Do observer differences in bird detection affect inferences from large-scale ecological studies?

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Abstract. Use of multiple observers in large-scale bird surveys is often unavoidable. But how significant are observer differences in bird detection? Do observer effects significantly influence inferences about environmental factors on birds? We conducted a field experiment to quantify differences between observers in the detection of birds at Booderee National Park, south-eastern Australia. We also re-analysed a large dataset from an observational study where multiple observers had participated in bird surveys. We identified highly significant observer differences for estimates of bird species richness and the probability of detection of three exemplar taxa. We demonstrated that observer effects would not substantially alter inferences we made about relationships between bird species and vegetation type or burning history. We believe that four features of our survey design and protocol limited the magnitude of observer effects on environmental inferences: (1) high levels of replication of classes of field sites – critical for relative comparisons of site (vegetation) types; (2) pre-survey screening to ensure that only experienced ornithologists participated in surveys; (3) repeat sampling of field sites by a different observer on a different day to reduce the impacts of observer heterogeneity and 'day' effects; and (4) precluding surveys during poor weather or long after dawn, also to limit 'day' effects.

Introduction

Field surveys are a critical part of almost all empirical ecological studies (Krebs 2008) and data gathered using them is important for natural resource management and conservation planning (Ralph *et al*. 1983; Feria and Peterson 2002; Sutherland 2006; Ausden 2007). In the case of particular groups such as birds, many observers may be involved in the collection of field data; examples include several well-known large-scale studies such as the British Breeding Bird Survey (Bibby *et al*. 1998) and the Australian Bird Atlas (Barrett *et al*. 2003). Multiple observers are a necessity in these studies because, for example, the sites being surveyed range over far too large an area for any one person to cover. Many studies have shown that observers differ in their ability to detect birds (e.g. Kavanagh and Recher 1983; Pyke and Recher 1985; Emlen and DeJong 1991; Morin and Conant 1994; Cunningham *et al*. 1999; Diefenbach *et al*. 2003). It is critical to understand the magnitude of differences between observers (Link and Sauer 1997) because if they are large, the influence of environmental factors (e.g. landscape change or habitat fragmentation) might be masked by the effects of observer heterogeneity (van der Meer and Camphuysen 1996).

In this study, we conducted both a field experiment and a large-scale observational study to quantify the magnitude of observer differences within different vegetation types and burned and unburned areas in a nature reserve in south-eastern Australia. We posed two key questions: Are there significant differences between observers in the detection of birds? And, if so, do these observer differences influence the interpretation of environmental and other kinds of effects? We addressed these questions for species richness and then for several individual bird species. Of particular interest was to test observer and other effects for the nationally endangered Eastern Bristlebird (*Dasyornis brachypterus*). This was because our study area in Booderee National Park, on Jervis Bay, now supports the largest known remaining population of the species in the world (Baker 2000; Lindenmayer *et al*. 2008*a*) and the recovery plan for the species stipulates special management practices in the areas where its occurrence has been confirmed (Department of Environment, Water, Heritage and the Arts 2008). Based on our findings, we make general recommendations about how bird surveys should be conducted when multiple observers are involved.

Methods

Study area

We conducted this study at Booderee National Park, a ~6500 ha area co-managed by the Wreck Bay Aboriginal Community and Parks Australia (a section of the Commonwealth Department of the Environment, Water, Heritage and the Arts). Booderee National Park is located ~200 km south of Sydney, and 20 km south of the city of Nowra, on the south coast of New South Wales, south-eastern Australia (approximate midpoint is 35°10′S, 150°40′E). The area has a temperate maritime climate with an average annual rainfall of 1150 mm spread rather evenly over the year. Average minimum and maximum air temperatures are 18–24°C for January (summer) and 9.5−15°C for July (winter) (Bureau of Meteorology 2008).

