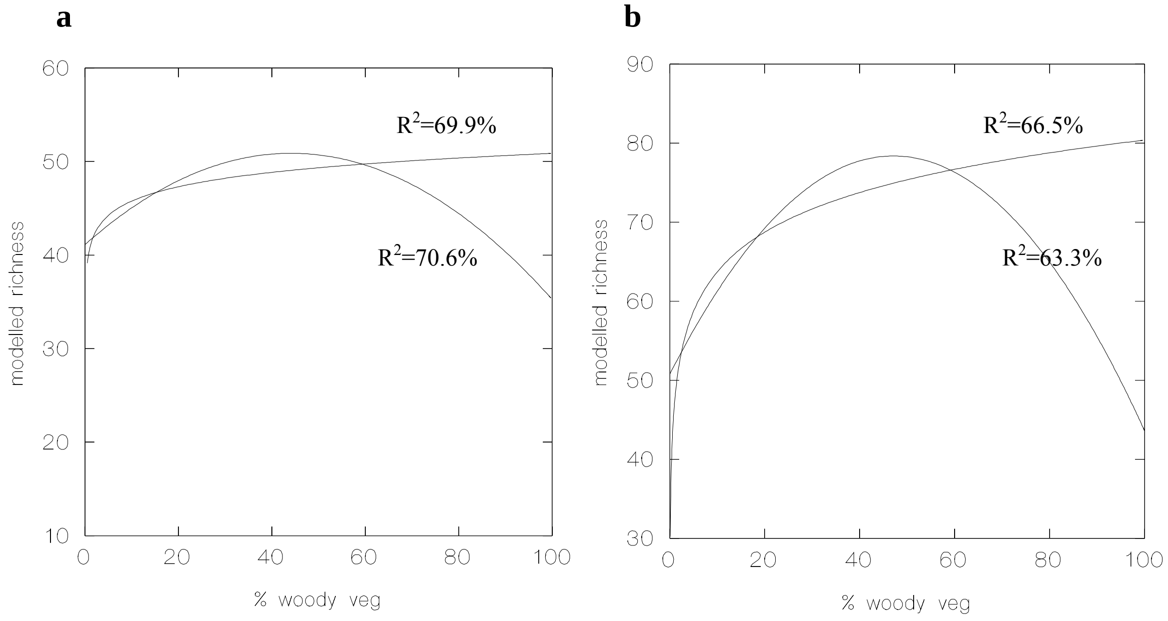


Figure 5. Modelled species richness of **a)** Mobile and **b)** Woodland bird groups against remnant vegetation cover (with observer effort held at 20 sheets), contrasting logarithmic and quadratic response functions.

In seven of the ten groups of birds (response groups) modelled, the amount of variance explained by fitting the combination of observer effort and percent vegetation cover exceeded 50% (full data sets). Only Declining, Threatened and all At Risk species have less than 50% variance explained by these two predictors.

While more variance was generally explained using the full data set (215 Atlas squares) compared with the subset of 142 squares, the gap in variance explained between the two data sets reduced when the vegetation term(s) were fitted (Table 4 a-c). In six cases using the reduced data set, adding the log-transformed vegetation term dramatically improved the fit of the models.

The model for all landbird species richness (*S*) from the full data set (215 squares) can be used to examine sampling efficiency in the original Bird Atlas scheme. The full model is:

$$S = 31.2735 + 3.17462\ \text{DSHEET} - 0.03957\ \text{DSHEET}^2 + 7.25809\ \text{LOGZW}.$$

The humped fit of the quadratic terms for sampling effort reveals that 40 observer sheets per square are required to obtain full coverage at the 10' scale, and that this predicted maximum number of landbirds is 128 species (assuming 100% vegetation cover). Ninety percent coverage (115 species) is achieved with 22.1 observer sheets. Slightly greater sampling effort

(23.1 sheets) is required when the exercise is repeated at 10% vegetation cover. Twenty sheets, the standard number I have used in subsequent model prediction exercises, equates to 112 species or 88% expected coverage of all landbirds (at 100% woody vegetation cover). This figure is double the average observer effort that the original Atlas achieved in the study region. The maximum number of landbird species predicted in any 10' square represents 64.7% of the 198 species of landbird recorded in the region during the Atlas. In Figure 7 the actual distribution of species richness of all landbird species is graphed alongside the modelled distribution, to show the smoothing effects of regression modelling.

Alternative Models for Species Richness

The terms for latitude, longitude and their interaction significantly improved the fit for species richness models in over half the cases (Table 4d). However, with terms fitted at $P < 0.05$, the gain in increased variance explained against increased model complexity was considered unnecessary for the category All Landbird species. For instance each of the three location terms could be fitted to the model ($P < 0.05$), yet the increased fit was less than 1% over the result presented in Table 4b. For the three ‘species of concern’ categories (Threatened, Declining, At Risk), inclusion of one to three terms improved model fit by more than 5% (Table 4d). Final models for all categories of birds apart from Threatened species achieved a fit of greater than 50%.

The model for Declining species was significantly improved by inclusion of the three locational terms (increase in variance explained of 7.4%). With observer effort and percent vegetation cover held constant, the resulting modelled pattern of richness (Fig. 6) showed there are fewest Declining species remaining in the south-eastern portion of the region (Yass), maximum numbers in the south-western corner (Temora), with moderate numbers in the north. The effect of the interaction term is striking – while predicted Decliner richness increased from east to west along any line of latitude, the trends along meridians underwent an interesting reversal. Decliners may be affected by winter food shortages to a greater degree than other woodland birds. Neither Woodland nor ‘Bennet & Ford’ Woodland richness models were improved with the inclusion of locational terms, even though these categories include most of the Declining species.

The major geographic trend shown by Threatened species is for their predicted richness to increase from north to south – from 1.1 species in the north-east increasing west and south to a predicted 2.4 species in the south-western corner. This means that together, independently of the amount of remnant vegetation and survey effort, we would expect to find most At Risk species in the south-western corner of the region. Whether this information has management applicability is uncertain, but it may mean that for a given amount (acreage) of revegetation effort the results measured in terms of increases in desirable bird species may be greatest in the south-west. This area is not the most extensively cleared district in the region, but it has lost more vegetation than most districts (eg Figs 4 & 10). In reality, though, it may be difficult to restore mallee and broombush vegetation communities. It is probably the historical occurrence of these communities in the south-west that explains why Threatened species richness peaks there – Reid (1999) showed that many NSW listed species are mallee birds. That the models predict a higher occurrence of Declining species in this area is more significant, and revegetation efforts targeting woodland formations may prove particularly beneficial for this suite of species in the south-west of the region.

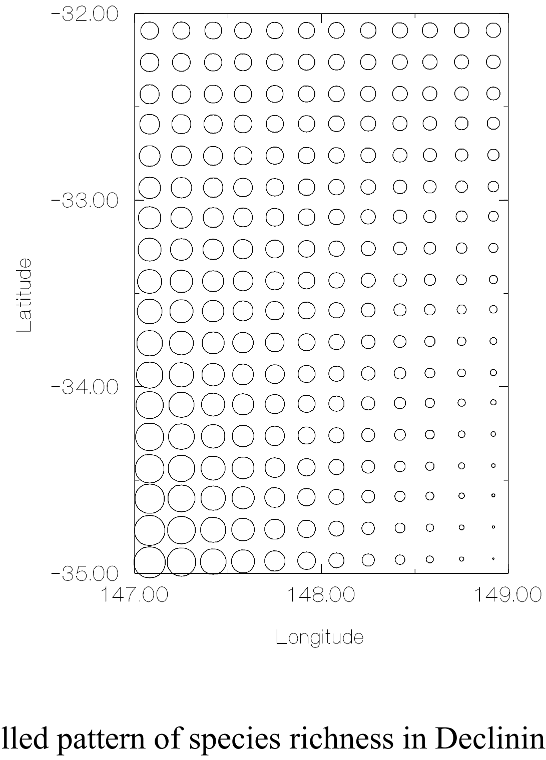


Figure 6. Modelled pattern of species richness in Declining birds across the study region holding observer effort and vegetation cover constant at 20 sheets and 10% respectively. The scale is deliberately exaggerated – maximum richness is predicted to be 18.9 Decliners at 35° S 147° E, with a minimum of 12.3 species at 35° S 149° E.

Increasers were the only category of landbirds for which the basic observer effort model could not be improved with the addition of vegetation cover or location terms, ie they showed no meaningful relationship with these variables.

To compare the above results with those of Bennet & Ford (1997) I have constructed graphs of the same form as their Figure 7 for woodland birds (Fig. 8). Graphs are not presented for Increasers and Other birds as these groups showed no relationship with vegetation cover. The other species group with a flattish response was Mobile birds. Threatened birds did not show a strong pattern with percent cover either, and this probably reflects the scarcity of data that in turn is a true reflection of their patchy distribution. These graphs accentuate the effect of vegetation cover as other explanatory variables have not been fitted. When the full model with fitted location terms was plotted for species richness of Declining birds (Fig. 9), the shape of the response is similar to that presented in Fig. 8.

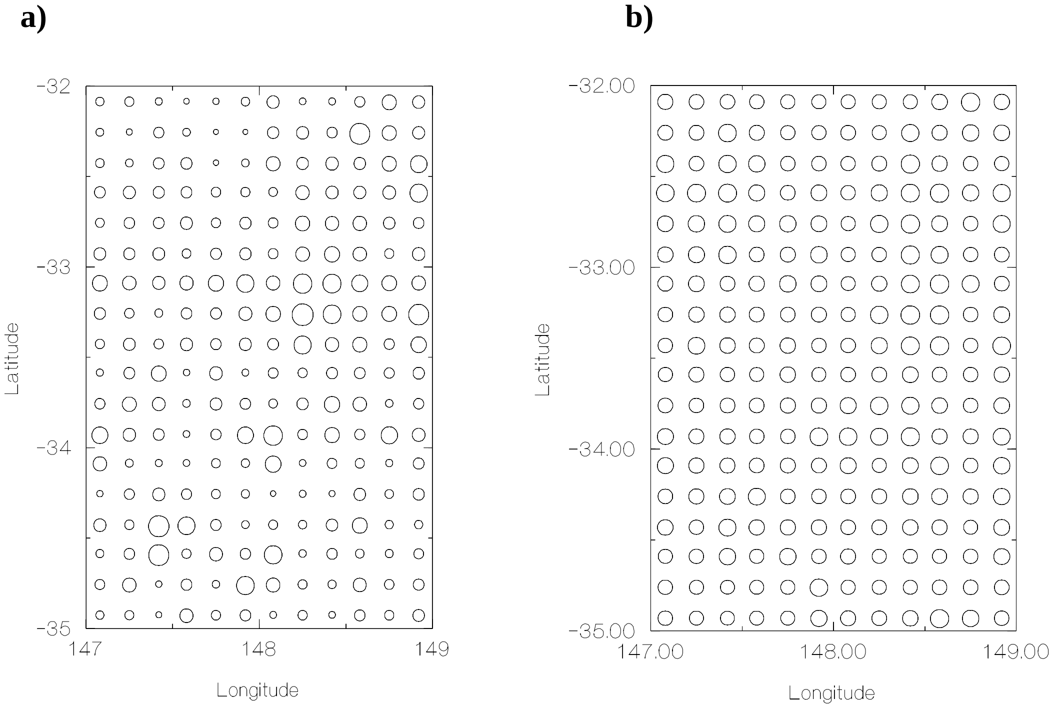


Figure 7. Comparison of **(a)** actual richness of all bird species, and **(b)** predicted richness given actual values of observer effort and vegetation cover, based on best-fit model. Same scale for richness used, so the degree of smoothing evident in the predictions from the regression model in b) is pronounced. Basically, predicted richness of all bird species does not vary geographically across the study region as greatly as actual richness did.

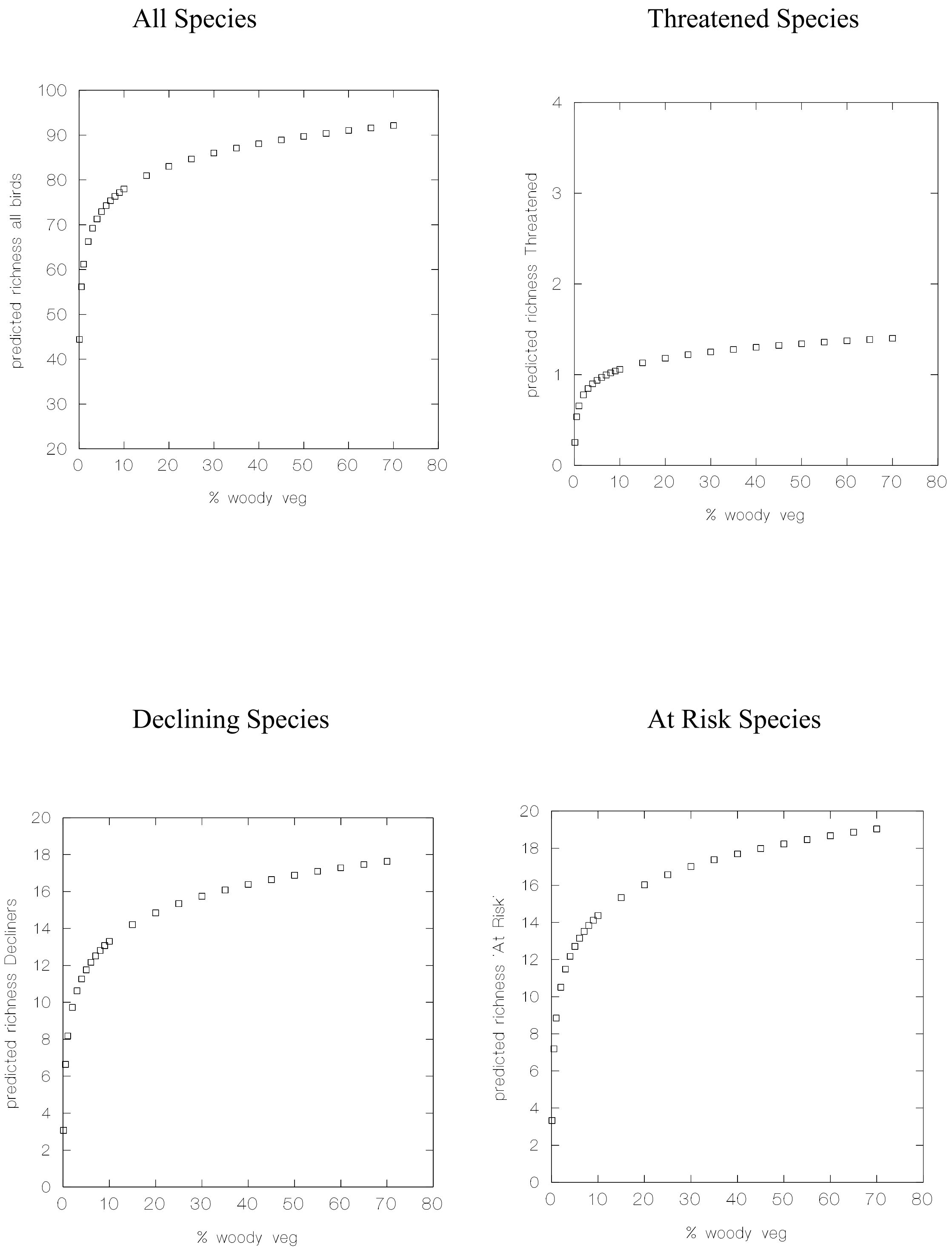
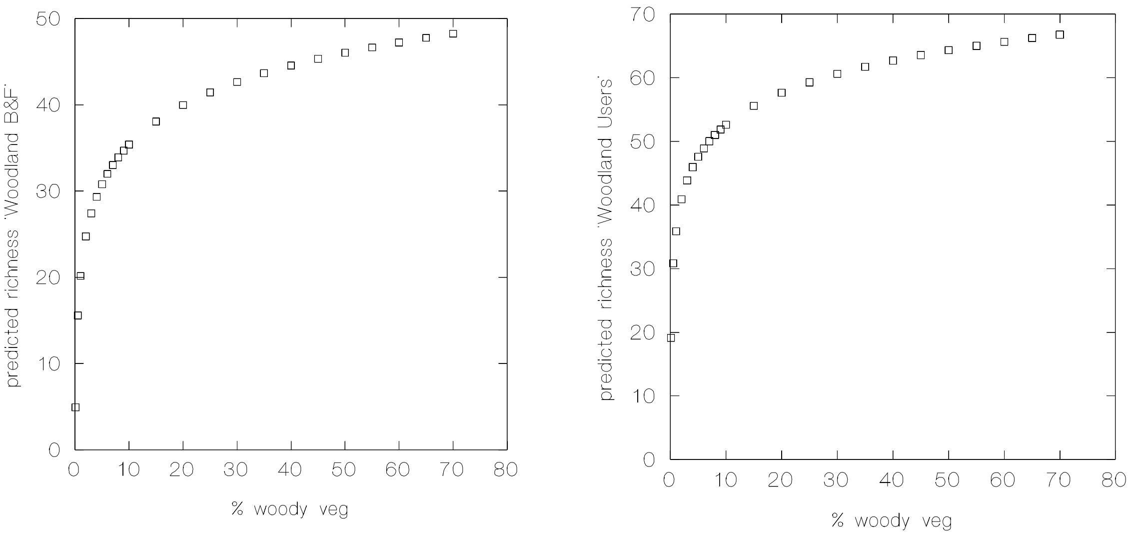


Figure 8. Predicted decrease in species richness of birds per Atlas square as a function of decreasing vegetation cover, with survey effort held constant at 20 sheets per square for eight of the 10 categories of birds. Increaser and Other species did not respond significantly to woodland cover. Location terms not included in these models.

‘Bennett & Ford’ Woodland Species

(author’s) Woodland Species



Mobile Species

Sedentary Species

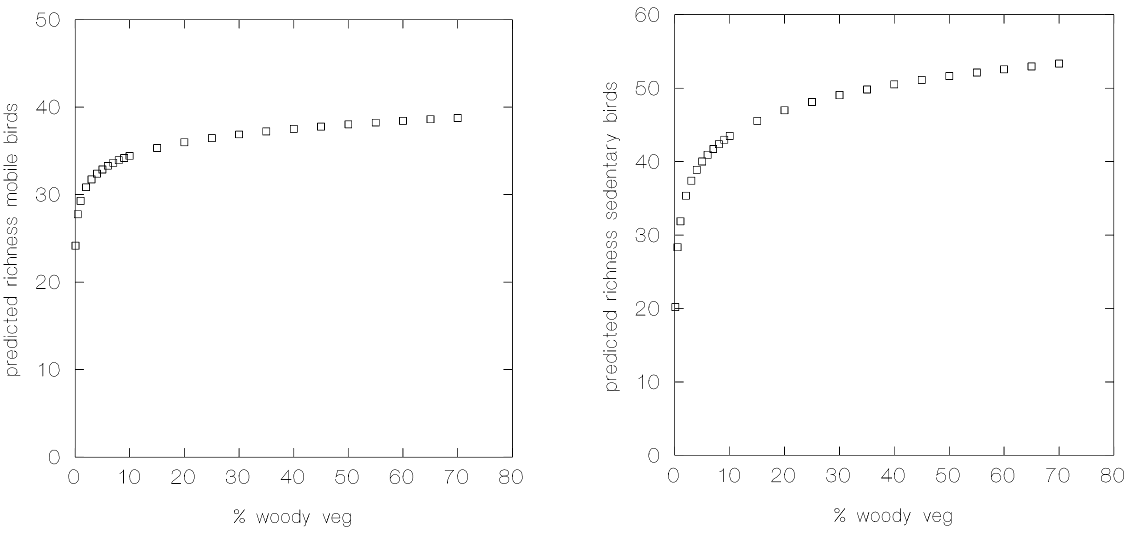


Figure 8. (cont.)

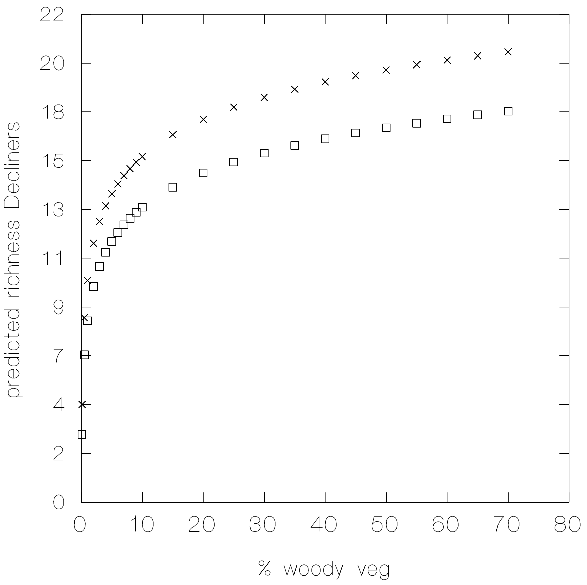


Figure 9. Full model (x) and partial model (□) for Declining bird species richness – shape is broadly similar over the low percent vegetation cover portions of the graphs. Survey effort held constant at 20 sheets in both models, and mid point of study region used in full model. Partial model is predicted species richness of Declining birds as a function of percent vegetation cover and survey effort. Full model contains the additional three location terms. The models diverge in their predictions of Declining bird species richness due to the greater weight given to survey effort (for the value of 20 sheets) in the full model. The partial model predicts a similar level of richness at other values of survey effort.

Partial Test of Influence of Large Remnants on Species Richness

Eighty-eight squares had less than 5% remnant vegetation, while 21 squares had at least 25% vegetation cover (‘high cover’) in the region (Fig. 10). Excluding all peripheral squares, 17 and 45 squares with < 5% vegetation cover (‘low-cover’ squares) are and are not, respectively, contiguous with one or more high-cover squares. Neither *t*-test on the residual species richness was significant (Decliners and Woodland birds, $P > 0.14$). In both cases the sign was in accordance with the expectation, ie residual richness was greater in squares adjacent to high-cover squares. Were the study region expanded (to increase power) and were spatial autocorrelation explicitly accounted for in the model, it seems possible that a significant result might be obtained. That is, Woodland bird species richness in low-cover landscapes adjacent to high-cover landscapes may be significantly greater than in those without the benefit of large amounts of native vegetation in close proximity.

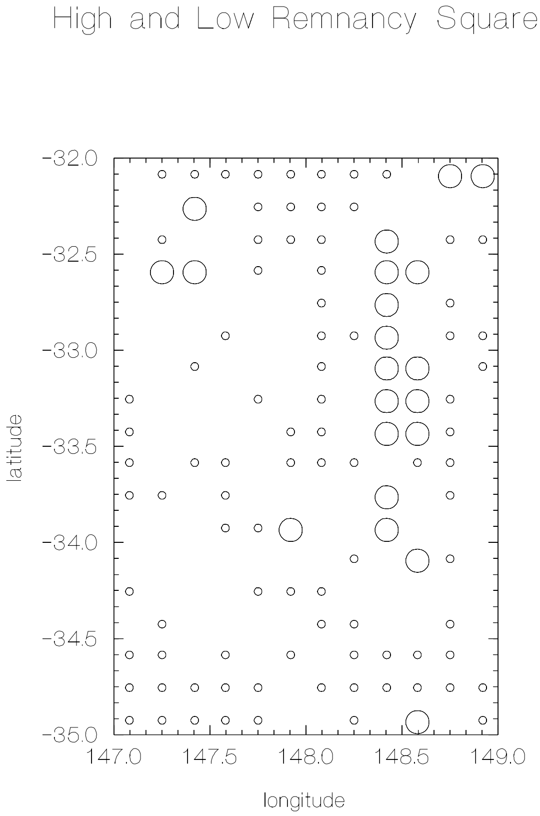


Figure 10. Location of 10' squares with high (○: > 25%) and low (○: < 5%) percent cover of woodland vegetation. Unfilled squares had intermediate remnancy levels.

Individual Species' Reporting Rates

Distribution of Remnant Vegetation

Figure 11 shows the distribution of 142 Atlas squares with at least six observer sheets. These squares are used for subsequent modelling and correlation of species' individual responses to variations in native vegetation cover across the landscape. First, however, I examine the distribution of remnant vegetation and whether percent cover is correlated with observer effort. Visual appraisal suggests that observer effort may not be randomly distributed throughout the study area (less effort in the north-west).

Remnant vegetation is not distributed evenly or randomly over the study region (Fig. 1). It is apparent much more native vegetation remains in the north-eastern sector, being found on the north-south aligned ranges and associated with higher rainfall. The distribution of vegetation cover is not significantly correlated with observer effort ($P > 0.1$). However, it is significantly correlated with both longitude and latitude as we might expect from Fig. 1.

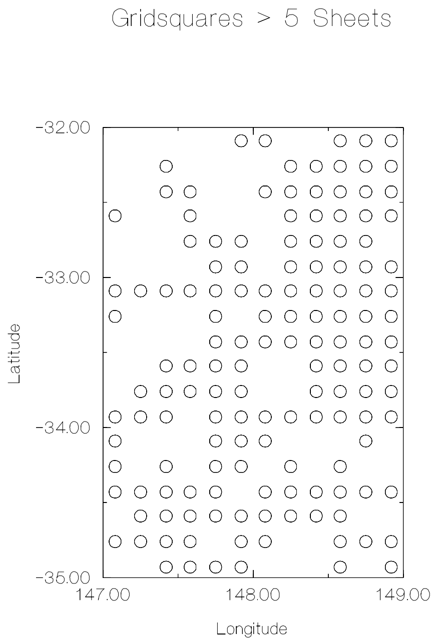


Figure 11. Map of study region showing 142 Atlas 10' squares for which at least six observer sheets were received, the basis for screening individual species' responses to differences in vegetation cover.

Multiple (least squares) stepwise regressions were undertaken to investigate these relationships further, both for the full (215) and reduced (142) data sets of Atlas squares. Using the log-transformed response variable (LOGZW), the linear, quadratic and interaction location terms were trialled in combination. Three terms were fitted: $(\text{LATI})^2$, the interaction (LATI*LONGI) and the linear LONGI term. The same combination of three terms was fitted at $P < 0.05$ when an alternative backward stepwise procedure was tested. The variance explained in log-transformed percent vegetation cover was 14.7% for the full and 15.0% for the reduced data sets. Although this represents only a small proportion of variation in the distribution of remnant native vegetation across the region, it was considered likely to confound some results if individual species happened to have similarly distributed variations in reporting rates (reflecting biogeographic patterns of distribution). The response of vegetation cover to the geographic variables is shown in Fig. 12. The geographical representation of this systematic variation is shown in Fig. 13. As graphed, the patchiness of remnant vegetation at medium spatial scales (related to the distribution of rugged ranges in the region) has been lost in the map of predicted vegetation cover. The smoothed response reveals the even larger-scale trends of generally small amounts of remnant vegetation in the south west, rising to the north and west, before subtly declining slightly in the extreme north (the quadratic term for latitude's effect).

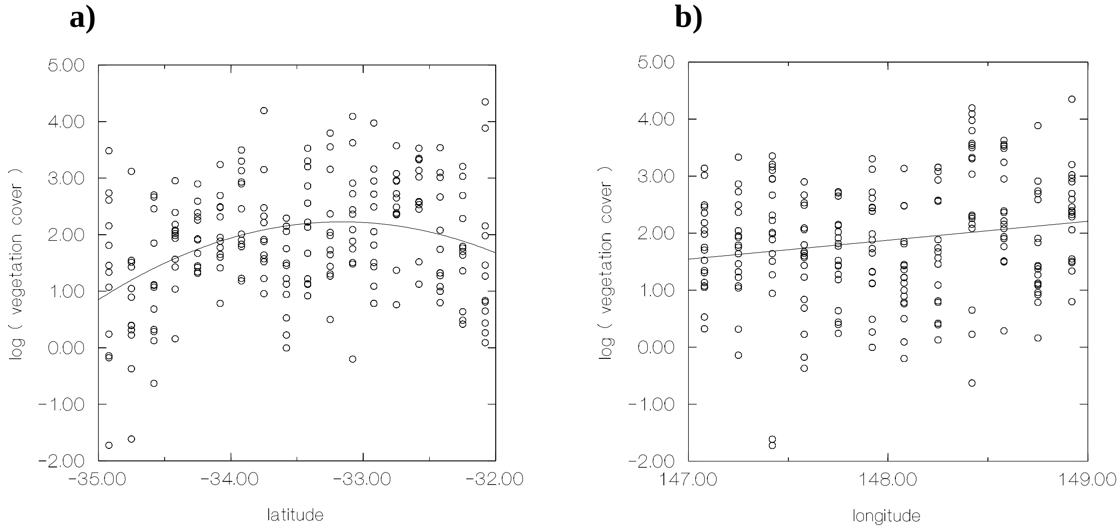


Figure 12. Response of vegetation cover (LOGZW = log (vegetation cover)) to **a)** latitude, and **b)** longitude, with fitted response functions (single-term models).

Although the three-term model (latitude, longitude and their interaction) accounted for the maximum amount of variance in LOGZW (log woody vegetation cover), it was decided to opt for a simpler model that did not contain a squared term. The reasoning here was that while remnant vegetation could certainly respond in this manner (evidenced in Fig. 12a), geographic trends in reporting rates of birds, independently of vegetation distribution, were unlikely to show pronounced unimodal responses. At most, monotonically increasing or decreasing biogeographic trends in abundance and distribution were expected. Accordingly the linear terms of latitude and longitude were fitted to the reduced data set (142 squares); together they accounted for 12.2% of the variance in LOGZW, the residuals were saved to the new variable ZWRS (residual of log-transformed vegetation cover). This variable can be thought of as that component of variation in vegetation cover that is independent of the large-scale geographic trends depicted in Fig. 13.

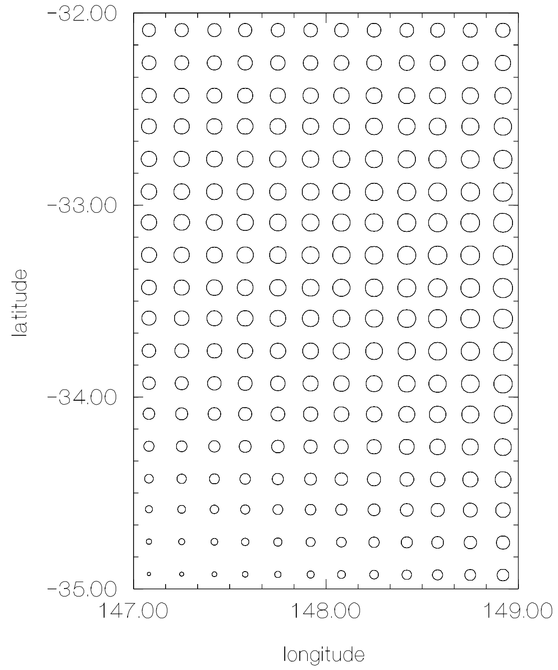


Figure 13. Mapped modelled response of vegetation cover (LOGZW) to location terms (latitude^2, longitude, and interaction term: $n = 215$, $R^2 = 14.7\%$).

Strength of Correlation of Declining vs Woodland Bird Species

To test the proposition that Declining species diagnosed by Reid (1999) would show a stronger dependency on remnant vegetation cover than Woodland birds, I conducted a one-tailed *t*-test on the Spearman rank correlation coefficients calculated for each species against the 'location-corrected' cover variable, ZWRS. The analysis was confined to passerine species (thereby excluding Emu, Whistling Kite and Painted Button-quail). With the White-browed Woodswallow also removed from the data set, 17 Declining passerines remained.

The mean rank correlation coefficient of Decliners was not significantly greater than that for the 38 'Bennett & Ford' Woodland passerine species with Decliner species first removed ($P = 0.10$), although the trend was in the expected direction. Mean rank correlation values were 0.387 for Decliner passerines and 0.312 for 'Bennett & Ford Woodland' species. The result was significant, however, for the author's Woodland group – these 52 passerine Woodland species (with Decliners removed) had a mean rank correlation coefficient of 0.265, significantly less than that of the Decliners ($P < 0.05$).

Other Patterns in the Rank Correlation Coefficient

The 149 species recorded in greater than 10 Atlas squares comprise 52 non-passerines and 97 passerines. There was a striking difference in their response as a whole to variation in vegetation cover across the study region. The mean Spearman rank correlation between reporting rates and location-corrected vegetation cover of non-passerines was 0.039 (*sd* 0.202), compared with 0.204 (*sd* 0.232) for passerines, a highly significant difference (*t*-test, $P < 0.001$). Most birds of prey (non-passerines) and most introduced species (passerines and non-passerines) generated negative correlations, often nominally significant at the 5% probability level (see Appendix 3 for all results). Overall, many more species returned positive correlation coefficients than negative ones.

Fifty-seven species could be unambiguously assigned to one of the broad Australian biogeographic categories of Bassian or southern, Eyrean or centralian, and Torresian or northern. Most species are not confined to a single climatic region, and they were excluded from this classification. For example, many Woodland bird species have distribution patterns that reflect a preference for the climatic interzone between wet forested regions on one hand and the open arid plains on the other; these were excluded. Finally, although the distinctive suite of mallee specialists shows a predominant Bassian affinity (Schodde 1990), they were excluded because their distribution pattern is again intermediate (and few mallee-specialist species were retained in the 149 species subset, most being recorded in less than 10 Atlas squares). However, even with this reduced data set, the results revealed striking differences between groups.

The 23 Bassian species exhibited a strong positive response to percent vegetation cover (mean and *sd* of rank correlation: 0.334, 0.171), significantly greater (*ANOVA* $P < 0.001$) than the correlations of 25 Eyrean and nine Torresian species with vegetation cover. These were weak to non-existent (mean, *sd*: 0.000, 0.195 and 0.053, 0.140, respectively) and not significantly different from each other. Species that have evolved in dense, forested (and scrubby, wet heath) southern environments appear to have been negatively impacted by the effects of vegetation clearance to a far greater degree than species that have evolved in open centralian environments and in the northern savannahs.

Table 5 shows the 29 species that generated correlation coefficients of the greatest magnitude with, respectively, positive (15 species) and negative (14 species) sign.

Table 5. Species with the strongest Spearman rank correlations between reporting rate and location-corrected log-transformed percent vegetation cover. Positive correlations were far more prevalent then negative correlations, and generally stronger.
Int = Introduced species; D = Declining species of Reid (1999).

+ve Response	R_s	-ve Response	R_s
Brown-headed Honeyeater	0.60	Cockatiel	-0.39
Eastern Yellow Robin (D)	0.59	Common Starling (Int)	-0.33
Grey Shrike-thrush	0.58	Brown Songlark	-0.30
White-throated Treecreeper	0.54	Black-shouldered Kite	-0.29
White-browed Babbler (D)	0.52	Spotted Harrier	-0.29
Jacky Winter (D)	0.52	Australian Hobby	-0.29
Yellow-faced Honeyeater	0.52	Nankeen Kestrel	-0.28
Grey Fantail	0.50	House Sparrow (Int)	-0.26
Yellow-tufted Honeyeater	0.49	Stubble Quail	-0.25
Speckled Warbler (D)	0.49	Brown Falcon	-0.25
Chestnut-rumped Heathwren	0.49	Rock Dove (Int)	-0.23
Spotted Pardalote	0.49	Barn Owl	-0.18
Varied Sittella (D)	0.47	White-winged Fairy-wren	-0.17
Weebill	0.47	Ground Cuckoo-shrike	-0.17
Common Bronzewing	0.47		

The first non-passerine, Common Bronzewing, enters the list of positive responses at 13th place, and so passerines dominate the top end of the list when ranked by correlation values. Declining species do not predominate in this group (five in top 15). The bronzewing is the only granivore in the list, and the remainder consume invertebrates mainly. Canopy feeders are well represented and only three species are mobile. At the other end of the list – birds with a strong negative response to percent vegetation cover – there are more non-passerines than passerines (eg raptors), and exotics, birds typically associated with grasslands, and arid-zone species such as the harrier, Cockatiel, fairy-wren and cuckoo-shrike predominate. Most are ground feeders and granivores are well represented. However, relatively few (three) of the native Increaser bird species of Reid (1999) are included in the negative-response list.

Based on a thorough inspection of the rank correlation values for all 149 landbird species, including the brief synopsis provided above (Table 5), I conclude that the relationship between a species' response to percent vegetation cover at this landscape scale and its propensity to decline or increase is not as tight as I had expected at the outset of the study. The trend for woodland-dependent species to decline with decreasing vegetation cover is, however, pervasive and strongly evident.

Examples of Modelling Individual Species' Reporting Rates

In this Section and the next, examples of the range in responses by species to variation in percent vegetation cover are given, including modelled responses. The species codes are presented so that summary statistics can be readily found in Appendices 2 & 3.

Yellow-throated Miner (B635) and Noisy Miner (B634)

Classified as Increasers, the Yellow-throated Miner species and its congener, the Noisy Miner, occur in parapatry in the study region. This means that their distributions overlap to a small extent where the two species meet. The Yellow-throated is the Eyrean or dry country form of the species pair, and so is confined to the north-western districts (Fig. 14) where it largely replaces the Noisy Miner, itself very common in the wetter country to the south and east, being widespread over most of this region. Hence we would expect both species to show strong correlations with location terms, but what of their response to percent vegetation cover? As Increasers they are expected to be negatively correlated with vegetation cover (LOGZW). Using the Spearman rank correlation coefficient, R_s, Noisy Miner's reporting rate was significantly negatively correlated with LOGZW ($R_s = -0.19$, $P < 0.05$) but Yellow-throated Miner was not ($R_s = +0.03$, *ns*). Both species were strongly correlated with various

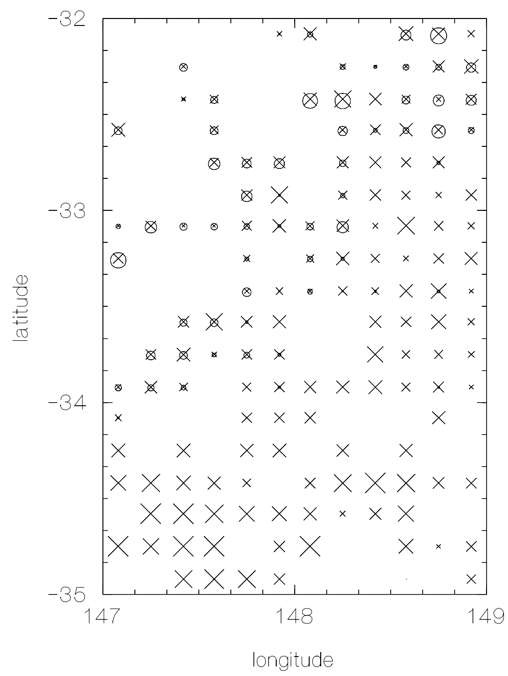


Figure 14. Parapatric distribution of congeners, Yellow-throated (○) and Noisy Miners (x). Size of symbol indicates reporting rate.

location terms. However, after fitting a logistic regression to the Yellow-throated Miner's response to location and saving the residuals, the residual term returned a significant negative rank correlation against vegetation cover ($R_s = -0.222$, $P < 0.01$). Plotting the residuals revealed that the species was exhibiting a classic hump-shaped response to increasing vegetation cover, rising in reporting rate initially but then declining strongly with increasing cover (Fig. 15a). Fitting a quadratic (using least-squares regression) returned a highly significant result ($P < 0.001$). The relationship between Yellow-throated Miner's reporting rate and the 'location-corrected' measure of woody vegetation cover, ZWRS, yielded a non-significant but negative correlation ($R_s = -0.139$, $P = 0.06$). Apparently, the strongly unimodal (hump-shaped) response of the species to vegetation cover caused the lack of good fit.

