

Comparative evaluation of new approaches to survey birds

David M. Watson

Applied Ornithology Group, The Johnstone Centre, Charles Sturt University,
PO Box 789, Albury, NSW 2640, Australia. Email: dwatson@csu.edu.au

Abstract. Two recently devised approaches for sampling bird communities – time-balanced area-proportionate transects and standardised searches – aim to yield bird surveys of improved resolution specifically for studying distribution of terrestrial birds in patchy landscapes. Here, I compare these two approaches with the two most common methods presently used in Australian ornithological research: the fixed-effort (or 20-min) search and the repeat transect. The woodland-dependent avifauna of four reserves was sampled using all four methods. Total woodland richness of the four reserves was estimated by combining exhaustive surveys and incidental records to provide a benchmark for subsequent comparisons.

The standardised search yielded the most complete richness estimates (i.e. closest to total woodland richness), averaging 78.4% under the strict stopping rule after an overall sampling effort of 740 min. Using a more lenient rule, mean completeness was slightly lower (72.5%) but overall sampling effort fell to 320 min. Coincidentally, this was the same total effort as required for the three fixed-effort methods, but resultant surveys were all less consistent and less complete. Fixed-effort searches (four 20-min searches per patch) yielded richness estimates with a mean completeness of 68.3%, compared with 37.1% for area-proportionate transects and 33.8% for repeat transects. Thus, for the same sampling effort, the lenient standardised search yielded data approximately twice as complete as transect-based methods. Moreover, resultant data are of uniform completeness and are expressed at the patch scale, and thus have greater biological value and relevance for management.

In addition to being the most efficient and yielding the most complete data, the standardised search also yielded incidence estimates for all species recorded. While subject to the same limitations as abundance estimates, this information can complement richness data and allows more subtle comparisons of habitat preference and site quality. The use of transect counts and other fixed-effort sampling methods is discouraged for studies comparing variable sites, and standardised searches and other approaches relying on results-based stopping rules are advocated.

Introduction

Most methods currently used for conducting terrestrial bird surveys use a fixed sampling effort to standardise data collection (Bibby *et al.* 1992; Rosenstock *et al.* 2002). Whether a standard-sized transect or a fixed-time survey, these approaches employ effort-based stopping rules (often unknowingly) to hold sampling effort constant, in an attempt to minimise various confounding factors and maximise comparability. While transects were developed initially to quantify bird densities (Merikallio 1958; Järvinen and Väisänen 1975), many authors have since recognised shortcomings with count statistics based on transect data (Emlen 1971; Shields 1979; Verner 1985; Rosenstock *et al.* 2002). While they are still used to generate estimates of relative abundance (Mac Nally 1996; Luck *et al.* 1999) these fixed-effort methods are now used primarily to estimate species richness, comparing the avifauna of different

habitats, locations or seasons (Arnold and Weeldenberg 1990; Slater 1995; Kutt 1996; Johnson and Mighell 1999).

These methods become increasingly unreliable, however, as among-patch variation in both patch attributes and composition of bird assemblages increase (Mac Nally and Horrocks 2002). Hence, when comparing a small poor-quality woodlot to a large high-quality forest, fixed-effort surveys in both yield biased data of different accuracy, probably underestimating richness in the large patch and overestimating richness in the smaller (Peterson and Slade 1998). Fixed-area methods such as transects have the added problem of spatial representation (Watson 2003a). Thus, researchers using transect counts for a fragmentation study are not studying bird distribution in fragments – rather, they are studying bird distribution in transects within fragments (Watson *et al.* 2000). While this may seem a subtle distinction, findings from this sort of a study can no longer

be framed relative to the fragments themselves, greatly reducing the potential application of the research. As more empirical studies aim to quantify bird occurrences in habitat fragments, islands and other variable patchy landscapes, it is becoming increasingly important to develop a reliable, rigorous and relevant sampling approach.

Two methods have been developed recently that try to circumvent some of these difficulties: time-balanced area-proportionate transects (Mac Nally and Horrocks 2002) and the standardised search (Watson 2003a). While devised specifically for studying bird distribution in discrete patches, both can be used more broadly and may be appropriate for other sampling applications. Mac Nally and Horrocks (2002) addressed the problem of variable spatial representation by holding total sampling effort constant while scaling the number of transects to the area of the patch. They suggested using multiple transects in larger patches, with the same number of transect counts from fewer transects in smaller patches. Even though sampling a larger proportion of the patch, resultant richness estimates are still area-limited and thus cannot be framed relative to the patch itself. Moreover, this method presupposes that area is the most important factor influencing avian occurrences and that the number of transects is scaled correctly – both highly equivocal assumptions in most landscapes (Mac Nally and Watson 1997; Watson 2003a).

Recently, I developed a new method that generates comparable richness estimates for the entire patch (Watson 2003a). Known as the ‘standardised search’, this approach uses a quantitative results-based stopping rule to determine when sampling is complete. Patches of varying size and quality may require different numbers of sampling periods to fulfil the rule but all resultant surveys are of comparable completeness. The actual time taken to complete a survey of a particular patch is immaterial (Peterson and Slade 1998; Watson 2003a).

The purpose of this paper is to compare these two new methods (time-balanced area-proportionate transects and standardised searches) with the two most commonly used methods (fixed-effort (20-min) searches and conventional

(repeat) transects). Rather than simply comparing them to one another, I will compare each method to a standard – an estimate of actual richness in each patch (after Verner 1985). This will allow a detailed appraisal of the benefits and drawbacks of each method and highlight which method (if any) is most appropriate for studying terrestrial bird distributions in patchy landscapes.