2003–07 observational study of birds

In 2003, we began a major 5-year study of the effects of wildfire on vertebrate biodiversity (Lindenmayer *et al.* 2008*a*, 2008*b*). A year after we began work, a major wildfire (in December 2003) burnt approximately half the native vegetation cover of Booderee National Park. Thus our work involved quantifying the post-fire recovery of birds and other vertebrates as well as contrasting the vertebrate biota of sites characterised by different fire histories dating back to 1972 and located in different vegetation types (Lindenmayer *et al.* 2008*a*). For the work, we recognised six broad vegetation types (rainforest; forest; woodland; heathland; shrubland; and sedgelands) based on extensive vegetation surveys conducted throughout Booderee National Park (Ingwersen 1977; Taws 1998). Within these broad vegetation types, we recognised several sub-categories. These were: casuarina forest; wet and dry heathland; and wet, dry and low shrubland. We provide a brief description of the floristic composition and coverage of the six vegetation types and their sub-categories in the Appendix.

At the start of the project, we established a protocol for selecting permanent field sites by using two key stratifying variables: (1) vegetation type (see Appendix); and (2) past fire history, classified into four classes of time since the last fire (0–10 years, 11–20 years, 21–30 years and >30 years). To facilitate the selection of sites, we overlaid maps of vegetation and fire history to form 'homogeneous' polygons characterised by the classifying factors. After excluding polygons that contained places sacred to the local Wreck Bay Aboriginal Community, we selected a stratified random sample of 109 polygons. This process ensured:

- The full range of vegetation type by fire-history classes was represented;
- There was replication of each class;
- The number of samples was proportional (although not directly proportional) to the total area occupied by each class; and
- There was a good geographical 'spread' of selected polygons throughout the national park to avoid potential problems with geographical bias.

A permanent 100-m long transect (i.e. a 'site') was then established within each of the 109 selected polygons. The choice of transect length was influenced by the substantial heterogeneity in vegetation cover at Booderee National Park where major changes in vegetation type often occur over a short distance. Transect lengths in excess of 100 m would have resulted in many transects spanning two vegetation types.

We completed two visits, of 5 min each, at each of the 20 m and 80 m permanent points placed along the transect at each of the 109 sites, for a total of 436 point interval counts (*sensu* Pyke and Recher 1983; Ralph *et al.* 1983) annually between 2003 and 2007 (Lindenmayer *et al.* 2008*a*). For each point count, we recorded all birds seen or heard in the following distance classes: 0–25 m, 25–50 m, 50–100 m, and >100 m. Given the density of the vegetation at Booderee National Park, most detections of birds were from calls rather than by sight.

A total of 12 highly experienced observers was involved in the counts of birds in the study between 2003 and 2007. We completed surveys in late September each year, which is the breeding season for most of the species and when summer migrants have arrived. In each survey year, each of our 109 field sites was surveyed twice on a different day with a different observer. We did not conduct surveys when it was raining, there was heavy cloud (fog) or high wind (exceeding 15 knots, ~27.7 km h^{-1}). We received weather reports from the Navy at Jervis Bay, from which we proceeded with or suspended surveys depending on their forecast for the following morning. We employed these protocols in an attempt to reduce day effects on detection and overcome potential observer heterogeneity problems (Cunningham *et al.* 1999; Field *et al.* 2002).

2007 bird observer experiment

We conducted a field experiment on differences between observers in their detection of birds in September 2007. Our aim was to quantify comparative observer differences that were consistent across sites. We selected five highly experienced observers from the 12 observers involved long-term in the work at Booderee National Park for the experiment. Each observer had a minimum of 15 years experience, but three had been involved in various kinds of field surveys for more than 25 years. We selected ten sites where the Eastern Bristlebird was likely to be detected. For the experiment we followed exactly the same counting protocols as described above for surveys in the major 2003–07 field study.

The experimental design involved each observer visiting four sites on each of 5 days, so that each site was visited by two different observers each day, and each observer visited every site twice. We allocated observers to sites so that all possible pairings of observers would be used on each day. No observer visited the same site twice on the same day. Within these constraints, on each day observers were allocated to sites at random, so that, after the removal of estimated site and day effects, any remaining systematic observer differences would not be confounded with the presence or absence of birds and the detectability of birds at a site on a particular day. We acknowledge that as each observer visited each site twice, the results obtained from the second visit may have been influenced by those from the first survey at the same site.

For our study, 'sites' were sampling units rather than specific territories for which it was appropriate to determine true occupancy. Therefore, although some birds may go undetected, this would not invalidate a comparative investigation like ours.