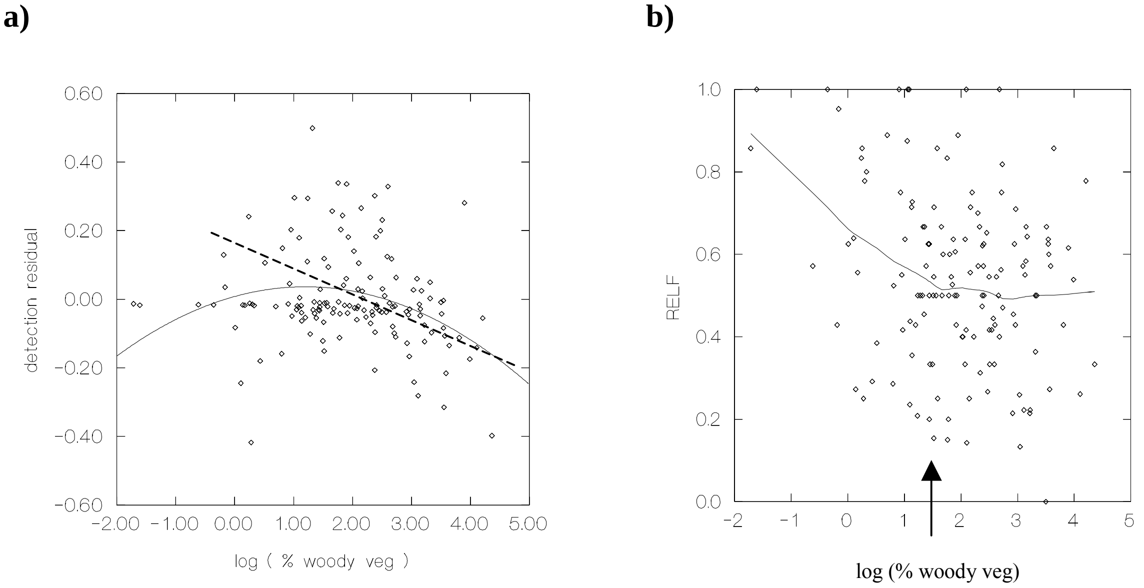


Figure 15. a) The residual reporting rate of Yellow-throated Miner (from logistic regression fitting the interaction of latitude and longitude) plotted against the logarithm of vegetation cover. Note basically negative response, almost linear (dashed line), but quadratic fitted better. **b)** Uncorrected reporting rate (RELF) of Noisy Miner vs logarithm of vegetation cover. The apparent trend (Systat default LOWESS curve fitted) is misleading, because when corrected for location the trend becomes non-significant and the apparent threshold effect at 4.5% vegetation cover (↑) disappears (see text for more details).

Figure 15a reveals that even Increaser species may reach their limits and decline when native vegetation becomes exceedingly scarce. The reporting frequency of the Yellow-throated Miner actually declines as landscape vegetation cover drops below *ca* 2%, hence the better fit of the quadratic term over the simple linear model (itself highly significant).

The Noisy Miner, surprisingly, shows the opposite pattern. Although its reporting rate was significantly and negatively correlated with percent vegetation cover (uncorrected: Fig. 15b) as we might expect *a priori*, when corrected for confounding location terms, the relationship though still negative was no longer significant ($P > 0.05$):

> for uncorrected reporting rate (URR) against LOGZW (percent vegetation cover), $R_s = -0.190$, $P < 0.05$;
> against location-corrected vegetation cover (ZWRS), $R_s = -0.078$, $P > 0.05$;
> residual reporting rate/correcting for location terms against LOGZW (two regression models tested): $R_s = -0.05$, -0.08, both $P > 0.05$.

This time, as was generally the case, the fit of the correlation (sign and significance level) between URR and ZWRS corresponded closely to the correlation between the reporting rate residual term (corrected for location) and LOGZW. The surprising result remains, however, that contrary to expectation perhaps, Noisy Miner reporting rate does not increase significantly as vegetation cover decreases.

<u>Restless Flycatcher</u> (B369)

The Restless Flycatcher was diagnosed as a Declining species by Reid (1999). Apparently Bennett & Ford (1997) did not consider it to be at risk in the northern box-ironbark landscapes of Victoria as they included it with the non-Woodland dependent ‘Others’. Hence, I chose to illustrate its response here.

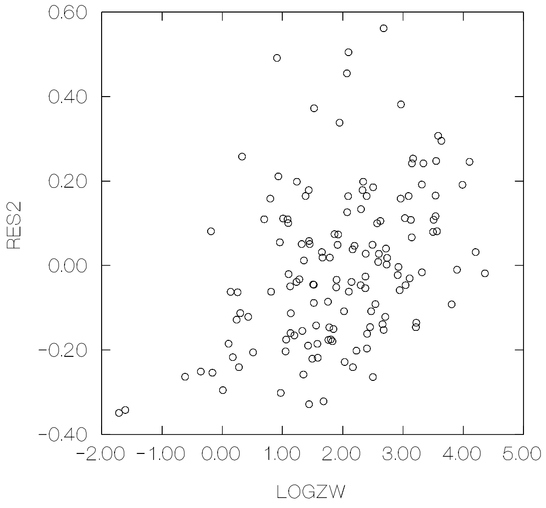


Figure 16. Residual reporting rate/accounting for the interaction location term against log-transformed percent woody vegetation cover for Restless Flycatcher.

The species is less frequently reported in the north in the study region. With the strong locational effects accounted for, its residual reporting rate correlates positively and highly significantly with increasing vegetation cover (Fig. 16).

The results again demonstrate the robustness of the partial correlation approach:

(1) URR against LOGZW: $R_s = +0.34$, $P < 0.001$;
(2) URR against ZWRS: $R_s = +0.43$, $P < 0.001$;
(3) residual RR/location against LOGZW: $R_s = +0.44$, $P < 0.001$, where

URR = uncorrected reporting rate, and 'residual RR/location' is the location-corrected measure. Note the similar values for R_s in (2) and (3).

Summary of Modelling Individual Species' Reporting Rates

The Spearman rank correlations for all 149 species against ZWRS (location-corrected, percent vegetation cover) are summarised by bird group in Table 6. Results by species are presented in Appendix 3. The trends are evident. Species in the groups of Decliners, Bennet & Ford Woodland, Woodland, and Sedentary species show the strongest and positive correlations with vegetation cover (the strength of correlation decreasing in the order listed). Species in two groups, Increasers and Others, show an average negative response to vegetation cover, ie their reporting rates tended to increase with a reduction in vegetation at the landscape scale. The variable response shown by the few Threatened species recorded in a sufficient number of Atlas squares suggests that for some of these species there may be threatening processes of greater import than the loss and degradation of natural vegetation. The results confirm earlier impressions (Reid 1999) that Decliners and Threatened species comprise distinct ecological entities as a whole, though undoubtedly some of the formally classified Threatened species show strong habitat dependencies similar to the Decliners.

The procedures adopted in this section are coarse; use of a rank correlation coefficient, as here, assumes there are monotonically increasing or decreasing relationships only. Use of the nominal 5% significance threshold for the Spearman rank correlation coefficient ($|R_s| >= 0.163$, as in Table 6) is an arbitrary figure chosen for the screening procedure. Evidence (see Fig. 15a, and more examples in next section) and theory would suggest that unimodal (= humped or 'valley') relationships would be expected for some species. However, if the unimodal relationships are distributed such that the turning point is located towards either end of the range of percent vegetation cover values, any strong linear component to the relationship will be captured by the correlation coefficient. Sixty-seven of the species (45%) screened in this manner generated a positive rank correlation of 0.163 or greater, indicating that the amount of remnant vegetation at the landscape scale plays an important role in the distribution and abundance of many landbirds in this region. Only 14 species (9%) generated a negative correlation of this magnitude (Tables 5 & 6). The majority of the balance of species had non-significant but positive relationships with the 'location-corrected' measure of vegetation cover (Table 6).

Table 6. Spearman rank correlation summary for relationships between species reporting rates and location-corrected, percent vegetation cover, by nine bird groups and a new category 'BWO'.

T= Threatened; D= Declining; I= Increasing; BW= Bennett & Ford Woodland birds; 'BWO'= those species not included in Bennett & Ford's Woodland group; W=broader (author's) Woodland group; O=non-Woodland Others; M= Mobile; S=Sedentary.

Significance (sig) threshold set at R_s = +/- 0.163; n.s. = not significant.

	All	**T**	**D**	**I**	**BW**	**BWO**	**W**	**O**	**M**	**S**
# spp	149	5	21	32	69	80	94	55	72	77
mean	0.146	0.168	0.332	-0.063	0.304	0.011	0.245	-0.023	0.095	0.194
s.d.	0.236	0.135	0.182	0.175	0.176	0.192	0.200	0.193	0.236	0.225
breakdown of # spp										
+ sig	67	2	17	3	52	15	59	8	26	41
- sig	14	0	0	7	0	14	1	13	11	3
+ n.s.	38	2	2	8	12	26	24	14	18	20
- n.s.	30	1	2	14	5	25	10	20	17	13

Three pairs of mutually exclusive categories of birds are presented in Table 6, one by mobility and the others by membership of the two Woodland classes. I contrasted the means of the rank correlation coefficients in these three dichotomous groupings using the *t*-test for unequal sample sizes, and the results were significant in each case. The correlation of sedentary birds' reporting rates with percent vegetation cover was significantly greater than those of mobile species ($P = 0.011$). The two classifications of Woodland birds showed much greater differences ($P << 0.001$) with Woodland birds being highly dependent on the amount of vegetation cover in the landscape (Table 6). The Bennett & Ford Woodland bird group (BW) yielded a higher mean correlation coefficient than the more general Woodland group (W), but its smaller membership results in the relegation of a considerable number of other woodland-dependent species to the ‘Other’ (BWO) group. This trade-off is evidenced by the change in sign of the mean correlation from negative in the Other (O) group to positive (BWO: Table 6). Arguably therefore, the Bennett & Ford classification of woodland birds can be expanded to include other woodland-dependent species for this study region at least.

Decliners

Most of the 21 Decliner species showed strong positive correlations with corrected and uncorrected measures of percent vegetation cover (Table 7; Figs 16, 17). The few that did not were Emu, Whistling Kite, Grey-crowned Babbler and White-browed Woodswallow. These exceptions were not surprising given their known habitat preferences. I had already raised doubts over the true status of the woodswallow in Reid (1999) – it and the kite display a tendency to have increased reporting rates in squares with lower amounts of native vegetation. None of these four species returned significantly negative correlations with corrected vegetation cover, the trend was negative only for the kite and woodswallow, while Emu was on the margin of significance for a positive correlation.

Table 7. Spearman rank correlation coefficients for 21 Declining bird species with vegetation cover. Critical thresholds for significance ($n = 142$): $R_s = 0.271$, $P < 0.001$; $R_s = 0.213$, $P < 0.01$; $R_s = 0.163$, $P < 0.05$. * denotes species with a significant correlation with one or more location terms. LOGZW: log percentage vegetation cover; ZWRS location-corrected, log percentage vegetation cover.

Species	**LOGZW**	**ZWRS**	**Species**	**LOGZW**	**ZWRS**	**Species**	**LOGZW**	**ZWRS**
*Emu	0.19	0.15	*Whistling Kite	-0.16	-0.13	Painted Button-quail	0.39	0.40
Brown Treecreeper	0.43	0.43	Speckled Warbler	0.51	0.49	*Ch-rumped Thornbill	0.24	0.25
*Southern Whiteface	0.27	0.37	Jacky Winter	0.52	0.52	*Red-capped Robin	0.34	0.42
*Hooded Robin	0.36	0.38	East Yellow Robin	0.55	0.59	*Grey-crown Babbler	0.00	0.04
*White-bro Babbler	0.48	0.52	Varied Sittella	0.41	0.47	*Crested Shrike-tit	0.20	0.25
*Crested Bellbird	0.25	0.26	Rufous Whistler	0.39	0.42	*Restless Flycatcher	0.35	0.43
*Wh-br W’swallow	-0.10	-0.04	*Dusky W’swallow	0.32	0.37	*Diamond Firetail	0.37	0.37

The Speckled Warbler is distributed throughout the region (non-significant correlations with location terms) and its uncorrected reporting rate (URR) showed a very strong positive correlation with percent vegetation cover:

URR with LOGZW, $R_s = +0.51$; and URR with ZWRS, $R_s = +0.49$; $Ps \ll 0.001$.

The Speckled warbler typifies the response of Declining and many woodland-dependent species (Fig. 17). For any species, the two values of the Spearman correlation coefficient

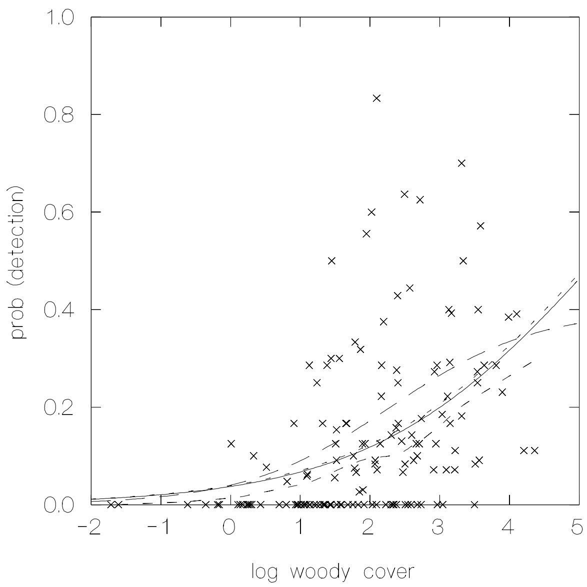


Figure 17. Reporting rate of Speckled Warbler against log-transformed percent vegetation cover. The modelled response is shown for three variants of logistic regression (solid curve shows usual form), and the truncated curve shows the LOWESS curve (default settings in SYSTAT for locally weighted least-squares regression). See text for further explanation.

presented in Table 6 tend to be similar when geographical effects are unimportant (eg Speckled Warbler). For other species which exhibit pronounced geographic trends in distribution of reporting rate (marked with asterisks in Table 6), the values of the Spearman coefficient tend to diverge more widely. They diverge widely when the species' geographic trends in distribution of reporting rate parallel those of vegetation cover.

Correlation coefficients of the magnitude ($R \approx 0.5$) found for the Speckled Warbler mean that percent vegetation cover accounts for only a minority (≈ 25%) of the variability (R^2) in reporting rates. A variety of generalised linear models were fitted to the Speckled Warbler data set (Fig. 17). It is difficult without the aid of diagnostics to determine which of the fitted response curves might be most appropriate, but the four curves depicted are all basically similar. The LOWESS (locally-weighted least squares regression) curve shows a steep increase in reporting rate at log (vegetation cover) = 2.6, or *ca* 15% vegetation cover. The usual logistic expression (of form $y = \exp(b_0 + b_1 x) / (1 + \exp(b_0 + b_1 x))$: solid curve in Fig. 17) shows reporting rate rising to a maximum of *ca* 0.4 at 100% vegetation cover. The slightly different bounded exponential curve (long dashes) was obtained by adding this maximum value as a leading coefficient, and re-estimating the linear terms, forcing the inflexion point (the point on the curve where the rising limb bends back to flatten) to the left ($y = 0.4 \exp(b_0 + b_1 x) / (1 + (\exp(b_0 + b_1 x))$, so that the response is bounded between 0 and

0.4. This model seems unrealistically optimistic, however, in terms of the position along the x-axis where reporting rate rises steeply. The log-linear model (of form $y = \exp(b_0 + b_1 x) - b_2$, not shown) yielded a similar fit to, but still higher than, the LOWESS curve.

The Emu has become extinct in the southernmost portion of the study region, and the Weddin Mountains now mark the south-easterly range limit locally (see map in Appendix 2). Accordingly, the Emu's distribution of reporting rate is significantly (if marginally) correlated with two location terms ($P = 0.03$, $P = 0.04$: Appendix 3). Although the species appears to be significantly and positively correlated with vegetation cover (for URR against LOGZW, $P < 0.05$: Table 6), against the location-corrected variable, ZWRS, the trend is no longer significant. When checked to see if this result was upheld by the alternative method – by correlating the residual variation in reporting rate having accounted for a location term (through logistic regression) with LOGZW – the non-significant result was confirmed.

There is much unexplained variation (ie the wide scatter of points around the fitted relationship) in all these data sets of individual species' reporting rates when graphed against vegetation cover. As exemplified by the Speckled Warbler example (Fig. 17), it would seem unwise to identify thresholds in vegetation cover which might serve as targets for levels of vegetation required in landscapes to retain (or attract back) particular species. There are too many other factors that obviously influence the likelihood of particular species persisting in landscapes for a given level of native vegetation. Such factors include the type of vegetation community, vegetation condition, surrounding landscape context, and terrain and climatic features.

Increasers

Twenty-five of the 29 native Increaser bird species of Reid (1999) were recorded in 10 or more Atlas squares within the study region. Most of these 25 species returned non-significant correlations between reporting rate and location-corrected log percent vegetation cover. The majority showed negative relationships with location corrected vegetation cover (with several species on the margin of significance). Four of the 25 native Increaser species showed negative and significant relationships with percent vegetation cover: Nankeen Kestrel, Cockatiel, Yellow-throated Miner and Brown Songlark. Three species returned positive and significant correlations: Peaceful Dove, White-plumed Honeyeater and Pied Currawong.

Woodland Birds

Most woodland species in both classifications returned significant and positive correlations with the location corrected measure of log-transformed percent vegetation cover. The more exclusive set of 'Bennett & Ford' Woodland species showed a stronger positive response as a group, but with most species in common to both classifications the results are similar. Only five species included in the Bennett & Ford Woodland group returned non-significant negative correlations (Table 5), namely Dollarbird (T), Superb Parrot, Singing Honeyeater (E), Little Friarbird (T) and Diamond Dove (E). Apart from the parrot, these species have Torresian (T) or Eyrean (E) biogeographic affinities, as indicated. For the broader Woodland group I adopted, more species showed a non-significant negative relationship with vegetation cover: Australian Hobby, Yellow-throated Miner (E), Whistling Kite, Red-backed Kingfisher (E), Noisy Miner, Red-rumped Parrot, Australian Magpie and White-browed Woodswallow (E). Raptors generally had negative correlations (Appendix 3), and the kite and the woodswallow have been previously discussed. Most of the others are Increasers. Three of the species including the woodswallow have Eyrean affinities.

The non-Woodland groups (Others) displayed a mixture of responses. The main difference between the two Woodland bird classifications is that there are 12 species not included in Bennet & Ford's Woodland birds grouping but included in mine – these 12 species showed non-significant but positive correlations with percent vegetation cover. The effect of classifying these 12 species differently was to change the sign of the average rank correlation from negative (in the author's non-Woodland Others group, O) to positive (in the non-Bennett & Ford Woodland Others group, BWO); see Table 6. In both classifications of non-Woodland species, a number of species returned positive and significant correlations with percent vegetation cover. For the BWO group they were Striated Pardalote, Striped Honeyeater, Superb Fairy-wren, *Variegated Fairy-wren, *Yellow-plumed Honeyeater, *Mallee Ringneck, *Crested Bellbird, *Pied Currawong, *Wedge-tailed Eagle, Double-barred Finch, Red-browed Firetail, Silvereye, *Spotted Quail-thrush, Restless Flycatcher and *Chestnut-rumped Heath-wren, and species preceded with an asterisk denote the eight species in the O group (the author's non-Woodland Others group). Some of these species did not occur in Bennett & Ford's (1997) northern Victorian study region, which is why they were assigned to the BWO group in Table 5. Only one of these 15 species, the Wedge-tailed Eagle, is a non-passerine.

Threatened Birds

Only five Threatened species were recorded in 10 or more Atlas squares. Two Threatened species, Turquoise Parrot and Gilbert's Whistler, returned strong positive correlations with percent vegetation cover. The response by Painted Honeyeater and Major Mitchell's Cockatoo was positive but below the significance threshold, while the Superb Parrot returned a non-significant, weak negative correlation.

Noisy Miners

There were few negative correlations between reporting rates of the Noisy Miner and 53 widespread Woodland species. Using actual (raw) Noisy Miner reporting rates only four species' reporting rates were negatively and significantly correlated with that of Noisy Miner, namely Striped Honeyeater, White-eared Honeyeater, Double-barred Finch and Mistletoebird. Some of these negative correlations would be anticipated on the grounds of complementarity in distribution patterns, drier-country species against the Noisy Miner's preference for wetter areas. Accordingly, the exercise was repeated using the residual variation in Noisy Miner reporting rate, having partialled out the effects of longitude and latitude through logistic regression. No significant and negative correlations were obtained this time, thus confirming the biogeographic influence in the above results. The surprising result remains, however – *at the landscape scale* Noisy Miner prevalence does not appear to affect the rates at which native Woodland bird species were reported in the original RAOU Bird Atlas scheme.

Using location-corrected and raw Noisy Miner reporting rates, 13 species in the author's Woodland group were positively and significantly correlated with Noisy Miners in both series of tests. These were Jacky Winter, Eastern Yellow Robin, Rufous Whistler, White-browed Woodswallow, Dusky Woodswallow, Striated Pardalote, Yellow-rumped Thornbill, Little Friarbird, White-plumed Honeyeater, Black-faced Cuckoo-shrike, White-winged Triller, Australian Magpie, Australian Raven, and White-winged Chough. The first five are Decliners while most of the remainder are species that are regarded to have generally adapted well to extensively cleared agricultural landscapes (eg Reid 1999).

An adverse impact of Noisy Miners on individual small woodland bird species in this study region cannot be detected at the landscape scale using these, admittedly coarse, data. Any negative impacts, therefore, operate at more localised scales, and presumably, specifically at that of the patch. However it is difficult to envisage the problem being too severe if the effects do not scale up to be detectable at the landscape scale. Alternatively, given the historical nature of these observations (the data set is 20 years old), the Noisy Miner problem could have become much more severe in recent times. Society should be careful not to scapegoat exotic and native species when more complex, broader-scaled, more pervasive land-degradation problems may be at play; unfortunately, single species do provide easy targets for blame.

As a check on the veracity of the above results for correlations with single species, I correlated Noisy Miner's reporting rate with species richness of All and (the author's) Woodland bird groups. Both the raw recording rate and that corrected for location terms for Noisy Miner were used, and the Spearman rank correlation coefficients were computed. The correlation between the location-corrected Noisy Miner reporting rate and the two species richness variables was weakly positive: $R_s = 0.024$ (All), 0.034 (Woodland); $P > 0.5$. The raw reporting rate correlations were weakly negative ($R_s = -0.084, -0.100$). Using the residuals of richness having accounted for the powerful effect of sampling effort did not alter the results greatly – all correlations were positive, those with location-corrected Noisy Miner reporting rate lying on the margin of significance ($R_s = 0.178, 0.165$; $P \approx 0.05$). Again, no evidence for a deleterious effect of Noisy Miners on woodland birds at the landscape scale could be detected, and if anything the opposite pattern was detected.

Discussion

The results reported here demonstrate that Bennett & Ford's (1997) results and conclusions from north-eastern Victoria apply to the southern New South Wales Sheep-Wheat Belt. There is no reason to believe that the pre-European historical pattern of landbird species richness within this study region departed significantly from a basically uniform distribution, with random variation, at this large landscape scale of almost 300 km^2. If we accept this assumption, the interpretations that follow from Bennett & Ford's work and that presented here are inescapable. At the landscape scale, many species of woodland birds have effectively gone extinct (local extinctions). This continuing process of local extinction causes species richness to decrease systematically with the loss of vegetation cover. Because the bird data analysed in this report were gathered 20 years ago and 15 years before the vegetation cover data were collected, the situation in extensively cleared landscapes is more serious than the models generated in this report suggest. This is the one point where I would depart slightly from the conclusions drawn by Bennett & Ford (1997). Their conclusions about bird conservation prospects in the northern Victorian plains are perhaps too sanguine to my mind. For example, they state (Bennett & Ford 1997: 256):

> '… the challenge is to be more explicit about a desirable level of tree cover in such rural environments. … below 10% cover species decline is rapid. We therefore recommend as a first approximation that at least 10% habitat cover should be a *minimum* goal for an infrastructure of natural vegetation among productive rural landscapes.' [their emphasis]

They emphasise this is a minimum target to aim for, with landscape reconstruction in mind, and they certainly do not imply that landscapes could be cleared down to this figure without detriment. They also stress elsewhere that the process of relaxation means that any such targets are probably overly optimistic in terms of the number of species that landscapes with this much cover can support. However, 10% sets a dangerously low bar for an idealised goal of healthy and biodiverse landscapes that society could embrace. I present figures below on how many species may be lost if we accept 10% as a reasonable minimum.

The species richness models can be used to predict the loss of birds at the landscape scale for the amount of remnant vegetation (percent cover) and for a given amount of survey effort (20 used here). In this section I present the predictions from the best-fit regression models for three of the bird groups, namely 'All Landbirds', Declining species, and Woodland species. The models used are those derived from the complete data set (198 species of landbird in all), and using data from 215 Atlas squares. For Declining species, I give figures for two scenarios due to the influence of geographic location on model predictions.

For **All Landbirds** in the region, the model predicts a maximum richness of *ca* 112 species at 100% vegetation cover (assuming a survey effort of 20 observer lists).

Spp Retention Rate		**No. Species Lost**	**% Woody Vegetation Target**
To retain	90%	13	17.06
	80%	26	3.91
	70%	39	0.50
	60%	51	0.01

The current median percent vegetation cover of 6.5% translates to a predicted loss of **20 species of all Landbirds**, ie the model predicts we have lost 20 species from one half of all landscapes in the study region.

The number of landbird species predicted to be lost from landscapes with 10% and 30% vegetation cover are, respectively, 16 (14.3%) and nine (8.0%).

For **Declining bird species**, the model predicts a maximum richness of *ca* 20 species at 100% vegetation cover (assuming a survey effort of 20 observer lists).

		No. Spp Lost	**% Woody Vegetation Target**	
Spp Retention			**Max. Location**	**Average Location**
To retain	90%	2	36.37	41.69
	80%	4	13.23	17.38
	70%	6	4.81	7.25
	60%	8	1.75	3.02
	50%	10	0.64	1.26

The current median percent vegetation cover of 6.5% translates to a predicted loss of **six Decliner bird species** from one half of all landscapes in the study region (from ‘average’ locations). ‘Max. location’ refers to the south-west of the study region, eg near Temora where the number of co-occurring Declining bird species is greatest.

The number of Declining species predicted to be lost from landscapes with 10% and 30% vegetation cover, at an average location are, respectively, five (25%) and three (15%).

For **Woodland bird** species, the model predicts a maximum richness of *ca* 88 species at 100% vegetation cover (assuming a survey effort of 20 observer lists).

Spp Retention		**No. Species Lost**	**% Woody Vegetation Target**
To retain	90%	9	29.86
	80%	18	8.92
	70%	26	2.66
	60%	35	0.80

The current median percent vegetation cover of 6.5% translates to a predicted loss of **20 Woodland bird species** from one half of all landscapes in the study region.

The number of Woodland species predicted to be lost for 10% and 30% vegetation cover scenarios are, respectively, 17 (19.3%) and nine (10.2%).

The amount of remnant vegetation at a landscape scale has a considerable effect on Woodland bird species richness. The prediction that 20 species of both Woodland birds and of the group All Landbirds are lost on average from landscapes with the median amount of remnant vegetation is reassuring only in a statistical sense, and alarming from the perspective of regional bird conservation objectives. It makes sense that the two quite different models should predict a similar loss of species, as we believe it is largely the Woodland-dependent component of All Landbirds that is adversely affected by habitat loss and deterioration. The predictions also indicate that the declining bird problem is not restricted to a small proportion of species, the 20 Decliners I diagnosed previously (Reid 1999). Their predicted losses account for less than one third of Woodland bird species losses. It seems most Woodland bird species face serious problems with local persistence in at least parts of their range within the Sheep-Wheat Belt as a consequence of the wholesale clearing for agricultural production.

The full model for Woodland bird species richness can also be applied to commonly cited vegetation remnancy or revegetation ‘targets’, of 10% and 30% vegetation cover in landscapes. These target figures translate to a predicted loss (local extinction) of 17 Woodland species (10% vegetation cover) and nine Woodland species (30% cover) respectively.

The bird data were collected before the process of declining birds in these landscapes had been detected by ornithologists. The extent of the problem has only become obvious in the past 10 years. The process of decline is continuing and seemingly accelerating. The superimposition of the trend with time on that of the landscape trend (in space) indicates that for the majority of landbirds in this region (and most regions dedicated predominantly to agricultural production), the response curves are shifting to the right (Fig. 18). That is, we expect and we are witnessing further local extinctions, even with no more clearing, and there is an urgent need for remedial action to be taken at patch and landscape scales if these trends are to be reversed.

We cannot predict graphically where the extinction process hypothesised in Fig. 18 will finish, but presumably the ‘re-equilibration’ point will vary among species. The process is driven mechanistically at the patch scale by decreasing densities and eventual patch extinctions, and this process is repeated but lagged at the landscape scale. Given, the following information –

- there is a strong temporal component to the process of bird decline in the region, and it lags behind the actual vegetation clearance events;
- the bird data are 20+ years out of date, and in some parts of the study region substantial clearance has occurred since 1980;

- we cannot predict how the system will 'equilibrate' now or when land clearance is effectively halted altogether;
- we suspect that the majority of remnant patches in the region, the smaller ones particularly, are deteriorating in habitat quality through time;
- we suspect that few of the small patches in the region are self-sustaining, in that effective recruitment of many plant species is probably not occurring –

therefore, we can expect many woodland species in the region to suffer local extinctions at the landscape scale, and we can expect at least some species to proceed to regional extinction. Based on the data presented for most woodland species and on the graphical model in Fig. 18, more than half of the landbirds in the region are likely to suffer further extinctions at the landscape scale. The likely number of regional extinctions is unknowable at this stage. This prediction will be able to be tested explicitly when the new Birds Australia Atlas data become available for analysis.

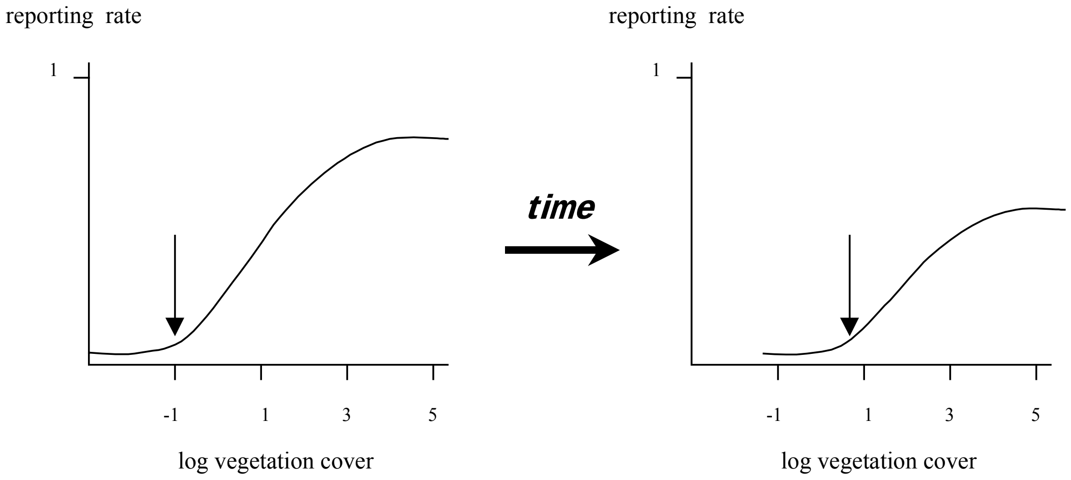


Figure 18. Likely pattern of decline in woodland-dependent birds in Sheep-Wheat Belt over time modelled as a logistic response for reporting rate of a single species against percent vegetation cover. Over time as the population declines it is suggested that maximum reporting rate declines and the point of effective local extinction (↓) shifts to the right, ie at higher values of percent remnant vegetation cover.

Habitat Fragmentation vs Habitat Loss and Loss of Habitat Quality

The issue of whether habitat loss or fragmentation is more important in causing species declines in altered landscapes is problematic (Mac Nally 1999). It seems one's stance depends partly on whether the investigator does or does not subscribe to metapopulation theories as the basic organising principle governing patchily distributed organisms – changed dispersal patterns assumes the utmost importance under the metapopulation declining-bird paradigm, as a consequence of fragmentation. An alternative perspective focuses on habitat suitability and quality, is rooted in niche theory (eg Brown 1995), and tends to play down the role of dispersal between patches – habitat loss and loss of habitat quality within patches become the focus of attention. While striking an appropriate balance between the two extremes would seem logical (eg Boudjemadi et al. 1999), the issues are clouded because ecologically similar or related species within the one higher taxon may behave very differently in the one landscape. Also different cause of decline could operate within the one species in different parts of its range. Some examples follow.

I have emphasised here and in earlier work (Reid 1999) that sedentary woodland birds have been harder hit by extensive land clearance than mobile species. The reason why mobile birds have generally fared better is probably because they have developed, over evolutionary time, strategies (for finding food and suitable habitat, evading predators, flying more swiftly and economically) which enable them to pass through unfavourable landscapes more readily and with less risk than sedentary species. Nomadic birds do not conform to the assumptions of metapopulation theory, as their rate of patch occupation and desertion relative to patch-residence time is too great (Gotelli 1998). The situation is more complex for some migratory woodland species that return to the same breeding territories each spring-summer (eg Rufous Whistler, Dusky Woodswallow). Ignoring their northern post-breeding movements, some of these species could perhaps be studied and modelled under the metapopulation theoretical framework. However, to the author's knowledge, there is insufficient information on the dispersal behaviour of fledged offspring of any of these migratory species, either in their birth summer or on their return in the following spring, to allow analysis.

A critical test of the applicability of metapopulation theory to the Declining woodland bird problem in the temperate agricultural zone of Australia will be to discriminate between the following alternative explanations for species' declines:

- selective clearance has removed the most favourable patches of habitat from the landscape, thereby reducing overall breeding success and survival;
- continuing degradation of remnant patches in extensively cleared landscapes is reducing overall breeding success and survival;
- the increased distance between habitat patches as a consequence of extensive clearing has resulted in increasing mortality during dispersal, thereby reducing the rate of patch occupancy.

Only the third explanation is consistent with metapopulation theory. I favour the first two explanations as the primary causes of decline and extinction in most cases, but there is evidence for the third process acting to disadvantage some bird species' movements in southern Australian agricultural landscapes (Brooker et al. 1999; Walters et al. 1999). All three processes probably act in concert in many instances.

Even in the one genus different species respond differently to the effects of habitat loss and fragmentation. Within the genus *Acanthiza*, there is the adaptable Yellow-rumped Thornbill which may well have increased in abundance over its pre-1750 levels in landscapes where moderate to large amounts of clearance has occurred. By comparison, the six other eastern Australian thornbills must have had their populations considerably diminished by extensive clearance of their mallee, woodland and forest habitats. Reporting rates of the latter six species were all highly positively correlated with percent vegetation cover in the region (R_s >= 0.25, all *P*s < 0.01; *cf* Yellow-rumped Thornbill, $R_s = 0.01$, *ns*). I argue that the reason for the contrasting response of these species lies in their habitat preferences, not in different dispersive capabilities as they are all sedentary (although this explanation is possible). The Yellow-rumped Thornbill favours open habitats as well as clearings in and the edges of denser mallee and woodland patches, and the species is often found feeding and breeding in pasture and grasslands under scattered trees. Two of the other six species have been identified as Decliners – Chestnut-rumped Thornbill in the NSW Sheep-Wheat Belt by Reid (1999), and Buff-rumped Thornbill in the Victorian box-ironbark woodland and forest ecosystems by R. Mac Nally *et al.* (in press) – but all six had positive and significant relationships with vegetation cover.

It is difficult to disentangle the effects of habitat loss from fragmentation, both conceptually and analytically (eg Fahrig 1997, but see Mac Nally 1999). In reality there may be no clear distinction as, in the context of wholesale conversion of regional landscapes from primarily wooded to primarily agricultural, fragmentation effects flow from the habitat loss. Having noted the above, it is important to recognise that the spatial patterning of remnant habitat patches in a landscape, and their connectivity, are likely to influence the composition of fauna communities. In terms of landscape restoration, therefore, these issues will need to be rigorously addressed, and restoration activities should be implemented under adaptive management frameworks, ie in an explicitly experimental fashion (Walters 1997).

Although there are many indices relating to connectivity, patch size and degree of habitat fragmentation that have been developed by landscape ecologists, a recent analysis concluded that the quantity of habitat, *p* itself, was the most important landscape measure (Hargis et al. 1998). Many of the other 'fragmentation' indices were strongly correlated with *p* and among themselves. Dr Ralph Mac Nally (Monash University, *personal communication*; also Mac Nally 1999) has recently asserted that the amount of habitat lost in south-eastern Australian woodlands wholly accounts for decreases in bird populations – he could not find evidence for fragmentation effects beyond their component effect contained in *p*, the amount of remnant habitat (percent vegetation cover).

Notwithstanding the overriding importance of habitat quantity, there is empirical evidence to demonstrate that connectivity matters for some species of declining birds in heavily cleared landscapes (Saunders 1977; Brooker et al. 1999; Walters et al. 1999). Also, a range of studies has found that the presence of larger woodland patches is central to the persistence of many species in these landscapes (Lambeck 1997; Major et al. 1998; Reid 1999; Freudenberger 1999; Seddon et al. 2000). The studies of Seddon et al. (2000) and Freudenberger (1999) clearly show that it is not necessarily size, *per se*, that accounts for the presence of seemingly area-dependent bird species. Habitat complexity or the presence of specific habitat attributes can also account for the presence of these species in the larger remnants. Habitat quality, independent of size, may be the key to understanding the decline of many woodland birds in these landscapes. If small patches degrade more quickly than larger patches when left as isolates in predominantly rural landscapes, as appears to be the general case, then this provides alternative explanations to those of classical metapopulation theory which tends to ignore habitat quality independent of remnant size. Patch size, independently of quality, is also important for certain sedentary woodland-dependent species with large home range requirements. Reid (1999) cited Speckled Warbler and Hooded Robin as examples of birds that individually need areas of up to 30 ha or more. Therefore, in extensively modified landscapes, reconstruction plans which include a strong biodiversity focus will need to consider all these factors. They are:

- **overridingly**, the amount of suitable habitat in a landscape;
- minimum patch size requirements for various species (eg **focal species approach**: Lambeck 1997; Seddon et al. 2000; Watson et al. in press);
- **habitat quality** and **complexity** within patches;
- **landscape connectivity**.

