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A COMPARISON OF SPECIES COUNTS AND DENSITY ESTIMATES DERIVED FROM AREA SEARCHES, LINE TRANSECTS AND POINT COUNTS IN THE JARRAH FOREST OF SOUTH-WESTERN AUSTRALIA

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No studies have examined differences between census methods for birds in south-western Australian forests, yet unique features of south-western forests may be responsible for differences from those recorded in studies conducted elsewhere. Differences in the number of bird species recorded and densities estimated by area searches, line transects and point counts in jarrah forests of south-western Australia were examined. All three methods detected a similar number of species but area searches gave higher estimates of overall bird density. This difference probably occurred because area searches were conducted for a longer period of time and detected more cryptic birds in a given area than the other two methods. These results were similar to studies conducted in eucalypt forests in south-eastern Australia and in non-forest habitats in western Australia, suggesting that differences between the three methods are consistent across different habitats and regions in Australia. However, density estimates should not be compared directly between studies using area searches and either line transects or point counts, even if the censuses are conducted for the same length of time.

INTRODUCTION

Recher (1984, 1988) reviewed bird census procedures in Australia and concluded that there was a need to investigate how density estimates derived from the various methods differed. This was because researchers in Australia have used a variety of methods to estimate bird densities, making comparisons between studies difficult. Recher (1984) suggested that studies comparing census methods would be particularly valuable if they were conducted by the same observer at the same site, therefore eliminating differences due to observer or site. Studies in Australia have generally censused bird communities using either area searches, line transects, point counts, territory mapping or mist-netting (Smith 1986; Recher 1988). Neither mist-netting nor territory mapping sample the entire bird community and are rarely used (for a full discussion see Recher 1988) leaving area searches, line transects and point counts as the main census methods used in Australia. However, few studies have compared census methods in Australia and none of them have been conducted in south-western forests (Loyn 1980; Arnold 1984; Shields and Recher 1984; Bell and Ferrier 1985; Arnold *et al.* 1987; Saffer 2001). Even fewer have compared all three census methods, and those that have were conducted in south-eastern Australia (Hermes 1977; Hewish and Loyn 1989).

The avifauna of the jarrah forest in south-western Australia differs from avifaunas of south-eastern forests in important ways. It is relatively depauperate in terms of species number and abundance, probably due to the small area of forest remaining and the poor potential for migratory avoidance of limiting food periods (Wykes 1985). In addition, some foraging guilds are particularly poorly represented, such as bark foragers (perhaps due to a shortage of decorticating bark) and leaf-litter foragers (Wykes 1985). Species composition is also quite different, with south-western forests containing many endemic species (e.g. Red-capped Parrot *Purpureicephalus spurius* and Red-winged Fairy-wren *Malurus elegans)* and some more common species being absent from south-eastern forests (e.g. Western Gerygone *Gerygone fusca* and Inland Thornbill *Acanthiza apicalis*). The structure of the jarrah forest is also unique, with the canopy being dominated by just one tree species (Dell and Havel 1989). Studies have shown that habitat structure has a significant impact on the detectability of bird calls (Wiley and Richards 1982; Waide and Narins 1988; Schieck 1997) and, thus, on the efficacy of various census methods. Owing to these differences, there is reason to believe that the comparability of different census methods in the jarrah forest may differ from results obtained from more diverse forests in south-eastern Australia.

This study compared area searches, line transects and point counts in the jarrah forest of south-western Australia. It aimed to determine whether the three census methods provided comparable results in the jarrah forest and, if not, whether the differences between the three census methods were similar to those found elsewhere.

METHODS

Study area

The study was conducted in Kingston, Walcott, Warrup and Winnejup forest management blocks located 20–30 kilometres north-east of Manjimup (34°03–10'S, 116°18–25'E). The canopy of the area was dominated by Jarrah *Eucalyptus marginata* although Marri *Corymbia calophylla* was co-dominant in some areas. Canopy height averaged 27 metres with occasional trees up to 53 metres. The midstorey was typically sparse and consisted primarily of Jarrah and Marri along with a few individuals of *Banksia grandis* and *Hakea oleifolia*. The understorey was typically quite open and common understorey species included *Bossiaea linophylla*, *Bossiaea ornata*, *Leucopogon capitellatus*, *Leucopogon propinquus*, *Macrozamia reidleii*, *Persoonia longifolia*, *Pteridium esculentum* and *Xanthorrhea gracilis*.

