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The fourth dimension: incorporating time into landscape-level biodiversity assessments

Principal investigator: Dr. James Radford

Collaborator: Assoc. Prof. Andrew Bennett

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Postal address: GPO Box 2182, Canberra ACT 2601

Office Location: Level 1, The Phoenix
86-88 Northbourne Ave, Braddon ACT

Telephone: 02 6263 6000

Facsimile: 02 6263 6099

Email Land&WaterAustralia@lwa.gov.au

Internet: lwa.gov.au

Project objectives

1. To survey birds using the protocols and sites established during DUV6 – surveys conducted in replicate landscapes that sample a gradient in native vegetation cover and contrasting configuration – thereby enabling temporal change to be assessed.
2. To evaluate differences in (a) species richness and (b) incidence of woodland bird species between the sampling periods (2002–03 and 2006–07) in relation to landscape composition and configuration.
3. To test the hypotheses that rates (i.e. change over time) of (a) species loss and (b) population decline are negatively correlated with (i) extent and (ii) aggregation of native vegetation in the landscape.
4. To establish the foundation for a landscape-level, long-term ecological monitoring program to evaluate landscape resilience.
5. To communicate knowledge of temporal change to key stakeholders in native vegetation planning and management.

Methods

During DUV6 'Landscape level thresholds for conservation of biodiversity in rural environments', we established a unique research infrastructure explicitly designed to examine the influence of whole-of-landscape attributes on selected faunal groups at the landscape level (Radford *et al.* 2005, Bennett *et al.* 2006). This infrastructure comprised a set of 24 study 'landscapes' (each 100 km^2) with 10 survey sites in each landscape, combined with data characterising the amount and configuration of native vegetation and the composition of each landscape. The study landscapes sampled a gradient in remnant vegetation cover from two per cent through to 60 per cent, and were strategically selected to identify pairs of landscapes with a similar amount but contrasting configuration (i.e. aggregated versus dispersed) of native vegetation. Survey sites were established in five landscape 'elements' – large remnants (>40 ha), small remnants (<40 ha), riparian vegetation, roadside vegetation and scattered paddock trees –approximately in proportion to their occurrence in the landscape. Four rounds of bird surveys were conducted at each of the 240 survey sites during 2002–03. We used 30-minute line-transects to survey the avifauna at each site. See Radford *et al.* (2005) and Radford and Bennett (2007) for full details of site selection, bird survey methods and landscape variables.

In this project, we re-surveyed all 240 sites originally surveyed in 2002–03, using the same methods. This entailed four rounds of surveys at each of 240 sites, conducted in October-November 2006 (spring), March-April 2007 (autumn), June-July 2007 (winter) and September-October 2007 (spring), which mirrors the seasonal spread of the original surveys. Garry Cheers, who did half of the 2002–03 surveys, conducted all of the 2006–07 surveys. There were no modifications to field methods from those outlined in the project proposal. This satisfies project objective 1: to repeat the sampling program of DUV6.

It is important to note that this study corresponds to an extended period of below-average rainfall in the study region, beginning around 1997 and continuing to the present day. Since 1997, annual rainfall has been more than 10 per cent above the long-term average in only 2000. The 2002–03 sampling period began in the spring of an exceptionally dry year (2002: 47 per cent below long-term average) and the entire 2006–07 sampling period occurred during years of severe rainfall deficit (2006: 44 per cent below long-term average; 2007: 30 per cent below long-term average). Moreover, there was an almost complete absence of eucalypt flowering in the autumn and winter of 2007.

This report presents data pertaining to several measures of the avifauna (response variables):

- *species richness*: the number of different species recorded per landscape
- *species incidence*: the number of surveys in which a particular species was recorded (note that we report on species incidence pooled across all landscapes and per landscape)
- *mean incidence*: the average species incidence for a group of species
- *turnover*: the number of colonisations (species recorded in 2006–07 but not 2002–03) plus the number of extinctions (species recorded in 2002–03 but not 2006–07) divided by the total number of species recorded in both sampling periods per landscape.