The landscape reconstruction challenge is to maximise the biodiversity gains for a given level of effort and finance, because both will always be in short supply. As emphasised by Reid

(1999), the need for flexibility in redesigning landscapes that are primarily devoted to food, fuel and fibre production will also be paramount. Local stakeholders, such as councils, individual farmers and Landcare groups, will all need to be involved from the ground up if landscape reconstruction initiatives are to succeed.

Individual Species' Responses to Vegetation Cover Loss

In contrast to the uniform distribution of Woodland bird species richness that existed across the study region prior to extensive land clearance, individual landbird species exhibit strong distributional gradients across the region. These distributional trends were partly corrected in a screening process. The vast majority of landbirds showed a positive correlation between reporting rate and percent vegetation cover corrected for location. For the categories of Declining, Threatened, Woodland and Sedentary birds, the mean Spearman correlation coefficient (for all species in each group) was greater than the critical 5% significance value. Within the broader classification of Woodland birds which I adopted, 11 of the 94 species yielded negative correlations. These few species were raptors, known Increasers or species with Eyrean or Torresian biogeographic affinities. As an earlier study showed, sedentariness and insectivory proved to be significant risk factors. Bassian species with distributions restricted to high-rainfall parts of southern and eastern Australia both reach the western limits of their range within the study region and proved to be highly susceptible to the impacts of extensive land clearance.

The results of screening individual Woodland birds' responses to variation in percent vegetation cover confirm that most Woodland bird species appear to be adversely affected by vegetation clearance at the landscape scale. Although rates of decline vary among species there does not appear to be a single, ecologically well-defined group (such as the 20 Decliners identified by Reid 1999) that is driving the extinction process in these landscapes. Rather, most of the Woodland species appear to be dropping out of at least some heavily modified landscapes, and, perhaps fortuitously, the identity of the species that go locally extinct varies from one location to the next.

What factors might be driving these individualistic and variable extinction processes? By their nature and definition, Woodland birds are heavily dependent on availability of suitable habitat. Each species probably responds individualistically to particular features of habitat (Brown 1995); this applies both within patches (eg microhabitat features) and among patches at the landscape scale (eg type of vegetation community). Although these variables are themselves under the strong control of geology, topography and climate, peculiarities of site history (disturbance, adjacent land use) vary across locations and so contribute differently to habitat suitability. In addition, there is probably an independent role for the interaction between climate and bird species' physiological tolerances and preferences (ie over and above its control of habitat type and quality). Also climatic control on abundance and composition of invertebrate communities undoubtedly operates at several time and spatial scales. Add a strong stochastic element to these processes and the outcomes (loss of particular species) may appear to operate seemingly haphazardly and individualistically.

Despite these complexities in the patterns of local extinctions and decline, it can be safely concluded that habitat loss in the south-western slopes region of the New South Wales Sheep-Wheat Belt has had a marked impact on woodland bird communities. Most woodland bird species appear to have suffered local extinctions in at least some heavily cleared landscapes, and the current situation is undoubtedly far worse than the results of analyses with these 20-year old data would suggest.

Recommendations for Landscape Reconstruction

Vegetation Clearance

***In landscapes where vegetation clearance for agricultural development continues**,* reasoned if arbitrary stopping rules need to be advanced from the biodiversity conservation perspective. While outside the scope of this report, the potential for land degradation (eg salinity hazard assessment, soil erosion risk) should also inform policy development and implementation on land clearing. Following the South Australian example, appropriate and sympathetic financial mechanisms are needed to allow the effective implementation of clearance regulations.

I have developed rules that could be applied to the regulation of land clearing. From the biodiversity perspective, I assume that landscapes or districts are of the order of 300 km^2, and that a prior vegetation survey has been conducted for the entire landscape so that all patches have been mapped and classified into broad vegetation communities.

Clearance Stopping Rule 1, Habitat Rarity Principle: Defined vegetation communities should not be cleared below 1% of the total landscape area (eg 3 km^2); this applies whether the community is naturally rare in the district or if it has become rare through past clearance.

Clearance Stopping Rule 2, Habitat Conservation and Ecosystem Function Principle: Defined vegetation communities should not be cleared below 30% of their original extent in that landscape.

Clearance Stopping Rule 3, Regional Landscape Conservation Principle: In total, all broad-acre clearance should cease if 50% or more of the landscape is cleared.

These rules are predicated on the following ecological principles that take a broader perspective than bird conservation matters alone:

- many small organisms (eg microfauna, invertebrates, cryptograms, herbs) operate and function ecologically at (eg are distributed over) very fine spatial scales, in response to environmental variation. In the absence of knowledge of the true distribution of these types of organisms, we have to assume that some species have very restricted distributions within landscapes and even regionally. Representative examples of each vegetation type need to be conserved in all landscapes, because a vegetation classification is probably the best surrogate available for attempting to conserve β–diversity in these organisms (*Habitat Rarity Principle*);
- retaining 30% of vegetation types in landscapes is an impossible goal for many vegetation communities and landscapes in the Sheep-Wheat Belt of New South Wales, because of the extent of historical clearing. The retention of 30% of any particular vegetation type in landscapes where this target is achievable should allow most organisms and ecological processes characteristic of that ecosystem to persist (*Habitat Conservation and Ecosystem Function Principle*);

- given the excessive level of clearing that has occurred in most regions, the extinction debt can be alleviated to some extent by securing high percentage vegetation cover in those few landscapes where the possibility exists to do so. Invoking theory (source-sink flows: Pulliam 1988; discussed by Reid 1999) and an Australian bird data set (Oliver et al. 1999), the retention of landscapes with >= 50% vegetation cover seems vital to the regional persistence of many species in agricultural regions (*Regional Landscape Conservation Principle*).

Landscape Reconstruction

Landscape reconstruction in those landscapes where broad-acre land clearance is no longer an issue, ie in landscapes already heavily cleared should focus on the protection and enhancement of existing natural vegetation. The major imperative is to prevent the deterioration in habitat quality of existing remnants, particularly remnants in the small to medium size class (10-250 ha). Principal threats facing these types of patches are firewood harvesting, 'cleaning up' the understorey and ground layer, over-heavy and continuous grazing, and insufficient regeneration (of plant species and more generally niches of a wide range of organisms).

In salinity prone districts the protection of existing remnants may involve extensive revegetation efforts targeted at recharge zones. However, in most cases where biodiversity enhancement is the principal aim, the benefits from revegetation are likely to be greater from increasing the size of existing small remnants rather than growing new patches. The benefits should be even greater if existing patches that provide linkages (eg as stepping stones) in extensively cleared landscapes are increased in size. Existing roadside and riparian corridor remnants provide the logical focus for these revegetation activities (Reid 1999). The principle for adding onto existing remnants rather than starting from scratch can be extended to 'remnants' consisting only of scattered indigenous trees – these big old war-horses provide habitat resources that young trees cannot.

The most cost-effective rehabilitation, patch enlargement and patch enhancement procedures will be those where direct revegetation activities, necessarily expensive, can be minimised or eliminated altogether. Fencing off, reducing grazing pressure and frequency, encouraging natural regeneration with disturbances are examples of measures that can be applied in areas where some of the original vegetation diversity and soil seed stocks remain. These landscapes, where grazing of unimproved and natural pastures is the predominant land use, while comprising a minority of lands in the Sheep-Wheat Belt provide the greatest potential for broad-acre, relatively cheap restoration, provided they are taken out of intensive and continuous livestock production.

In medium to medium-large sized remnants (eg 50-1000 ha), while management of grazing pressure remains an important issue, the opportunity exists to take a deliberate interventionist approach to management, and attempt to enhance biodiversity through implementing patchy habitat disturbances. The aim here is to present a greater range of habitat stages, structural types and niches for a wide range of organisms. There are many examples on private (and public) land of large patches of open forest and woodland of a uniform composition and stand structure, presumably arising from a past disturbance or clearance event. If the trees are closely spaced there is often little undergrowth present. The creation of open patches within these stands should allow them to support a greater diversity of species.

Large remnants are generally State-owned and managed for various uses, eg protection of water quality, timber production, conservation. Management for the continuation of natural disturbance regimes and broad-scale ecological processes should be encouraged in these reserves, particularly in the largest of them. Again, a mix of habitat types distributed across a range of successional states should be the driving biodiversity objective. These larger blocks of near-natural and semi-natural vegetation bear the major responsibility for the continued persistence of many, probably most, of the declining bird species in the Sheep-Wheat Belt in the immediate and medium-term future (refer back to the *Landscape and Regional Conservation Principle*).

A problem remains concerning where – precisely where and to what formula – rehabilitation and revegetation efforts should take priority and be targeted. Should restoration funds and effort be expended evenly throughout the Sheep-Wheat Belt of New South Wales, or should a greater proportion be given to the most beleaguered landscapes, or those in best condition? The only practical advice that can be tendered on these questions flows from the belief that increasing the area of 'habitat of some indeterminate threshold of quality' is the single most important action society can take. Therefore, the investment of funds in protecting and enhancing the quality of existing remnants (eg fencing and grazing management) and in increasing the size of remnants through natural processes of regeneration where this is possible (again fencing, grazing management, with some site preparation as needed) might produce the biggest bang for the buck. In terms of social equity, however, expenditure spread evenly across landscapes would be fairest. On practical grounds there are sound reasons to engage, at the outset at least, with those rural communities which embrace the imperative for landscape reconstruction and demonstrate a high level commitment to achieving change.

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APPENDICES

APPENDIX 1

198 species of landbird contained in RAOU's Atlas data set for study region, with summary statistics and group membership 5pp

APPENDIX 2

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APPENDIX 3

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APPENDIX 4

Species richness models for 10 bird categories 2pp

Appendix 1 – 198 species of landbird contained in RAOU's Atlas data set for study region, with summary statistics and group membership

Code	English Name	Species	Sheets	Squares	Ratio	T	D	AR	I	W	BW	M
B001	Emu	*Dromaius novaehollandiae*	79	41	1.93	0	1	1	0	0	0	1
B007	Malleefowl	*Leipoa ocellata*	7	5	1.40	1	0	1	0	0	0	0
B009	Stubble Quail	*Coturnix pectoralis*	52	31	1.68	0	0	0	0	0	0	1
B010	Brown Quail	*Coturnix ypsilophora*	10	6	1.67	0	0	0	0	0	0	1
B232	Black-shouldered Kite	*Elanus axillaris*	383	126	3.04	0	0	0	1	0	0	1
B233	Letter-winged Kite	*Elanus scriptus*	3	3	1.00	0	0	0	0	0	0	1
B229	Black Kite	*Milvus migrans*	16	12	1.33	0	0	0	0	0	0	1
B228	Whistling Kite	*Haliastur sphenurus*	190	91	2.09	0	1	1	0	1	0	1
B226	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	9	7	1.29	0	0	0	0	0	0	0
B218	Spotted Harrier	*Circus assimilis*	99	54	1.83	0	0	0	0	0	0	1
B219	Swamp Harrier	*Circus approximans*	31	14	2.21	0	0	0	0	0	0	1
B221	Brown Goshawk	*Accipiter fasciatus*	112	58	1.93	0	0	0	0	1	0	1
B220	Grey Goshawk	*Accipiter novaehollandiae*	1	1	1.00	0	0	0	0	0	0	0
B222	Collared Sparrowhawk	*Accipiter cirrhocephalus*	58	37	1.57	0	0	0	0	1	0	0
B224	Wedge-tailed Eagle	*Aquila audax*	235	112	2.10	0	0	0	0	0	0	0
B225	Little Eagle	*Hieraaetus morphnoides*	248	115	2.16	0	0	0	0	1	0	0
B239	Brown Falcon	*Falco berigora*	600	183	3.28	0	0	0	1	0	0	1
B235	Australian Hobby	*Falco longipennis*	123	72	1.71	0	0	0	0	1	0	1
B236	Grey Falcon	*Falco hypoleucos*	2	2	1.00	1	0	1	0	0	0	0
B238	Black Falcon	*Falco subniger*	52	38	1.37	0	0	0	0	0	0	1
B237	Peregrine Falcon	*Falco peregrinus*	38	29	1.31	0	0	0	0	1	0	0
B240	Nankeen Kestrel	*Falco cenchroides*	922	211	4.37	0	0	0	1	0	0	1
B018	Little Button-quail	*Turnix velox*	5	5	1.00	0	0	0	0	0	0	1
B014	Painted Button-quail	*Turnix varia*	38	20	1.90	0	1	1	0	1	1	0
B174	Bush Stone-curlew	*Burhinus grallarius*	5	5	1.00	1	0	1	0	1	1	0
B957	Rock Dove	*Columba livia*	241	72	3.35	0	0	0	1	0	0	0
B989	Spotted Turtle-Dove	*Streptopelia chinensis*	8	3	2.67	0	0	0	1	0	0	0
B034	Common Bronzewing	*Phaps chalcoptera*	381	130	2.93	0	0	0	0	1	1	0
B035	Brush Bronzewing	*Phaps elegans*	1	1	1.00	0	0	0	0	0	0	0
B043	Crested Pigeon	*Ocyphaps lophotes*	1229	211	5.82	0	0	0	1	0	0	0
B031	Diamond Dove	*Geopelia cuneata*	17	13	1.31	0	0	0	0	0	1	1
B030	Peaceful Dove	*Geopelia striata*	653	167	3.91	0	0	0	1	1	1	0
B032	Bar-shouldered Dove	*Geopelia humeralis*	16	14	1.14	0	0	0	0	0	0	0
B044	Wonga Pigeon	*Leucosarcia melanoleuca*	1	1	1.00	0	0	0	0	0	0	0
B265	Glossy Black-Cockatoo	*Calyptorhynchus lathami*	7	4	1.75	1	0	1	0	1	1	1
B268	Gang-gang Cockatoo	*Callocephalon fimbriatum*	8	4	2.00	0	0	0	0	0	0	1
B273	Galah	*Cacatua roseicapilla*	1585	216	7.34	0	0	0	1	0	0	1
B271	Little Corella	*Cacatua sanguinea*	2	1	2.00	0	0	0	1	0	0	1
B270	Major Mitchell's Cockatoo	*Cacatua leadbeateri*	26	17	1.53	1	0	1	0	0	0	0
B269	Sulphur-crested Cockatoo	*Cacatua galerita*	553	125	4.42	0	0	0	1	0	0	0

T: Endangered or Vulnerable; **D**: Declining. **I**: Increasing. **W**: 1=Woodland dependent birds (JR), 2='Other'; **BW**: Bennet&Ford's Woodland birds. **M**: Mobility – 0=Sedentary, 1=Semi-Nomadic to Migratory

Appendix 1 – 198 species of landbird contained in RAOU's Atlas data set for study region, with summary statistics and group membership

Code	English Name	Species	Sheets	Squares	Ratio	T	D	AR	I	W	BW	M
B274	Cockatiel	*Nymphicus hollandicus*	608	172	3.53	0	0	0	1	0	0	1
B254	Rainbow Lorikeet	*Trichoglossus haematodus*	1	1	1.00	0	0	0	0	0	0	1
B256	Scaly-breasted Lorikeet	*Trichoglossus chlorolepidotus*	1	1	1.00	0	0	0	0	0	0	1
B258	Musk Lorikeet	*Glossopsitta concinna*	8	6	1.33	0	0	0	0	0	1	1
B260	Little Lorikeet	*Glossopsitta pusilla*	119	50	2.38	0	0	0	0	1	1	1
B281	Australian King-Parrot	*Alisterus scapularis*	4	3	1.33	0	0	0	0	0	0	0
B280	Red-winged Parrot	*Aprosmictus erythropterus*	2	2	1.00	0	0	0	0	0	0	1
B277	Superb Parrot	*Polytelis swainsonii*	161	74	2.18	1	0	1	0	1	1	1
B282	Crimson Rosella	*Platycercus elegans*	137	40	3.43	0	0	0	0	0	0	0
B284	Yellow Rosella	*Platycercus e. flaveolus*	2	2	1.00	0	0	0	0	0	1	0
B288	Eastern Rosella	*Platycercus eximius*	1104	195	5.66	0	0	0	1	1	0	0
B291	Mallee Ringneck	*Barnardius zonarius barnardi*	236	88	2.68	0	0	0	0	0	0	0
B297	Blue Bonnet	*Northiella haematogaster*	391	129	3.03	0	0	0	1	0	0	0
B309	Swift Parrot	*Lathamus discolor*	9	7	1.29	1	0	1	0	1	1	1
B295	Red-rumped Parrot	*Psephotus haematonotus*	1293	215	6.01	0	0	0	0	1	0	0
B296	Mulga Parrot	*Psephotus varius*	20	14	1.43	0	0	0	0	0	0	0
B310	Budgerigar	*Melopsittacus undulatus*	55	41	1.34	0	0	0	0	0	0	1
B302	Turquoise Parrot	*Neophema pulchella*	66	26	2.54	1	0	1	0	1	1	0
B337	Pallid Cuckoo	*Cuculus pallidus*	197	100	1.97	0	0	0	0	0	0	1
B339	Brush Cuckoo	*Cacomantis variolosus*	1	1	1.00	0	0	0	0	0	0	1
B338	Fan-tailed Cuckoo	*Cacomantis flabelliformis*	117	63	1.86	0	0	0	0	1	1	1
B341	Black-eared Cuckoo	*Chrysococcyx osculans*	16	14	1.14	0	0	0	0	1	1	1
B342	Horsfield's Bronze-Cuckoo	*Chrysococcyx basalis*	120	57	2.11	0	0	0	0	1	1	1
B344	Shining Bronze-Cuckoo	*Chrysococcyx lucidus*	40	25	1.60	0	0	0	0	1	1	1
B347	Common Koel	*Eudynamys scolopacea*	1	1	1.00	0	0	0	0	0	0	1
B246	Barking Owl	*Ninox connivens*	14	7	2.00	1	0	1	0	1	1	0
B242	Southern Boobook	*Ninox novaeseelandiae*	107	53	2.02	0	0	0	0	1	1	1
B249	Barn Owl	*Tyto alba*	75	39	1.92	0	0	0	0	0	0	1
B313	Tawny Frogmouth	*Podargus strigoides*	83	58	1.43	0	0	0	0	1	0	0
B331	Spotted Nightjar	*Eurostopodus argus*	20	10	2.00	0	0	0	0	1	1	1
B317	Australian Owlet-nightjar	*Aegotheles cristatus*	29	21	1.38	0	0	0	0	1	1	0
B322	Laughing Kookaburra	*Dacelo novaeguineae*	1182	212	5.58	0	0	0	0	1	0	0
B325	Red-backed Kingfisher	*Todiramphus pyrrhopygia*	65	37	1.76	0	0	0	0	1	0	1
B326	Sacred Kingfisher	*Todiramphus sanctus*	354	144	2.46	0	0	0	0	1	1	1
B329	Rainbow Bee-eater	*Merops ornatus*	486	169	2.88	0	0	0	0	0	0	1
B318	Dollarbird	*Eurystomus orientalis*	272	120	2.27	0	0	0	0	1	1	1
B350	Superb Lyrebird	*Menura novaehollandiae*	1	1	1.00	0	0	0	0	0	0	0
B558	White-throated Treecreeper	*Cormobates leucophaeus*	435	111	3.92	0	0	0	0	1	1	0
B560	Red-browed Treecreeper	*Climacteris erythrops*	6	2	3.00	0	0	0	0	0	0	0
B555	Brown Treecreeper	*Climacteris picumnus*	706	196	3.60	0	1	1	0	1	1	0

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Code	English Name	Species	Sheets	Squares	Ratio	T	D	AR	I	W	BW	M
B529	Superb Fairy-wren	*Malurus cyaneus*	590	114	5.18	0	0	0	0	1	0	0
B532	Splendid Fairy-wren	*Malurus splendens*	10	9	1.11	0	0	0	0	0	0	0
B536	Variegated Fairy-wren	*Malurus lamberti*	107	41	2.61	0	0	0	0	0	0	0
B535	White-winged Fairy-wren	*Malurus leucopterus*	39	28	1.39	0	0	0	0	0	0	0
B565	Spotted Pardalote	*Pardalotus punctatus*	266	99	2.69	0	0	0	0	1	1	1
B566	Yellow-rumped Pardalote	*Pardalotus xanthopygus*	4	4	1.00	0	0	0	0	0	0	1
B976	Striated Pardalote	*Pardalotus striatus*	780	210	3.71	0	0	0	0	1	0	1
B488	White-browed Scrubwren	*Sericornis frontalis*	50	20	2.50	0	0	0	0	1	1	0
B498	Chestnut-rumped Heathwren	*Hylacola pyrrhopygia*	51	20	2.55	0	0	0	0	0	0	0
B499	Shy Heathwren	*Hylacola cauta*	1	1	1.00	1	0	1	0	0	0	0
B504	Speckled Warbler	*Chthonicola sagittata*	271	113	2.40	0	1	1	0	1	1	0
B465	Weebill	*Smicrornis brevirostris*	568	178	3.19	0	0	0	0	1	1	0
B463	Western Gerygone	*Gerygone fusca*	253	112	2.26	0	0	0	0	1	1	1
B453	White-throated Gerygone	*Gerygone olivacea*	66	46	1.43	0	0	0	0	1	1	1
B475	Brown Thornbill	*Acanthiza pusilla*	67	37	1.81	0	0	0	0	1	1	0
B476	Inland Thornbill	*Acanthiza apicalis*	199	86	2.31	0	0	0	0	1	1	0
B481	Chestnut-rumped Thornbill	*Acanthiza uropygialis*	233	100	2.33	0	1	1	0	1	1	0
B484	Buff-rumped Thornbill	*Acanthiza reguloides*	220	75	2.93	0	0	0	0	1	1	0
B486	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	979	214	4.57	0	0	0	1	1	0	0
B471	Yellow Thornbill	*Acanthiza nana*	553	166	3.33	0	0	0	0	1	1	0
B470	Striated Thornbill	*Acanthiza lineata*	68	35	1.94	0	0	0	0	1	1	0
B466	Southern Whiteface	*Aphelocephala leucopsis*	235	106	2.22	0	1	1	0	1	1	0
B638	Red Wattlebird	*Anthochaera carunculata*	399	99	4.03	0	0	0	0	1	1	1
B640	Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	285	106	2.69	0	0	0	0	1	1	1
B585	Striped Honeyeater	*Plectorhyncha lanceolata*	264	116	2.28	0	0	0	0	1	0	0
B645	Noisy Friarbird	*Philemon corniculatus*	293	112	2.62	0	0	0	0	1	1	1
B646	Little Friarbird	*Philemon citreogularis*	397	164	2.42	0	0	0	0	1	1	1
B603	Regent Honeyeater	*Xanthomyza phrygia*	3	3	1.00	1	0	1	0	1	1	1
B641	Blue-faced Honeyeater	*Entomyzon cyanotis*	163	94	1.73	0	0	0	0	1	1	0
B634	Noisy Miner	*Manorina melanocephala*	1108	210	5.28	0	0	0	1	1	0	0
B635	Yellow-throated Miner	*Manorina flavigula*	322	103	3.13	0	0	0	1	1	0	0
B614	Yellow-faced Honeyeater	*Lichenostomus chrysops*	170	54	3.15	0	0	0	0	1	1	1
B608	Singing Honeyeater	*Lichenostomus virescens*	32	23	1.39	0	0	0	0	0	1	0
B617	White-eared Honeyeater	*Lichenostomus leucotis*	226	75	3.01	0	0	0	0	1	1	0
B619	Yellow-tufted Honeyeater	*Lichenostomus melanops*	185	42	4.40	0	0	0	0	1	1	1
B622	Yellow-plumed Honeyeater	*Lichenostomus ornatus*	57	28	2.04	0	0	0	0	0	0	0
B623	Grey-fronted Honeyeater	*Lichenostomus plumulus*	5	5	1.00	0	0	0	0	0	0	0
B613	Fuscous Honeyeater	*Lichenostomus fuscus*	226	68	3.32	0	0	0	0	1	1	1
B625	White-plumed Honeyeater	*Lichenostomus penicillatus*	1148	213	5.39	0	0	0	1	1	1	0
B580	Black-chinned Honeyeater	*Melithreptus gularis*	89	45	1.98	0	0	0	0	1	1	0

T: Endangered or Vulnerable; **D**: Declining. **I**: Increasing. **W**: 1=Woodland dependent birds (JR), 2='Other'; **BW**: Bennet&Ford's Woodland birds. **M**: Mobility – 0=Sedentary, 1=Semi-Nomadic to Migratory

Appendix 1 – 198 species of landbird contained in RAOU's Atlas data set for study region, with summary statistics and group membership

Code	English Name	Species	Sheets	Squares	Ratio	T	D	AR	I	W	BW	M
B583	Brown-headed Honeyeater	*Melithreptus brevirostris*	306	116	2.64	0	0	0	0	1	1	0
B578	White-naped Honeyeater	*Melithreptus lunatus*	88	35	2.51	0	0	0	0	1	1	1
B598	Painted Honeyeater	*Grantiella picta*	30	18	1.67	1	0	1	0	1	1	1
B630	Crescent Honeyeater	*Phylidonyris pyrrhoptera*	1	1	1.00	0	0	0	0	0	0	1
B631	New Holland Honeyeater	*Phylidonyris novaehollandiae*	1	1	1.00	0	0	0	0	0	0	1
B591	Eastern Spinebill	*Acanthorhynchus tenuirostris*	55	23	2.39	0	0	0	0	1	1	1
B589	Black Honeyeater	*Certhionyx niger*	3	3	1.00	0	0	0	0	0	0	1
B449	Crimson Chat	*Epthianura tricolor*	30	23	1.30	0	0	0	0	0	0	1
B450	Orange Chat	*Epthianura aurifrons*	14	9	1.56	0	0	0	0	0	0	1
B448	White-fronted Chat	*Epthianura albifrons*	137	66	2.08	0	0	0	0	0	0	1
B377	Jacky Winter	*Microeca fascinans*	550	166	3.31	0	1	1	0	1	1	0
B380	Scarlet Robin	*Petroica multicolor*	78	35	2.23	0	0	0	0	1	0	0
B381	Red-capped Robin	*Petroica goodenovii*	462	149	3.10	0	1	1	0	1	1	1
B382	Flame Robin	*Petroica phoenicea*	155	88	1.76	0	0	0	0	0	0	1
B384	Rose Robin	*Petroica rosea*	7	6	1.17	0	0	0	0	0	0	1
B385	Hooded Robin	*Melanodryas cucullata*	226	111	2.04	0	1	1	0	1	1	0
B392	Eastern Yellow Robin	*Eopsaltria australis*	492	147	3.35	0	1	1	0	1	1	0
B441	Southern Scrub-robin	*Drymodes brunneopygia*	1	1	1.00	1	0	1	0	0	0	0
B443	Grey-crowned Babbler	*Pomatostomus temporalis*	435	151	2.88	0	1	1	0	1	1	0
B445	White-browed Babbler	*Pomatostomus superciliosus*	359	114	3.15	0	1	1	0	1	1	0
B436	Spotted Quail-thrush	*Cinclosoma punctatum*	15	11	1.36	0	0	0	0	0	0	0
B549	Varied Sittella	*Daphoenositta chrysoptera*	177	94	1.88	0	1	1	0	1	1	0
B416	Crested Shrike-tit	*Falcunculus frontatus*	278	108	2.57	0	1	1	0	1	1	0
B419	Crested Bellbird	*Oreoica gutturalis*	52	27	1.93	0	1	1	0	0	0	0
B403	Gilbert's Whistler	*Pachycephala inornata*	47	11	4.27	1	0	1	0	1	1	0
B398	Golden Whistler	*Pachycephala pectoralis*	182	99	1.84	0	0	0	0	1	1	1
B401	Rufous Whistler	*Pachycephala rufiventris*	640	188	3.40	0	1	1	0	1	1	1
B408	Grey Shrike-thrush	*Colluricincla harmonica*	780	189	4.13	0	0	0	0	1	1	0
B365	Leaden Flycatcher	*Myiagra rubecula*	30	22	1.36	0	0	0	0	1	1	1
B366	Satin Flycatcher	*Myiagra cyanoleuca*	4	3	1.33	0	0	0	0	0	0	1
B369	Restless Flycatcher	*Myiagra inquieta*	633	193	3.28	0	1	1	0	1	0	0
B415	Magpie-lark	*Grallina cyanoleuca*	1522	216	7.05	0	0	0	1	0	0	0
B362	Rufous Fantail	*Rhipidura rufifrons*	8	8	1.00	0	0	0	0	0	0	1
B361	Grey Fantail	*Rhipidura fuliginosa*	438	151	2.90	0	0	0	0	1	1	1
B364	Willie Wagtail	*Rhipidura leucophrys*	1416	216	6.56	0	0	0	1	0	0	0
B424	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	1057	211	5.01	0	0	0	1	1	0	1
B425	White-bellied Cuckoo-shrike	*Coracina papuensis*	59	29	2.03	0	0	0	0	1	1	1
B429	Cicadabird	*Coracina tenuirostris*	2	2	1.00	0	0	0	0	0	0	1
B423	Ground Cuckoo-shrike	*Coracina maxima*	87	55	1.58	0	0	0	0	0	0	1
B430	White-winged Triller	*Lalage sueurii*	294	139	2.12	0	0	0	0	1	1	1

T: Endangered or Vulnerable; **D**: Declining. **I**: Increasing. **W**: 1=Woodland dependent birds (JR), 2='Other'; **BW**: Bennet&Ford's Woodland birds. **M**: Mobility – 0=Sedentary, 1=Semi-Nomadic to Migratory

Appendix 1 – 198 species of landbird contained in RAOU's Atlas data set for study region, with summary statistics and group membership

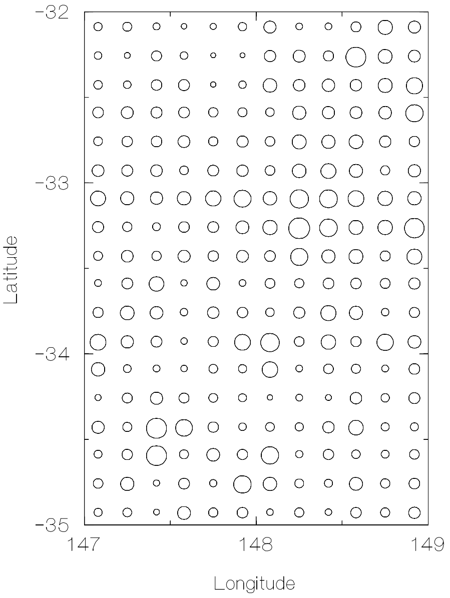
Code	English Name	Species	Sheets	Squares	Ratio	T	D	AR	I	W	BW	M
B671	Olive-backed Oriole	*Oriolus sagittatus*	119	72	1.65	0	0	0	0	1	1	1
B543	White-breasted Woodswallow	*Artamus leucorynchus*	48	26	1.85	0	0	0	0	0	0	1
B544	Masked Woodswallow	*Artamus personatus*	70	41	1.71	0	0	0	0	0	0	1
B545	White-browed Woodswallow	*Artamus superciliosus*	360	156	2.31	0	1	1	0	1	0	1
B546	Black-faced Woodswallow	*Artamus cinereus*	239	108	2.21	0	0	0	1	0	0	0
B547	Dusky Woodswallow	*Artamus cyanopterus*	512	153	3.35	0	1	1	0	1	1	1
B548	Little Woodswallow	*Artamus minor*	1	1	1.00	0	0	0	0	0	0	1
B702	Grey Butcherbird	*Cracticus torquatus*	464	162	2.86	0	0	0	0	1	0	0
B700	Pied Butcherbird	*Cracticus nigrogularis*	845	193	4.38	0	0	0	1	0	0	0
B705	Australian Magpie	*Gymnorhina tibicen*	1575	216	7.29	0	0	0	1	1	0	0
B694	Pied Currawong	*Strepera graculina*	510	130	3.92	0	0	0	1	0	0	1
B697	Grey Currawong	*Strepera versicolor*	9	7	1.29	0	0	0	0	0	0	0
B930	Australian Raven	*Corvus coronoides*	1027	212	4.84	0	0	0	1	1	0	0
B954	Little Raven	*Corvus mellori*	204	122	1.67	0	0	0	1	0	0	1
B691	Little Crow	*Corvus bennetti*	5	4	1.25	0	0	0	0	0	0	1
B693	White-winged Chough	*Corcorax melanorhamphos*	1061	215	4.93	0	0	0	1	1	1	0
B675	Apostlebird	*Struthidea cinerea*	633	168	3.77	0	0	0	0	1	1	0
B680	Spotted Bowerbird	*Chlamydera maculata*	3	3	1.00	0	0	0	0	0	0	0
B648	Singing Bushlark	*Mirafra javanica*	64	39	1.64	0	0	0	0	0	0	1
B993	Skylark	*Alauda arvensis*	6	6	1.00	0	0	0	1	0	0	0
B647	Richard's Pipit	*Anthus novaeseelandiae*	695	190	3.66	0	0	0	1	0	0	0
B995	House Sparrow	*Passer domesticus*	817	172	4.75	0	0	0	1	0	0	0
B994	Eurasian Tree Sparrow	*Passer montanus*	32	6	5.33	0	0	0	0	0	0	0
B653	Zebra Finch	*Taeniopygia guttata*	242	108	2.24	0	0	0	1	0	0	1
B655	Double-barred Finch	*Taeniopygia bichenovii*	281	117	2.40	0	0	0	0	1	0	0
B661	Plum-headed Finch	*Neochmia modesta*	47	37	1.27	0	0	0	0	0	0	1
B662	Red-browed Finch	*Neochmia temporalis*	124	42	2.95	0	0	0	0	1	0	0
B652	Diamond Firetail	*Stagonopleura guttata*	352	129	2.73	0	1	1	0	1	1	0
B657	Chestnut-breasted Mannikin	*Lonchura castaneothorax*	1	1	1.00	0	0	0	0	0	0	0
B996	European Goldfinch	*Carduelis carduelis*	306	79	3.87	0	0	0	1	0	0	1
B564	Mistletoebird	*Dicaeum hirundinaceum*	267	120	2.23	0	0	0	0	1	1	1
B509	Rufous Songlark	*Cincloramphus mathewsi*	463	180	2.57	0	0	0	1	0	0	1
B508	Brown Songlark	*Cincloramphus cruralis*	241	114	2.11	0	0	0	0	0	0	1
B574	Silvereye	*Zosterops lateralis*	248	83	2.99	0	0	0	0	1	0	1
B447	Bassian Thrush	*Zoothera lunulata*	1	1	1.00	0	0	0	0	0	0	1
B991	Common Blackbird	*Turdus merula*	124	25	4.96	0	0	0	1	0	0	0
B999	Common Starling	*Sturnus vulgaris*	1242	215	5.78	0	0	0	1	0	0	1
B998	Common Myna	*Acridotheres tristis*	1	1	1.00	0	0	0	1	0	0	0

T: Endangered or Vulnerable; **D**: Declining. **I**: Increasing. **W**: 1=Woodland dependent birds (JR), 2='Other'; **BW**: Bennet&Ford's Woodland birds. **M**: Mobility – 0=Sedentary, 1=Semi-Nomadic to Migratory

APPENDIX 2

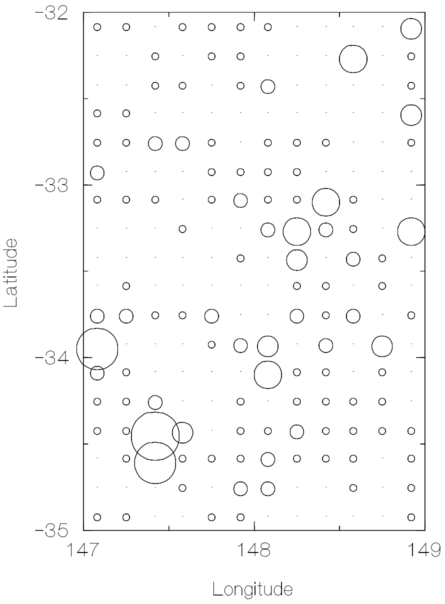
Distribution of species richness in 10 categories of bird species – as surveyed, not modelled.