Census methodology

Censuses were conducted at eight sites located in unlogged jarrah forest. Sites were located at least 1.2 kilometres apart to avoid counting the same individuals at different sites. At each site, a one-hectare plot was established that was a 100 metres square aligned north-south. Each corner was marked with a metal fence dropper and each side by a line of pink flagging tape tied to vegetation.

All three census methods were conducted at each site. Area searches were conducted by searching each one-hectare plot for 30 minutes and recording all birds seen or heard on that plot during that time. Birds seen or heard outside the plot were also recorded but did not contribute to the density estimates. Birds outside the plot were recorded to provide data comparable with point counts and line transects because those census methods often sample the bird community to an infinite distance rather than within a defined area. The counts from all area searches at a site were combined and density estimates, in birds per hectare, were calculated using the formula (from Edwards *et al.* 1981):

$$D = \frac{n}{m}$$

where D equals the density in birds per hectare, n is the total number of individuals counted within the plot and m is the total number of area searches conducted in that plot.

Line transects were conducted using the north and south boundaries of each one hectare plot as transect lines. These 100 metres transect lines were censused one after another for eight minutes each. During each transect all the birds seen or heard were assigned to one of two distance categories: (1) within an inner band extending 20 metres either side of the transect line in a perpendicular direction or (2) beyond that band. Pink flagging tape was used to delineate the inner band. Data from all line transects at a site were combined and density estimates (birds per hectare) calculated using the formula (from Järvinen and Väisänen 1975):

$$D = \frac{5\left\{\frac{-\ln(1-p)}{w}\right\}N}{L}$$

where D equals the density in birds per hectare, L is the length of all line transects conducted in kilometres, N is the total number of birds counted, w is the perpendicular width of the inner band from the transect line and p is the proportion of birds within the inner band.

Point counts were conducted using two opposite corners of each one-hectare plot as count stations. The point counts were conducted one after the other and lasted for a total of five minutes at each count station. During each five minute period all birds seen or heard were assigned to one of two distance categories: (1) within a fixed radius of 20 metres from the counting station or (2) beyond a fixed radius of 20 metres from the counting station. Pink flagging tape was used to delineate the 20 metres radius. Data from all point counts at a site were combined and density estimates (birds per hectare) calculated using the formula (from Bibby *et al.* 2000):

$$D = \left\{\ln\left(\frac{n}{n_2}\right)\right\}\left\{\frac{n}{m(\pi r^2)}\right\}$$

where D equals the density in birds per hectare, n is the total number of birds counted, n_2 is the number of birds counted beyond the fixed radius, m is the total number of point counts conducted and r is the fixed radius in decametres.

For area searches, only species recorded within the plot had an estimated density for that site greater than zero. Species only recorded outside the plot had a density estimate of zero. For line transects and point counts the proportion of individuals recorded in the inner band (i.e. closer than 20 m from the transect or count station) determined the density estimate for that site. If a species was only recorded outside the inner band the density estimate for that species for that site was zero. In this paper the number of species recorded per site will refer to all species recorded at a site including those species whose density estimate was zero. During all censuses a note was made of the direction in which birds flew to avoid counting the same individuals twice. However, as it was unusual to encounter more than one group of a species at different times during a census, double counting is unlikely to have taken place. For all censuses, birds were recorded for the duration of the census, even individuals that had not been present when the census commenced.

Each area search and each pair of line transects and point counts were repeated three times at each site giving a total of three area searches, six line transects and six point counts conducted at each site. All eight sites were censused on the same day between 0500 and 1000 hours and whether an area search, line transect or point count was conducted at a particular site on a particular morning was determined randomly. Each site was only censused once a day and, although time of day does not influence density estimates in the study area (Craig and Roberts 2001), the order in which area searches, line transects and point counts were conducted on each morning was randomized with respect to time of day. Censuses were conducted on eight days between 14 December 1993 and 14 January 1994 during light winds with no rain.

Statistical analyses

The variables estimated by the three census methods were compared with a one factor Analysis of Variance using Statview 4.0. The variables compared were the overall density of birds, the number of species recorded at each site, the number of species recorded at each site that had a density estimate greater than zero and the densities of each of the ten most common species. Treatment variances were analysed using a Hartley's test and found to be homogeneous. Treatment means were compared post-hoc using Fisher's Protected LSD as recommended by Day and Quinn (1989).

RESULTS

All three census methods recorded a similar number of species. Area searches recorded 32 species, line transects 30 species and point counts 29 species. The total number of species recorded per site did not differ significantly between the three census methods ($F_{2,21}$ = 0.57, P = 0.574) (Fig. 1). In contrast, the number of species recorded at each site that contributed to the density estimate was significantly different between the three census methods ($F_{2,21}$ = 17.43, P = 0.001). The number of species that contributed to the density estimate was significantly higher for area searches than for line transects, which was significantly higher than for point counts (Fig. 1). There was no significant correlation between the number of species that contributed to the density estimate and the area of either the area search or the inner bands of the line transects and point counts (r_1 = 0.92, P = 0.251).