Study Area

Bird surveys were conducted in four Travelling Stock Reserves north of Albury, New South Wales, containing remnants of grassy box woodland (reserve attributes summarised in Table 1). Dominant tree species varied, but all reserves supported woodland with a canopy coverage of 20–40%. While all four remnants have been subject to considerable grazing historically (primarily cattle, but also sheep), the recent grazing history varied from little recent evidence to ongoing heavy grazing (Table 1). The region is typified by hot summers and cool to mild winters, with an average annual rainfall of 770 mm falling mainly in spring and autumn (data for Albury).

Methods

The avifauna of these four remnants was sampled by two techniques, each applied in two different ways: single strip-transect sampled repeatedly (Järvinen and Väisänen 1975), multiple strip-transects (time-balanced area-proportionate sampling: Mac Nally and Horrocks 2002), fixed number of 20-min searches (Loyn 1986) and variable number of 20-min searches (standardised search: Watson 2003a). To maximise comparability of the four methods, sample duration was held constant at 20 min for all methods, and sampling effort held constant at four samples (i.e. 80 min) per reserve for the three fixed-effort methods. All sampling was conducted during 9–23 October 2002 in the 210 min after dawn and the 210 min before dusk and was not carried out if wind or rain were excessive. Visitation order was determined prior to commencement, alternating between methods and ensuring that all four sampling approaches in each site were carried out over at least two days including both morning and afternoon samples. All surveys were conducted by the author and birds were identified to species primarily by call, with visual cues also used when possible.

Repeat transects

A single 2-ha strip transect (250 m × 80 m) was located in each remnant using a random protocol stratified by vegetation type and distance to edge to ensure that it was at least 40 m from patch boundaries (after Mac Nally and Watson 1997) (Fig. 1). Transect boundaries were marked out with flagging tape at least one day prior to the first transect

Table 1. Attributes of the four Travelling Stock Reserves near Albury, New South Wales

Variable	Thurgoona	Gerogery	Gerogery West	Jindera
Area (ha)	42	40	11	9
Grazing regime	Low, absent	Moderate, absent	Moderate, recent	High, ongoing
Standing water	Dam, creek	Dam, spring	Creek	Dam
Understorey	Native grasses, dense stands of saplings, <i>Acacia</i> (replanted)	Native grasses, rushes, stands of saplings	Native grasses, occasional <i>Casuarina</i> and <i>Acacia</i> stands	Exotic grasses, stands of saplings
Main canopy species	Yellow box	White box	River red gum	River red gum
Mistletoe	Occasional	Absent	Moderate	Absent
Matrix	Scattered trees, pasture	Pasture	Scattered trees, residential	Pasture, residential
Approximate age (years)	150	110	110	120

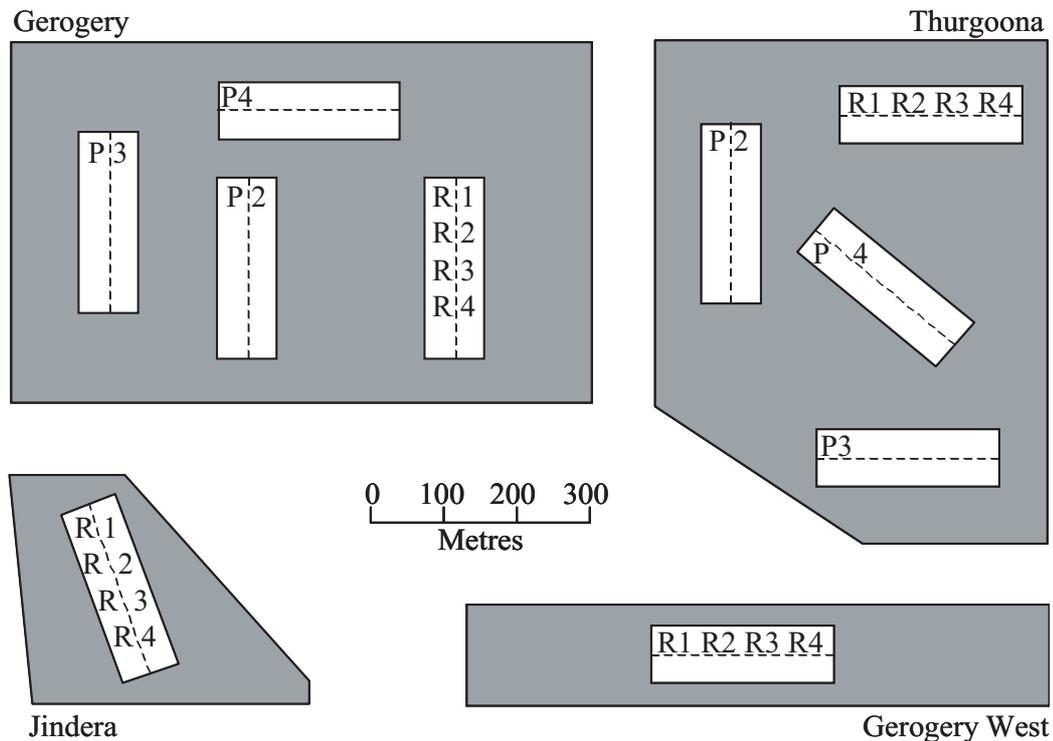


Fig. 1. Schematic diagram of the four Travelling Stock Reserves near Albury, New South Wales. Four repeat transects (R1–R4) were conducted in each patch, with the first of these in the two larger reserves also used as the first area-proportionate transect (i.e. R1 = P1). Subsequent area-proportionate transects were conducted in the other three transects (P2–P4).

count. After an initial 5-min waiting period outside the transect, I walked along the midline at a steady pace, taking 20 min to complete the transect. All individual birds within the transect boundaries were recorded. Species heard calling outside the transect or seen flying over the transect were not included in the sample. Transect counts were conducted four times in each reserve (morning and afternoon) over at least two days, alternating the direction travelled along the midline.