All Landbirds



RMODC.wmf

Threatened Birds



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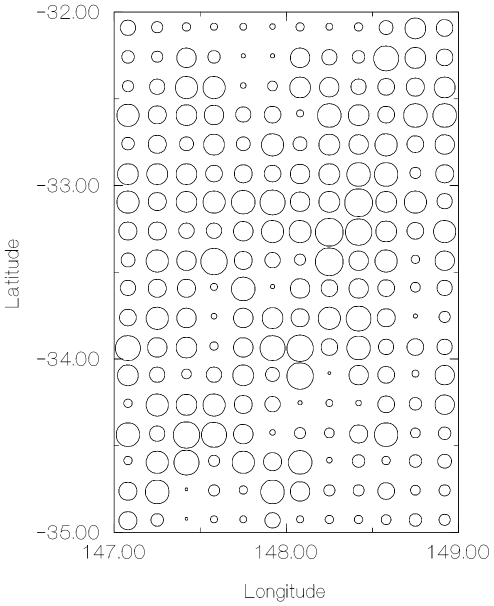
Declining Birds



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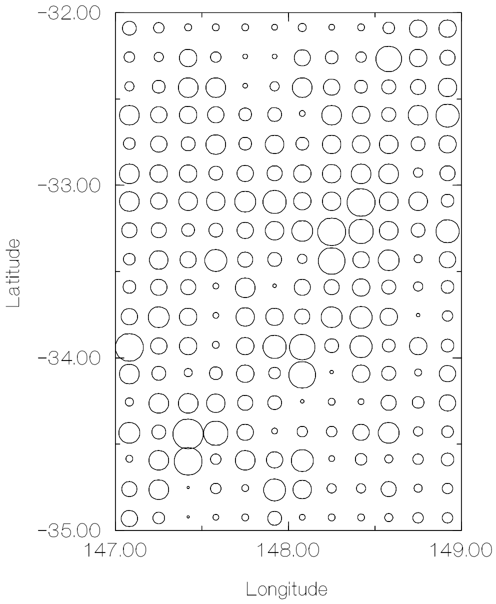
At Risk Birds



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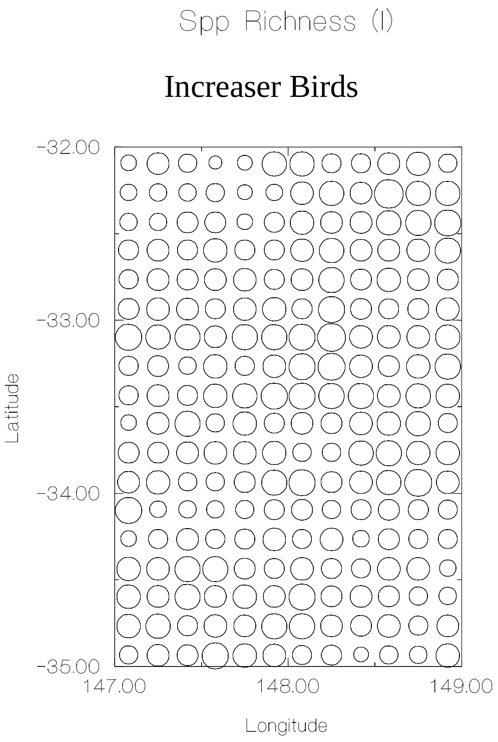
Increaser Birds



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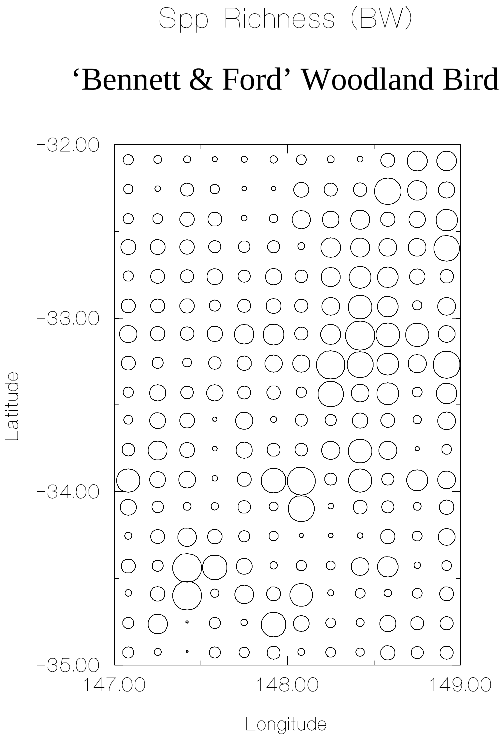
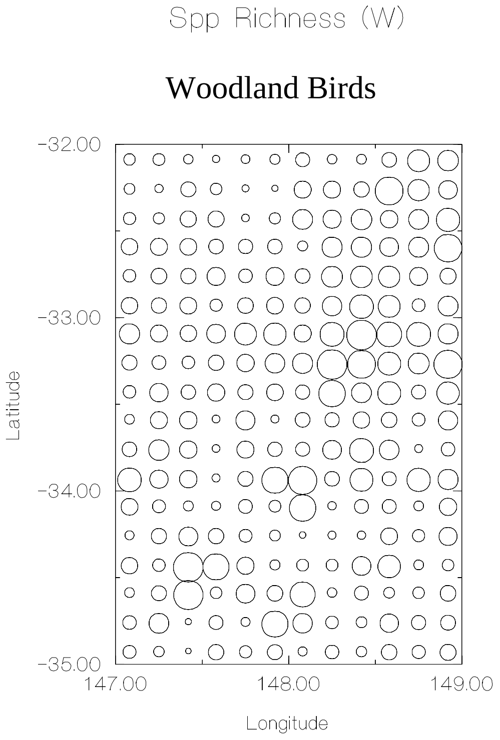
'Bennett & Ford' Woodland Birds



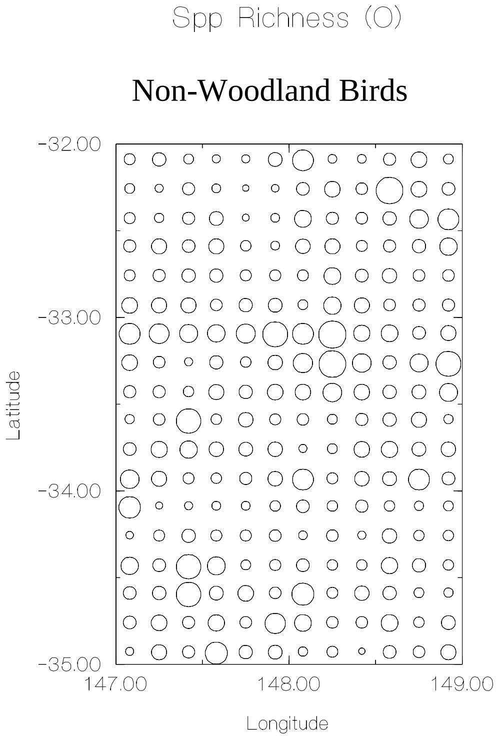
RMODBW.wmf

Woodland Birds



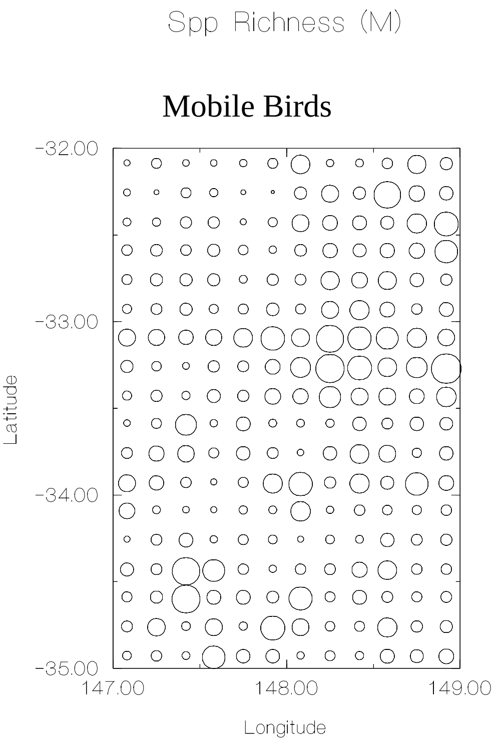
RMODC.wmf

Non-Woodland Birds



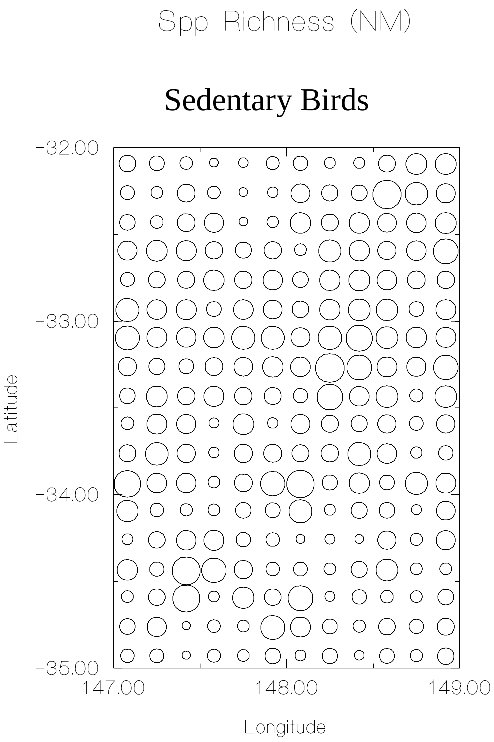
RMODO.wmf

Mobile Birds



RMODBM.wmf

Sedentary Birds



RMODBNM.wmf

Appendix 3.1. Spearman rank correlation coefficients (R_s) between uncorrected reporting rate (URR) and two vegetation cover and three location variables

LOGZW: log-transformed percentage vegetation cover;
ZWRS: location-corrected (the residual of) log-transformed percentage vegetation cover;
LATI: latitude (midpoint of each Atlas square used);
LONGI: longitude (midpoint of each Atlas square used);
LLPROD: interaction term, LATI*LONGI.

Critical thresholds for significance (n = 142): $R_s = 0.271$, $P < 0.001$; $R_s = 0.213$, $P < 0.01$; $R_s = 0.163$, $P < 0.05$.

Code	**English Name**	**LOGZW**	**ZWRS**	**LATI**	**LONG**	**LLPROD**
B001	Emu	0.19	0.15	0.26	-0.21	0.30
B009	Stubble Quail	-0.21	-0.25	0.06	0.10	0.05
B232	Black-shouldered Kite	-0.22	-0.29	0.04	0.15	0.02
B229	Black Kite	0.03	0.05	0.05	-0.16	0.08
B228	Whistling Kite	-0.15	-0.11	-0.05	-0.20	-0.02
B218	Spotted Harrier	-0.28	-0.29	-0.03	-0.19	0.00
B219	Swamp Harrier	-0.04	-0.01	-0.04	-0.11	-0.03
B221	Brown Goshawk	-0.01	0.02	-0.10	0.13	-0.12
B222	Collared Sparrowhawk	0.10	0.08	0.09	0.08	0.08
B224	Wedge-tailed Eagle	0.29	0.33	-0.12	0.22	-0.16
B225	Little Eagle	0.08	0.11	-0.05	0.15	-0.07
B239	Brown Falcon	-0.31	-0.25	-0.36	0.01	-0.36
B235	Australian Hobby	-0.26	-0.29	0.04	0.00	0.05
B238	Black Falcon	-0.02	-0.01	0.01	0.11	0.00
B237	Peregrine Falcon	0.04	0.07	-0.10	0.05	-0.10
B240	Nankeen Kestrel	-0.24	-0.28	-0.08	0.20	-0.10
B014	Painted Button-quail	0.40	0.40	0.03	0.09	0.02
B957	Rock Dove	-0.21	-0.23	0.01	0.16	-0.01
B034	Common Bronzewing	0.42	0.47	0.04	-0.22	0.07
B043	Crested Pigeon	-0.27	-0.16	-0.34	-0.29	-0.31
B031	Diamond Dove	0.02	-0.01	0.08	0.04	0.08
B030	Peaceful Dove	0.38	0.39	0.06	0.07	0.05
B032	Bar-shouldered Dove	0.13	0.06	0.27	-0.15	0.29
B273	Galah	-0.14	-0.09	-0.31	-0.02	-0.32
B270	Major Mitchell's Cockatoo	0.13	0.12	0.18	-0.32	0.23
B269	Sulphur-crested Cockatoo	0.08	0.00	-0.09	0.65	-0.19
B274	Cockatiel	-0.38	-0.39	0.09	-0.40	0.16
B260	Little Lorikeet	0.39	0.24	0.33	0.48	0.27
B277	Superb Parrot	-0.20	-0.04	-0.49	-0.08	-0.49
B282	Crimson Rosella	-0.03	-0.01	-0.33	0.43	-0.40
B288	Eastern Rosella	0.01	0.08	-0.44	0.23	-0.48
B291	Mallee Ringneck	0.29	0.25	0.36	-0.43	0.43
B297	Blue Bonnet	-0.12	-0.11	0.26	-0.63	0.36
B295	Red-rumped Parrot	-0.17	-0.07	-0.34	-0.14	-0.33
B296	Mulga Parrot	0.07	0.09	0.09	-0.31	0.15
B310	Budgerigar	0.00	0.00	0.14	-0.18	0.17
B302	Turquoise Parrot	0.30	0.29	0.09	0.12	0.07
B337	Pallid Cuckoo	0.20	0.16	0.14	-0.05	0.16
B338	Fan-tailed Cuckoo	0.36	0.37	0.05	0.08	0.05
B341	Black-eared Cuckoo	0.29	0.31	0.03	-0.01	0.03
B342	Horsfield's Bronze-Cuckoo	0.11	0.14	-0.02	-0.06	-0.00
B344	Shining Bronze-Cuckoo	0.33	0.35	-0.06	0.13	-0.07
B242	Southern Boobook	0.06	0.06	-0.05	0.09	-0.06
B249	Barn Owl	-0.16	-0.18	-0.07	0.11	-0.09
B313	Tawny Frogmouth	0.10	0.09	0.03	0.14	0.01
B331	Spotted Nightjar	0.09	0.13	-0.05	-0.19	-0.02
B317	Australian Owlet-nightjar	0.14	0.17	0.07	-0.14	0.09

Appendix 3 – 149 species of landbird recorded in 10 or more Atlas squares

Code	**English Name**	**LOGZW**	**ZWRS**	**LATI**	**LONG**	**LLPROD**
B322	Laughing Kookaburra	0.08	0.15	-0.37	0.17	-0.41
B325	Red-backed Kingfisher	-0.05	-0.11	0.19	-0.07	0.21
B326	Sacred Kingfisher	0.03	0.03	-0.07	0.16	-0.09
B329	Rainbow Bee-eater	0.07	0.16	-0.31	0.14	-0.33
B318	Dollarbird	-0.09	-0.09	-0.20	0.35	-0.26
B558	White-throated Treecreeper	0.53	0.54	-0.12	0.40	-0.17
B555	Brown Treecreeper	0.43	0.43	0.10	0.05	0.09
B529	Superb Fairy-wren	0.29	0.19	0.01	0.80	-0.11
B536	Variegated Fairy-wren	0.14	0.22	0.01	-0.49	0.09
B535	White-winged Fairy-wren	-0.17	-0.17	0.20	-0.33	0.26
B565	Spotted Pardalote	0.53	0.49	0.08	0.33	0.04
B976	Striated Pardalote	0.14	0.17	-0.12	0.08	-0.13
B488	White-browed Scrubwren	0.02	0.01	-0.19	0.44	-0.25
B498	Chestnut-rumped Heathwren	0.48	0.49	0.07	0.07	0.06
B504	Speckled Warbler	0.51	0.49	0.14	0.09	0.13
B465	Weebill	0.49	0.47	0.25	-0.15	0.28
B463	Western Gerygone	0.24	0.23	0.25	-0.26	0.30
B453	White-throated Gerygone	0.28	0.23	0.05	0.30	0.01
B475	Brown Thornbill	0.41	0.41	-0.07	0.32	-0.11
B476	Inland Thornbill	0.35	0.28	0.33	-0.19	0.37
B481	Chestnut-rumped Thornbill	0.24	0.25	0.23	-0.51	0.32
B484	Buff-rumped Thornbill	0.49	0.45	0.03	0.49	-0.03
B486	Yellow-rumped Thornbill	-0.04	0.01	-0.26	0.01	-0.26
B471	Yellow Thornbill	0.39	0.41	0.14	-0.27	0.18
B470	Striated Thornbill	0.27	0.27	-0.11	0.32	-0.16
B466	Southern Whiteface	0.27	0.37	-0.12	-0.24	-0.09
B638	Red Wattlebird	0.30	0.40	-0.38	0.28	-0.43
B640	Spiny-cheeked Honeyeater	0.20	0.16	0.39	-0.40	0.46
B585	Striped Honeyeater	0.27	0.18	0.49	-0.20	0.54
B645	Noisy Friarbird	0.39	0.30	0.16	0.51	0.09
B646	Little Friarbird	0.00	-0.03	0.07	-0.01	0.08
B641	Blue-faced Honeyeater	0.06	0.06	0.19	-0.26	0.24
B634	Noisy Miner	-0.19	-0.08	-0.38	-0.19	-0.37
B635	Yellow-throated Miner	0.03	-0.14	0.64	-0.22	0.69
B614	Yellow-faced Honeyeater	0.52	0.52	-0.02	0.35	-0.07
B608	Singing Honeyeater	0.00	-0.04	0.18	-0.17	0.23
B617	White-eared Honeyeater	0.54	0.45	0.27	0.19	0.26
B619	Yellow-tufted Honeyeater	0.45	0.49	-0.10	0.11	-0.12
B622	Yellow-plumed Honeyeater	0.16	0.23	-0.01	-0.38	0.05
B613	Fuscous Honeyeater	0.40	0.34	0.09	0.43	0.02
B625	White-plumed Honeyeater	0.15	0.22	-0.21	0.09	-0.23
B580	Black-chinned Honeyeater	0.38	0.39	0.02	0.22	-0.02
B583	Brown-headed Honeyeater	0.60	0.60	0.12	-0.02	0.13
B578	White-naped Honeyeater	0.45	0.44	-0.01	0.29	-0.05
B598	Painted Honeyeater	0.09	0.13	-0.05	-0.06	-0.05
B591	Eastern Spinebill	0.41	0.39	0.04	0.32	-0.01
B449	Crimson Chat	-0.13	-0.14	0.06	-0.06	0.08
B448	White-fronted Chat	-0.12	-0.02	-0.27	-0.27	-0.24
B377	Jacky Winter	0.52	0.52	0.15	0.06	0.15
B380	Scarlet Robin	0.04	0.08	-0.28	0.38	-0.34
B381	Red-capped Robin	0.34	0.42	0.05	-0.44	0.12
B382	Flame Robin	-0.05	0.09	-0.53	0.06	-0.56
B385	Hooded Robin	0.36	0.38	0.10	-0.20	0.13
B392	Eastern Yellow Robin	0.55	0.59	0.06	-0.15	0.08
B443	Grey-crowned Babbler	0.00	0.04	0.13	-0.51	0.20
B445	White-browed Babbler	0.48	0.52	0.12	-0.25	0.16
B436	Spotted Quail-thrush	0.42	0.41	0.10	0.20	0.08
B549	Varied Sittella	0.41	0.47	-0.09	-0.03	-0.08

Appendix 3 – 149 species of landbird recorded in 10 or more Atlas squares

Code	English Name	LOGZW	ZWRS	LATI	LONG	LLPROD
B416	Crested Shrike-tit	0.20	0.25	-0.24	0.31	-0.29
B419	Crested Bellbird	0.25	0.26	0.15	-0.29	0.21
B403	Gilbert's Whistler	0.25	0.34	-0.11	-0.14	-0.09
B398	Golden Whistler	0.45	0.45	0.07	0.10	0.06
B401	Rufous Whistler	0.39	0.42	0.02	-0.14	0.05
B408	Grey Shrike-thrush	0.57	0.58	0.06	0.13	0.05
B365	Leaden Flycatcher	0.21	0.23	-0.04	0.11	-0.05
B369	Restless Flycatcher	0.35	0.43	-0.12	0.01	-0.12
B415	Magpie-lark	-0.15	-0.07	-0.34	-0.05	-0.34
B361	Grey Fantail	0.50	0.50	0.04	0.14	0.03
B364	Willie Wagtail	0.00	0.07	-0.34	0.04	-0.35
B424	Black-faced Cuckoo-shrike	0.01	0.04	-0.22	0.18	-0.25
B425	White-bellied Cuckoo-shrike	0.27	0.21	0.23	0.10	0.21
B423	Ground Cuckoo-shrike	-0.08	-0.17	0.32	-0.04	0.34
B430	White-winged Triller	0.01	0.12	-0.23	-0.20	-0.21
B671	Olive-backed Oriole	0.30	0.29	0.07	-0.02	0.08
B543	White-breasted Woodswallow	-0.06	-0.06	0.09	-0.19	0.12
B544	Masked Woodswallow	0.07	0.09	0.06	-0.12	0.07
B545	White-browed Woodswallow	-0.10	-0.04	-0.17	-0.07	-0.17
B546	Black-faced Woodswallow	-0.18	-0.13	0.04	-0.45	0.10
B547	Dusky Woodswallow	0.32	0.37	-0.18	0.29	-0.23
B702	Grey Butcherbird	0.10	0.10	0.26	-0.43	0.33
B700	Pied Butcherbird	-0.08	-0.16	0.32	-0.28	0.38
B705	Australian Magpie	-0.18	-0.06	-0.52	-0.05	-0.52
B694	Pied Currawong	0.30	0.32	-0.27	0.39	-0.33
B930	Australian Raven	0.03	0.09	-0.34	0.08	-0.36
B954	Little Raven	-0.03	-0.04	0.11	-0.20	0.14
B693	White-winged Chough	-0.01	0.13	-0.31	-0.26	-0.28
B675	Apostlebird	-0.02	0.03	0.14	-0.59	0.23
B648	Singing Bushlark	-0.05	-0.03	0.05	0.00	0.05
B647	Richard's Pipit	-0.17	-0.14	-0.33	0.24	-0.37
B995	House Sparrow	-0.30	-0.26	-0.40	0.31	-0.46
B653	Zebra Finch	-0.05	-0.03	0.07	-0.20	0.11
B655	Double-barred Finch	0.45	0.33	0.44	0.21	0.42
B661	Plum-headed Finch	0.11	0.00	0.26	0.24	0.23
B662	Red-browed Finch	0.34	0.33	-0.09	0.38	-0.15
B652	Diamond Firetail	0.37	0.37	0.03	0.23	-0.01
B996	European Goldfinch	-0.05	0.03	-0.49	0.38	-0.56
B564	Mistletoebird	0.44	0.35	0.39	0.06	0.40
B509	Rufous Songlark	-0.05	-0.04	-0.06	0.00	-0.07
B508	Brown Songlark	-0.37	-0.30	-0.35	-0.03	-0.35
B574	Silvereye	0.43	0.40	0.08	0.29	0.04
B991	Common Blackbird	-0.12	-0.13	-0.15	0.30	-0.19
B999	Common Starling	-0.38	-0.33	-0.42	0.19	-0.46

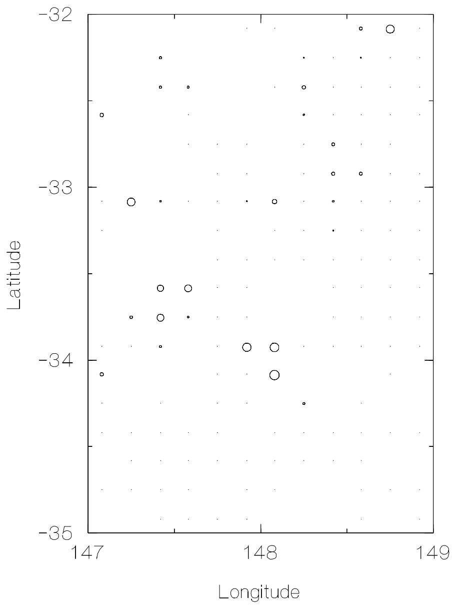
Appendix 3.2

Atlas Maps of Bird Species Recorded in > 10 Gridsquares

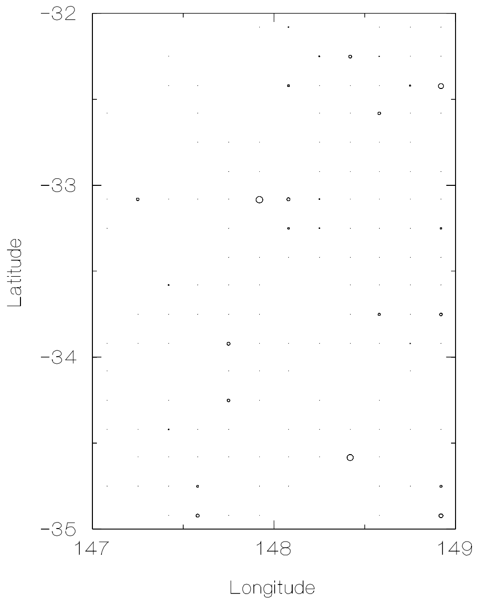
Uncorrected Reporting Rate for 149 Landbird species recorded in at least 10 Atlas squares is mapped. Only 10´ Atlas squares with at least six observer sheets (minimun survey effort for calculating reporting rate) are shown. Size of circle is proportional to reporting rate, with same scale used for all maps and species.