Area searches, point counts and line transects produced significantly different estimates of the overall density of birds ($F_{2,21}$ = 3.91, P = 0.036). Area searches produced significantly higher density estimates than either point counts or line transects although there was no significant difference in the density estimates derived from point counts and line transects (Table 1). The density estimates were not significantly correlated with the time taken to conduct the census (r_1 = 0.95, P = 0.207).

There was no significant difference in the density estimates calculated from the three methods for any of the ten most common species (Table 2), although the difference in the density estimates for the Striated Pardalote *Pardalotus striatus* was almost significant with area searches giving the highest value (Table 2).

DISCUSSION

The three census methods did not differ significantly in their ability to sample the entire bird community. All three methods recorded a similar number of total species and a similar number of species per census. Arnold (1984) also found that, in wandoo woodlands of Western Australia, the

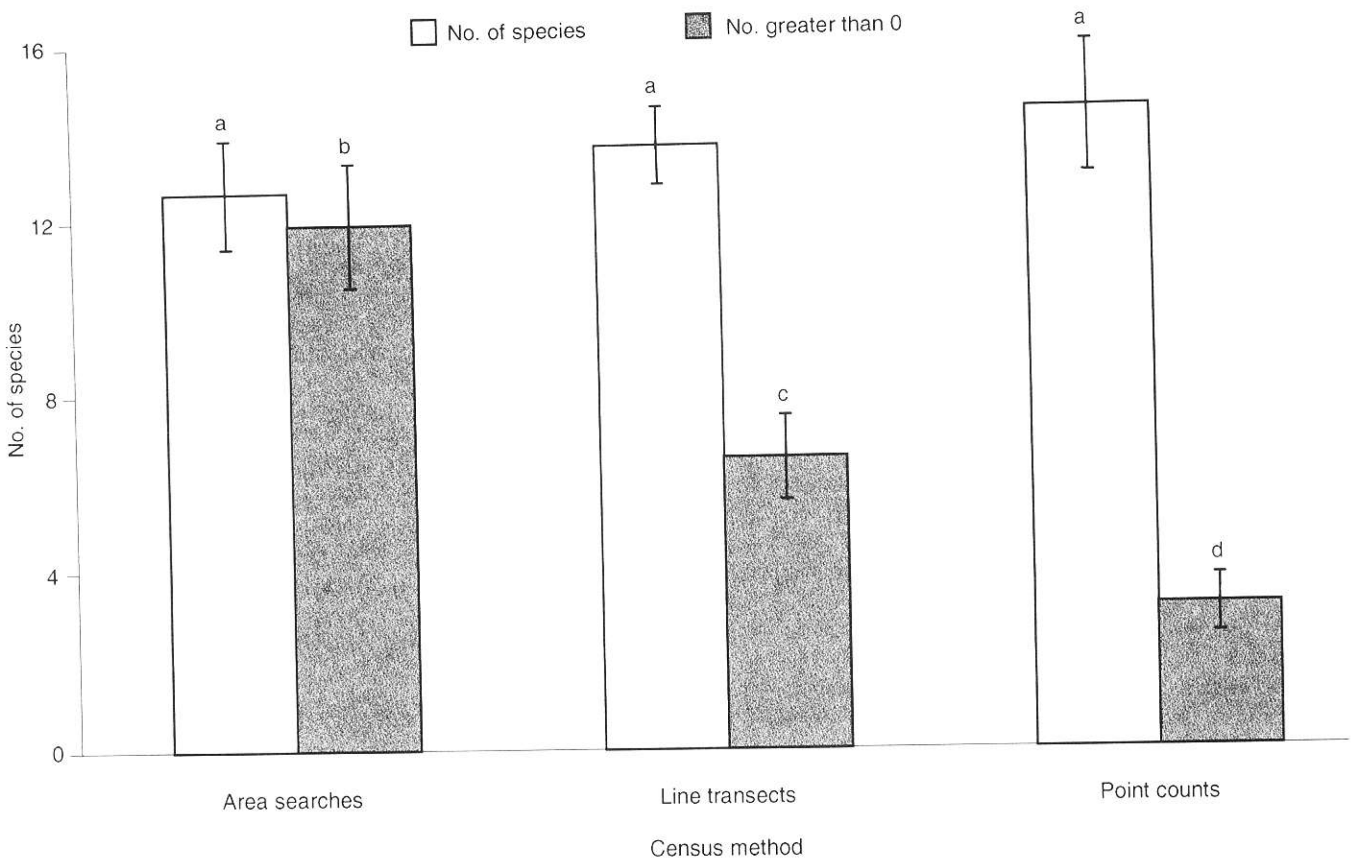

Figure 1. *The average number of species recorded per census (Number of species) and the average number of species recorded per census that contributed to the density estimate (Number greater than 0) for each of the three census methods. Values given are means ± S.E. The same superscript letter indicates that means were not significantly different.*