Time-balanced area-proportionate transects

The number of transects was scaled to the area of the reserve, with approximately one transect used for each 10-ha area (after Mac Nally and Horrocks 2002). Thus, the two smaller reserves (9 ha and 11 ha) were sampled using a single 2-ha transect and four separate 2-ha transects were used for the two larger reserves (42 ha and 40 ha) (Fig. 1). They were located using the same approach as for the single repeat transect (randomly locating the transects while controlling for proximity to edge) and ensuring that they were no closer than 100 m to each other (to avoid double counting). Sampling effort was held constant, with four transect counts for all four remnants – four counts from the single transect in the Gerogery West and Jindera reserves (same data as repeat strip transects), and one count from each of the four transects in the Thurgoona and Gerogery patches (follows method of Mac Nally and Horrocks 2002). The first of four transect counts for the larger patches was common to both methods (see Fig. 1).

Fixed-effort search

I walked throughout the remnant for 20 min (after Loyn 1986), actively pursuing unfamiliar calls and recording all species seen or heard within the remnant (similar to the ‘area search’ used by Fortin and Arnold

1997). An area of ~5–7 ha was covered in each sample and species seen flying over or heard calling outside the remnant were not recorded. Four 20-min searches were conducted in each reserve, spanning at least two days and both morning and afternoon.

Standardised search

Rather than using a fixed number of searches, I continued conducting 20-min searches until I satisfied the stopping rule with the same rule applied in all four reserves (Watson 2003a). The first four sampling periods for each reserve constituted the ‘fixed-effort search’ discussed above. Two different rules were used, lenient and strict, both pertaining only to woodland-dependent species.

Lenient stopping rule: stop when the number of singletons (species seen in a single sampling period) is less than or equal to the number of doubletons (species seen in two sampling periods).

Strict stopping rule: stop after three consecutive sampling periods in which no new (i.e. previously unencountered) species are recorded.

As discussed in Watson (2003a), stopping rules should be carefully selected to minimise the chances of being prematurely tripped by a single depauperate sample. Both rules used here require a minimum of three samples, and thus are relatively robust to time-of-day and weather effects.

Total richness

In addition to these four methods, it was important to establish an estimate of actual richness of woodland-dependent birds occurring in each reserve, providing a standard against which the four sampling methods could be evaluated (as recommended by Verner 1985). One means of estimating total richness of a site is using various predictive

equations that extrapolate the rate of discovery of new species to estimate the number of species present but not observed (Colwell and Coddington 1994; Herzog *et al.* 2002). As discussed in Watson (2003a), however, this is problematic in ornithology, as researchers are often more interested in *which* species were recorded, rather than simply how many. So instead of using a predictive approach, total richness for each site was estimated by combining all woodland species observed during sampling and all woodland species seen incidentally. While this includes species that were only seen flying over the woodland or calling from outside the reserve, they presumably inhabit the reserve, if only occasionally; thus it is a realistic estimate of the total number of woodland-dependant species using the reserve at that time.

Comparisons

Richness estimates derived from the four methods were tallied for each of the four reserves, and divided by total richness to give values of percentage completeness. Overall performance of the methods across all sites was gauged using mean completeness and an associated coefficient of variation. Given that all data were collected contemporaneously, that some samples were shared by two approaches and the small number of sites, further statistical analysis of methods was not warranted.

Results

Total recorded bird species richness for the four reserves was 48, 24, 31 and 24 for Thurgoona, Gerogery, Gerogery West and Jindera, respectively (hereafter, results are given in order from largest to smallest reserve). Excluding records of waterbirds, exotics and open country species, the total richness of woodland-dependant birds (including incidentals) was 39, 13, 30 and 18 (Table 2).

Four repeat transects were conducted in each of the four reserves, yielding 16 richness values ranging from 7.7 to 30.8% of total woodland richness for that reserve. In terms of mean richness recorded in single transects for each reserve, 17.9, 19.2, 18.3 and 21.1% of total woodland richness was recorded. Combining all four repeat transects for each patch yielded 28.9, 30.8, 36.7 and 38.9% completeness (Table 3).

Using the time-balanced area-proportionate approach, the same data were used for the two smaller patches but data for the two larger reserves were drawn from four separate transects (Fig. 1). For one of the two larger patches (Gerogery) results were alike, with the same four species (30.8% complete) recorded using both transect approaches. For the other large reserve (Thurgoona), 16 woodland bird species were recorded from the four area-proportionate transects (42.1% complete) compared with 11 species (28.9% complete) from the four repeat transects (Tables 2, 3).

In total, 33 species occurrences were recorded using repeat transects, compared with 38 for the area-proportionate transects (Table 2). Overall, the species recorded during transect counts (either area-proportionate or repeat) were highly detectable, comprising abundant species (eastern rosella, *Platycercus eximius*; noisy miner, *Manorina melanocephala*), canopy-feeding species that tolerate close approaches (striated pardalote, *Pardalotus striatus*; weebill,

Smicrornis brevirostris) and large-bodied predatory species (laughing kookaburra, *Dacelo novaeguineae*; pied butcherbird, *Cracticus nigrogularis*). Of the 48 species occurrences drawn from the 22 transect counts, three (common bronzewing, *Phaps chalcoptera*, and yellow-rumped thornbill, *Acanthiza reguloides*, at Thurgoona and red-rumped parrot, *Psephotus haematonotus*, at Gerogery) were not recorded during 20-min searches.