Statistical analysis

Because survey plots at a site were close together (60 m apart, see above), we did not treat them as independent. Rather, we pooled the two counts by a given individual observer at a given survey site. We considered a bird species to be present at a site if it was recorded by an observer on at least one survey plot.

We fitted quasi-binomial generalised linear models (GLM; McCullagh and Nelder 1989) to the data we gathered for the Eastern Bristlebird in the 2007 experiment, and quasi-Poisson GLMs for species richness data (i.e. the total number of species recorded). We used the statistical program GENSTAT (11th edition, VSN International Ltd, Hemel Hempstead, UK) for all statistical analyses.

For the 2007 experiment, the explanatory factors and variables we considered were: observer; time after dawn (linear and quadratic effects); wind (on a scale of 0, calm, to 4, winds >15 knots, >~27.7 km h^{-1}); cloud cover (on a scale of 0, no cloud, to 4, completely overcast); and site. We assessed the effect of observer differences and the influence of time after dawn, wind and cloud cover by estimating between-site differences with and without adjustment for these effects.

For our data from the major field study, we fitted quasi-binomial and quasi-Poisson GLMs. We considered the effects of observer differences and survey characteristics on the estimated effects of vegetation type and burning rather than individual site effects. We examined effects for: (1) the total number of species recorded, which we term 'species richness'; and (2) three individual bird species – the Eastern Bristlebird, the Eastern Whipbird (*Psophodes olivaceus*) and the Brown Thornbill (*Acanthiza pusilla*).

We used *F*-distribution approximations to deviance ratios to calculate the significance of effects.

Results

2007 bird observer experiment

Overall there were 191 bird detections (i.e. the total number of birds seen or heard by all observers in our experiment) within 25 m of the observers and 599 between 25 and 50 m from the observers. If distance had no effect on the detectability of a bird we would expect three times as many to be observed between 25 and 50 m as were observed within 25 m. The corresponding figures we gathered for the Eastern Bristlebird were 22 and 77. In neither case was there any evidence for departure from the theoretical proportion. In the case of some species, such as the Eastern Whipbird, the proportion of birds observed at a distance of 25–50 m (53 out of 55) was greater than would have been expected by chance. Notably, we did not analyse data for distance categories beyond 50 m because, in many cases, this would have resulted in detections being from a different vegetation type.

We found significant differences between observers for both detections of the Eastern Bristlebird ($F_{4,70} = 7.9$, $P < 0.001$) and for species richness ($F_{4,70} = 19.1$, $P < 0.001$). One observer in particular performed very badly (Table 1). However, when we omitted data for this observer, significant observer differences remained for species richness ($F_{3,52} = 5.4$, $P = 0.002$), but not for Eastern Bristlebird detections ($F_{3,52} = 1.0$, $P = 0.38$).

We identified a significant reduction in Eastern Bristlebird detections with time elapsed since dawn ($F_{1,70} = 10.4$, $P = 0.002$).

However, we found that these effects had little effect on the estimates of differences between sites (Tables 2 and 3), although adjusting for observer differences reduced the standard errors of the estimates appreciably, indicating that the main effect of observer differences was to increase the overall variability of our data.

Observer and other effects in the main study

We gathered extensive data between 2003 and 2007 for over 90 species of birds at Booderee National Park (see Lindenmayer *et al.* 2008b). We chose to focus our analyses of observer (and other) effects using data we gathered immediately after the 2003 wildfire (i.e. 2004). In 2004, our bird data were recorded by the same five observers as in the 2007 experiment (see above) together with five other highly experienced observers with 10 or more years experience in surveying birds in south-eastern Australia.