Atlas Maps of Bird Species Recorded in >10 Gridsquares

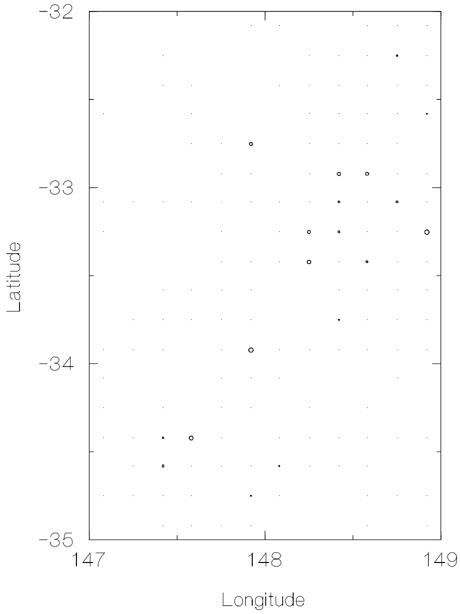
Emu, B001



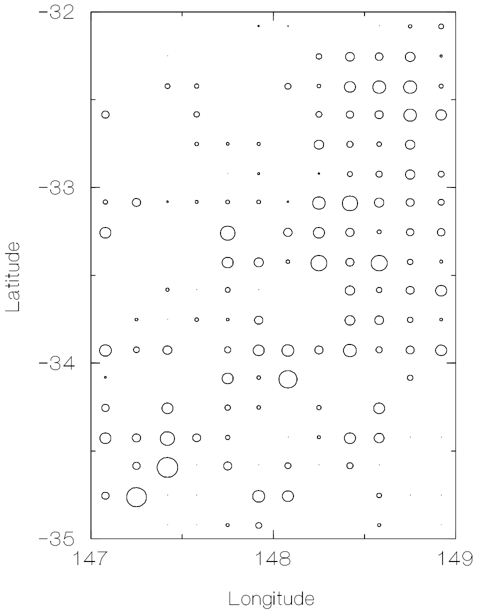
Stubble Quail, B009



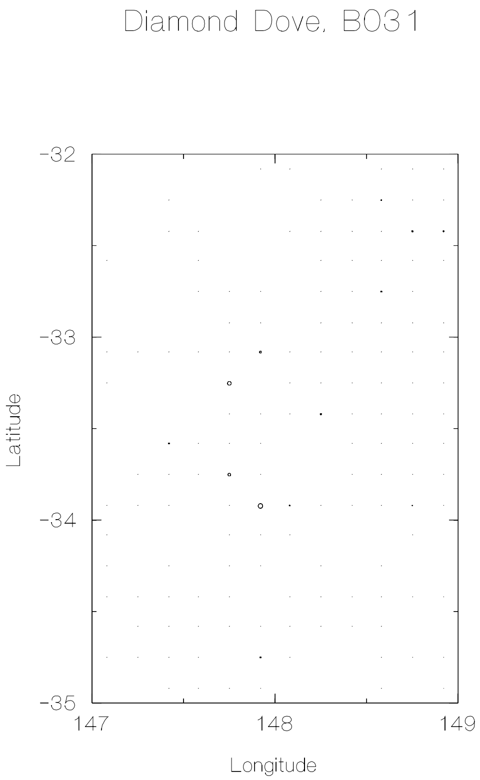
Painted Button-quail, B014

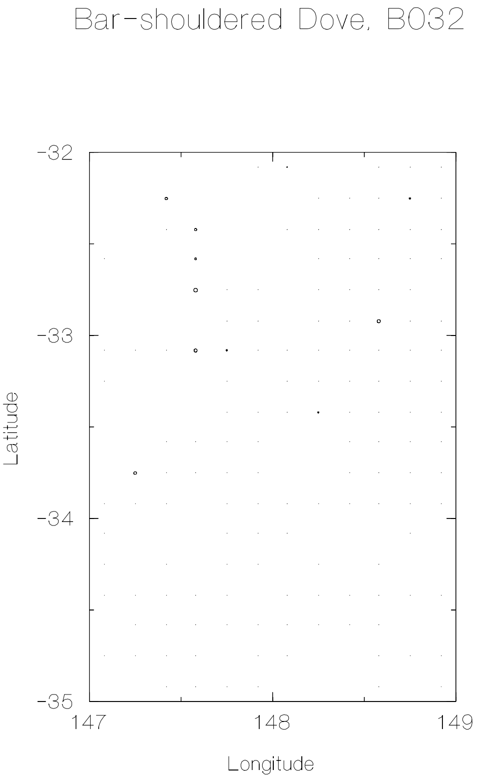


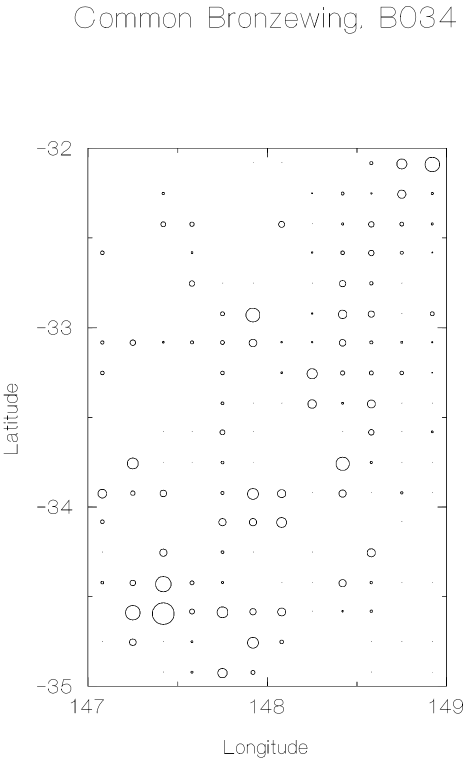
Peaceful Dove, B030

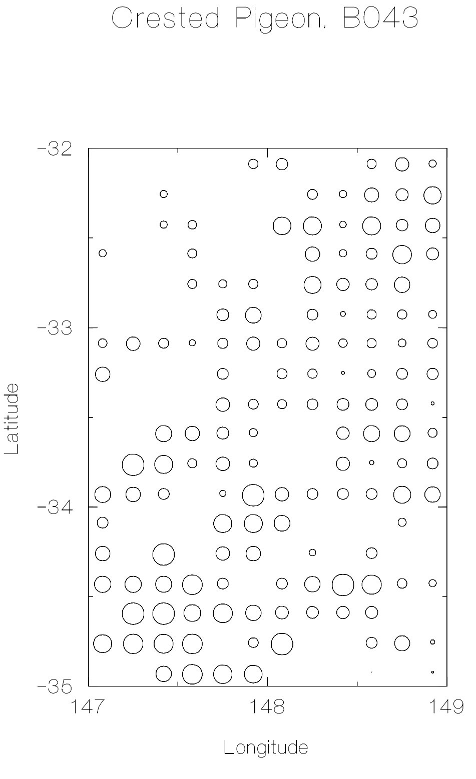


Atlas Maps of Bird Species Recorded in >10 Gridsquares

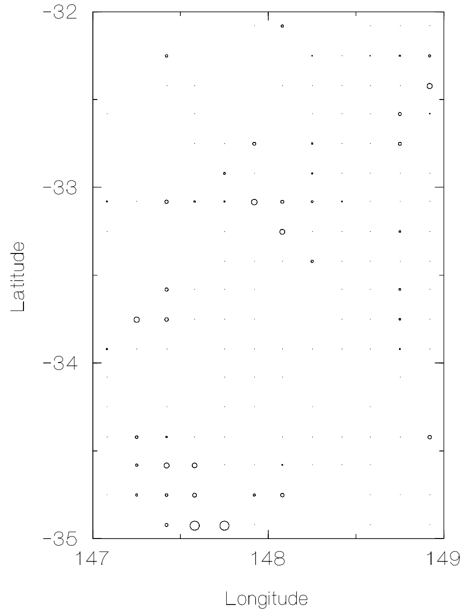


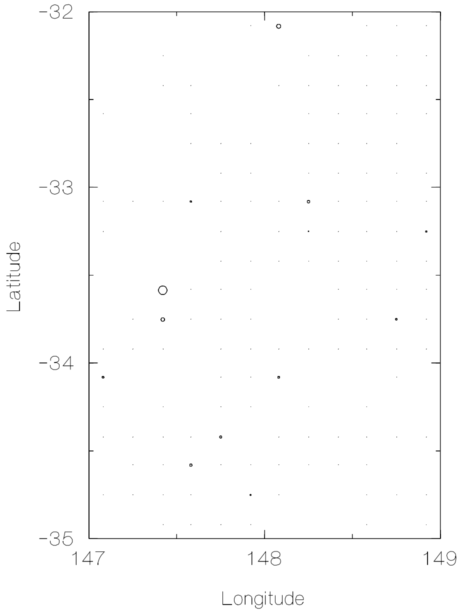


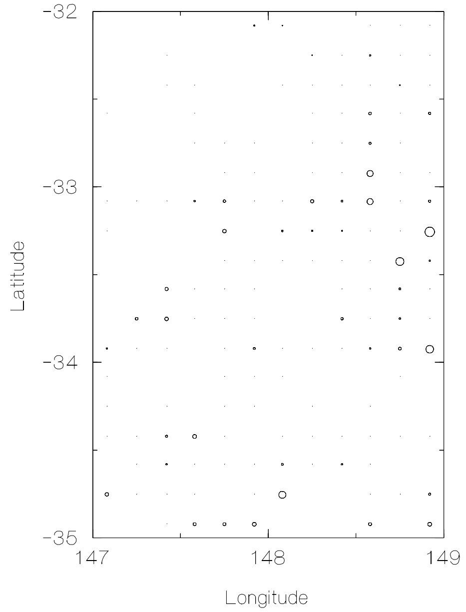


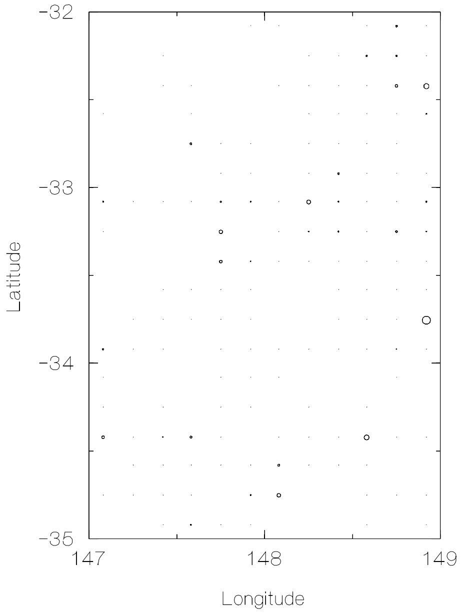


Atlas Maps of Bird Species Recorded in >10 Gridsquares

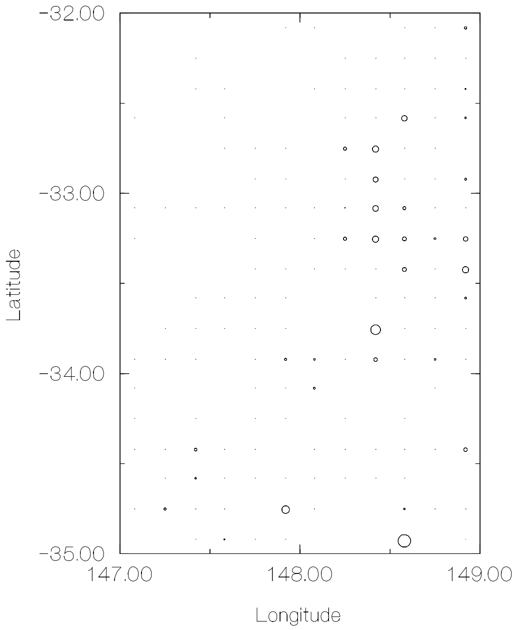

Spotted Harrier, B218

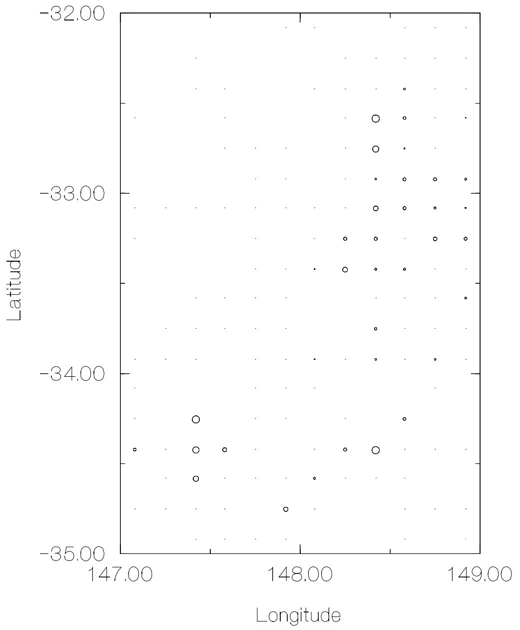

Swamp Harrier, B219

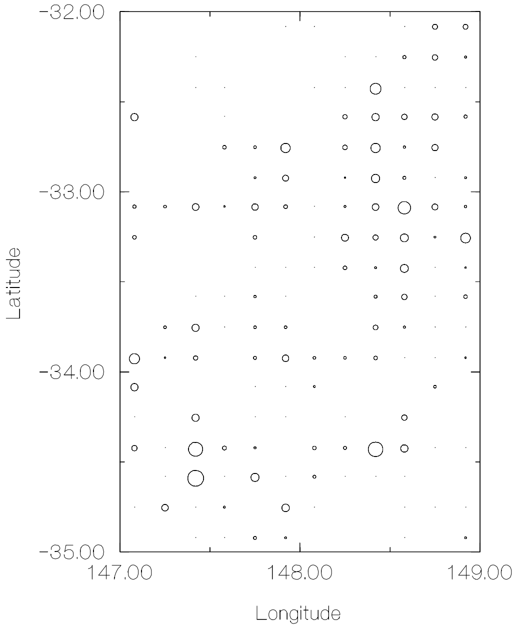

Brown Goshawk, B221

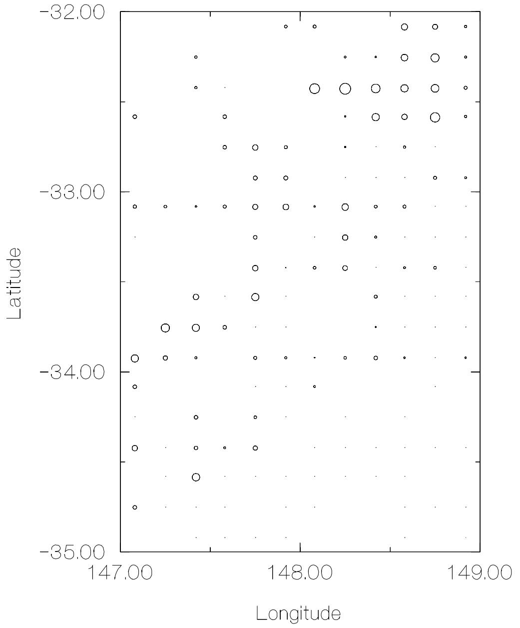

Collared Sparrowhawk, B222

Atlas Maps of Bird Species Recorded in >10 Gridsquares

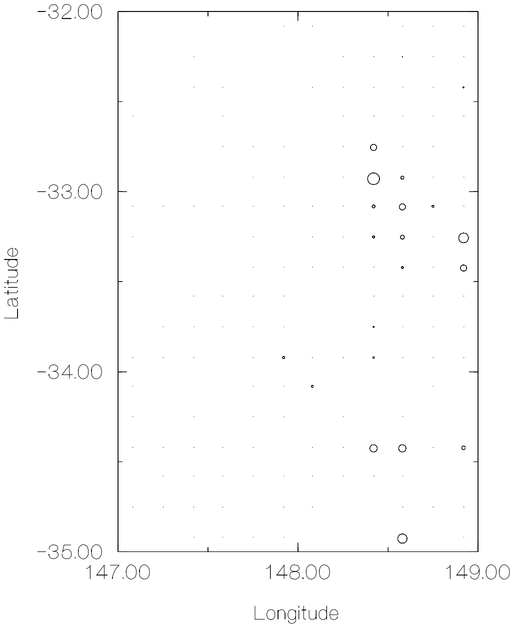

White-naped Honeyeater, B578

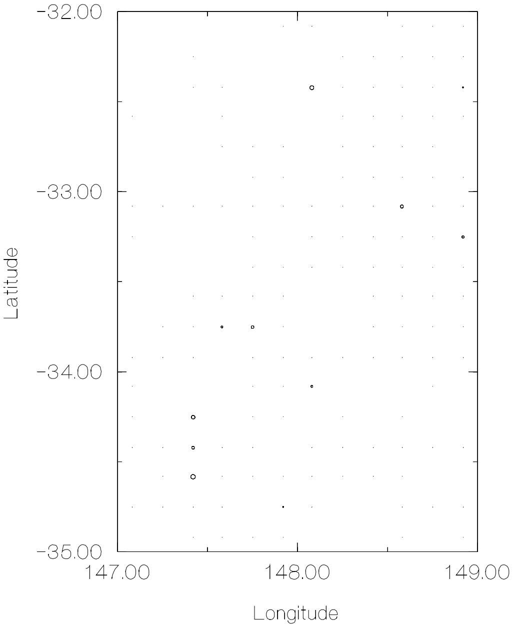

Black-chinned Honeyeater, B580

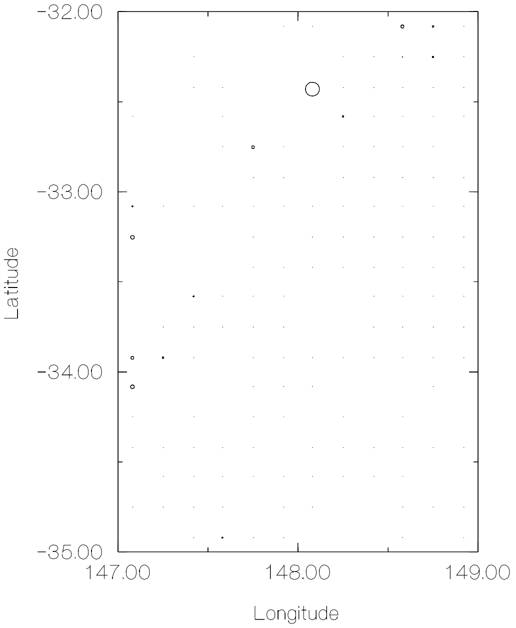

Brown-headed Honeyeater, B583

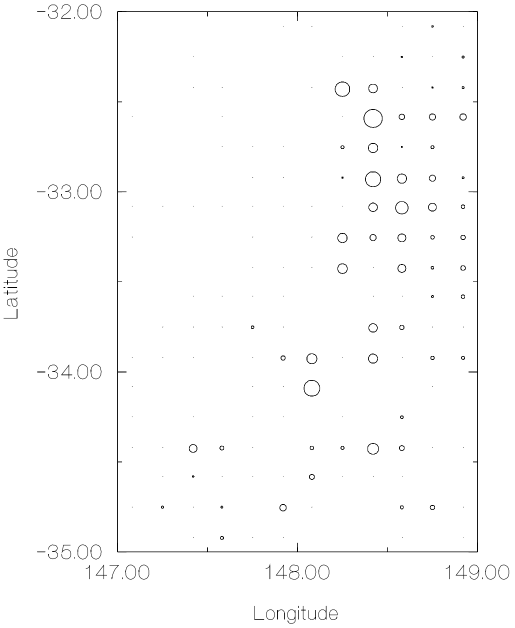

Striped Honeyeater, B585

Atlas Maps of Bird Species Recorded in >10 Gridsquares

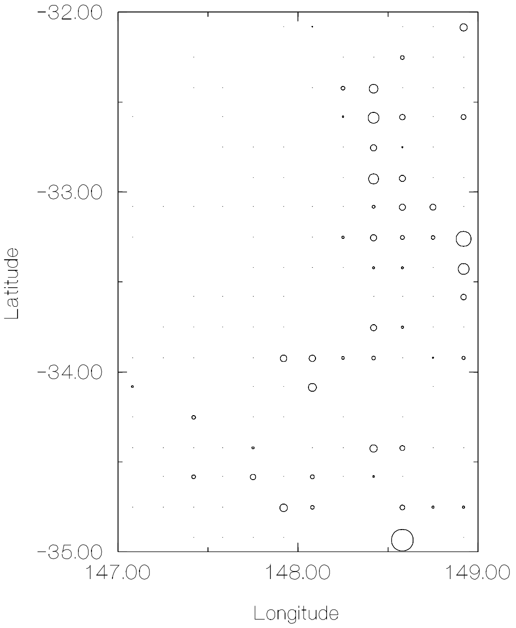

Eastern Spinebill, B591

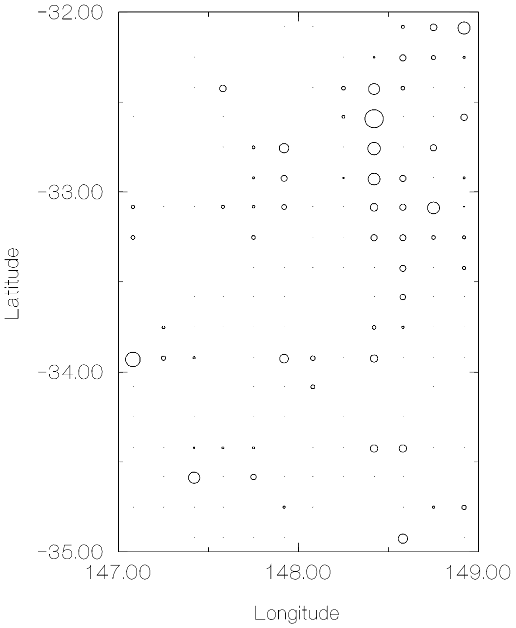

Painted Honeyeater, B598

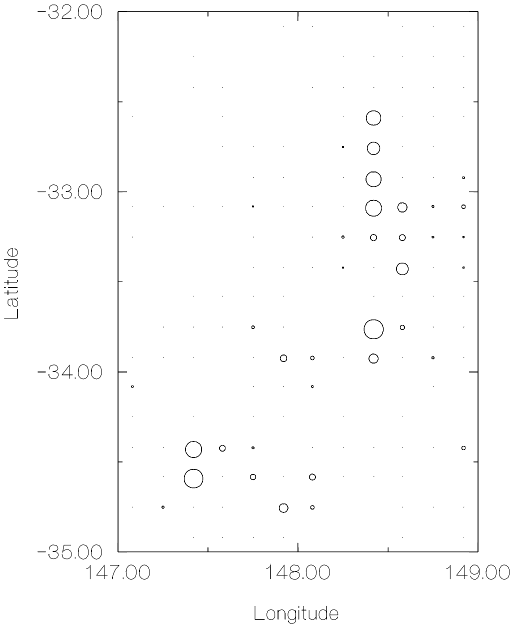

Singing Honeyeater, B608

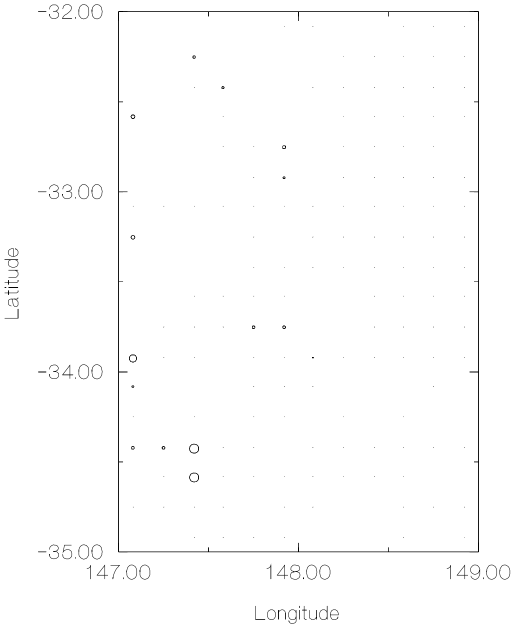

Fuscous Honeyeater, B613

Atlas Maps of Bird Species Recorded in >10 Gridsquares


Yellow-faced Honeyeater, B614

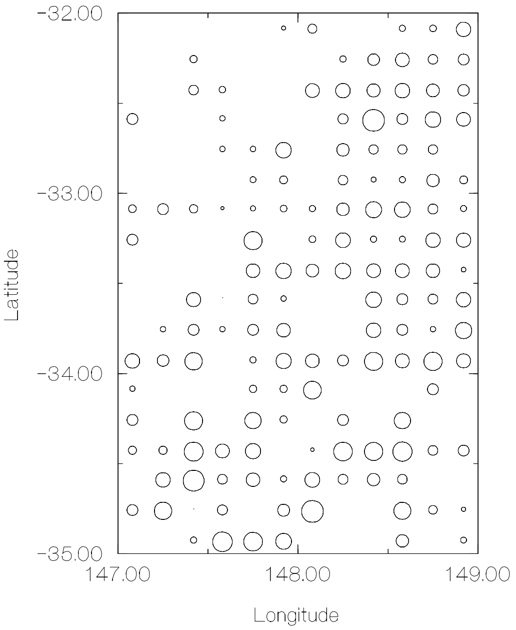

White-eared Honeyeater, B617


Yellow-tufted Honeyeater, B619

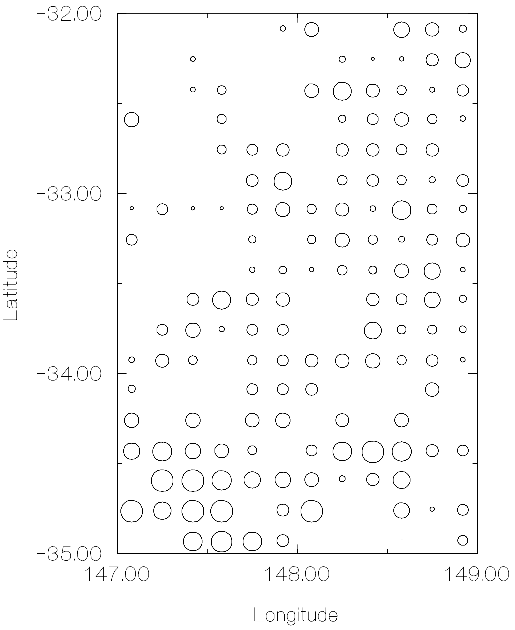

Yellow-plumed Honeyeater, B622

Atlas Maps of Bird Species Recorded in >10 Gridsquares

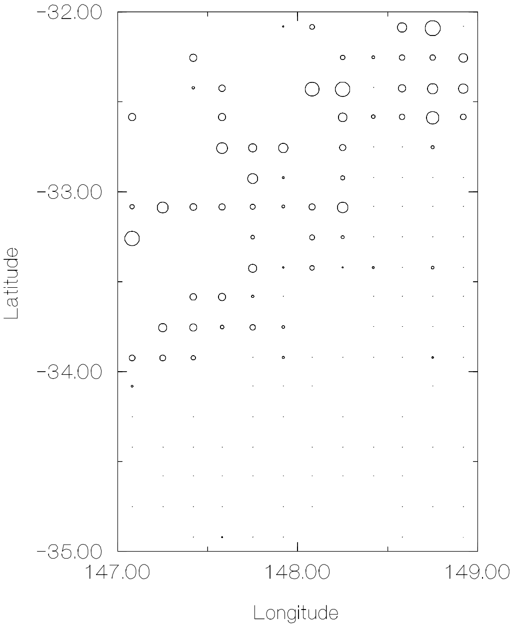
White-plumed Honeyeater, B625



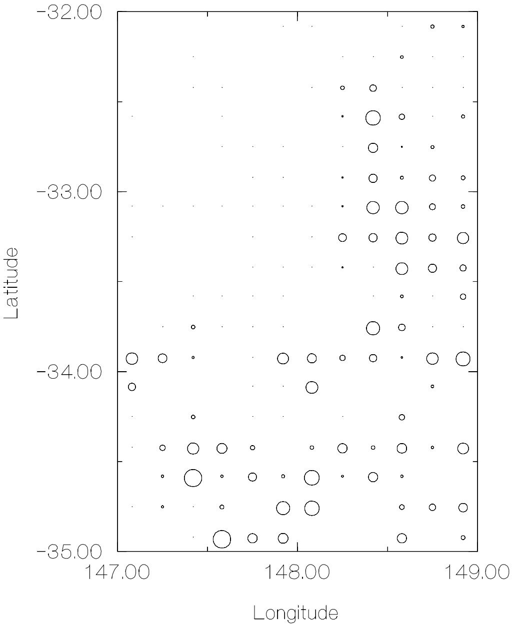
Noisy Miner, B634



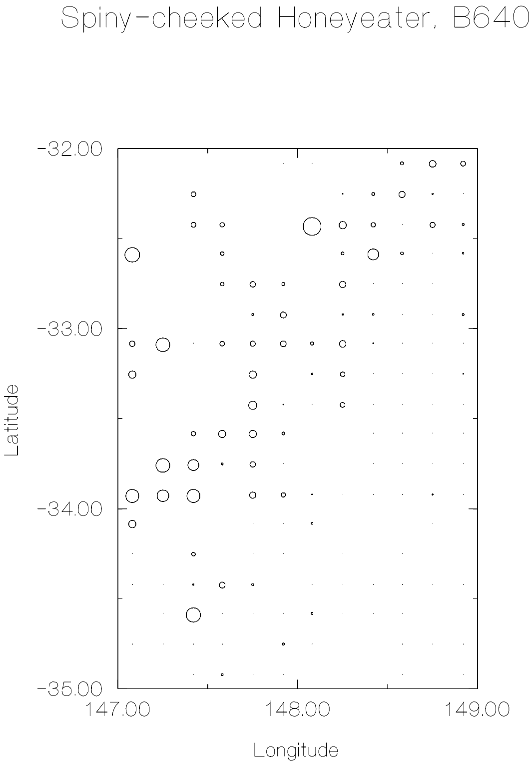
Yellow-throated Miner, B635

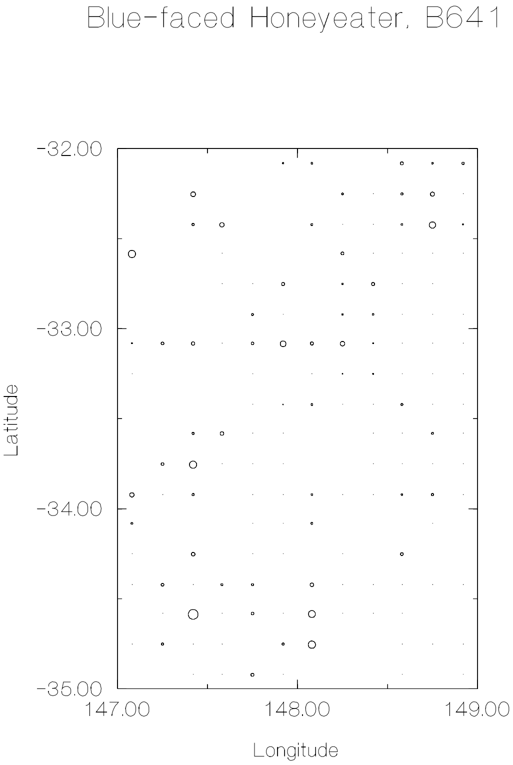


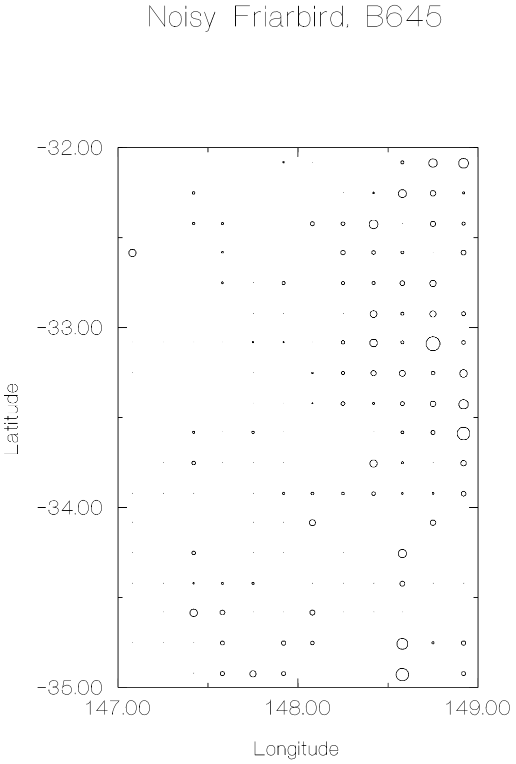
Red Wattlebird, B638

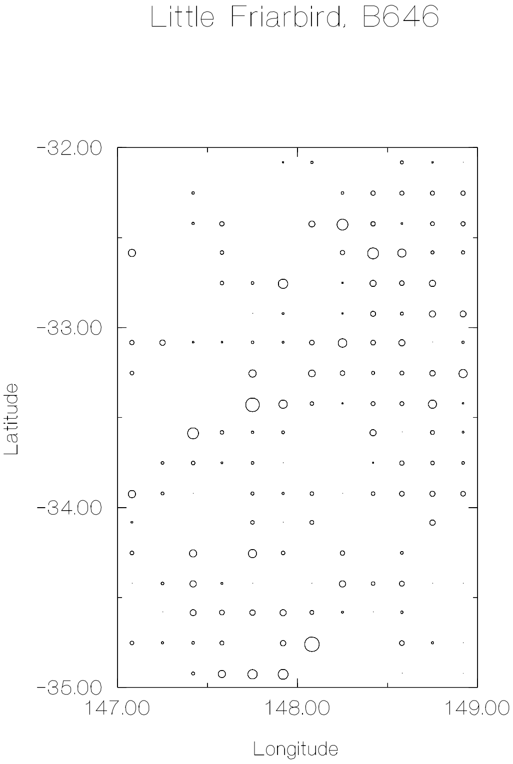


Atlas Maps of Bird Species Recorded in >10 Gridsquares

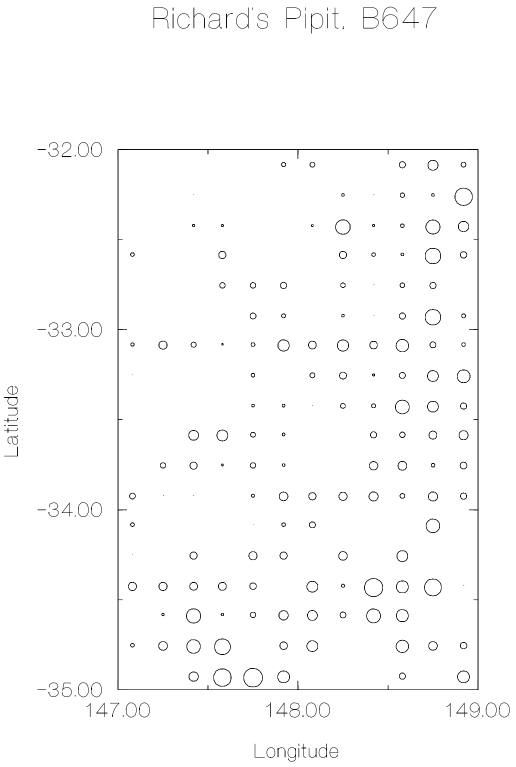


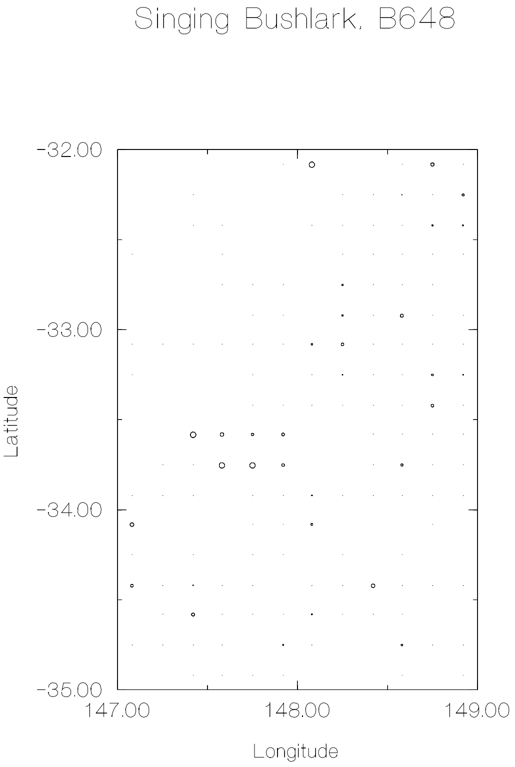


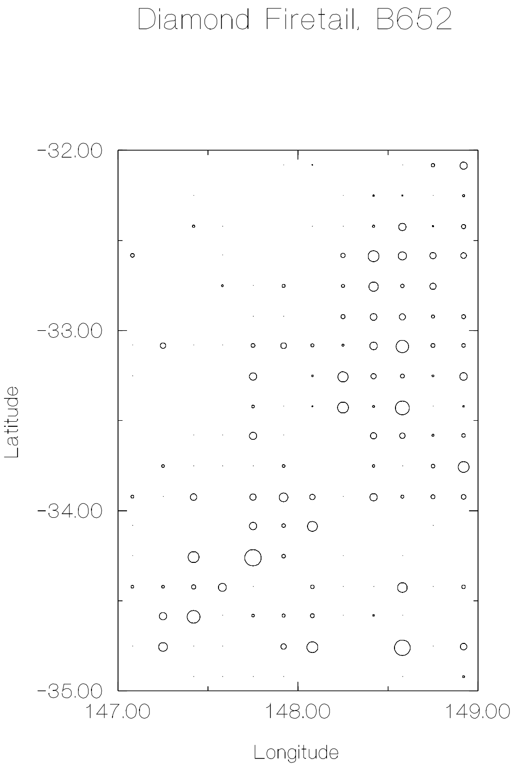


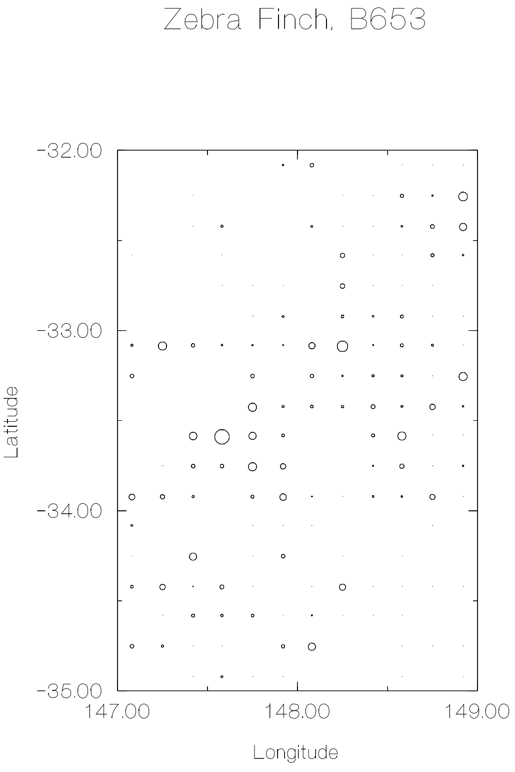


Atlas Maps of Bird Species Recorded in >10 Gridsquares



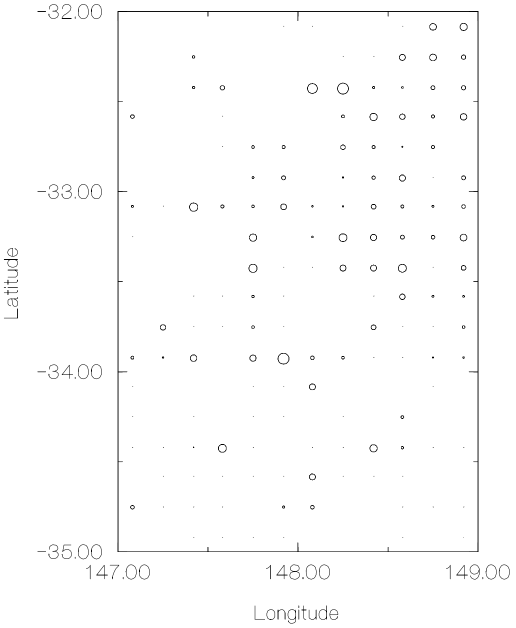




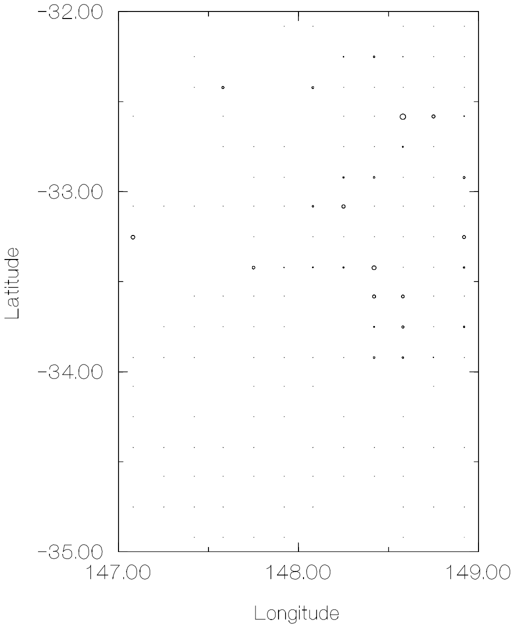


Atlas Maps of Bird Species Recorded in >10 Gridsquares

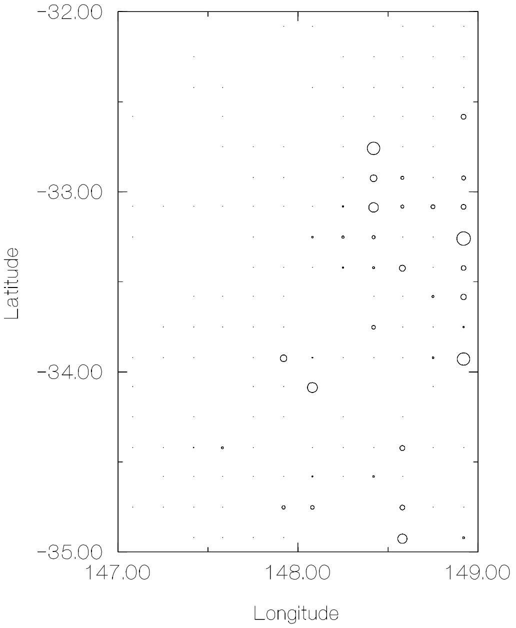
Double-barred Finch, B655



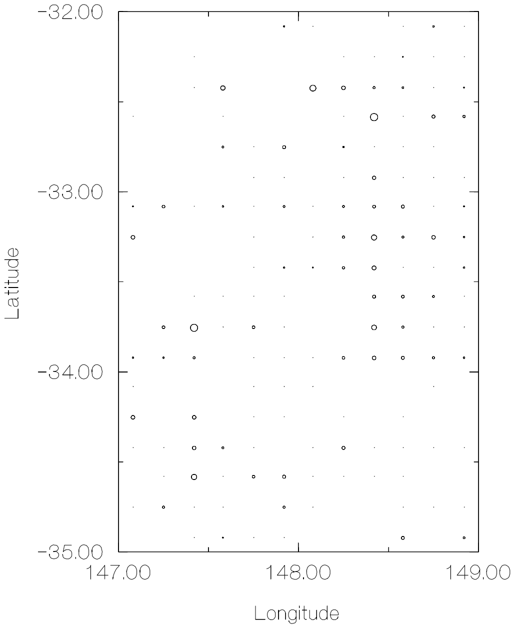
Plum-headed Finch, B661



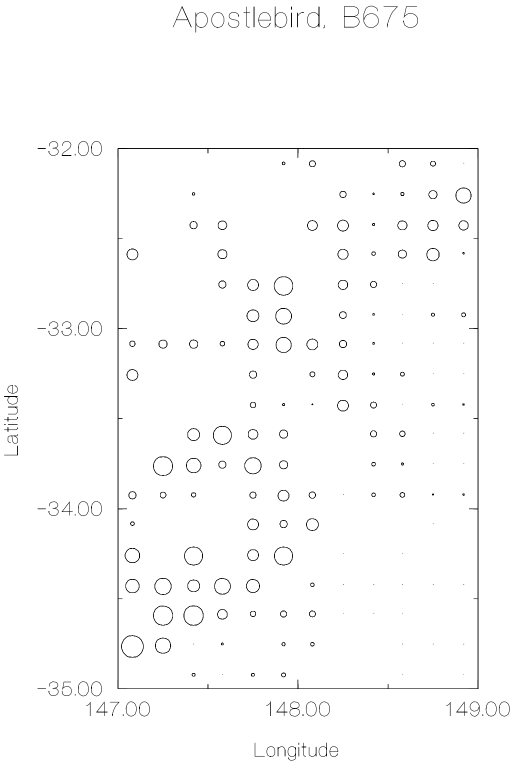
Red-browed Finch, B662

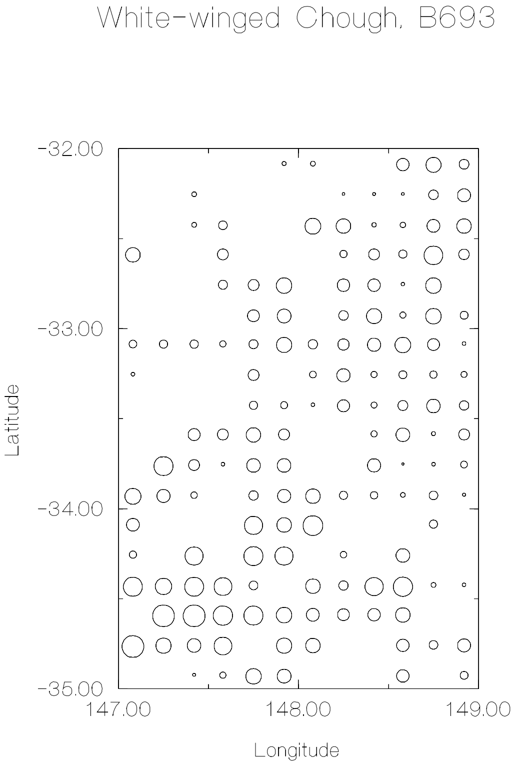


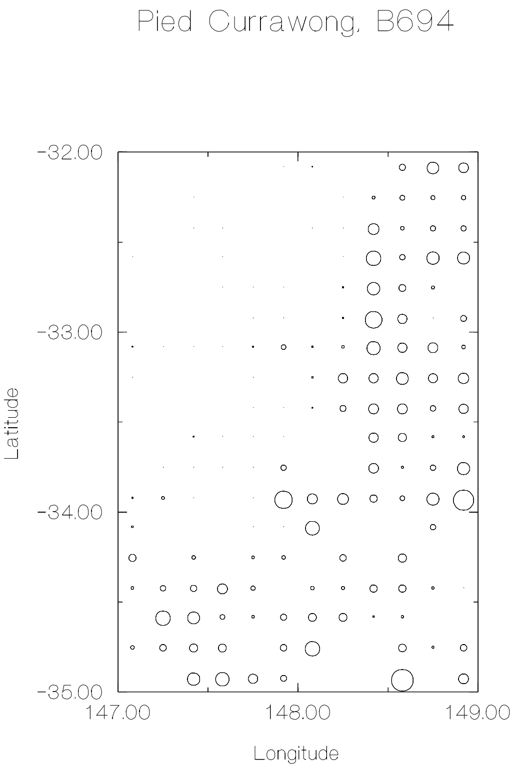
Olive-backed Oriole, B671

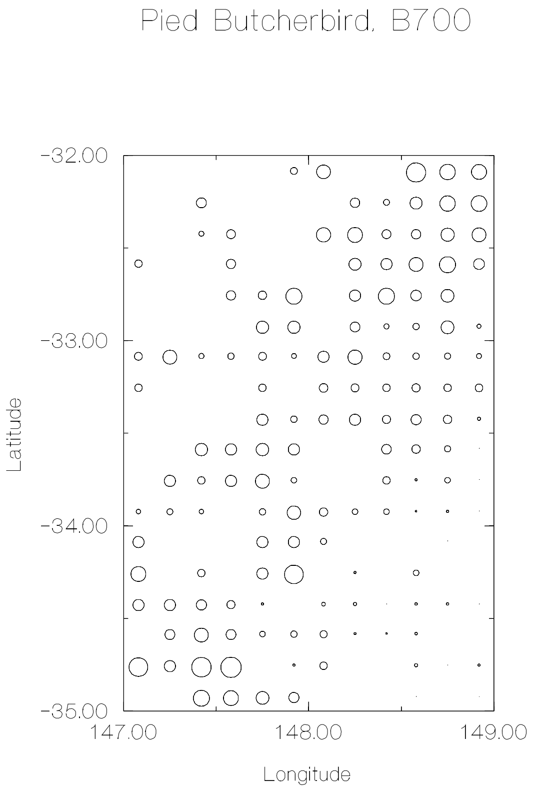


Atlas Maps of Bird Species Recorded in >10 Gridsquares

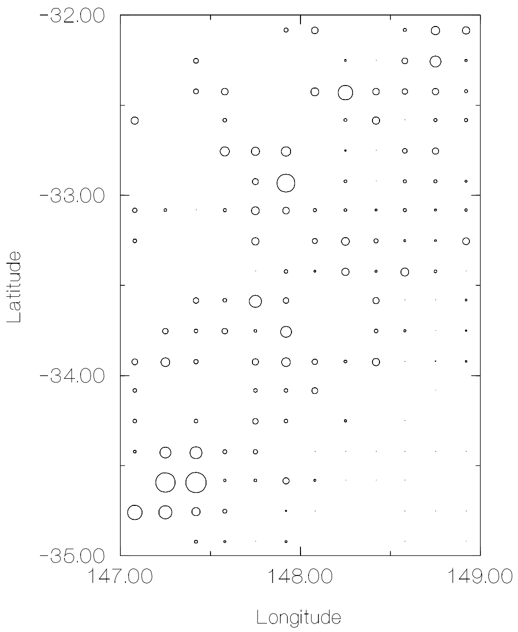


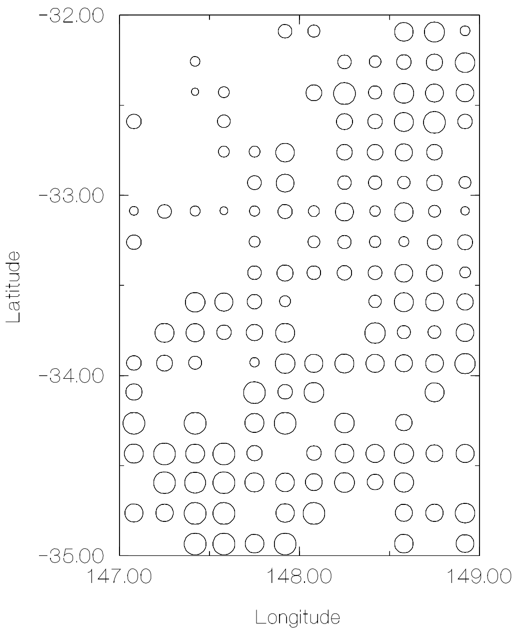


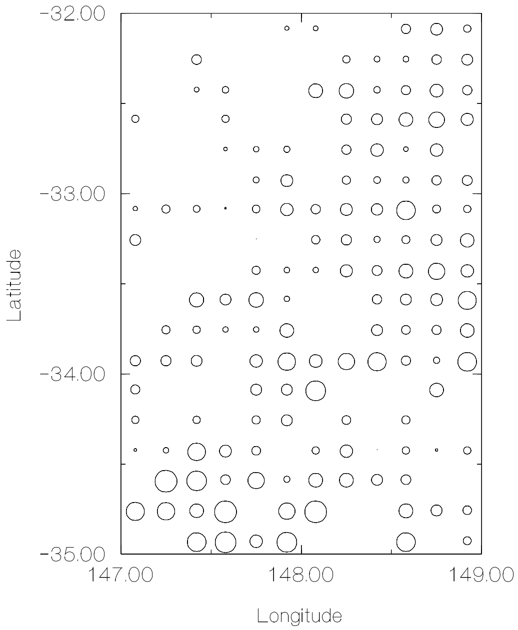


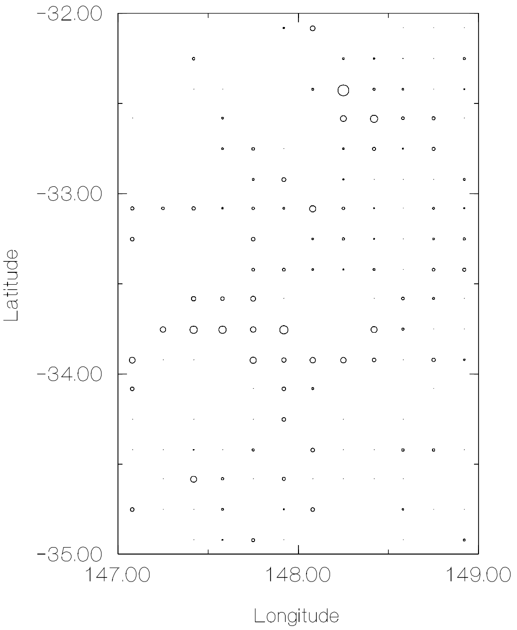


Atlas Maps of Bird Species Recorded in >10 Gridsquares

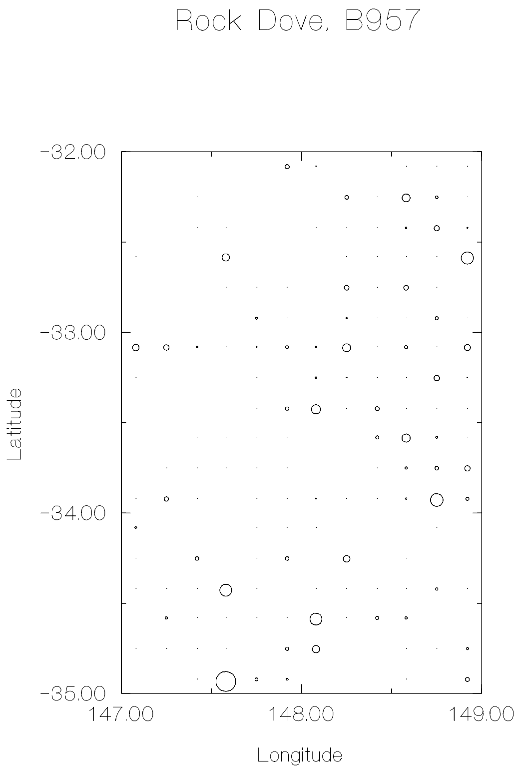

Grey Butcherbird, B702

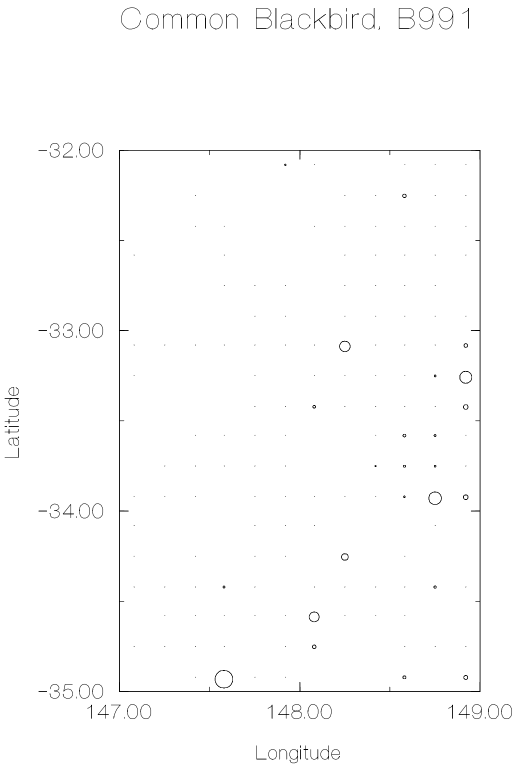

Australian Magpie, B705

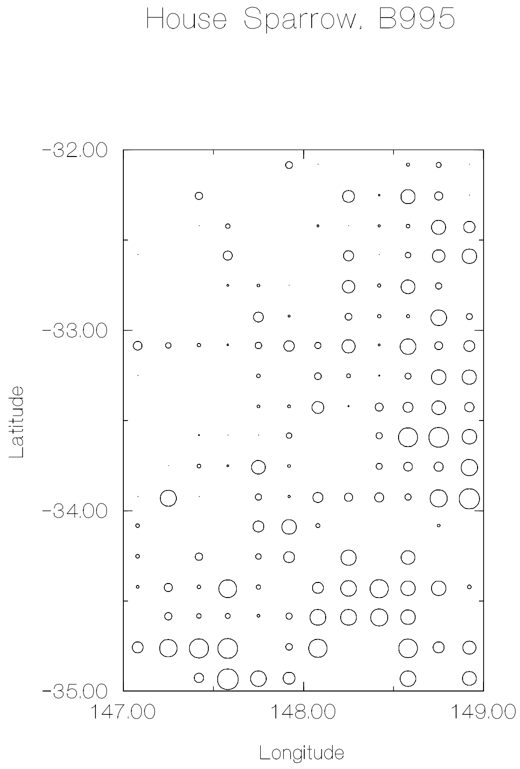

Australian Raven, B930

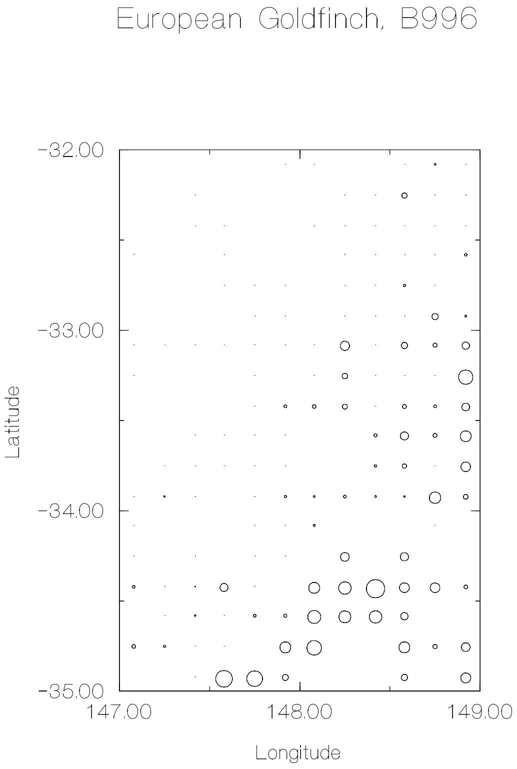

Little Raven, B954

Atlas Maps of Bird Species Recorded in >10 Gridsquares









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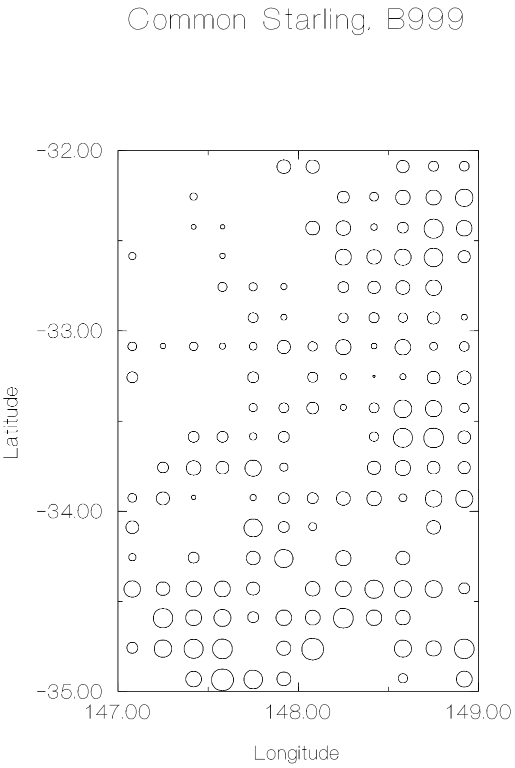