We used a range of analytical techniques to analyse the data. Details are provided in the technical report and will be expanded upon further in scientific papers as these are produced. Here, it is sufficient to note that all the major techniques employed (linear mixed models; multiple linear regression using all-subsets comparisons; univariate modeling; Bayesian logistic regression) examined change in the response variables in relation to sampling period (temporal contrast) and one or more landscape variables (spatial contrast).

Note that we modeled both absolute change (i.e. the difference between the sampling periods) and per cent change (i.e. the difference between the sampling periods as a percentage of the value in 2002–03) from 2002–03 to 2006–07 for both species richness and mean incidence.

Statement of key results, interpretation and practical significance against objectives

Key result 1

Difference in species richness between sampling periods in relation to landscape composition and configuration.
(objective 2a)

- Species richness of all woodland-dependents, insectivores and nectarivores decreased significantly between 2002–03 and 2006–07, with a mean decrease per landscape of:
    - 7.96 ± 0.93 woodland-dependent species
    - 4.00 ± 0.69 insectivorous species
    - 3.38 ± 0.41 nectarivorous species.
- Species richness of all woodland-dependents, insectivores and nectarivores was positively related to extent of tree cover in both sampling periods.
- Absolute change of all woodland-dependent species between sampling periods was positively related to the number of patches and the amount of riparian vegetation in the landscape, and negatively related to the extent of tree cover in the landscape and mean patch shape complexity.
- Per cent change of all woodland-dependent species between sampling periods was positively related to the number of patches in the landscape and distance from a potential source patch (> 10,000 hectares), and negatively related to mean patch shape complexity.

Interpretation and practical significance

There was a significant, systematic and dramatic decline in species richness of all woodland-dependent species, and of insectivorous and nectarivorous species, respectively, in the agricultural landscape of north-central Victoria between 2002–03 and 2006–07. This marked decline occurred in all landscapes.

Higher-cover landscapes experienced greater absolute declines but, because they supported more species, the loss of species relative to landscape-level species richness was similar in all landscapes.

Landscapes with more riparian vegetation experienced smaller declines, suggesting riparian vegetation provides refuge for some woodland species in times of stress. Protection and restoration activities focusing on riparian vegetation should be a priority in all landscapes.

In general, more species and a greater proportion of species were lost from less fragmented landscapes – those with fewer patches (accounting for extent of tree cover), more complex patch shapes (reflecting greater inter-patch connectivity) and relatively close to large source blocks.

These results are consistent with the expression of an extinction debt as species progressively disappear from the most fragmented and modified landscapes to less fragmented landscapes. However, given the magnitude and breadth of change detected in a relatively short interval, we hypothesize that declines have been compounded and accentuated by the added environmental stress imposed by more than 10 years of dry conditions.

Key Result 2

Difference in the incidence of woodland bird species between sampling periods in relation to landscape composition and configuration.
(objectives 2b & 3b)

(i) Overall species incidence (pooled across all landscapes)

- Of 128 terrestrial species that were recorded at least four times in one of the sampling periods:
  - 48 species (38 per cent) declined in incidence by >50 per cent
  - A further 41 species (32 per cent) declined by 20–50 per cent
  - Eleven species (nine per cent) increased by 20 per cent or more.
- Of 69 woodland-dependent species recorded four times or more in one of the sampling periods:
  - 33 species (48 per cent) declined in incidence by more than 50 per cent
  - A further 19 species (28 per cent) declined by 20–50 per cent
  - Four species (six per cent) increased by 20 per cent or more.
- 12 of 16 (75 per cent) nectarivorous species declined in overall incidence by >50 per cent
- 16 of 38 (42 per cent) insectivorous species declined in overall incidence by >50 per cent and a further 14 insectivores (37 per cent) declined by more than 20 per cent.