As in the 2007 experiment, our 2004 survey data contained evidence of highly significant observer differences for all four response variables we examined (Table 4) viz. the Eastern Bristlebird ($F_{9,128} = 2.5$, $P = 0.011$), Eastern Whipbird ($F_{9,132} = 2.7$, $P = 0.007$) and the Brown Thornbill ($F_{9,125} = 4.9$, $P < 0.001$) and species richness ($F_{9,204} = 10.6$, $P < 0.001$). We adjusted species richness for the effects of wind intensity. The effect of wind was not significant, although fewer species were

Table 1. Comparison of probabilities of detecting the Eastern Bristlebird and species richness for different observers in the 2007 experiment (see text)

Observer	Estimated detection probability (±s.e.)	Estimated species richness (±s.e.)
A	0.27 ± 0.070	3.3 ± 0.41
B	0.48 ± 0.080	5.6 ± 0.56
C	0.55 ± 0.075	6.0 ± 0.56
D	0.38 ± 0.079	3.9 ± 0.47
E	0.02 ± 0.022	1.2 ± 0.27

Table 2. Comparison of estimates of probability of detection (±s.e.) of the Eastern Bristlebird after adjusting for differences between observers and time after dawn, adjusting for time after dawn only, and with no adjustment for data from 2007 experiment (see text)

Site	All adjustments	Adjusting for time	No adjustment
6–149	0.22 ± 0.094	0.22 ± 0.117	0.20 ± 0.113
6–42	0.17 ± 0.089	0.16 ± 0.106	0.15 ± 0.100
6–45	0.06 ± 0.061	0.06 ± 0.067	0.06 ± 0.068
6–59	0.16 ± 0.086	0.18 ± 0.115	0.17 ± 0.110
6–76	0.32 ± 0.099	0.34 ± 0.129	0.40 ± 0.138
7–1	0.47 ± 0.111	0.44 ± 0.149	0.44 ± 0.147
7–44	0.38 ± 0.102	0.40 ± 0.137	0.45 ± 0.140
7–44B	0.56 ± 0.101	0.56 ± 0.141	0.60 ± 0.138
7–45	0.53 ± 0.107	0.51 ± 0.150	0.50 ± 0.148
7–68	0.52 ± 0.101	0.52 ± 0.143	0.55 ± 0.140

Table 3. Comparison of estimates of species richness (±s.e.) after adjusting for differences between observers and time after dawn, adjusting for time after dawn only, and with no adjustment based on data gathered from 2007 experiment (see text)

Site	All adjustments	Adjusting for time after dawn	No adjustment
6–149	6.0 ± 0.81	6.0 ± 1.11	5.8 ± 1.09
6–42	5.0 ± 0.76	5.0 ± 1.01	4.7 ± 0.98
6–45	3.6 ± 0.68	3.3 ± 0.86	3.2 ± 0.85
6–59	4.7 ± 0.73	5.1 ± 1.07	4.9 ± 1.05
6–76	5.5 ± 0.75	5.5 ± 1.01	6.0 ± 1.11
7–1	2.8 ± 0.57	2.7 ± 0.76	2.8 ± 0.79
7–44	3.5 ± 0.59	3.5 ± 0.80	3.7 ± 0.87
7–44B	4.0 ± 0.63	4.0 ± 0.86	4.3 ± 0.94
7–45	2.7 ± 0.56	2.6 ± 0.75	2.7 ± 0.78
7–68	2.2 ± 0.47	2.2 ± 0.63	2.3 ± 0.68

Table 4. Estimated probabilities of detecting the Eastern Bristlebird, Eastern Whipbird and the Brown Thornbill, and species richness (all figures ± s.e.) for different observers based on data gathered in the 2004 main study (see text)

Observer	Eastern Bristlebird	Eastern Whipbird	Brown Thornbill	Estimated species richness
A	0.14 ± 0.065	0.29 ± 0.079	0.30 ± 0.085	5.7 ± 0.66
B	0.29 ± 0.069	0.42 ± 0.069	0.49 ± 0.068	9.6 ± 0.74
C	0.42 ± 0.092	0.31 ± 0.085	0.65 ± 0.082	9.5 ± 0.89
D	0.19 ± 0.097	0.30 ± 0.093	0.40 ± 0.092	5.9 ± 0.71
E	0.07 ± 0.043	0.22 ± 0.101	0.15 ± 0.088	4.9 ± 0.76
F	0.31 ± 0.070	0.18 ± 0.058	0.42 ± 0.077	5.2 ± 0.53
G	0.11 ± 0.063	0.11 ± 0.046	0.12 ± 0.044	5.5 ± 0.52
H	0.18 ± 0.081	0.22 ± 0.084	0.38 ± 0.098	6.1 ± 0.81
J	0.10 ± 0.059	0.18 ± 0.079	0.18 ± 0.080	3.0 ± 0.52
K	0.15 ± 0.062	0.07 ± 0.050	0.33 ± 0.075	5.5 ± 0.58