total number of species detected by area searches and point counts was similar. In contrast, area searches provided density estimates that were greater than zero for a significantly greater number of species at each site than the other two methods. A major reason for this is because the area sampled to derive a density estimate greater than zero was higher in area searches (1.00 hectare) than in line transects (0.80 hectare) and point counts (0.25 hectare). In support of this idea is the fact that there were no significant differences in the overall number of species recorded at each site (when the area sampled was the same for all three methods). However, the area sampled does not explain all of the differences between the census methods because there was no correlation between the area sampled and the number of species with a density estimate greater than zero. In addition, the number of species with a density estimate greater than zero in area searches was almost twice as high as in line transects although the area sampled

TABLE 1
The time taken to complete each census and the overall bird density (birds per hectare) estimated by each of the three census methods. Density estimate are means ± S.E. The same superscript letter indicates that means were not significantly different.

Census method	Length of census (min)	Density estimate
Area search	30	$13.33^{a} \pm 3.04$
Line transect	16	$6.02^{b} \pm 1.04$
Point count	10	$6.26^{b} \pm 1.71$

TABLE 2
The density (birds per hectare) of the ten most common species estimated by the three different census methods and the probability of the ANOVA test comparing the three values. Values are means ± S.E.

Species	Area search	Line transects	Point counts	*P* of $F_{2,21}$
Red-capped Parrot *Purpureicephalus spurius*	0.17 ± 0.09	0.14 ± 0.09	0.68 ± 0.68	0.564
Striated Pardalote *Pardalotus striatus*	1.37 ± 0.42	0.17 ± 0.08	0.54 ± 0.39	0.051
White-browed Scrubwren *Sericornis frontalis*	0.58 ± 0.35	0.53 ± 0.31	0.00 ± 0.00	0.258
Western Gerygone *Gerygone fusca*	1.21 ± 0.39	1.02 ± 0.22	1.25 ± 0.44	0.897
Inland Thornbill *Acanthiza apicalis*	1.25 ± 0.47	1.64 ± 0.59	1.80 ± 0.79	0.820
Western Thornbill *Acanthiza inornata*	0.67 ± 0.19	1.10 ± 0.72	0.28 ± 0.28	0.460
Western Yellow Robin *Eopsaltria griseogularis*	0.54 ± 0.32	0.56 ± 0.24	0.96 ± 0.70	0.776
Grey Fantail *Rhipidura fuliginosa*	0.83 ± 0.29	0.41 ± 0.17	0.76 ± 0.29	0.475
Tree Martin *Hirundo nigricans*	1.91 ± 1.59	0.00 ± 0.00	0.94 ± 0.55	0.394
Silvereye *Zosterops lateralis*	1.20 ± 0.53	0.38 ± 0.19	0.23 ± 0.23	0.134

was only slightly larger. This suggests that area searches may have detected more species than the other methods, even if the area sampled to derive density estimates was standardized between the three methods. It is possible that area searches are better at detecting cryptic species because areas of dense vegetation can be thoroughly searched to detect non-singing individuals but there is no evidence to support this. I concluded that a large part of the difference in the number of species with a density estimate greater than zero was due to the different areas sampled but the possibility that area searches did detect more species should be investigated further.

The three census methods differed significantly in their estimate of overall bird density with area searches giving a significantly higher density estimate than either point counts or line transects. These results are similar to other studies in Australia that have compared these methods (Hermes 1977; Arnold 1984; Arnold *et al.* 1987; Hewish and Loyn 1989). Arnold (1984) found that the overall density of birds estimated by point counts was 49 per cent lower than the density estimated from area searches, compared to 53 per cent lower in this study. Arnold *et al.* (1987) found that the density of the six most common species estimated by line transects was 61 per cent lower than the density estimated by area searches, whereas this study found that the density of the six most common species was 55 per cent lower when estimated by line transects compared to area searches. Hermes (1977) found that for a given area the density estimates derived from area searches were higher than for either point counts or line transects.