(ii) Landscape-level species incidence (Bayesian logistic regression)

- We modelled change in landscape-level incidence from 2002–03 to 2006–07 for 128 species:
  - 84 species (66 per cent) showed strong support for a decrease in incidence
  - 43 species (33 per cent) showed no change.
  - One species (Brown Songlark) showed strong support for an increase in incidence.
- The proportion of species that declined did not depend on habitat preference (woodland-dependent vs. woodland-associated vs. open-county), mobility (migrant vs. itinerant vs. resident), foraging substrate, diet, biogeographic range (xeric vs. mesic vs. widespread) or conservation status (‘of concern’ vs. ‘secure’).

Interpretation and practical significance

There were systematic and dramatic declines in the incidence of a majority of species between 2002–03 and 2006–07. A key finding was that the proportion of species that declined was very similar, irrespective of foraging or nesting guilds, spatial dynamics or conservation concern. Other reports of widespread change in avifaunas have found differences attributable to these kinds of classification (e.g. Woinarski and Catterall 2004; La Sorte 2006). In our case, it seems likely that these declines are climate-driven, or at least reflect the added stresses of sharp reductions in rainfall and increases in temperatures over the past decade in southern Australia.

(iii) Mean incidence

- The mean incidence of all woodland-dependents, insectivores and nectarivores decreased significantly between 2002–03 and 2006–07, with mean value per landscape declining from:
  - 3.3 to 2.0 (37.7 per cent decrease) for all woodland-dependent species
  - 3.0 to 2.1 (29.7 per cent decrease) for insectivorous species
  - 6.2 to 3.3 (46.9 per cent decrease) for nectarivorous species.
- Mean incidence of all woodland-dependents, insectivores and nectarivores was significantly positively related to extent of tree cover in both sampling periods.
- Absolute and per cent change in mean incidence of all woodland-dependent species between sampling periods was negatively related to the extent and the degree of aggregation of tree cover in the landscape, and positively related to the amount of riparian vegetation in the landscape.

Interpretation and practical significance

Mean incidence represents the number of surveys in which the "average" species was detected in the "average" landscape and thus is a surrogate for overall abundance of a species group.

There was a dramatic decline in mean incidence (i.e. abundance) of woodland-dependent species between sampling periods and the decrease in both absolute and proportional mean incidence was greater in higher cover and less fragmented landscapes. Nonetheless, abundance remained higher in higher cover landscapes.

The magnitude of the decline was lower in landscapes with more riparian vegetation, suggesting riparian areas provide refugia for woodland birds at the landscape scale.

These results are not consistent with expectations under extinction debt and suggest a more pervasive driver. All else being equal, there is no clear reason why species should decline faster in more intact landscapes. The result points to differential habitat quality (e.g. prevalence of predators, habitat condition) or land-use history as the driving factors rather than composition or configuration *per se*.

These results challenge the paradigm that relatively 'intact' landscapes are more resistant to population declines and suggest that relatively intact landscapes may not be relied upon to sustain species under current conditions and management practices.

Key Result 3

Rates of species loss are negatively correlated with (i) extent and (ii) aggregation of native vegetation in the landscape.
(objective 3a)

Rates of species loss of all woodland-dependent species and nectarivores were negatively related to extent of tree cover. There was no significant relationship between rate of species loss of insectivores and extent of tree cover.

- Rate of species loss of nectarivorous species was negatively related to aggregation of tree cover. There was no significant relationship between rate of species loss of all woodland-dependent species nor insectivores with aggregation of tree cover.
- Rate of species loss of all woodland-dependent species, insectivores and nectarivores was positively related to number of patches in the landscape (extent of fragmentation).

Interpretation and practical significance

These results are consistent with the scenario that the extinction debt may already have been fully realized in landscapes with low native vegetation cover, whereas landscapes with medium and high cover continue to lose species. Therefore, remedial actions to increase landscape resilience to dampen the legacy of historical clearing should be directed towards medium to high cover (~10–30 per cent extant tree cover) landscapes to stem losses in these landscapes.

Species loss was faster in less fragmented landscapes (fewer patches, more aggregated), suggesting that the extinction debt may already have been fully realized in more fragmented landscapes, whereas less fragmented landscapes continue to lose species.

Key Result 4

Threshold relationship between tree cover and species richness of woodland birds.