observed for moderate winds compared with light winds and calm conditions. The first five observers in Table 4 were the same five observers that participated in the 2007 experiment (Table 1). The differences were consistent, except that Observer E performed better in 2004 than in the 2007 experiment (Table 4, cf. Table 1). We found that the effects of weather conditions on both species richness and detections of the Eastern Bristlebird were small, although detections of the Eastern Bristlebird varied significantly from day to day ($F_{6,128} = 4.3$, $P < 0.001$) and with time after dawn ($F_{1,128} = 6.5$, $P = 0.012$).

Our 2004 data were obtained during the first survey after the 2003 wildfire, so it was important to estimate the effect of that fire, as well as the differences between vegetation types. To see whether observer differences could be explained in terms of difficulty in identifying uncommon species, which we defined as those that occurred in fewer than 15% of the surveys, we analysed the total number of uncommon species observed as well as species richness. There were 54 such uncommon species from a total of 71 species observed in 2004.

We found that estimates of species richness among different vegetation types changed little irrespective of whether we adjusted for observer effects or no adjustments were made (Table 5). The result was consistent both for all species and uncommon species (Table 5).

We identified similar results for species richness on burned and unburned sites as we described above for vegetation type. That is, adjusting for observer effects made little difference to estimates of species richness for all species and for uncommon species (Table 6). Indeed, the numbers of uncommon species per site were small, showing that the 17 more-common species accounted for most of the differences between observers, between vegetation types, and between burned and unburned sites.

Finally, our results for the estimated probability of detection of the Eastern Bristlebird, Eastern Whipbird and the Brown Thornbill on burned and unburned sites in 2004 changed little if we adjusted for observer effects (Table 7).

Discussion

Our data, both from the 2007 experiment and the 2004 survey, revealed highly significant observer effects. This was apparent

Table 5. Comparison of estimates of species richness (±s.e.), after adjusting for differences between observers, and with no adjustment for the different vegetation types

The results are based on the data gathered in 2004 (see text)

Vegetation type	All species		Uncommon species	
	Adjusting for observer	No adjustment	Adjusting for observer	No adjustment
Casuarina forest	7.5 ± 0.93	7.1 ± 0.94	2.3 ± 0.50	2.1 ± 0.44
Dry heathland	4.9 ± 0.53	4.8 ± 0.57	0.9 ± 0.19	0.8 ± 0.20
Dry shrubland	4.9 ± 0.61	5.4 ± 0.73	1.0 ± 0.25	1.1 ± 0.28
Forest	9.0 ± 0.63	9.1 ± 0.71	2.9 ± 0.33	3.1 ± 0.35
Low shrubland	7.4 ± 0.87	6.4 ± 0.80	1.2 ± 0.33	0.9 ± 0.26
Rainforest	8.2 ± 0.86	8.9 ± 1.04	2.6 ± 0.44	2.8 ± 0.50
Sedgeland	6.0 ± 0.77	6.0 ± 0.86	1.3 ± 0.33	1.3 ± 0.34
Wet heathland	2.9 ± 0.61	3.2 ± 0.74	0.7 ± 0.28	0.8 ± 0.30
Wet shrubland	5.9 ± 1.09	5.1 ± 1.05	1.2 ± 0.48	1.0 ± 0.39
Woodland	5.3 ± 0.40	5.6 ± 0.47	1.4 ± 0.19	1.6 ± 0.21

Table 6. Comparison of estimates of species richness (±s.e.), after adjusting for differences between observers, and with no adjustment for burned and unburned sites

The results are based on the data gathered in 2004 (see text)

	All species		Uncommon species	
	Adjusting for observer	No adjustment	Adjusting for observer	No adjustment
Unburned	8.0 ± 0.37	8.3 ± 0.43	2.0 ± 0.17	2.1 ± 0.18
Burned	4.7 ± 0.27	4.5 ± 0.29	1.3 ± 0.13	1.2 ± 0.13