Twenty-minute searches were carried out in each reserve, yielding richness values of 27.8–61.1% completeness, with mean values for each reserve ranging from 41.3 to 43.8% completeness (Table 3). Combining the first four 20-min searches for each patch yielded 68.4, 66.7, 76.9 and 61.1% of total woodland richness.

The lenient standardised search entailed multiple 20-min searches until the stopping rule was satisfied – 3, 3, 3 and 7 sampling periods for the four reserves respectively (i.e. overall total of 16 20-min searches), with richness estimates of 66.7–77.8% completeness (Table 3).

It took 12, 6, 10 and 9 20-min searches to satisfy the strict stopping rule (i.e. 37 20-min searches overall), yielding richness estimates of 76.9–80.0% completeness. Of 78 species occurrences recorded under the strict stopping rule, eight were not recorded under the lenient stopping rule (Table 2).

Comparing the different methods, the strict standardised search yielded the most complete data with the highest consistency (78.4%, $V = 1.7$, $n = 4$). While the lenient standardised search was less complete (72.5%, $V = 7.9$, $n = 4$) the overall sampling effort was 320 min (less than half of the 740 min required for the four strict standardised searches) (Table 4). The same sampling effort equally spread over the four reserves (i.e. four 20-min searches each) yielded less complete data of higher variability (68.3%, $V = 8.9$, $n = 4$). Despite requiring the same sampling effort, transect-based methods yielded data of substantially lower completeness and higher variability, area-proportionate transects (37.1%, $V = 12.8$, $n = 4$) being slightly better than repeat transects (33.8%, $V = 14.0$, $n = 4$) (Table 4).

Discussion

The standardised search was clearly the best survey technique in terms of maximising completeness. More importantly it was also the most consistent: internal variation was minimal and resultant richness estimates closely matched total richness values for the four woodland reserves. While the strict stopping rule yielded higher levels of both completeness and consistency, more than double the sampling effort was required. Coincidentally, the total sampling effort required under the lenient stopping rule was exactly the same as for the other three methods, making it the most efficient method.

As discussed in Watson (2003a), the most important criterion for selecting a sampling method is the nature of the

question or hypothesis being addressed. Thus, if the question were ‘How many woodland-dependent species are found in these reserves?’ the method generating the highest completeness should be selected (i.e. strict standardised search). However, if the question were ‘Which reserve contains the most woodland-dependent species?’ absolute numbers are less critical and the most efficient and consistent method should be selected (i.e. lenient standardised search).

In assessing the number of samples required to fulfil the lenient stopping rule, it was interesting to note that the smallest reserve required the greatest effort. Rather than being driven by higher overall richness, this was related to the dynamic nature of the avifauna inhabiting the small reserve. Birds repeatedly moved in and out of the reserve, coming from surrounding scattered trees and suburban gardens, making it difficult to determine when the survey was complete. This is demonstrated by the low incidences of many species (Table 2) – while many species occasionally foraged within the woodland, most ranged more widely and were frequently recorded as absent. In designing a study of this sort of patch, total richness would therefore be far less meaningful than richness of birds found breeding within the reserve (Remsen 1994).

The trouble with transects

Both transect-based approaches were similar in completeness and consistency, yielding approximately one-third of total woodland richness. Rather than being a representative subset, the species recorded within transects were highly detectable, common species. More secretive species and species occurring at low densities were consistently missed, although some were noted incidentally. It is just these ecological attributes that make these species more sensitive and, therefore, of greater interest to ecologists and land-managers alike, suggesting that transects are an inappropriate tool for community-level ecological comparisons.

While the time-balanced area-proportionate approach was slightly higher in consistency and completeness, this was driven solely by differences in one site (Thurgoona). Both larger reserves were relatively homogeneous and area-proportionate sampling may yield a more marked improvement in habitats that are more variable (see Mac Nally and Watson 1997 for example). Note, however, that area appeared to have little effect overall in explaining richness patterns. Despite being approximately one-quarter the area of Gerogery reserve, Gerogery West supported over twice the richness of woodland species, further evidence that *a priori* area-proportionate approaches are inadvisable (Watson 2003a).

Given the poor performance of transect-based methods, it is worth examining the purpose for which they were originally developed. Despite their current use, transects

were not originally developed as an inventory method, but primarily to quantify densities. The method was pioneered by Merikallio (1958), working in highly seasonal homogeneous coniferous forests in Fennoscandia, a low-diversity system in which differences in density are far more meaningful than changes in species richness. Since then, many authors have identified difficulties with resultant density estimates (see below), but transects remain one of the most popular methods for obtaining inventories of birds and account for most studies of bird distribution in Australia. Unlike the coniferous forests of northern Europe, most Australian habitats have higher diversities and higher intrinsic variability in terms of habitat, seasonality and resource availability (Recher 1988). The reason for the popularity of strip transects is unclear, but may stem from their ease of use and apparent objectivity (compared with the perceived subjectivity of variable-area methods).

In sum, strip-transects yield richness data of low completeness and variable consistency that cannot be extrapolated to the patch level or other biologically relevant scales. While useful for quantifying temporal variation at a single site (Mac Nally 1996), the results can be overwhelmed by among-site variation in larger-scale studies. As such, instead of being the default method for estimating richness of terrestrial birds in Australia and elsewhere, strip transects and other limited-area fixed-effort methods should be regarded as unreliable unless demonstrated otherwise.

Fixed-effort searches

Despite taking a quarter of the time, single 20-min searches yielded more complete data than either of the two transect-based approaches. Among-sample variation was slightly higher, however, driven partly by the difference in sample size (16 compared to 4). Controlling for sampling effort, four 20-min searches per reserve yielded richness estimates of substantially greater completeness, approximately double the estimates derived from both transect methods. Moreover, the data were collected at the patch level and thus can be used to examine patch-scale factors affecting diversity. Note, however, that few studies using fixed-effort searches spend 80 min per survey. Rather, 20–30 min is standard (Loyn 1986; Craig and Roberts 2001) and, on the basis of the data presented here, this effort is insufficient even in small, structurally simple habitat patches.