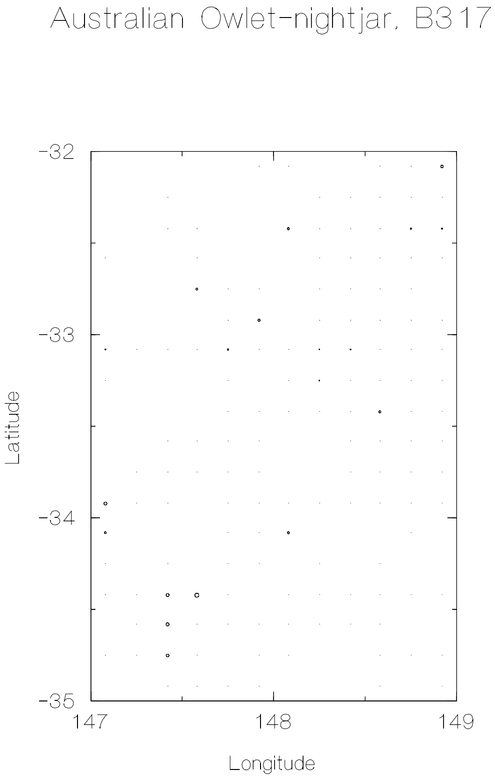

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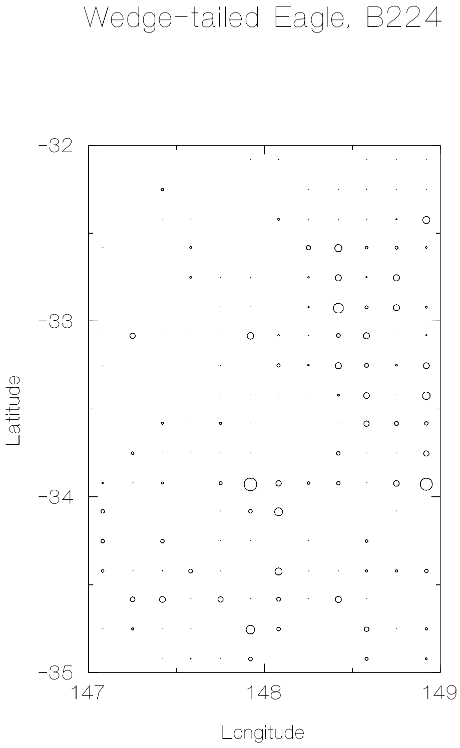
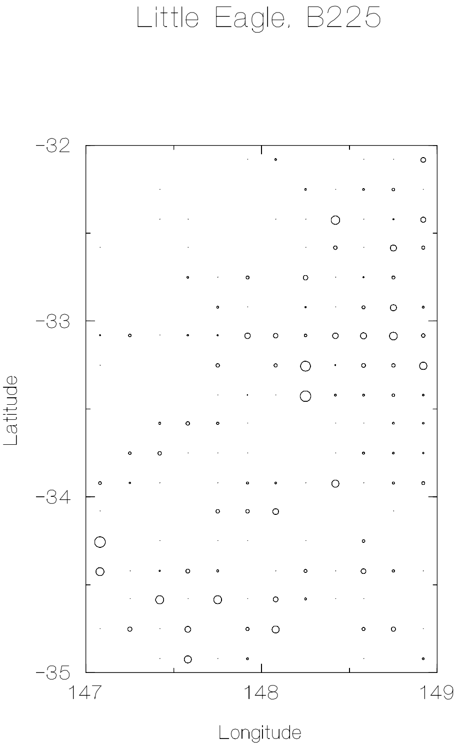
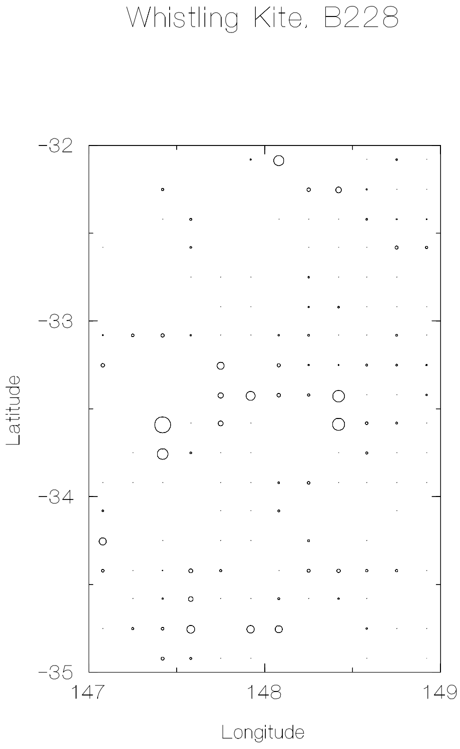
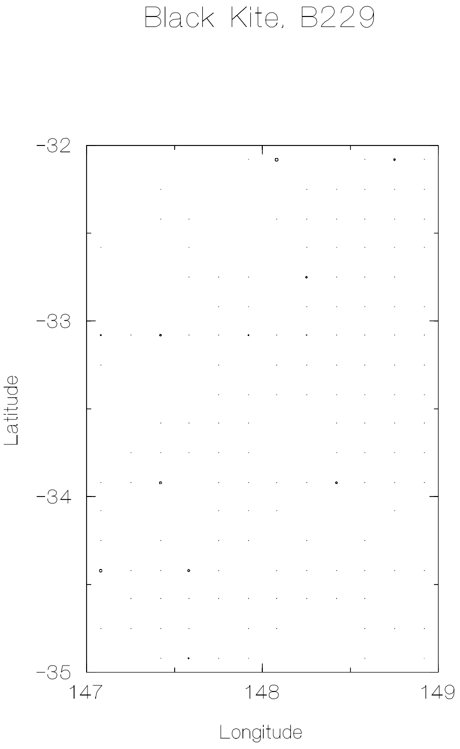