Why do area searches provide higher estimates of overall bird density and, possibly, the density of individual species? I propose that there are two explanations as to why area searches provided higher density estimates than line transects or point counts in this study. One reason is because, in this study, area searches were conducted for longer time periods than for either point counts or line transects. Several observers have noted that density estimates provided by the same method increase as the length of the census increases due to the continual accumulation of birds moving on to the plot (Granholm 1983; Harden *et al.* 1986). Because area searches in this study took nearly twice as long as line transects and three times longer than point counts (Table 1) we would expect them to provide higher estimates of density estimate. However, this cannot account for all of the differences in density estimates. Firstly, there is no correlation between the density estimates and the length of time taken to conduct the census. Secondly, Arnold (1984) conducted his point counts and area searches for the same length of time (10 min.) and found that area searches still gave an estimate of overall density that was 28 per cent higher. This suggests that area searches would provide higher density estimates than line transects or point counts, even if all three methods were conducted for the same length of time. I postulate that this difference occurs because in area searches fewer individuals are missed than in point counts or line transects. In area searches the whole area from which the density estimate is derived is traversed whereas in point counts and line transects only a small proportion of the area from which the density estimate is derived is traversed. Traversing an area increases the likelihood of detecting cryptic individuals that are perching quietly, not singing or in dense undergrowth, because these individuals can be flushed no matter where they occur on the plot (Loyn 1986; Arnold *et al.* 1987). There are two pieces of evidence that suggest that area searches detect more birds than the other two methods. Firstly, by dividing the number of birds detected in the inner band of the line transect by the area of that band a density estimate for a fixed-width strip transect (which is essentially an area search where the observer is only allowed to walk down the middle of the area) could be calculated. The density estimates from the fixed-width strip transects were much lower than the area searches (5.10 versus 13.33 birds per hectare), which suggests that the fixed-width strip transects failed to detect many birds that were detected during the area searches. This explanation is supported by Hermes (1977) who found that in a given area line transects detected fewer birds than area searches. Secondly, area searches detect more birds by sight than other methods. Arnold (1984) found that point counts detected 69 per cent of birds by sound alone whereas area searches detected only 44 per cent of birds by sound alone. This suggests that area searches detect many non-singing birds that are not detected by line transects and point counts. I concluded that differences in density estimates between the three census methods were partly because each method was conducted for a different length of time but also because areas searches gave inherently higher density estimates.

There were no significant differences between the density estimates of the ten most common species derived from each census method. This is surprising as evidence from the overall density estimates suggests that area searches are better at detecting cryptic individuals. However, an examination of the data reveals that, although some species show little difference in density between the three methods, others, particularly Striated Pardalote, Tree Martin and Silvereye, show large differences (Table 2). These species probably show large variations because they are flocking species, which would decrease the probability of detecting a flock during all censuses and lead to large variations in density estimates. The large variations in density also suggest that differences may exist between the methods at the species level but that the experiment lacked enough power to detect them because of the low number of replicates. The possibility that density estimates differ between the three methods for individual species should be investigated further.

The question of which census method is the most accurate is impossible to answer. Two studies in Australia have combined territory mapping of extensively colour-banded populations with nest searches to provide a true density with which to judge the accuracy of other census methods (Shields and Recher 1984; Bell and Ferrier 1985). Those studies found that line transects underestimated the overall density of birds by 14 per cent and 28 per cent respectively. Even these differences represent the minimum underestimates because the colour-banding studies will miss some non-breeding birds and floaters. The fact that line transects underestimate density may lead one to conclude that area searches, which detect more birds, provide a more accurate estimate of density than other methods. I believe that area searches do provide a better estimate of density than the other methods, particularly in open habitats. However, it is not possible on current evidence to assess how accurate area searches are (but see Craig and Roberts 2001). It is likely that accurate estimates of bird density are probably not obtainable in terrestrial habitat in Australia for any except a small minority of species (Recher 1988).

CONCLUSION

Area searches, point counts and line transects in the jarrah forest of south-western Australia all detected a similar number of species but area searches gave higher estimates of overall bird density than the other two methods. The reasons why area searches gave higher density estimates is partly because they were conducted for a longer time period in this study and is partly because they detected a greater number of non-singing birds than the other methods. These results are similar to those obtained in eucalypt forests in south-eastern Australia and in non-forest habitats in western Australia. This suggests that differences between area searches and the other census methods are consistent across many habitats and regions in Australia. Density estimates should not be compared between studies using area searches and either line transects or point counts, even if the different census methods are standardized with respect to time.

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