The fixed-effort search and lenient standardised search yielded the same richness estimates for three reserves; however, the standardised search took 60 min less effort (Fig. 2). Conversely, the fixed-effort search under-sampled the other reserve (Jindera). Thus, even though overall sampling effort was the same for both methods, the lenient standardised search minimised under- and over-sampling. As discussed earlier, the avifauna of the Jindera reserve was highly dynamic, and thus required increased sampling effort

Table 2. Summary of species occurrence data for the four Travelling Stock Reserves near Albury, New South Wales, used to evaluate efficacy of different sampling methods

For all species recorded during the strict standardised search, an incidence value is given (proportion of samples in which it was recorded), with 's' denoting species recorded only during the strict standardised search (i.e. missed during the lenient standardised search). For species seen during transects, the maximum number of individuals recorded is given (Max. No.). Species noted only during area-proportionate transects (p) or repeat transects (r) are distinguished from species seen when both transect-based methods were used. Species recorded incidentally (seen or heard outside sampling area or seen flying over) are indicated (+) and were included in the total richness estimate for each reserve. Asterisks distinguish breeding records recorded during standardised searches

Linnean name	Common name	Thurgoona		Gerogery		Gerogery West		Jindera	
		Incidence	Max. No.	Incidence	Max. No.	Incidence	Max. No.	Incidence	Max. No.
<i>Haliastur spheurnus</i>	Whistling kite								
<i>Accipiter cirr-hoecephalus</i>	Collared sparrowhawk	+							
<i>Falco subniger</i>	Black falcon								
<i>Geopelia striata</i>	Peaceful dove	0.17s							
<i>Phaps chalcoptera</i>	Common bronzewing		1r						
<i>Platyercus elegans</i>	Yellow rosella	0.50	2	1.00	3	1.00	3	0.89	4
<i>Platyercus eximius</i>	Eastern rosella	1.00	6	1.00	2	+		+	
<i>Psephotus haematonotus</i>	Red-rumped parrot	0.17							
<i>Chrysococcyx basalis</i>	Horsfield's bronze-cuckoo	0.42				0.50			
<i>Chrysococcyx lucidus</i>	Shining bronze-cuckoo	0.33							
<i>Dacelo novaeguineae</i>	Laughing kookaburra	0.33s		0.33		0.50	1	0.56	2
<i>Todiramphus sanctus</i>	Sacred kingfisher	0.25s*				0.80			
<i>Cormobates leucophaeus</i>	White-throated treecreeper	0.17s							
<i>Climacteris picumnus</i>	Brown treecreeper	0.25				1.00	1		
<i>Pardalotus punctatus</i>	Spotted pardalote	0.33							
<i>Pardalotus striatus</i>	Striated pardalote	0.92	7	0.83	3	1.00	11	0.89	3
<i>Gerygone olivacea</i>	White-throated gerygone	0.58	1p			0.30		0.44	
<i>Acanthiza chrysorrhoa</i>	Yellow-rumped thornbill		2p			+		0.44	
<i>Acanthiza lineata</i>	Striated thornbill	0.75	1					0.33	
<i>Dicaeum hirundinaceum</i>	Mistletoe bird					0.30			
<i>Smicrornis brevirostris</i>	Weebill	0.83	2			0.70	1	1.00	1
<i>Anthochaera carunculata</i>	Red wattlebird	0.17				0.20			
<i>Philemon corniculatus</i>	Noisy friarbird	+				0.5s			
<i>Philemon citreogularis</i>	Little friarbird	0.75	2	0.33		0.20	1		
<i>Entomyzon cyanotis</i>	Blue-faced honeyeater							+	
<i>Manorina melanocephala</i>	Noisy miner	0.75	4	1.00	15	0.90	4	1.00	4
<i>Lichenostomus penicillatus</i>	White-plumed honeyeater	0.83	3p	0.33		1.00	7	0.22	1
<i>Melithreptus brevirostris</i>	Brown-headed honeyeater	0.33	3p					0.22	
<i>Melithreptus gularis</i>	Black-chinned honeyeater					0.10s			
<i>Microeca fasciata</i>	Jacky winter	0.83*							
<i>Petroica goodenovii</i>	Red-capped robin	0.50*							
<i>Daphoenositta chrysoptera</i>	Variied sitella	+							
<i>Falcunculus frontatus</i>	Crested shrike-tit	0.17				0.30s			

<i>Pachycephala rufiventris</i>	Rufous whistler	0.75							
<i>Colluricincla harmonica</i>	Grey shrike-thrush	+	0.3		0.20	1			
<i>Myiagra inquiteta</i>	Restless flycatcher	0.83			0.50	1			
<i>Rhipidura fuliginosa</i>	Grey Fantail	0.92		1p	0.40*				
<i>Coracina novaehollandiae</i>	Black-faced Cuckoo-shrike	0.75	0.33	2	0.60	1		0.22	
<i>Artamus superciliosus</i>	White-browed woodswallow	+	+		0.20s			0.44	
<i>Artamus personatus</i>	Masked woodswallow	+	+		+			+	
<i>Artamus cyanopterus</i>	Dusky woodswallow				0.30				
<i>Cracticus nigrogularis</i>	Pied butcherbird	0.50*		3	+			0.33	1
<i>Cracticus torquatus</i>	Grey butcherbird		0.50						
<i>Grallina cyanoleuca</i>	Magpie-lark	1.00*	0.67	1r	0.70			0.78	
<i>Sturnera graculina</i>	Pied currawong				0.20				
<i>Corvus coronoides</i>	Australian raven			1p					+
<i>Corcorax melanorhamphos</i>	White-winged chough	0.50*		7p					