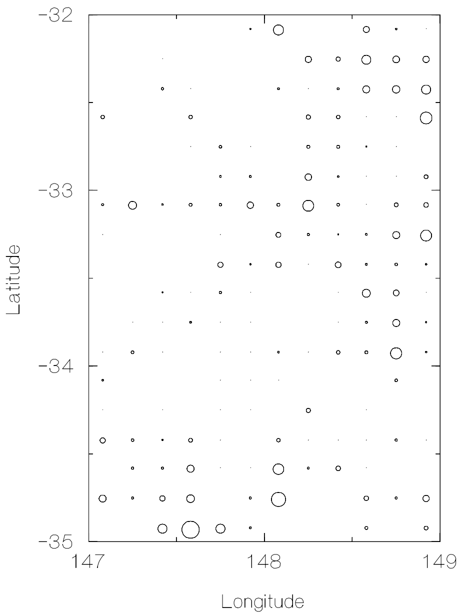




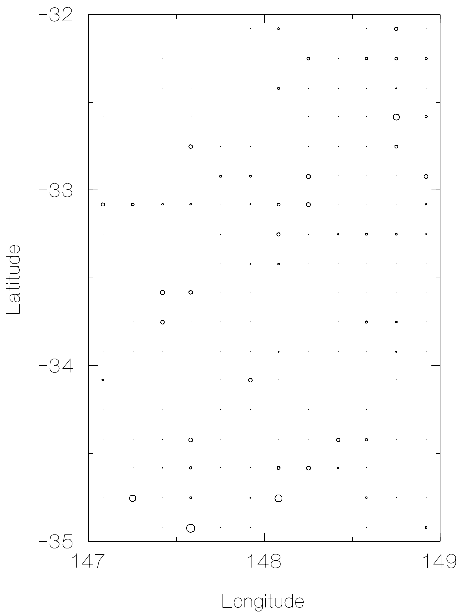


Atlas Maps of Bird Species Recorded in >10 Gridsquares

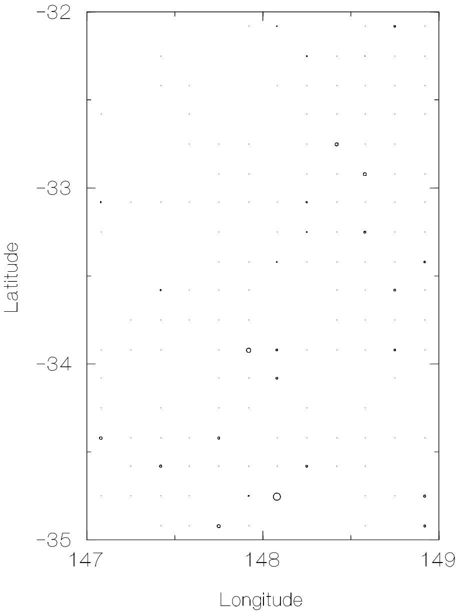
Black-shouldered Kite, B232



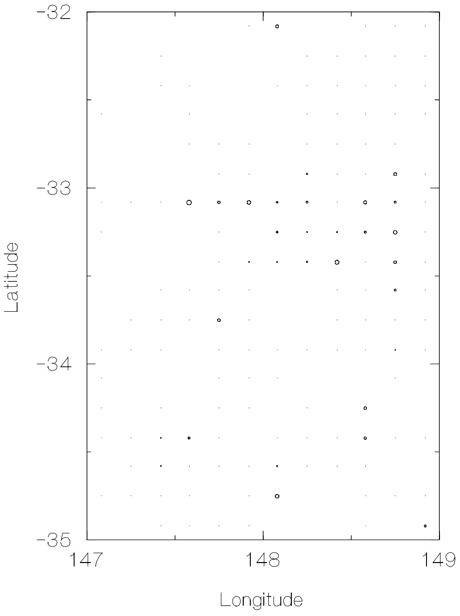
Australian Hobby, B235



Peregrine Falcon, B237

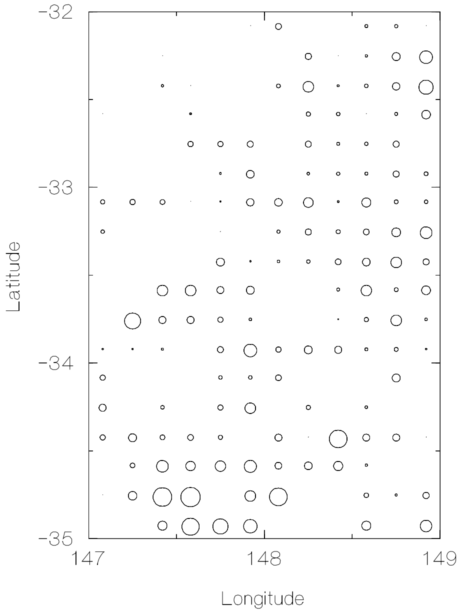


Black Falcon, B238

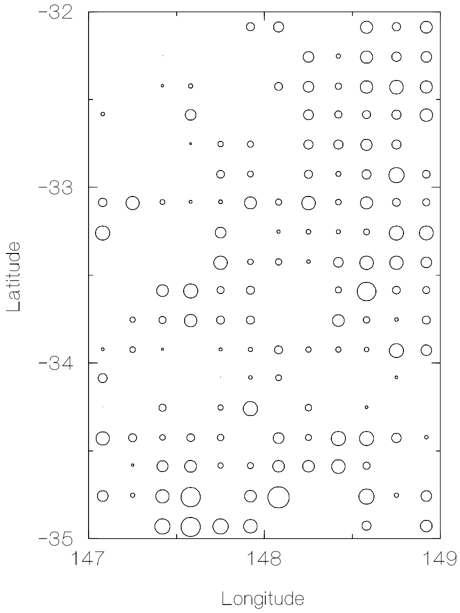


Atlas Maps of Bird Species Recorded in >10 Gridsquares

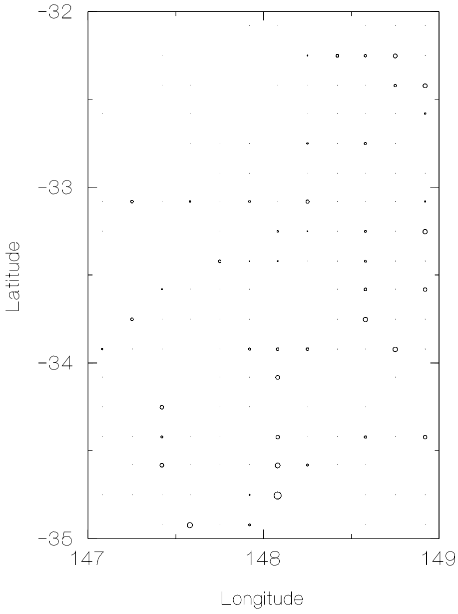
Brown Falcon, B239



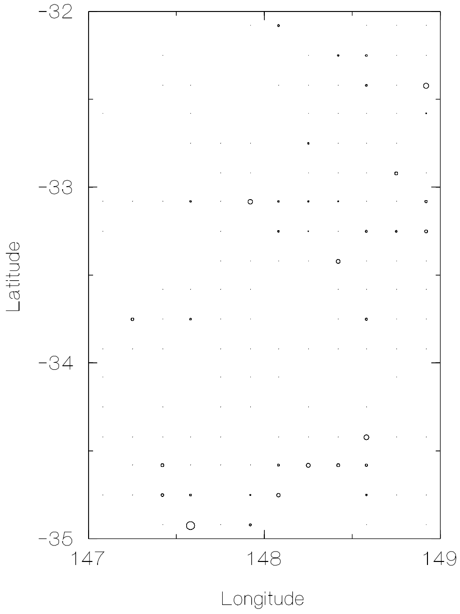
Nankeen Kestrel, B240



Southern Boobook, B242

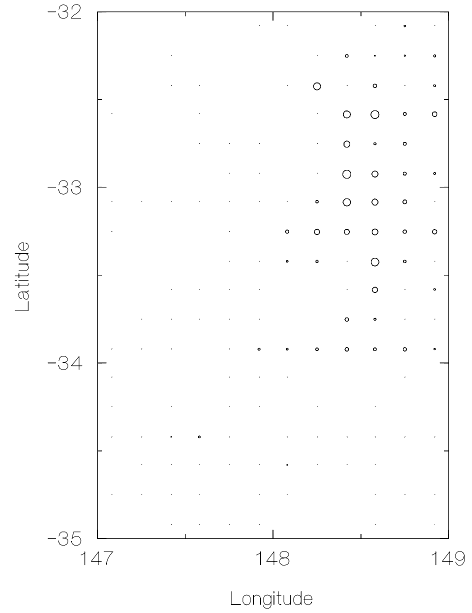


Barn Owl, B249

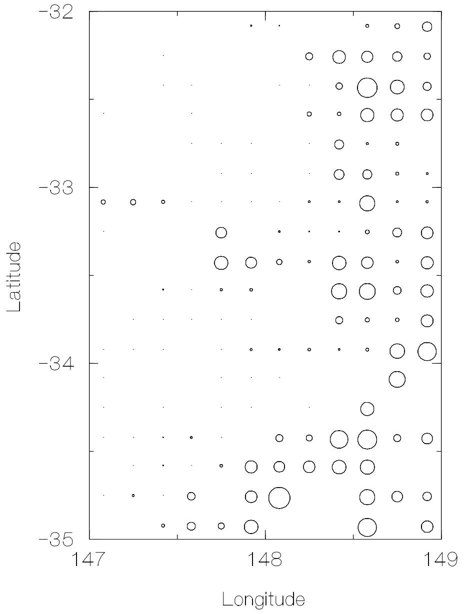


Atlas Maps of Bird Species Recorded in >10 Gridsquares

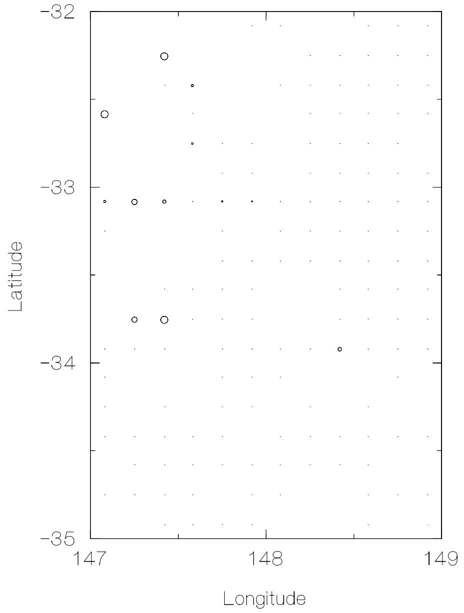
Little Lorikeet, B260



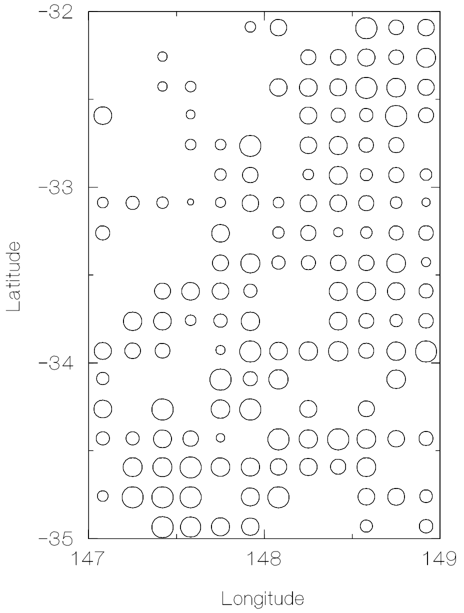
Sulphur-crested Cockatoo, B269



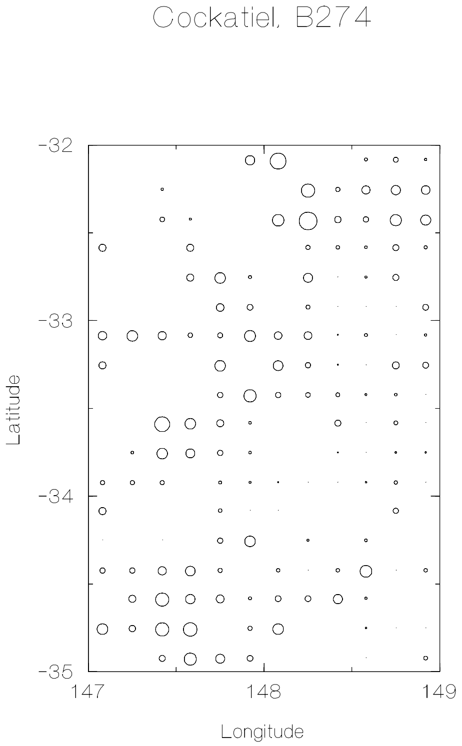
Major Mitchell's Cockatoo, B270

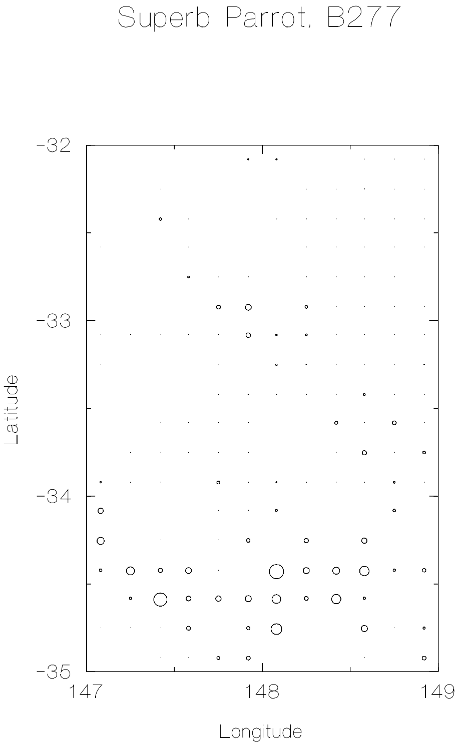


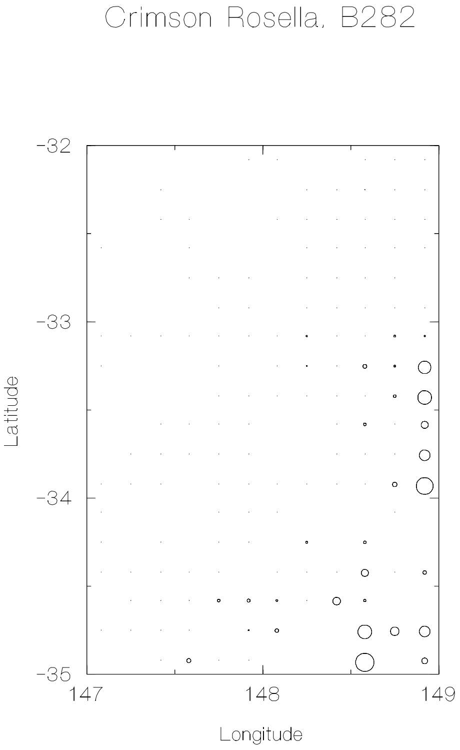
Galah, B273

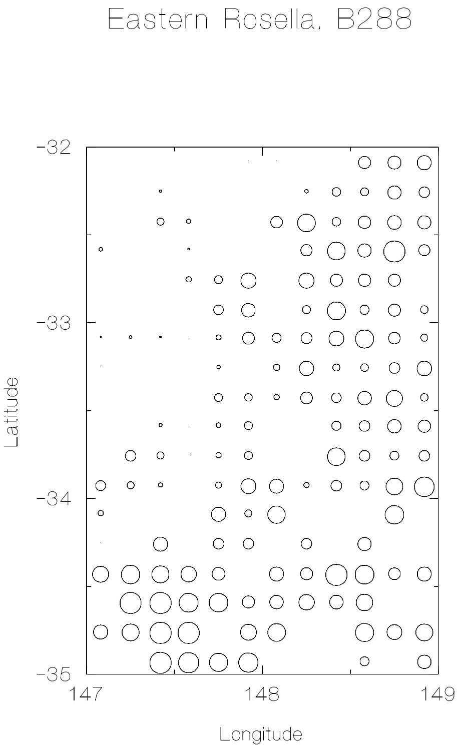


Atlas Maps of Bird Species Recorded in >10 Gridsquares



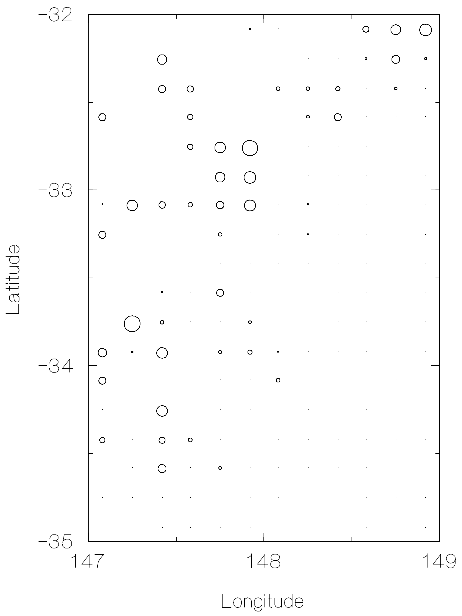




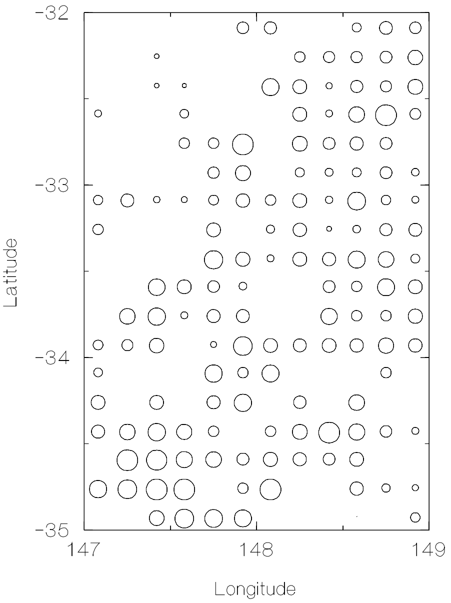


Atlas Maps of Bird Species Recorded in >10 Gridsquares

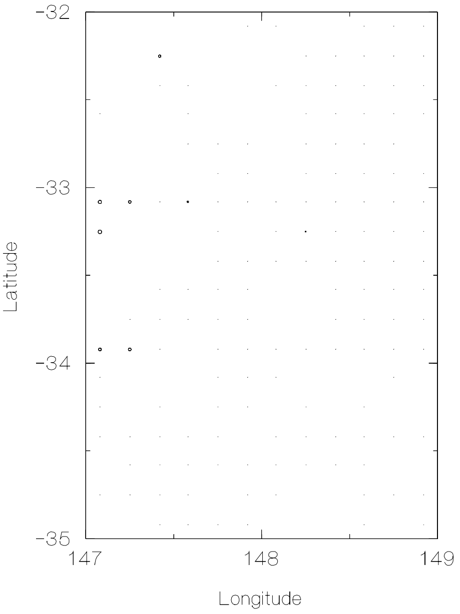
Mallee Ringneck, B291



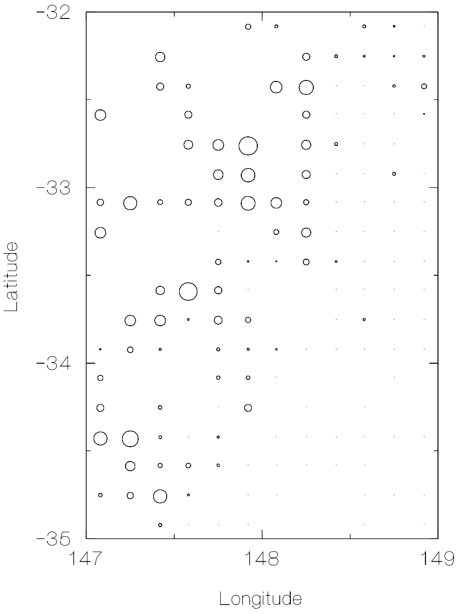
Red-rumped Parrot, B295



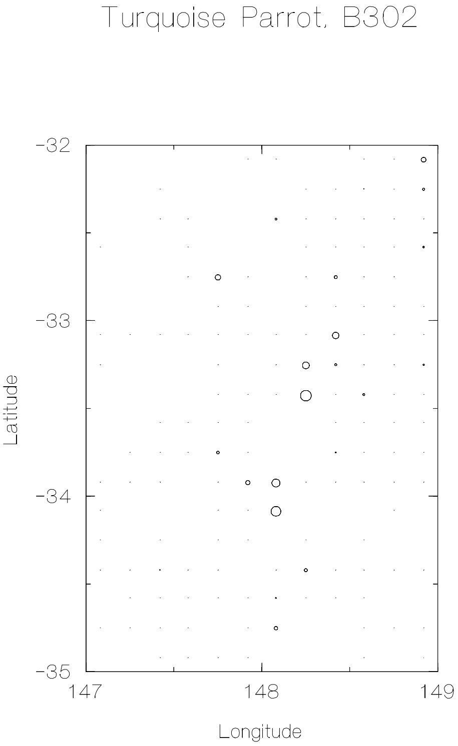
Mulga Parrot, B296

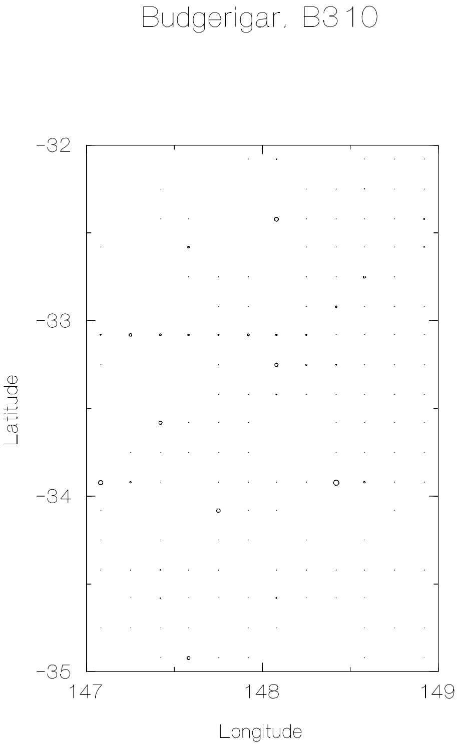


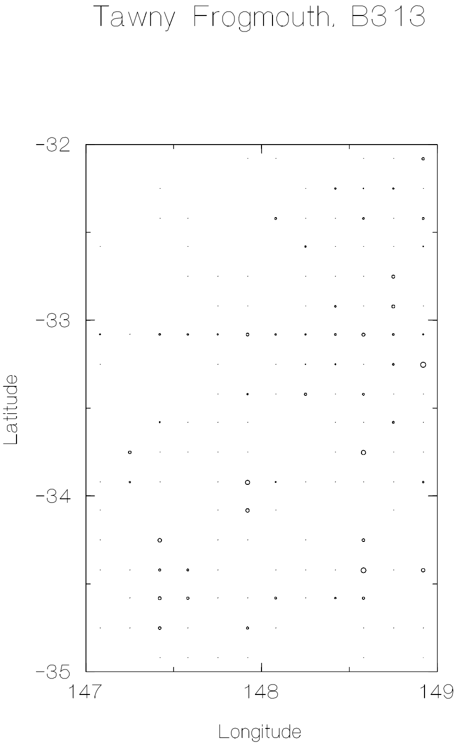
Blue Bonnet, B297

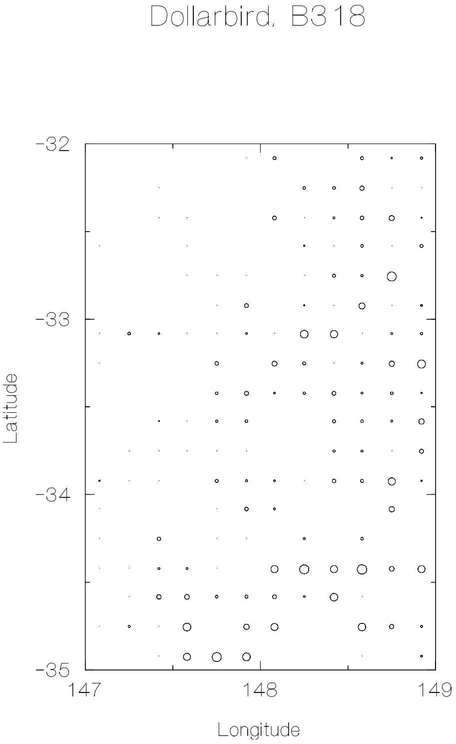


Atlas Maps of Bird Species Recorded in >10 Gridsquares



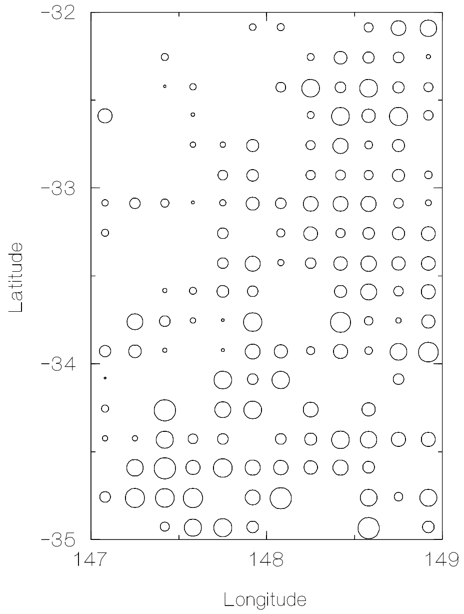




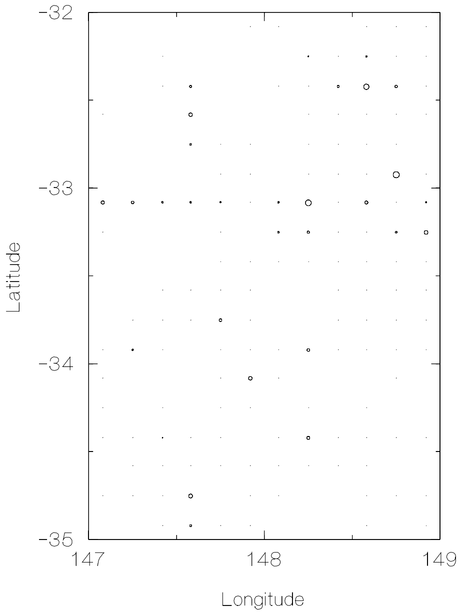


Atlas Maps of Bird Species Recorded in >10 Gridsquares

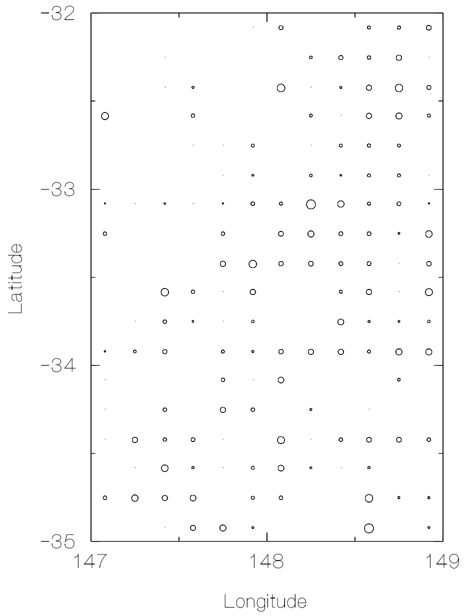
Laughing Kookaburra, B322



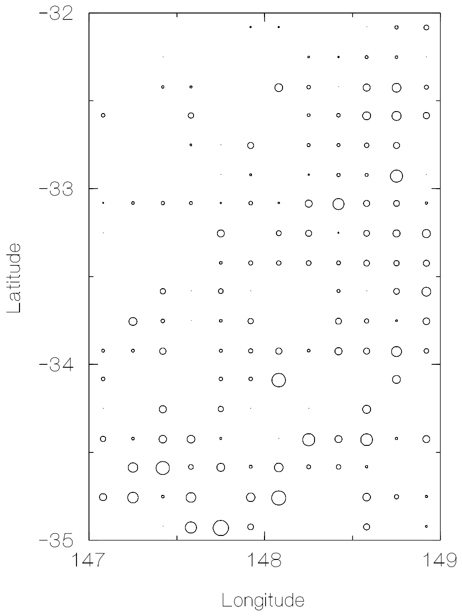
Red-backed Kingfisher, B325



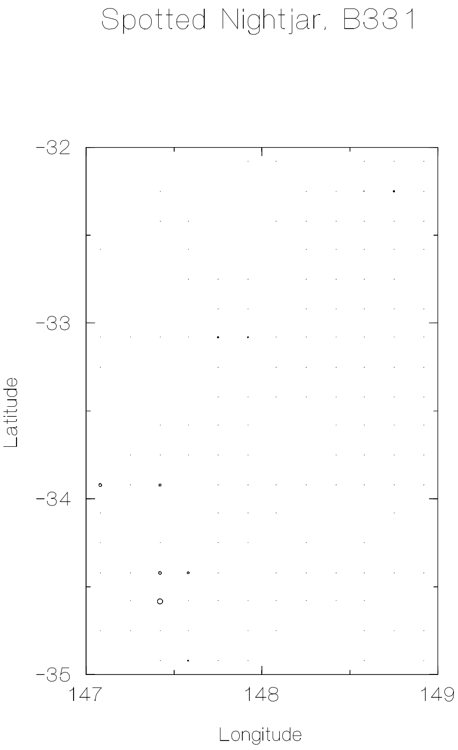
Sacred Kingfisher, B326

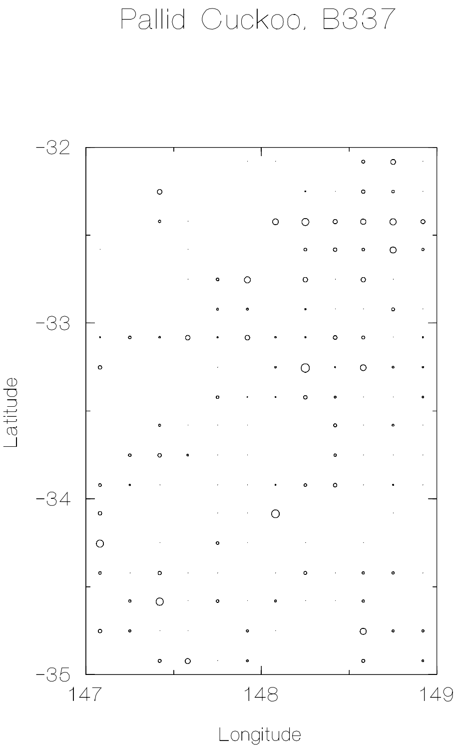


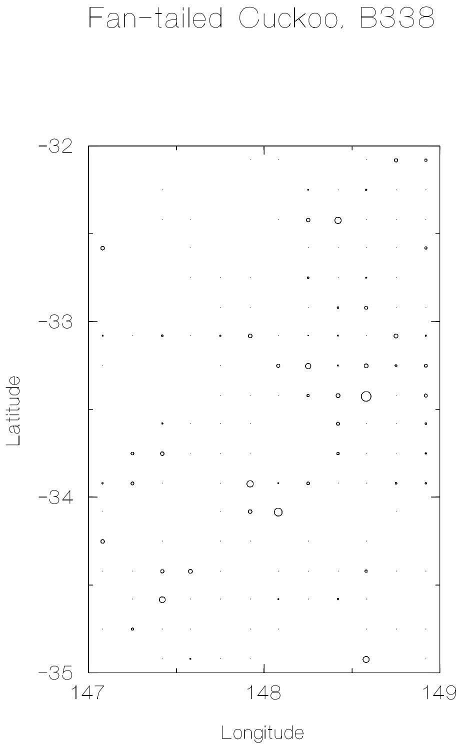
Rainbow Bee-eater, B329

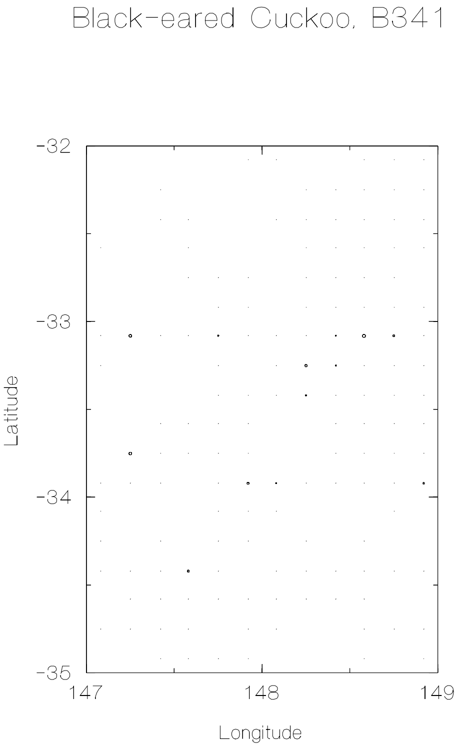


Atlas Maps of Bird Species Recorded in >10 Gridsquares









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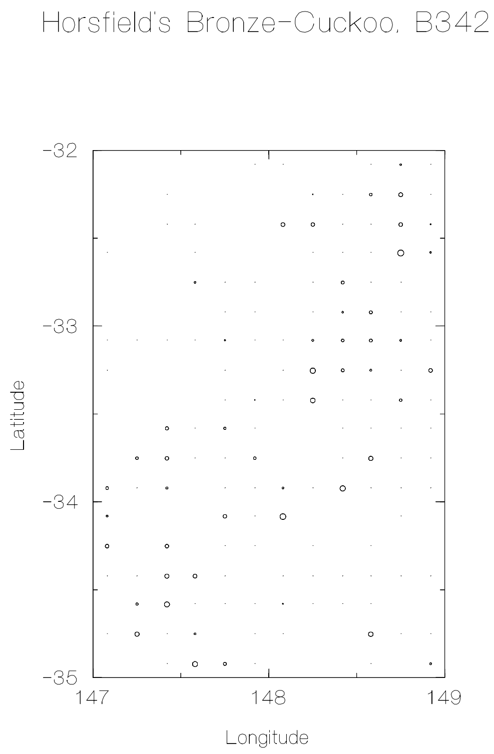
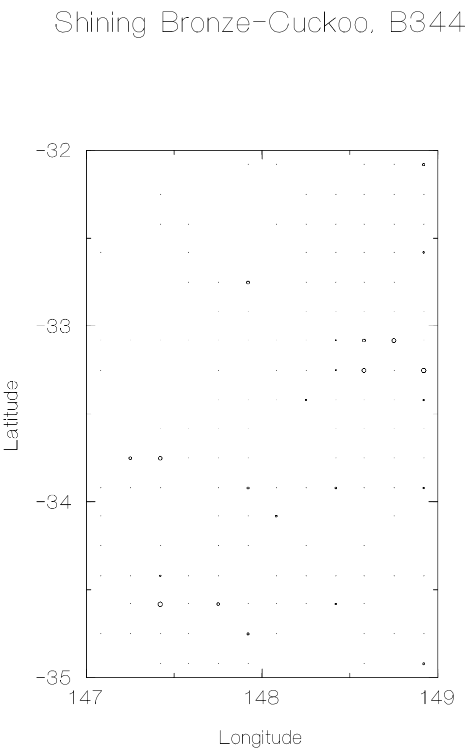
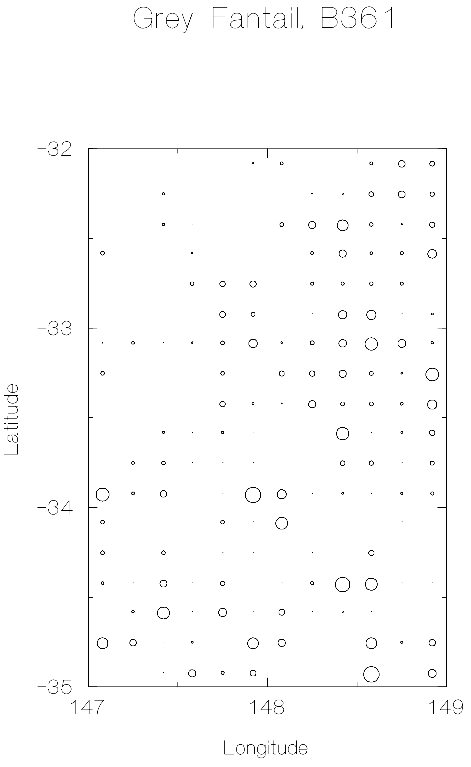
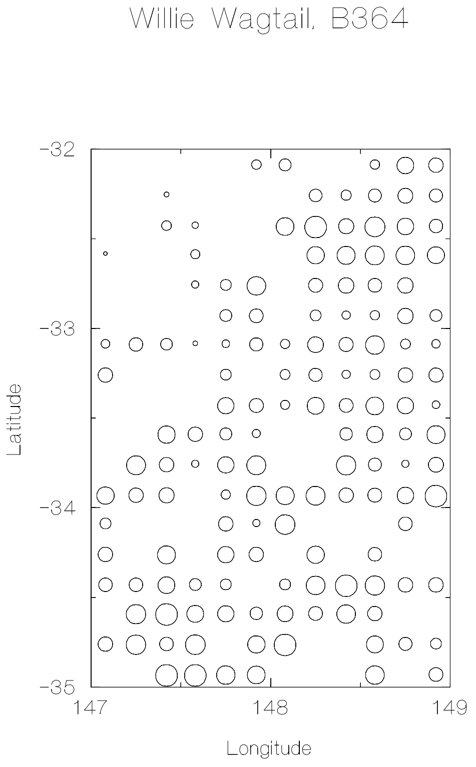


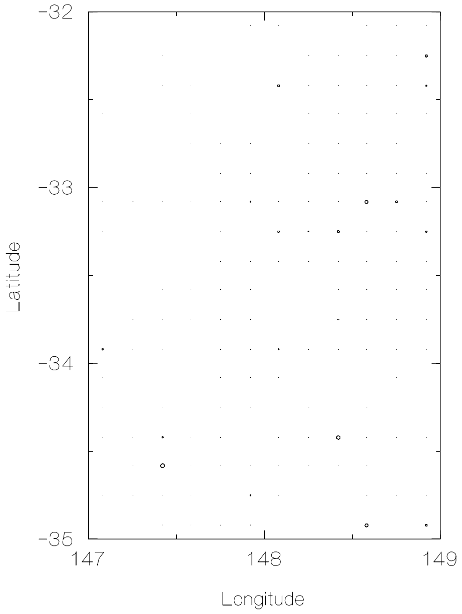




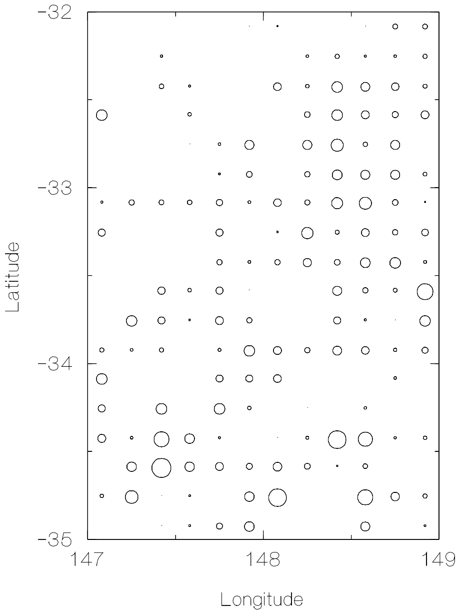


Atlas Maps of Bird Species Recorded in >10 Gridsquares

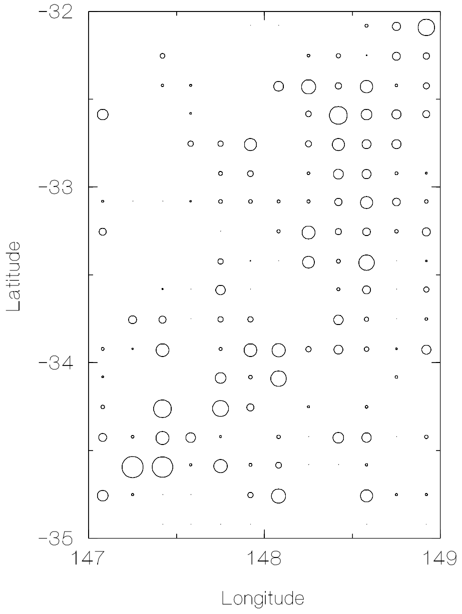
Leaden Flycatcher, B365



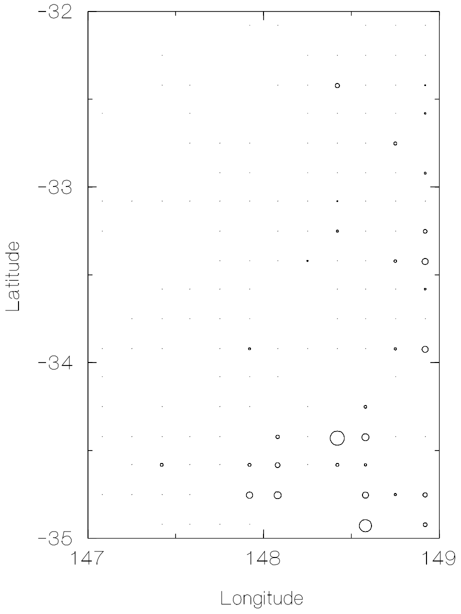
Restless Flycatcher, B369



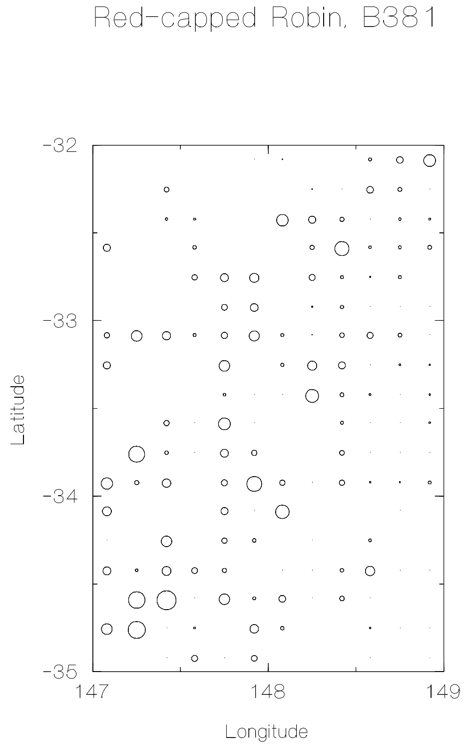
Jacky Winter, B377

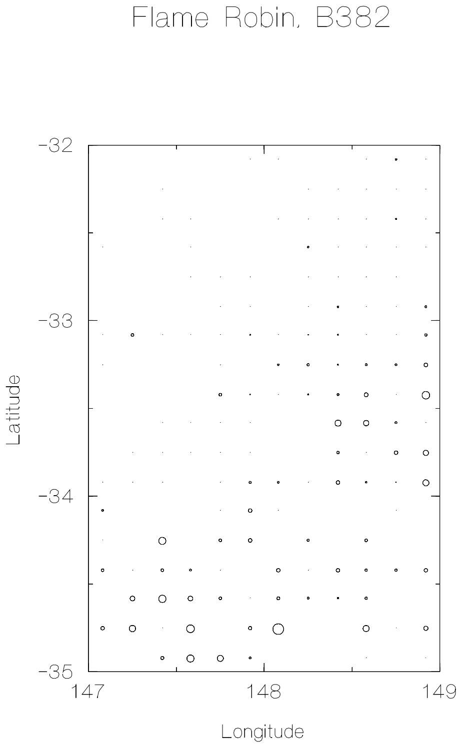


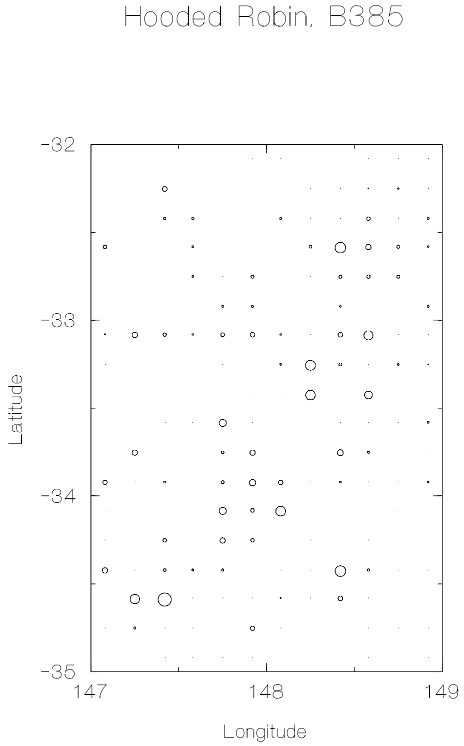
Scarlet Robin, B380

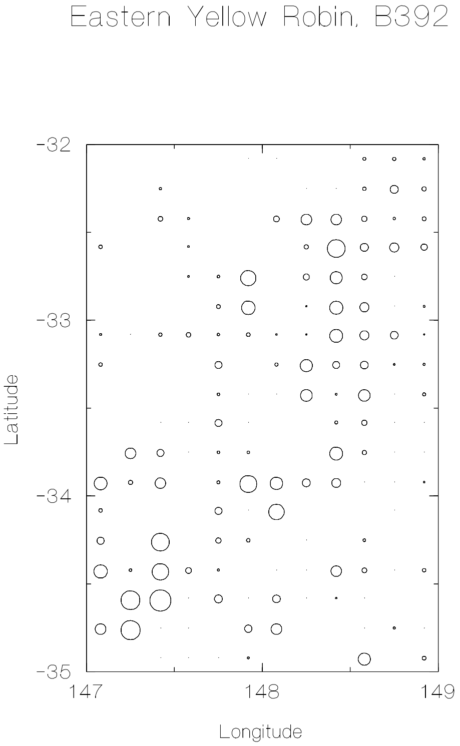


Atlas Maps of Bird Species Recorded in >10 Gridsquares

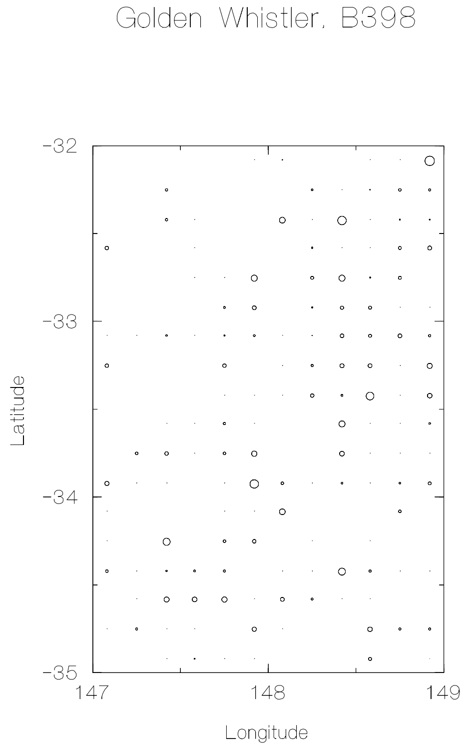


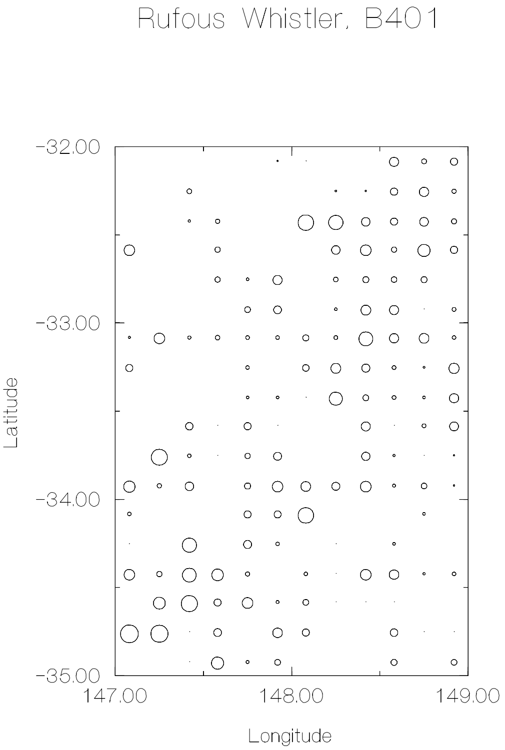


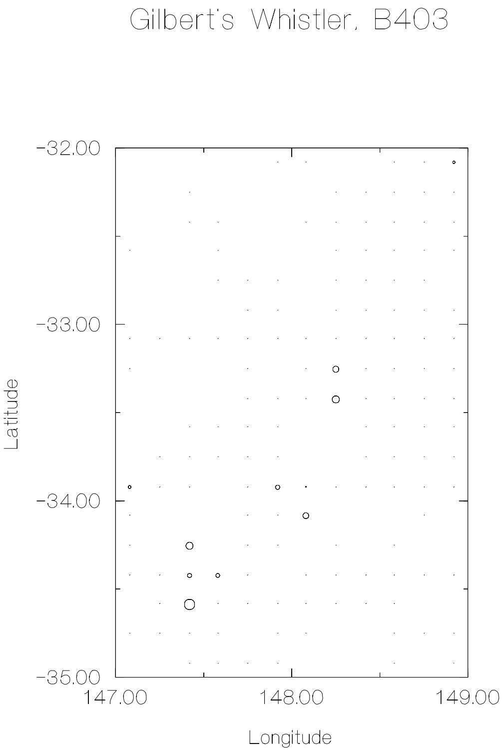


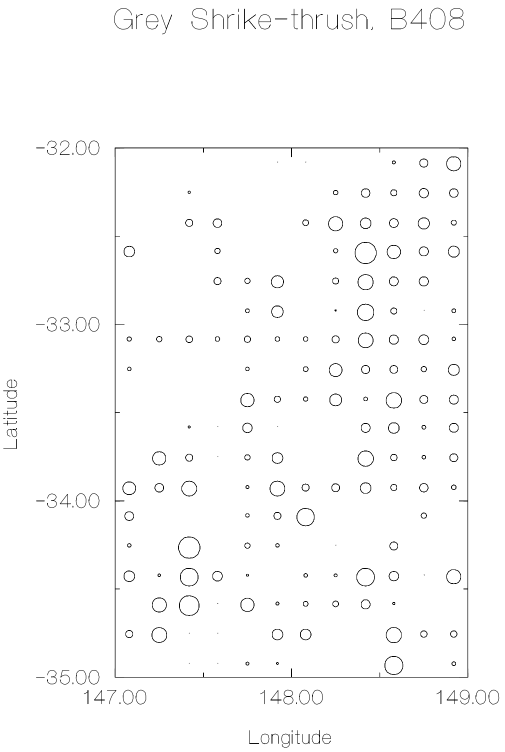


Atlas Maps of Bird Species Recorded in >10 Gridsquares









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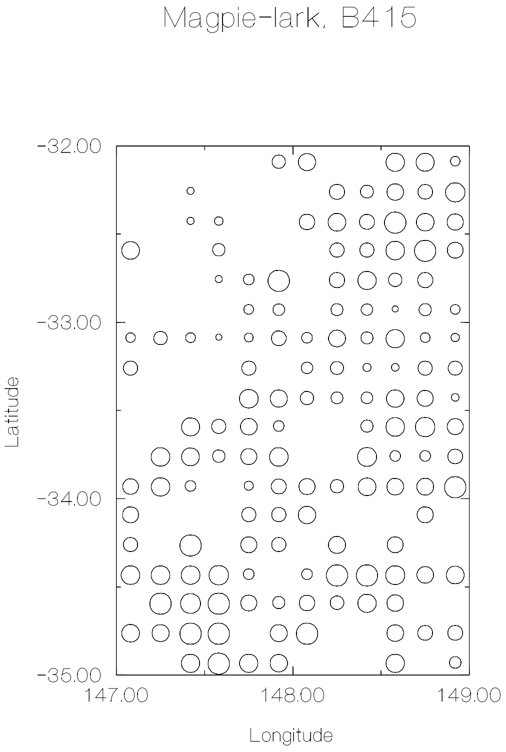

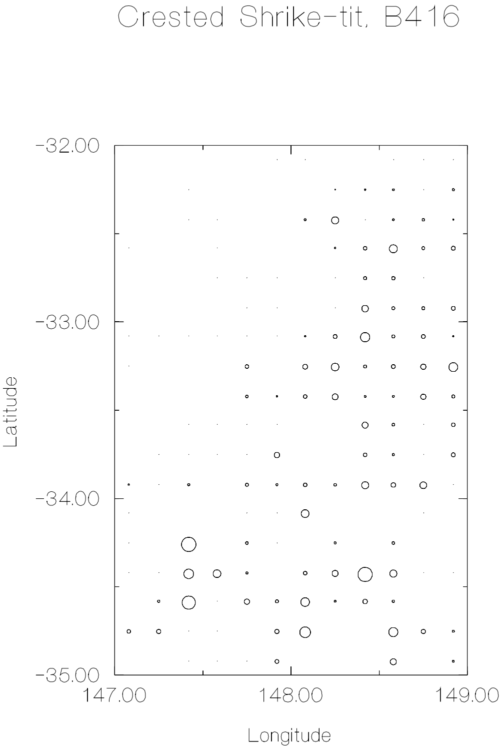

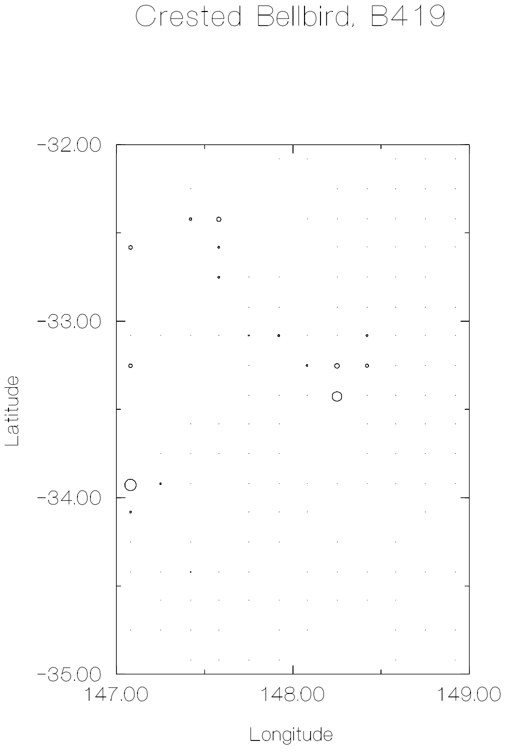

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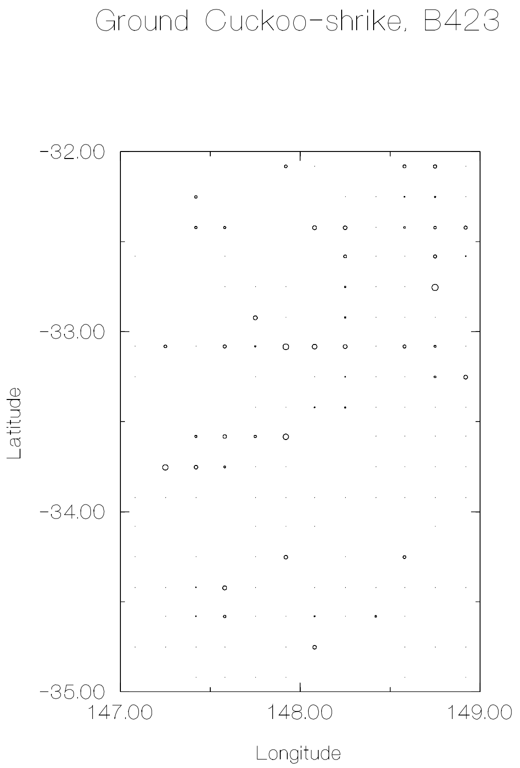
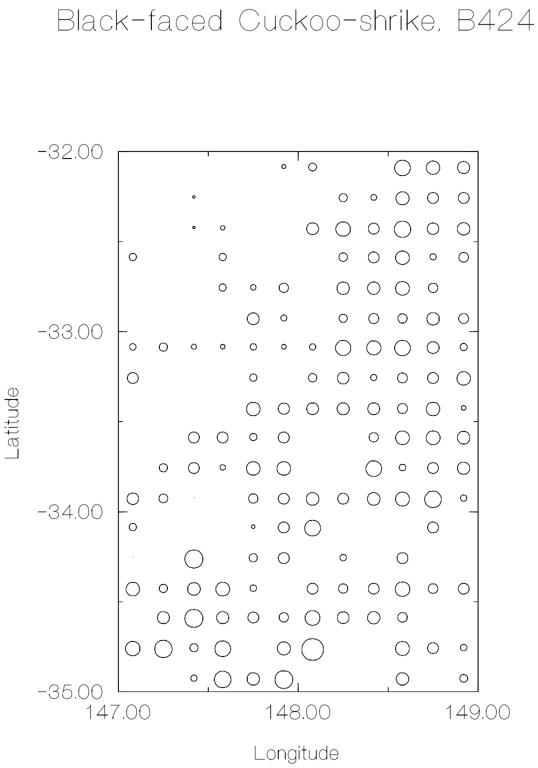
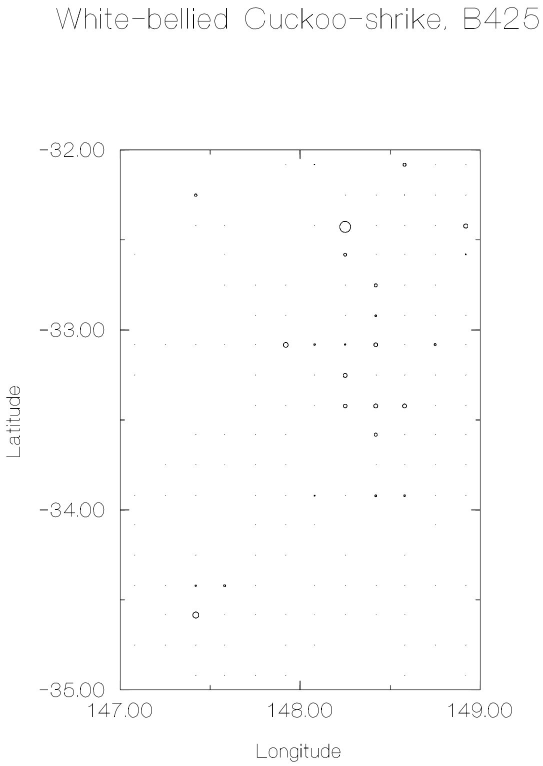
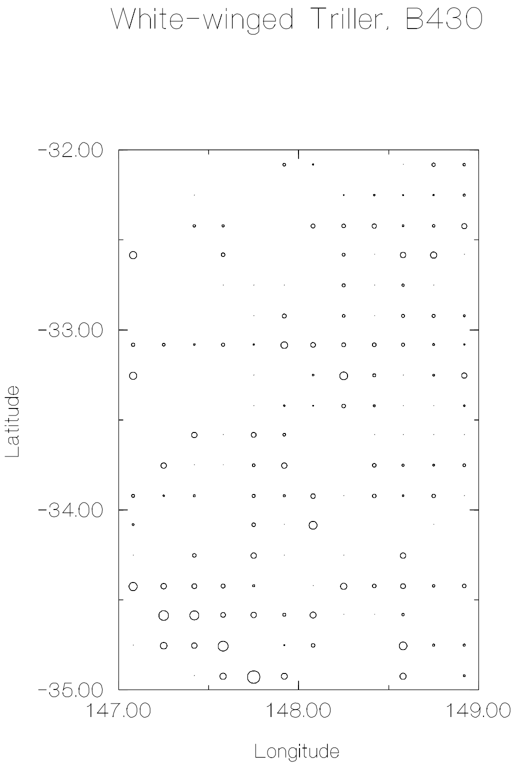
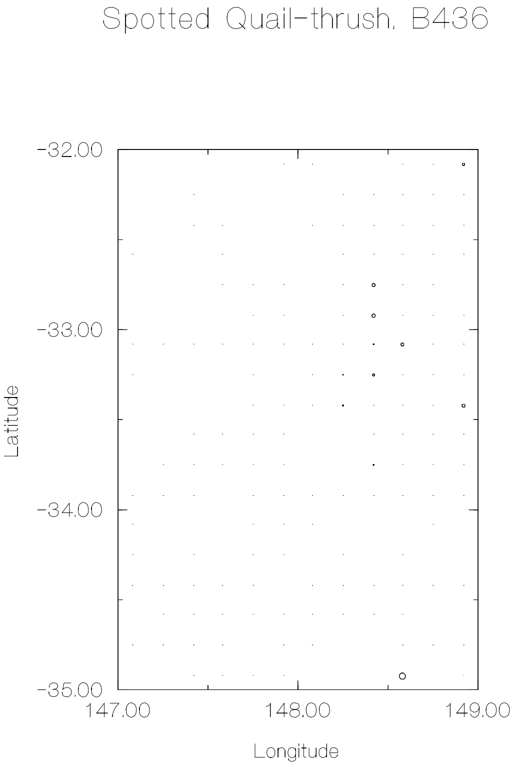