- The relationship between species richness of woodland birds and landscape-level tree cover in 2006–07 was best explained by broken-stick (piece-wise) or power regression models.
- The break-point for species richness shifted (non-significantly) slightly, from 10.05 per cent in 2002–03 to 10.27 per cent in 2006–07.

Interpretation and practical significance: The threshold relationship between landscape-level tree cover and species richness of woodland-dependent birds detected in DUV6 and reported in Radford *et al.* (2005) was re-affirmed in these results. This is an important finding because it indicates the threshold response that generated so much interest when first reported is a robust and repeatable outcome. While the break-point has not moved significantly in the interval between sampling periods, the shift was in the direction predicted in Radford *et al.* (2005), and is consistent with continued loss of species in moderate cover landscapes, as reported above. This has significant management and policy implications because it suggests there are particular landscapes where restoration activities could achieve substantially greater benefits for similar investment (i.e. in the steepest part of the response curve) and it provides a quantitative measure for setting minimum levels of tree cover. We re-iterate our conclusions from Radford *et al.* 2005 that the threshold value of 10 per cent tree cover is produced by multiple extinctions at the landscape level when tree cover falls below 15 per cent. Safe levels must be established well above the threshold. We recommend a goal of 25–35 per cent tree cover in agricultural landscapes. Evidence that the threshold is moving to higher levels of tree cover supports this conservative approach.

Key result 5

Species turnover in relation to extent of tree cover.

Species turnover was negatively related to landscape-level tree cover: that is, turnover was higher in low-cover landscapes, for all terrestrial birds and for woodland-dependent species.

Interpretation and practical significance

These results confirm greater volatility in assemblage-level composition in low-cover landscapes: that is, not only is species richness lower but relatively more species are experiencing local (perhaps temporary) extinctions and re-colonisations in the interval between sampling periods than in high-cover landscapes, where composition was relatively stable. This dynamism in community composition is not reflected in the analysis of species richness or incidence. The instability in community composition in lower cover landscapes suggests those communities are more prone to dramatic fluctuations in population size, and thus more vulnerable to local extinctions.

Conclusions

These results demonstrate substantial and rapid species loss and population declines across all groups of woodland bird species in all landscapes, irrespective of landscape composition and configuration. These results are alarming and suggest that dire predictions of massive species extinctions across the temperate woodlands of southern Australia (Robinson & Traill 1996; Recher 1999) are not only ringing true but may be occurring even sooner than predicted. These results should serve as a call to arms that unless dramatic remedial action is commenced immediately, and preventive measures are enacted to prevent further declines, we are likely to preside over the disappearance of many relatively common and widespread woodland birds over the coming decades.

There was an indication that the magnitude of species loss and population decline was greater in higher cover and less fragmented landscapes. This may reflect the expression of an 'extinction debt' – a time lag effect in which the consequences of historical clearing and landscape modification are continuing to be realised as species are lost progressively from the most fragmented and modified landscapes to less fragmented landscapes. It is likely that the only species persisting in low-cover landscapes in 2002–03 were relatively tolerant to landscape change because fragmentation-sensitive species had long since been eliminated from these landscapes. Thus, there was relatively little change in species richness and smaller declines in incidence in these landscapes. In contrast, high-cover landscapes supported a host of species at low density that underwent substantial declines during the interval between sampling periods such that they were undetectable in 2006–07.

While the results are consistent with time lags associated with an extinction debt, the cosmopolitan nature of the declines and the magnitude of change detected in a relatively short period suggest a more pervasive driver. We hypothesise that declines due to any extinction debt have been compounded and accentuated by the added environmental stress imposed by the extended dry period during which this study was conducted. That is, we suggest that much of the observed change reflects the impacts of a drying climate on landscapes that, under more favourable climatic conditions, had been able to support more diverse and abundant woodland bird assemblages.

The mechanisms by which this marked decrease in rainfall influences the avifauna is likely to relate to on-going reduction in habitat quality and food availability. At a regional scale, there has been relatively little loss of wooded vegetation in recent decades, but habitat quality continues to decline (Department of Sustainability and Environment 2008). The collapses in species richness and incidence reported here suggest strongly that the availability of all types of food has crashed.