Table 3. Results of different bird-sampling methods being evaluated, summarised for the four Travelling Stock Reserves near Albury, New South Wales

Total woodland richness combines all species recorded during sampling with all incidental records. Estimates of woodland-dependent bird species richness using different methods are provided for each reserve, and were divided by total woodland richness to yield values of percentage completeness. For individual transects and 20-min searches, means and ranges are provided, with associated completeness values calculated from the mean. For the two standardised searches, richness and number of samples required to fulfil the stopping rule (n) are given

Variable	Thurgoona	Gerogery	Gerogery West	Jindera
Total woodland richness	38	13	30	18
Transect: mean richness, range	6.8, 4–10	2.5, 1–4	5.5, 5–6	3.8, 2–5
Transect: completeness (mean)	17.9%	19.2%	18.3%	21.1%
Repeat transects: richness	11	4	11	7
Repeat transects: completeness	28.9%	30.8%	36.7%	38.9%
Area-proportionate transects: richness	16	4	11	7
Area-proportionate transects: completeness	42.1%	30.8%	36.7%	38.9%
20-min search: mean richness, range	16.6, 13–20	5.7, 4–7	12.4, 11–16	7.8, 5–11
20-min search: completeness (mean)	43.7%	43.8%	41.3%	43.3%
Fixed-effort search: richness	26	10	20	11
Fixed-effort search: completeness	68.4%	76.9%	66.7%	66.1%
Standardised search – lenient: richness, n	26, 3	10, 3	20, 3	14, 7
Standardised search – lenient: completeness	68.4%	76.9%	66.7%	77.8%
Standardised search – strict: richness, n	30, 12	10, 6	24, 10	14, 9
Standardised search – strict: completeness	78.9%	76.9%	80.0%	77.8%

Table 4. Synthesis of the different bird-sampling methods being evaluated

Mean completeness and the associated coefficient of variation are provided for each method ($n = 4$ for all methods except single transect (16) and single 20-min. search (37)). Total sampling effort is the sum of time spent conducting each method in all the four reserves

Method	Mean completeness	Coefficient of variation	Total sampling effort (min)
Single transect	19.0%	34.1	80
Repeat transects	33.8%	14.0	320
Area-proportionate transects	37.1%	12.8	320
Single 20-min search	42.9%	17.1	80
Fixed-effort search	68.3%	8.9	320
Standardised search – lenient	72.5%	7.9	320
Standardised search – strict	78.4%	1.7	740

to derive an accurate estimate of richness. This sort of discrepancy would be magnified as among-site variation increased, so even though the fixed-effort search was a marked improvement over transects it would still provide unreliable estimates of species richness in patchy landscapes. This is exemplified by a study of resident birds in montane forests of southern Mexico (Watson 2003b) in which standardised searches were used to survey fragments spanning five orders of magnitude in area. Any fixed-effort approach would greatly over-sample some patches while under-sampling others, diminishing any underlying patterns between area and richness. Hence, rather than using an arbitrary criterion to constrain sampling, it makes better biological sense to sample all sites to the same degree, maximising consistency and ensuring comparability.

Density and incidence

Despite poor performance in terms of completeness and consistency, the advantage of fixed-area methods is that they can be used to derive count statistics (Mac Nally 1996; Luck *et al.* 1999) or coupled with detectability measures to generate density estimates (Rosenstock *et al.* 2002). Improving the accuracy of these estimates has motivated numerous recent contributions (Rosenstock *et al.* 2002; Thompson 2002 and references therein), but many confounding effects cannot be removed and a reliable community-level technique remains elusive. Regardless of how densities are calculated, most woodland-dependent species of interest were not recorded during transect counts in this study, so their densities could not be estimated. Of the eight ‘declining woodland species’ recorded in the four