Table 7. Estimated probabilities (±s.e.) of detecting the Eastern Bristlebird, Eastern Whipbird and the Brown Thornbill with and without adjustment for observer effects for burned and unburned sites

The results are based on the data gathered in 2004 (see text)

	Adjusted for observer	No adjustment
Eastern Bristlebird		
Unburned	0.23 ± 0.043	0.24 ± 0.048
Burned	0.16 ± 0.031	0.16 ± 0.032
Eastern Whipbird		
Unburned	0.34 ± 0.043	0.35 ± 0.045
Burned	0.14 ± 0.027	0.13 ± 0.027
Brown Thornbill		
Unburned	0.46 ± 0.041	0.48 ± 0.046
Burned	0.24 ± 0.035	0.23 ± 0.037

both for species richness and the probability of detection of individual bird species. We conducted detailed analyses of data for survey years in addition to 2004 (i.e. 2003, 2005, 2006; data not shown) as well as for many other bird species in addition to the three ones presented in this paper (data not shown). These analyses produced results similar to the ones we have outlined here. That is, significant observer differences were apparent for every species in every year. Indeed, this occurred even for very common species such as the Brown Thornbill, a finding similar to that of other workers (Pyke and Recher 1985).

Despite the fact that observer differences were large, we were able to show that adjusting for them made only a small difference

to estimates of species richness or the probability of detection of individual species. Thus, we conclude that observer effects would not significantly influence conclusions drawn about bird responses to key environmental factors such as vegetation type or the impacts of the 2003 wildfire (see Lindenmayer *et al.* 2008*a*, 2008*b*). We believe this was an outcome of several key attributes of the design of our main (2003–07) study together with the field protocols that we have used regularly over the past 13 years to gather field data on birds (e.g. see Lindenmayer *et al.* 2002; Cunningham *et al.* 2008).

First, a key attribute was that we averaged over multiple sites in particular vegetation types or fire-history classes. Hence, we argue that it is essential to have replication of sites within treatment classes (e.g. vegetation type or burning history) to overcome the inherent variability that will characterise any one site. This is essential for quantifying *relative* effects across multiple sites in any given treatment class. For example, surveys with multiple observers may result in species richness being underestimated in some cases, but this need not invalidate relative comparisons of species richness across multiple sites in given vegetation types or multiple burned and multiple unburned sites. However, problems may arise when there are only a very small number of sites in a given class.

Second, we pre-screened our field observers to ensure that only highly experienced ornithologists participated in the surveys. Nevertheless, our data showed (e.g. for Observer E in Table 1) that highly experienced observers may not always be highly skilled observers. Large differences, such as those we identified for Observer E, suggest there may be value in researchers examining their datasets for these kinds of effects and perhaps excluding such observers for subsequent surveys where possible.

Third, the field protocol we employed involved counting each site twice using different observers. Moreover, we ensured that during each survey, each observer surveyed sites in different vegetation types as well as sites that were burned in 2003 and those that remained unburned. In an earlier study, Cunningham *et al.* (1999) showed that such a protocol can help limit the extent of observer heterogeneity effects; a finding consistent with the outcomes of the work we report here. An ideal survey design would entail complete randomisation of sites to which observers are allocated – as we have done for the 2007 experiment that we have reported in this paper. However, usually there are major logistical constraints to doing this, particularly when there are a large number of sites that have to be surveyed on a repeated basis by a small number of observers.

Fourth, the field protocol we employed precluded surveying when weather conditions were poor. This served to limit the extent of day effects, an important consideration in counts of birds (Field *et al.* 2002). Nevertheless, we identified some effects of wind and cloud cover, although these were small, most probably because we constrained the weather conditions under which we surveyed as part of our field protocol. In addition, field surveys were time-constrained to ensure that surveys finished within 3–4 h of dawn, when levels of vocalisations by birds tends to decrease (Cunningham *et al.* 2004).