The mass exodus of nectarivores from central Victoria during the autumn and winter of 2007 was probably due to the complete failure of eucalypts to flower, an unusual but not unprecedented event (Mac Nally *et al*. in press). However, if complete flowering failure becomes more frequent under climate change, as would be expected from rainfall-flowering-nectar-honey production models (Porter 1978) and as appears to be occurring (Keatley & Hudson 2007 *cf.* Mac Nally *et al.* in press), such migrations may occur more often than has historically been the case – perhaps in the order of every second year rather than once every six years. Although nectarivores are generally mobile and able to track resources over large distances, few are truly migratory, and thus capable of frequent long-distance migrations. While nectarivore abundance rebounded somewhat in 2008 (pers. obs.), mass migrations must impose substantial energy and mortality costs at a population level for many species. The cumulative impost of frequent mass migrations will soon become unsustainable, resulting in permanent population decreases.

The consistent and substantial declines in the sedentary (and migratory breeding) insectivores are even more alarming. Many insectivores, especially residents, have limited capacity to move to alternative habitats (Mac Nally 1995), so their decline signals mortality without replacement, rather than movement. We suggest these declines reflect an ongoing and consistent erosion of their resource base stemming from numerous threatening processes and compounded by the drying climate. Together, these threats have resulted in diminishing food resources and deteriorating nest-site quality (fewer sites with increased exposure) that has severely limited recruitment over successive years, culminating in the observed population collapses. Recovery of these species depends not only on improved climatic conditions but also on concerted management to alleviate the threats that continue to degrade their habitat.

Adoption of outputs

The climatic conditions expected under rapid climate change render avifaunal populations even less robust and resilient to land use change than previously postulated. Simply protecting remnant habitat and incremental increases in revegetation trajectories will not be sufficient to prevent widespread extinctions. The urgency and magnitude of remedial action required is several fold greater than current practice. Increased community awareness of the current situation is a prerequisite of policy reform, and policy levers can induce radical land-use change (e.g. tax reform for managed investments leading to timber plantations or olive groves).

Three broad strategies are required. First, the condition of public estate forests, which comprise the largest contiguous blocks of native vegetation, must be improved through an overhaul of current fire management practices, native herbivore control and eliminating extractive industries. Second, extensive revegetation programs on more fertile land to induce accelerated growth must be instituted (Mac Nally 2008). Many species will breed in vigorous replantings (Selwood *et al.* 2009) from which recruits may disperse to other parts of the landscape. Multiple pathways for movement at multiple scales (from inter-patch to sub-continental) must be created through strategic enhancement of existing habitat and revegetation. A national program to buffer all riparian and wetland systems with native vegetation (e.g. buffer to 1-in-100-year flood line) could form the backbone for a network of biolinks. Third, a renewed focus on managing ecological processes (MacGregor *et al.* 2008) will re-focus governments, agencies and individuals towards a landscape perspective (Soulé *et al.* 2005).

The instruments for implementing new strategies are largely politico-social: tax reform to encourage biodiversity-focused revegetation and remnant protection, participation in the carbon market with a premium for biodiversity-carbon plantings and restoration, government intervention to acquire high-productivity properties and manage them for biodiversity, and a mix of legislative requirements and incentives to promote revegetation and sustainable practices on freehold land.

Communication and 'adoption' activities to date

- Letters posted to each landholder with results of surveys on their property
- Presentations at Bird Observation and Conservation Australia / Australian Bird Study Association scientific day (March 2008) and Bendigo Field Naturalists Club (November 2008)
- Baringhup Landcare Group
- Contribution to North Central BioLinks Project.

Magazine articles
News and Views Spring 2007
Thinking Bush Issue 5 2007

Assessment of any commercial potential

Not applicable.

Publications

Mac Nally, R., Bennett, A.F., Thomson, J.R., Radford, J.Q., Unmack, G., Horrocks, G. & Vesk, P.A. (in press) Collapse of an avifauna: climate change appears to exacerbate habitat loss and degradation. Diversity and Distributions.

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