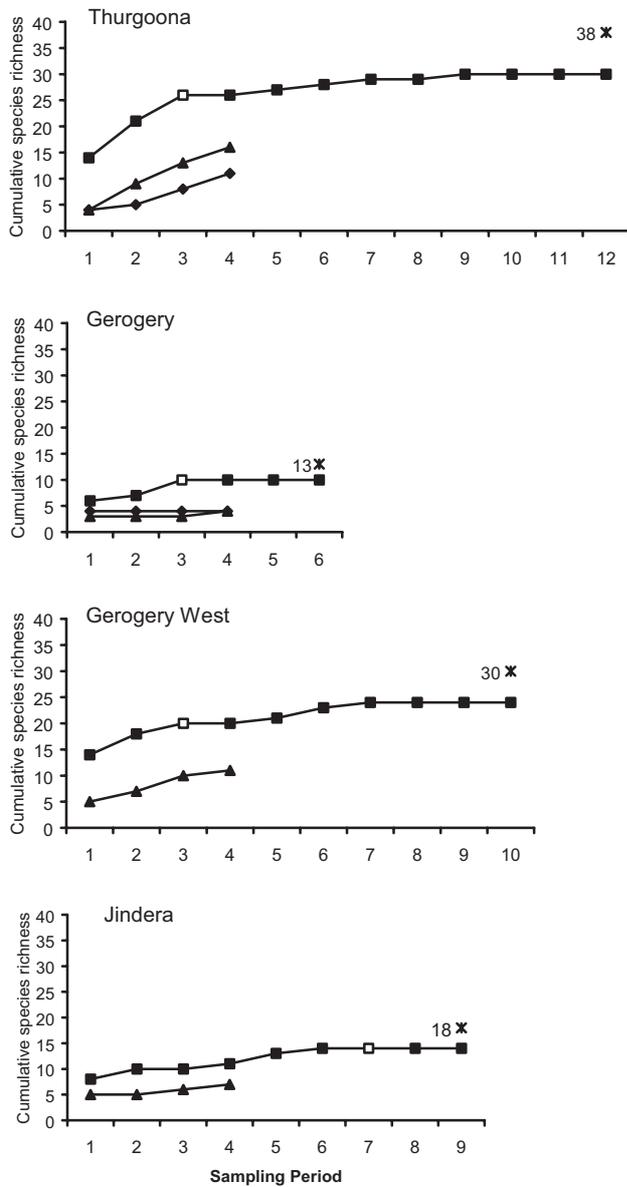


Fig. 2. Species-accumulation curves for the four different methods used in each reserve. All sampling periods are 20 min in duration, with cumulative species richness relating only to woodland-dependent bird species (Table 2). Triangles designate repeat transects, diamonds denote area-proportionate transects in the two larger reserves, and squares designate 20-min searches. The open square indicates when the lenient stopping rule was fulfilled, while the end of the line is when the strict stopping rule was satisfied. The fixed-effort search equates to the first four points, while the cross indicates total estimated woodland richness for each reserve.

reserves, only one occurrence (brown treecreeper, *Climacteris picumnus*, in Gerogery West) was noted during a transect count, compared with 11 occurrences of seven species using the strict standardised search (Table 2).

As the standardised search is not area-limited, density estimates cannot be made but distribution patterns can be evaluated by calculating species incidences (proportion of sampling periods in which it was recorded: Dawson 1981). As discussed in Watson (2003a) this variable is subject to many of the same shortcomings as density but, in this instance, it has two distinct advantages. First, since hearing a single vocalisation and recording a large flock in a sampling period both count as a presence, this measure is more robust to variation in detectability, apparency and various other confounding effects (although it is necessarily more course grained). Second, because the standardised search yielded richness estimates approximately twice as complete as transect counts, incidence can be calculated for a much greater proportion of the community, including most of the species of interest. Thus, while the transect data for Gerogery indicates that there was at least one brown treecreeper present, the incidence value indicates that it was recorded as present in all 10 sampling intervals. In addition, three other declining woodland species had incidences of 0.3–0.4 and a fourth was seen once, all indicating that the reserve has high conservation value for this group. Nonetheless, great care should be taken in interpreting incidence estimates, and researchers considering using this variable are strongly advised to understand the shortcomings of the measure (see Dawson 1981; Wright 1991 and references therein) and consider territory-mapping or other intensive approaches better able to measure densities directly (Rosenstock *et al.* 2002; Thompson 2002).

Procedural issues

In addition to generating data of higher quality, the standardised search is much simpler to conduct than are transect counts, as discussed by Loyn (1986). During transects and other fixed-area approaches, the observer has to continually judge whether or not a particular individual is inside the transect boundaries, decide whether an individual counted earlier flew ahead and should be ignored, and try to distinguish how many individuals of various species are in a mixed-feeding flock in the canopy. During a standardised search, the spatial extent of sampling is the entire patch, hence the only judgement needed is whether or not a species is within the patch. If you catch a fleeting glimpse of a bird or hear an unfamiliar call, you are free to track it down. Being less constrained and able to wander throughout the patch, you can better appreciate within-patch variation in habitat and bird distribution, important information for interpreting analyses and understanding distribution patterns. Moreover, you are better able to gauge breeding status of birds. During the standardised searches in these four reserves, I found several nests, observed birds carrying nesting material and feeding fledglings (Table 2) – valuable data for quantifying the value of these reserves to woodland-dependent birds.

One of the most important factors in using the standardised search is to design an appropriate stopping rule (Watson 2003a). As with all stopping rules, it reflects a compromise between required resolution and available resources. The lenient standardised search used here relied on a compound stopping rule that was not affected by sample order (the number of required samples was the same regardless of sample order) and hence had a low probability of being tripped prematurely. To minimise the confounding effect of time-of-day, I recommend alternating between sites and incorporating both morning and afternoon samples. This need not compromise larger-scale sampling design (e.g. randomisation of visitation order) as long as the design is sufficiently flexible to allow a variable number of samples per patch.

Determining how frequently to survey depends on the temporal scale of the question being asked. If an aim of the study were to measure seasonality, then I would advocate one standardised search for each patch every season. Often, however, seasonality is not deemed important and the patches can be adequately sampled in one survey, timed to coincide with maximum richness of species of interest (i.e. spring for woodland-dependent breeders). By reducing the total sampling effort per patch, a greater number of patches can be included for the same total sampling effort, increasing the statistical power and spatial relevance of the research (Brooker 2002).

Closing remarks

While the two conventional methods were out-performed by the standardised search in terms of sample completeness and efficiency, both yielded data of adequate internal consistency (i.e. sample completeness was reasonably uniform across the four reserves). Thus, both repeat transects and fixed-effort searches were able to identify the most diverse reserve and the least diverse reserve. Hence, although previous studies relying on these methods may contain incomplete data, their findings may still be valid in relative terms.

In designing a new study, however, it makes little sense to restrict your research to purely relative comparisons. Using standardised searches, resultant data are of higher completeness and consistency that is measured at the patch scale. Moreover, as illustrated by the comparisons presented here, this approach need not require a greater overall sampling effort. As such, a greater number of sites can be sampled, allowing greater resolution of factors influencing richness patterns.

Acknowledgments

I am grateful to the Hume Rural Lands Protection Board for giving me permission to survey the reserves, and to Matt Herring for assisting with site selection. Initial discussions with Ralph Mac Nally contributed to my reasoning, and

Maggie Watson and an anonymous referee helped clarify an earlier version of the manuscript.