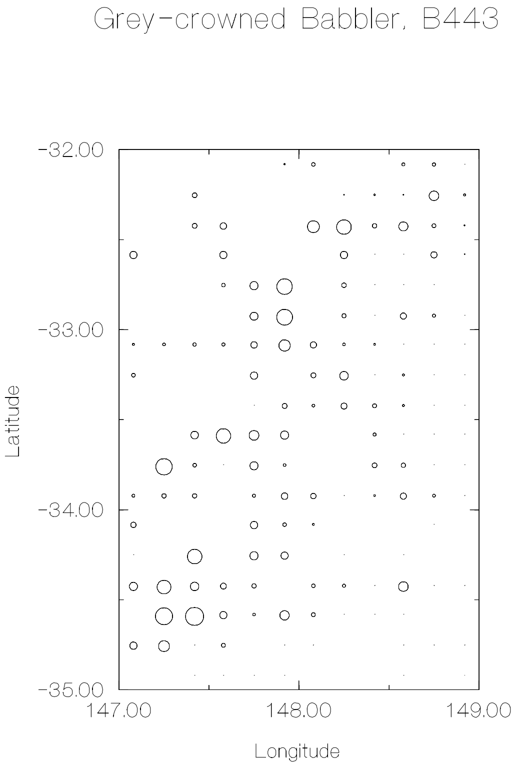


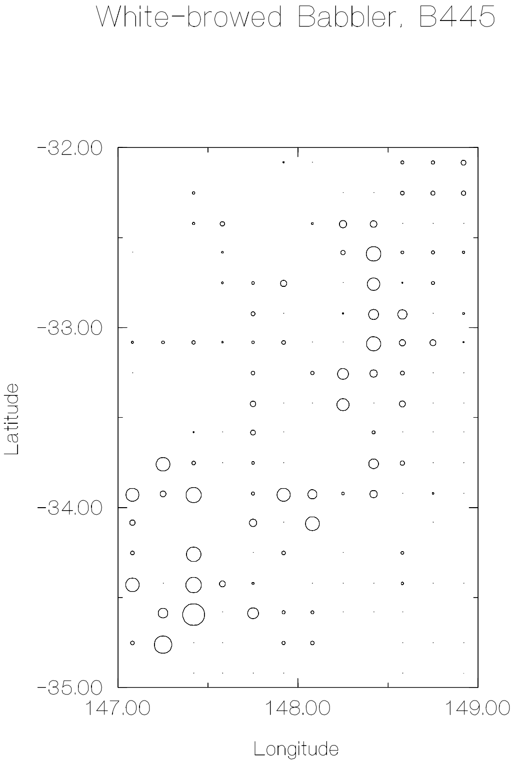


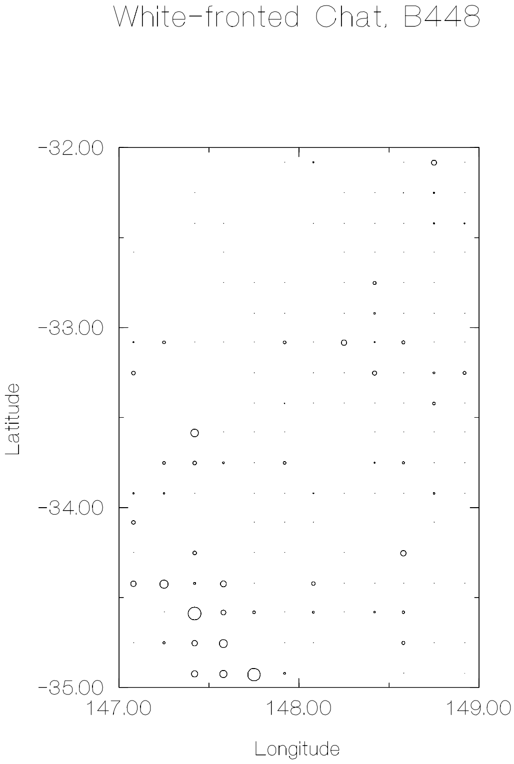


Atlas Maps of Bird Species Recorded in >10 Gridsquares



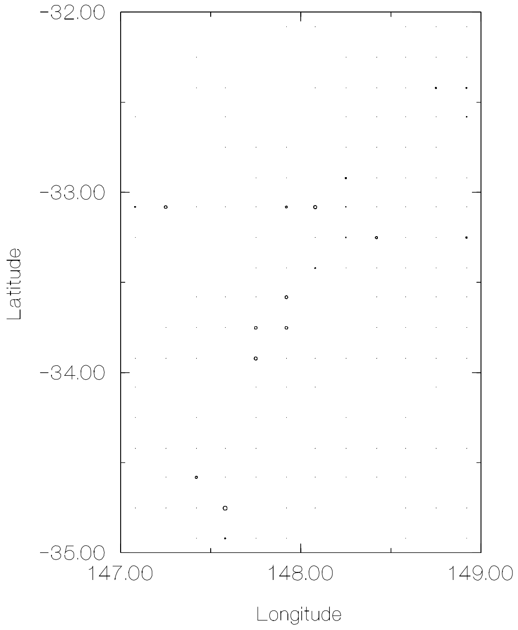




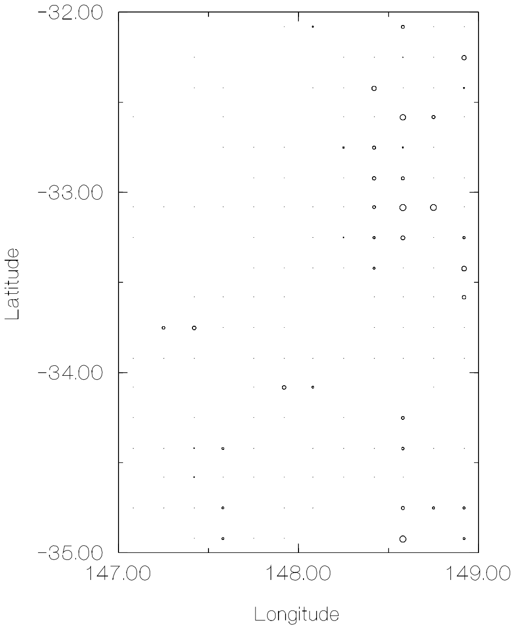


Atlas Maps of Bird Species Recorded in >10 Gridsquares

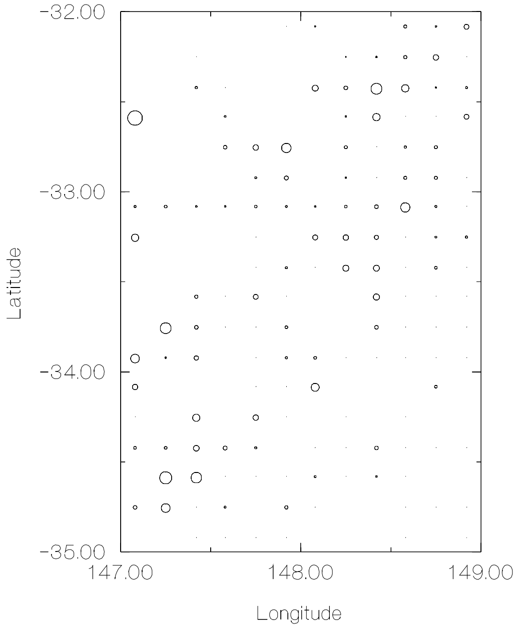
Crimson Chat, B449



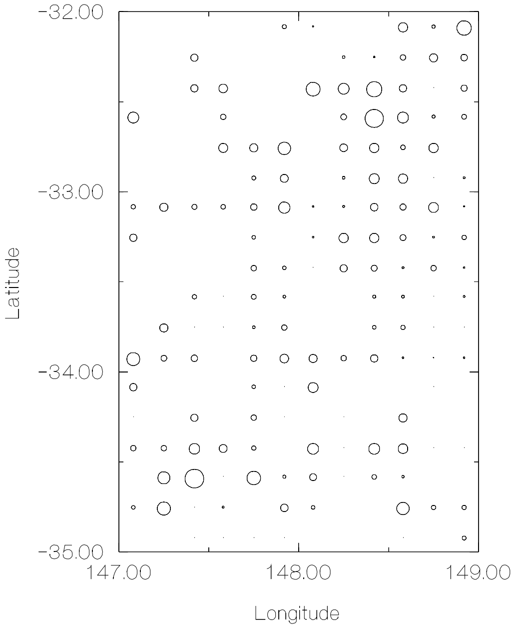
White-throated Gerygone, B453



Western Gerygone, B463



Weebill, B465



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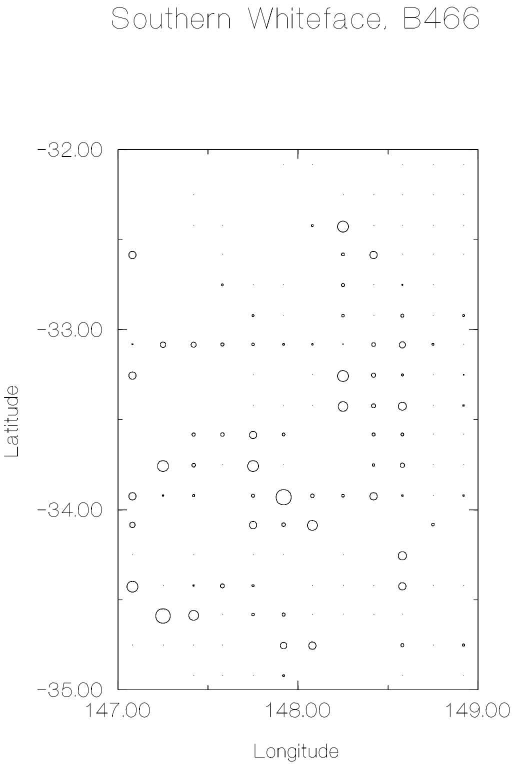
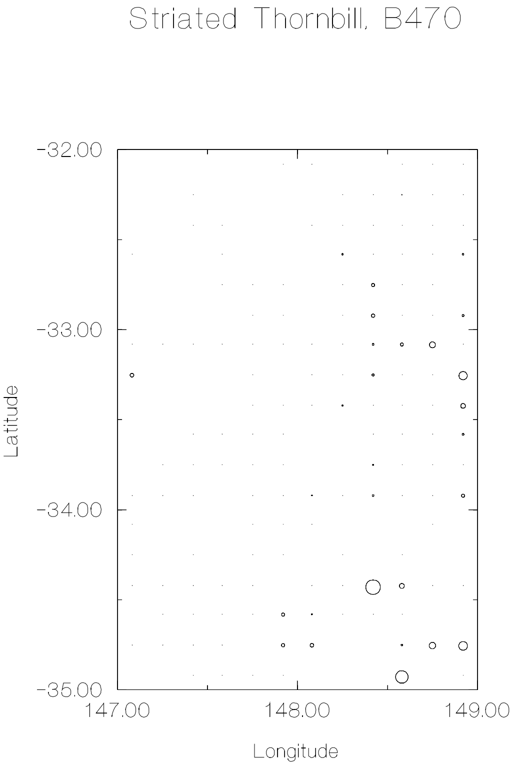
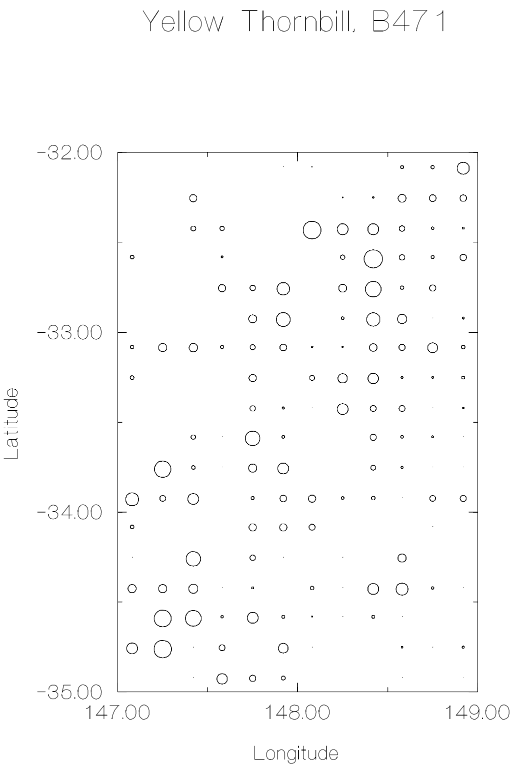
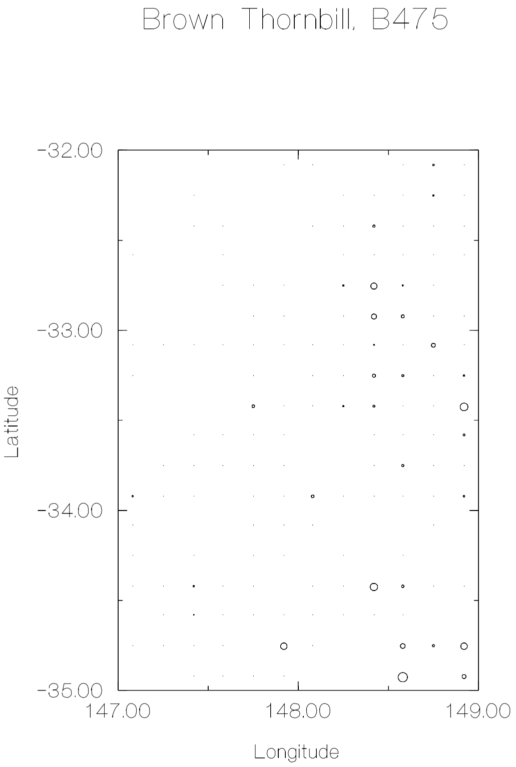


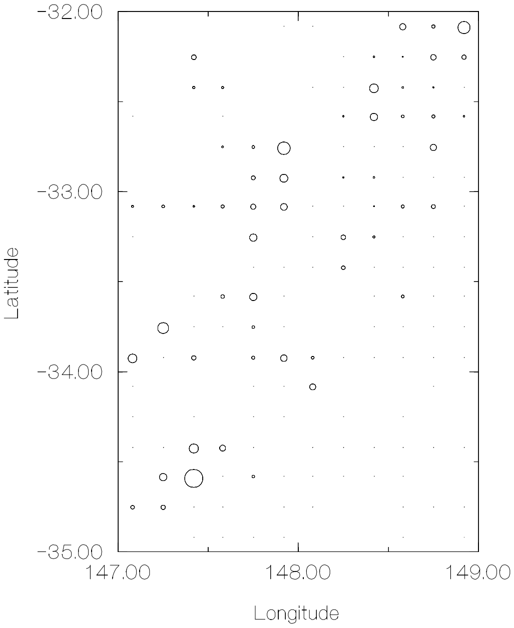




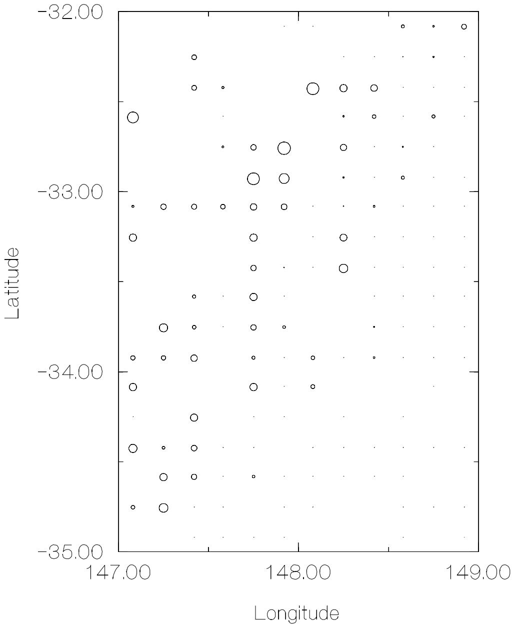


Atlas Maps of Bird Species Recorded in >10 Gridsquares

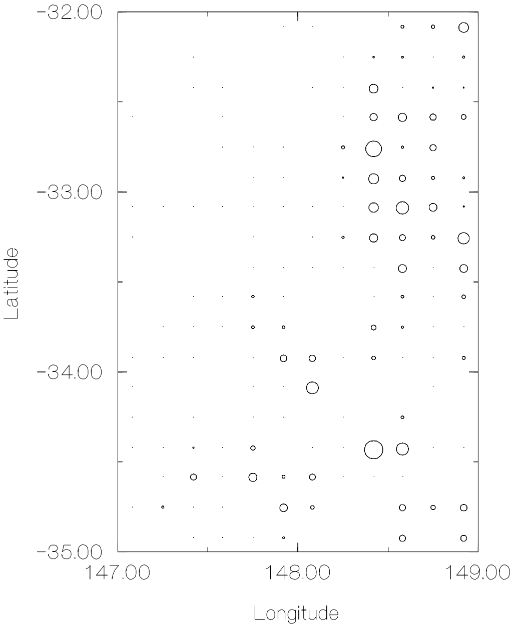
Inland Thornbill, B476



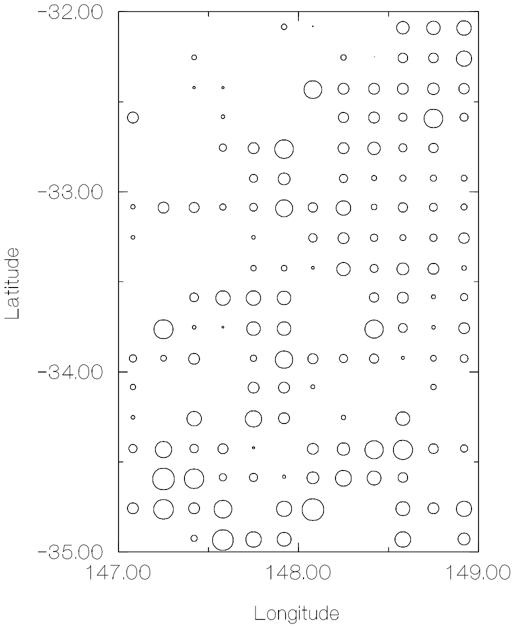
Chestnut-rumped Thornbill, B481



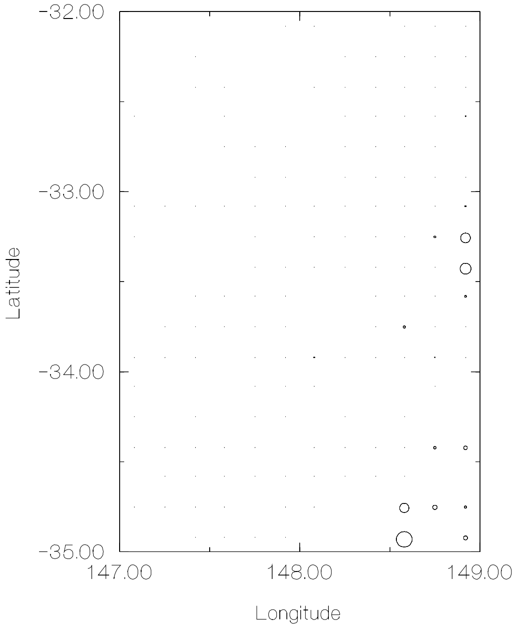
Buff-rumped Thornbill, B484

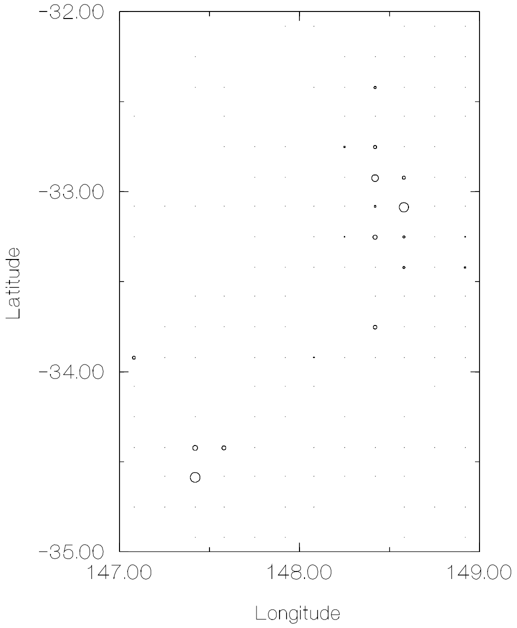


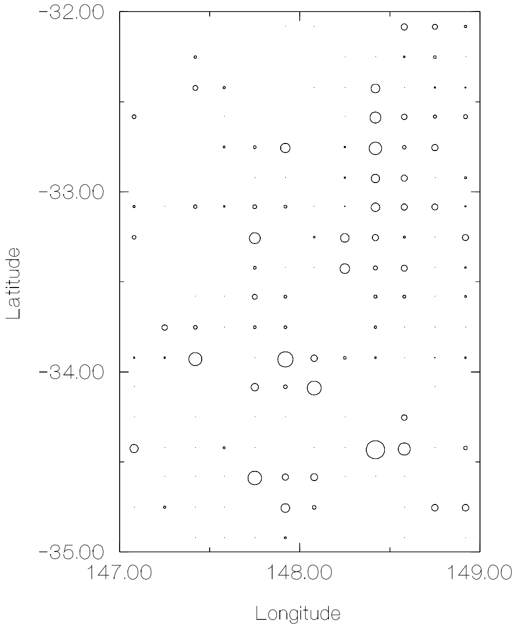
Yellow-rumped Thornbill, B486

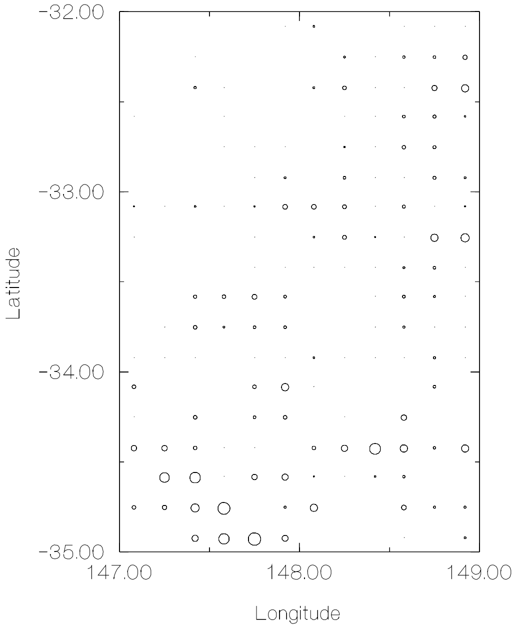


Atlas Maps of Bird Species Recorded in >10 Gridsquares

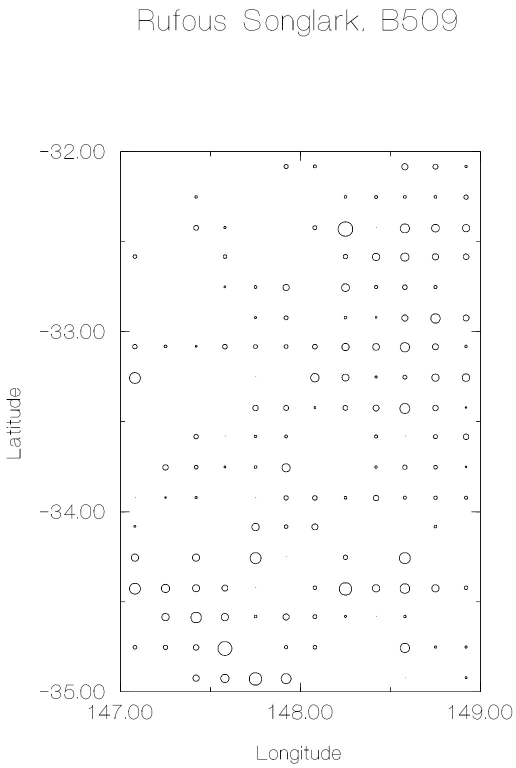

White-browed Scrubwren, B488

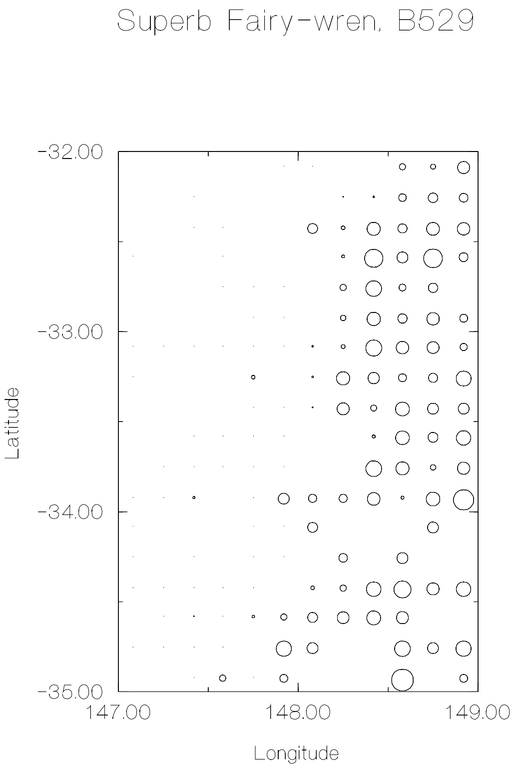

Chestnut-rumped Heathwren, B498

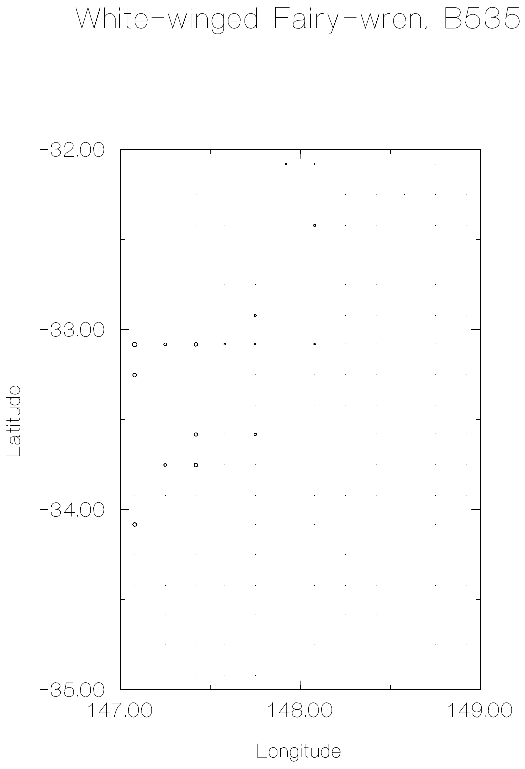

Speckled Warbler, B504

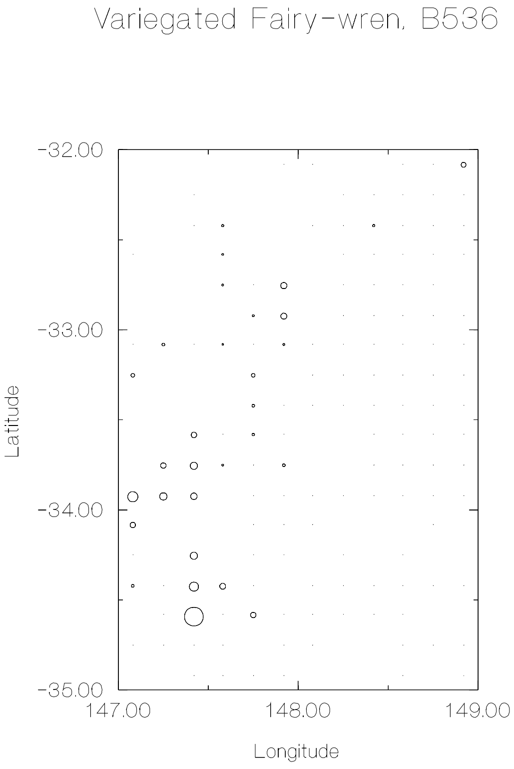

Brown Songlark, B508

Atlas Maps of Bird Species Recorded in >10 Gridsquares



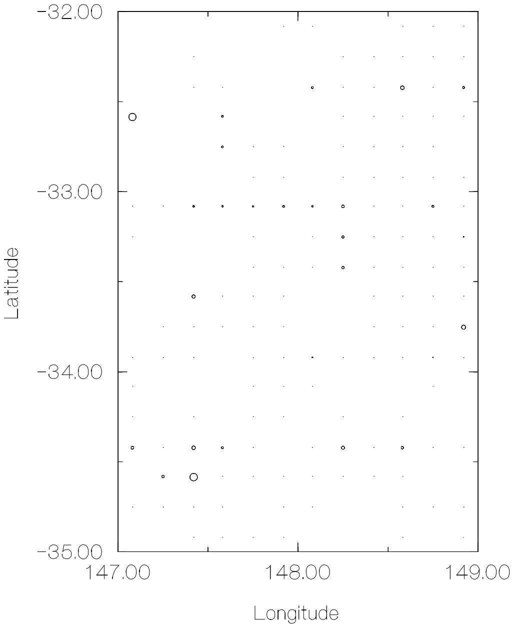




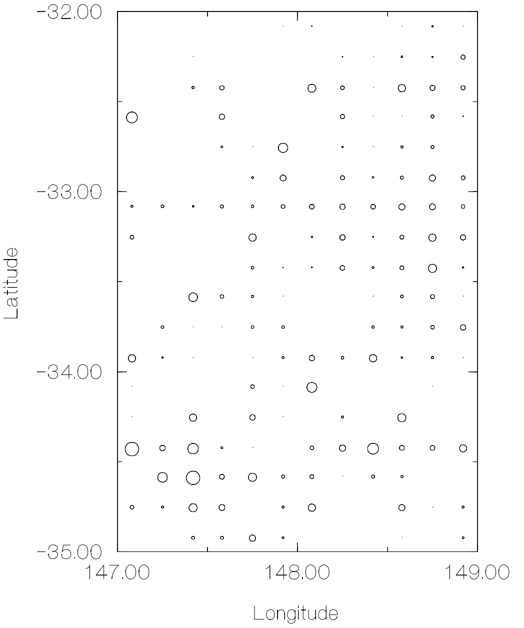


Atlas Maps of Bird Species Recorded in >10 Gridsquares

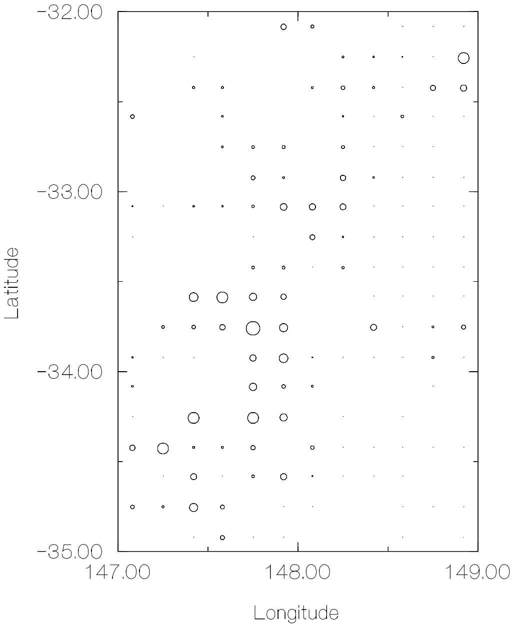
Masked Woodswallow, B544



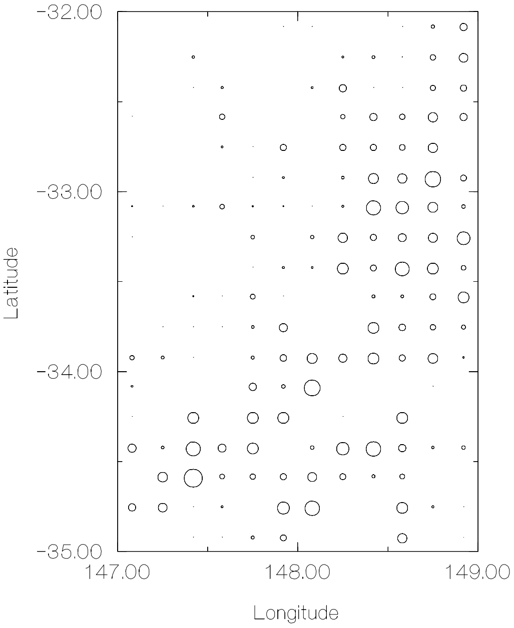
White-browed Woodswallow, B545



Black-faced Woodswallow, B546

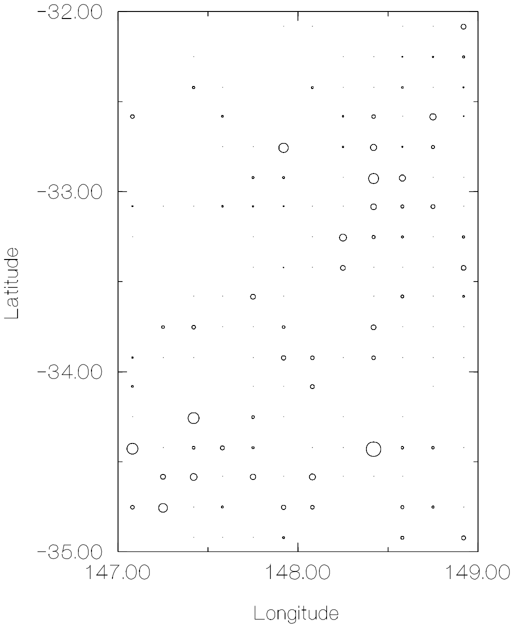


Dusky Woodswallow, B547

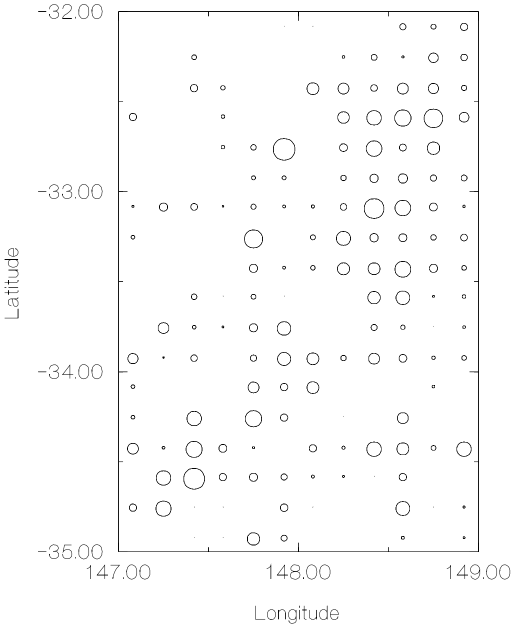


Atlas Maps of Bird Species Recorded in >10 Gridsquares

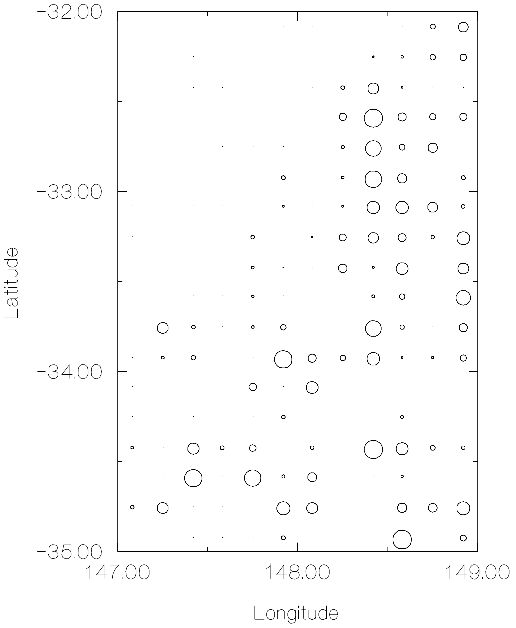
Varied Sittella, B549



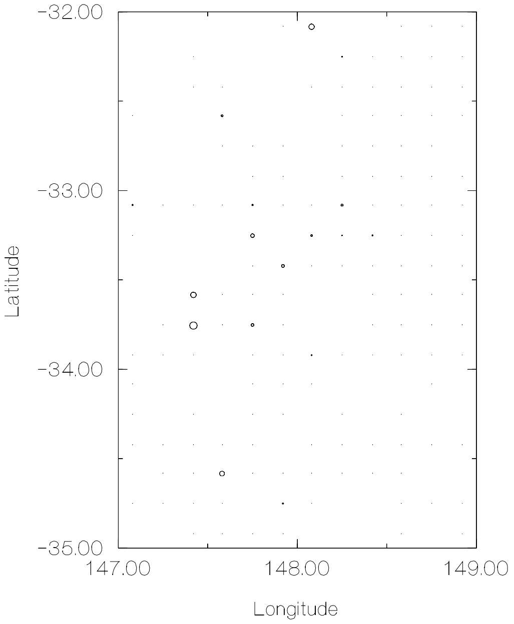
Brown Treecreeper, B555



White-throated Treecreeper, B558



White-breasted Woodswallow, B543



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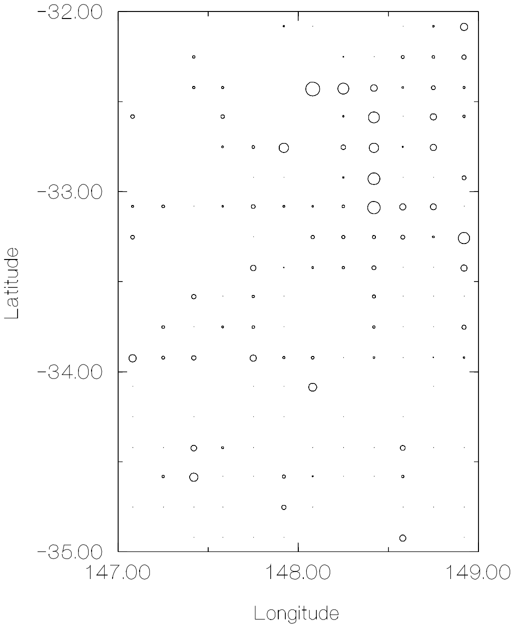
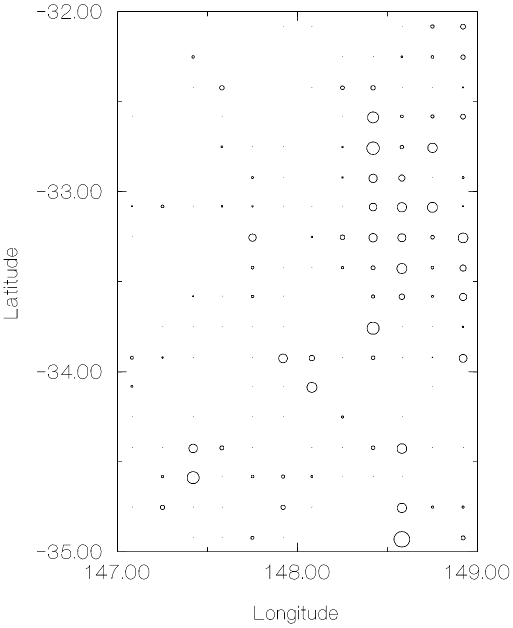
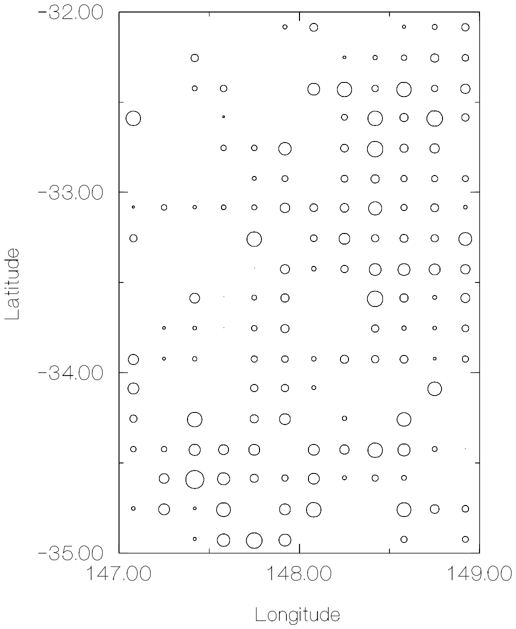


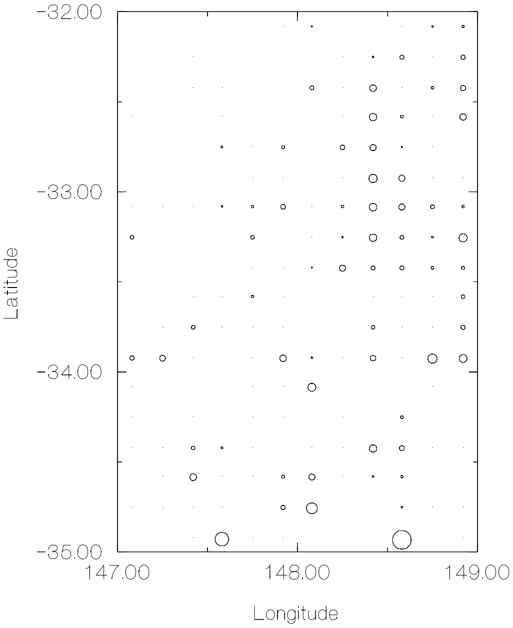
Mistletoebird, B564



Spotted Pardalote, B565



Striated Pardalote, B976



Silvereye, B574

Appendix 4

Full regression models for species richness in 10 categories of bird, using the **a)** $n = 215$, and **b)** $n = 141$ Atlas squares data sets. Models were built using forward and backward stepwise addition of terms at the $P < 0.05$ significance level for entry (and removal) of terms.

All landbirds (CRICH)

a) CRICH = 31.2719 + 3.1745 * DSHEET – 0.0396 * $(\text{DSHEET})^2$ + 7.2590 * LOGZW; $R^2 = 0.693$

b) CRICH = 31.9592 + 3.012 * DSHEET – 0.0351 * $(\text{DSHEET})^2$ + 7.4263 * LOGZW; $R^2 = 0.603$

Threatened landbirds (CUMTP)

a) CUMTP = –8.7063 + 0.0025 * DSHEET + 0.2742 * LOGZW – 1.7726 * LATI + 0.0102 * (LONGI*LATI); $R^2 = 0.307$

b) CUMTP = –15.4985 + 0.0024 * $(\text{DSHEET})^2$ + 0.3872 * LOGZW – 2.2161 * LATI + 0.0119 * (LONGI*LATI); $R^2 = 0.347$

Declining landbirds (CUMDP)

a) CUMDP = –5287.7695 + 0.501 * DSHEET – 0.0102 * $(\text{DSHEET})^2$ + 2.4275 * LOGZW + 35.7501 * LONGI + 1.1259 * LATI – 166.6573 * (LONGI*LATI); $R^2 = 0.503$

b) CUMDP = 336.8778 + 0.1371 * DSHEET + 2.4502 * LOGZW – 2.2324 * LONGI; $R^2 = 0.474$

At Risk landbirds (CUMAP)

a) CUMAP = 336.7039 + 0.619 * DSHEET – 0.0108 * $(\text{DSHEET})^2$ + 2.5766 * LOGZW – 2.4275 * LONGI; $R^2 = 0.523$

b) CUMAP = 413.8379 + 0.2191 * DSHEET + 2.7222 * LOGZW – 2.7557 * LONGI; $R^2 = 0.504$

Increaser landbirds (CUMIP)

a) CUMIP = 19.7874 + 0.7482 * DSHEET – 0.0136 * $(\text{DSHEET})^2$ – 0.0006 * $(\text{ZWOODY})^2$; $R^2 = 0.595$

b) CUMIP = 20.6887 + 0.5889 * DSHEET – 0.0095 * $(\text{DSHEET})^2$; $R^2 = 0.440$

"Bennett & Ford" Woodland landbirds (CUMBWP)

a) CUMBWP = 6.0285 + 1.7725 * DSHEET – 0.0232 * $(\text{DSHEET})^2$ + 6.5829 * LOGZW; $R^2 = 0.653$

b) CUMBWP = 11.2885 + 0.7103 * DSHEET + 7.092 * LOGZW; $R^2 = 0.586$

(the author's) Woodland landbirds (CUMWP)

a) CUMWP = 16.7118 + 2.1095 * DSHEET – 0.0297 * $(\text{DSHEET})^2$ + 7.2421 * LOGZW; $R^2 = 0.665$

b) CUMWP = 23.2755 + 1.024 * DSHEET + 7.7454 * LOGZW; $R^2 = 0.585$

Others (non-Woodland) landbirds (CUMOP)

a) CUMOP = 375.553 + 1.2334 * DSHEET – 0.0137 * $(\text{DSHEET})^2$– 2.4461 * LONGI; $R^2 = 0.663$

b) CUMOP = 379.4626 + 1.2596 * DSHEET – 0.0142 * $(\text{DSHEET})^2$– 2.4746 * LONGI; $R^2 = 0.591$

Appendix 4 – Species richness models for 10 bird categories (see Table 4)

Mobile landbirds (CUMMMP)

a) $\text{CUMMMP} = 11.5719 + 1.8726 * \text{DSHEET} - 0.0198 * (\text{DSHEET})^2 + 0.4422 * \text{ZWOODY} - 0.0050 * (\text{ZWOODY})^2$; $R^2 = 0.706$

[**a)** $\text{CUMMMP} = -28.1966 + 1.854 * \text{DSHEET} - 0.0189 * (\text{DSHEET})^2 - 2.4299 * \text{LOGZW} - 0.0078 * (\text{LONGI*LATI})$; $R^2 = 0.705$]

b) $\text{CUMMMP} = -62.5726 + 1.9325 * \text{DSHEET} - 0.0207 * (\text{DSHEET})^2 - 2.8044 * \text{LOGZW} - 0.0145 * (\text{LONGI*LATI})$; $R^2 = 0.601$

Sedentary (non-Mobile) landbirds (CUMNMP)

a) $\text{CUMNMP} = 517.0939 + 1.4616 * \text{DSHEET} - 0.0234 * (\text{DSHEET})^2 + 5.2934 * \text{LOGZW} - 3.3663 * \text{LONGI}$; $R^2 = 0.617$

b) $\text{CUMNMP} = 477.567 + 1.2809 * \text{DSHEET} - 0.0184 * (\text{DSHEET})^2 + 5.3758 * \text{LOGZW} - 3.093 * \text{LONGI}$; $R^2 = 0.580$

The names of other predictor variables used in models and correlations are:

ZWOODY – % remnant woody vegetation cover per square;
LOGZW – natural logarithm of % remnant woody vegetation;
LONGI – midpoint of longitude of each 10' square;
LATI – midpoint of latitude of each 10' square;
DSHEET – number of observer sheets per square.