References

- Arnold, G. W., and Weeldenberg, J. R. (1990). Factors determining the number and species of birds in road verges in the wheatbelt of Western Australia. *Biological Conservation* **53**, 295–315. doi:10.1016/0006-3207(90)90098-A
- Bibby, C. J., Burgess, N. D., and Hill, D. A. (1992). 'Bird Census Techniques.' (Academic Press: London.)
- Brooker, L. (2002). The application of focal species knowledge to landscape design in agricultural lands using the ecological neighbourhood as a template. *Landscape and Urban Planning* **60**, 185–210. doi:10.1016/S0169-2046(02)00055-5
- Colwell, R. K., and Coddington, J. A. (1994). Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London B* **345**, 101–118.
- Craig, M. D., and Roberts, J. D. (2001). Evaluation of the impact of time of day, weather, vegetation density and bird movements on outcomes of area searches for birds in eucalypt forests of south-western Australia. *Wildlife Research* **28**, 33–39. doi:10.1071/WR99103
- Dawson, D. G. (1981). The usefulness of absolute ('census') and relative ('sampling' or 'index') measures of abundance. *Studies in Avian Biology* **6**, 554–558.
- Emlen, J. T. (1971). Population densities of birds derived from transect counts. *Auk* **88**, 323–342.
- Fortin, D., and Arnold, G. W. (1997). The influence of road verges on the use of nearby small shrubland remnants by birds in the central wheatbelt of Western Australia. *Wildlife Research* **24**, 679–689.
- Herzog, S. K., Kessler, M., and Cahill, T. M. (2002). Estimating species richness of tropical bird communities from rapid assessment data. *Auk* **119**, 749–769.
- Järvinen, O., and Väisänen, R. A. (1975). Estimating relative densities of breeding birds by the line transect method. *Oikos* **26**, 316–322.
- Johnson, D. D. P., and Mighell, J. S. (1999). Dry-season bird diversity in tropical rainforest and surrounding habitats in north-east Australia. *Emu* **99**, 108–120.
- Kutt, A. S. (1996). Bird population density in thinned, unthinned and old lowland regrowth forest, east Gippsland, Victoria. *Emu* **96**, 280–284.
- Loyn, R. H. (1986). The 20 minute search – a simple method for counting forest birds. *Corella* **1**, 59–60.
- Luck, G. W., Possingham, H. P., and Paton, D. C. (1999). Bird responses at inherent and induced edges in the Murray Mallee, South Australia. 1. Differences in abundance and diversity. *Emu* **99**, 157–169.
- Mac Nally, R. (1996). A winters' tale – among-year variation in bird community structure in a south-eastern Australian forest. *Australian Journal of Ecology* **21**, 280–291.
- Mac Nally, R., and Horrocks, G. (2002). Proportionate spatial sampling and equal-time sampling of mobile animals: a dilemma for inferring areal dependence. *Austral Ecology* **27**, 405–415. doi:10.1046/J.1442-9993.2002.01194.X
- Mac Nally, R., and Watson, D. M. (1997). Distinguishing area and habitat heterogeneity effects on species richness: birds in Victorian buloke remnants. *Australian Journal of Ecology* **22**, 227–232.
- Merikallio, E. (1958). Finnish birds: their distribution and numbers. *Fauna Fennica* **5**, 1–81.
- Peterson, A. T., and Slade, N. A. (1998). Extrapolating inventory results into biodiversity estimates and the importance of stopping rules. *Diversity and Distributions* **4**, 95–105. doi:10.1046/J.1365-2699.1998.00021.X

- Recher, H. F. (1988). Counting terrestrial birds: use and application of census procedures in Australia. *Australian Zoological Review* **1**, 25–45.
- Remsen, J. V., Jr (1994). Use and misuse of bird lists in community ecology and conservation. *Auk* **111**, 225–227.
- Rosenstock, S. S., Anderson, D. R., Giesen, K. M., Leukering, T., and Carter, M. F. (2002). Landbird counting techniques: current practices and an alternative. *Auk* **119**, 46–53.
- Shields, W. M. (1979). Avian census techniques: an analytical review. In 'The Role of Insectivorous Birds in Forest Ecosystems'. (Eds J. G. Dickson, R. N. Connor, R.R. Fleet, J. C. Kroll and J.A. Jackson.) pp. 23–51. (Academic Press: New York.)
- Slater, P. J. (1995). The interaction of bird communities with vegetation and season in Brisbane Forest Park. *Emu* **95**, 194–207.
- Thompson, W. L. (2002). Overview: Towards reliable bird surveys: accounting for individuals present but not detected. *Auk* **119**, 18–25.
- Verner, J. (1985). Assessment of counting techniques. In 'Current Ornithology. Vol. 2'. (Ed. R. F. Johnstone.) pp. 247–301. (Plenum Press: New York.)
- Watson, D. M. (2003a). The 'standardized search': an improved way to conduct bird surveys. *Austral Ecology* **28**, 515–525. doi:10.1046/J.1442-9993.2003.01308.X
- Watson, D. M. (2003b). Long-term consequences of habitat fragmentation – highland birds in Oaxaca, Mexico. *Biological Conservation* **111**, 283–303. doi:10.1016/S0006-3207(02)00271-9
- Watson, D. M., Mac Nally, R., and Bennett, A. F. (2000). The avifauna of severely fragmented buloke *Allocasuarina luehmanni* woodland in western Victoria, Australia. *Pacific Conservation Biology* **6**, 46–60.
- Wright, D. H. (1991). Correlations between incidence and abundance are expected by chance. *Journal of Biogeography* **18**, 463–466.

Manuscript received 31 March 2003; accepted 11 February 2004