All of the data we have presented show that it was possible to take observer differences into account and adjust species richness or detection data accordingly. This can be important as it might

help increase the precision of inferences made from surveys where multiple observers are required by necessity. Another important outcome of the experiment and other analyses we have presented in this paper, was that it enabled us to perform a test of observer ability and identify which observers, if any, were performing poorly (e.g. Table 1). We also were able to discern that much of the source of observer differences came from detections of the common species rather than uncommon ones (Tables 5 and 6), a result consistent with the findings of earlier work (e.g. Pyke and Recher 1985). This suggested that improved observer performance might be achieved by improving skills in detecting the more common species of birds. Notably, we did not identify substantial distance effects between the 0–25 m and 25–50 m categories for which we analysed bird data in the 2007 experiment. This suggests that some of the differences we found between observers were not strongly influenced by distance but rather by other factors, such as a failure to detect particular species of birds, for example those with high-frequency vocalisations.

In summary, our studies have shown that observer heterogeneity can be large and it is critically important to be aware of these effects in gathering and then interpreting field survey data. However, particular approaches to field survey protocols and experimental design can limit the extent to which observer effects can influence the inferences made from field data. These are to: (1) have high levels of replication of different classes of sites to enable robust relative comparisons to be made; (2) complete repeat surveys of sites with different observers on different days; and (3) preclude surveys on days of poor weather. These features of our survey design and protocols might be useful for other workers to follow as part of increasing the quality of field data gathered in large-scale bird surveys involving multiple observers.

Acknowledgements

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Appendix.   Description of the major vegetation types at Booderee National Park

Six broad vegetation types were recognised. Several sub-types were recognised within the broader types of 'Forest', 'Heathland' and 'Shrubland' so that a total of ten vegetation types or sub-types were surveyed for birds (see text and Table 5)

Rainforest	The overstorey of rainforest is dominated by *Eucalyptus pilularis* and *E. botryoides* with scattered *Livistona australis* and *Acmena smithii*. The mid-storey comprises *Endiandra sieberi*, *Pittosporum undulatum*, *Elaeocarpus reticulata* and *Synoum glandulosum*. Understorey species include *Lomandra longifolia*, *Pteridium esculentum* and *Cissus hypoglauca*. Rainforests comprise ~1% of the vegetation cover of Booderee National Park.
Forest	*Forest* typically has an overstorey dominated by *Eucalyptus pilularis*, *Corymbia gummifera* and *E. botryoides*. The mid-storey is dominated by *Banksia serrata*, *Acacia longifolia* and *Monotoca eliptica* with *Elaeocarpus reticulatus* occurring on moister sites. The understorey is dominated by *Pteridium esculentum* and *Lomandra longifolia*. A sub-type of forest is dominated by *Casuarina glauca* interspersed with *Eucalyptus botryoides* and *B. integrifolia*, and with a mid-storey and understorey of *B. integrifolia*, *C. glauca*, *Chrysanthemoides monilifera*, *L. longifolia*, *P. esculentum* and *Hibbertia scandens*. Forest is the most extensive vegetation type in the study area, comprising ~50% of the native vegetation cover of Booderee National Park.
Woodland	The woodland vegetation type is a community where the tree crowns are clearly separated. The overstorey is typically comprised of *Eucalyptus sclerophylla, Corymbia gummifera* and *Banksia serrata*. The mid-storey is mainly comprised of *B. serrata* and *C. gummifera*. The understorey comprises *Pteridium esculentum, B. serrata, Lambertia formosa, Acacia longifolia, A. suaveolens* and *Lomandra longifolia*. Approximately 15% of the native vegetation cover of Booderee National Park is woodland.
Heathland	*Heathland*, as defined by Taws (1998), is vegetation dominated by shrubs with small narrow leaves, usually growing to less than 2 m tall. There are two sub-types of heathland in Booderee: (1) Dry heathland, which is dominated by *Banksia ericifolia, Allocasuarina distyla, Isopogon anemonifolius* and *Hakea teretifolia*; and (2) Wet heathland, which is mainly dominated by *B. ericifolia* but may also be dominated by *Leptospermum or Meleleuca* species; *Gahnia clarkei* and *Gleichenia dicarpa* are also prevalent. The two sub-types of heathland together comprise ~18% of the native vegetation cover of Booderee National Park.
Shrubland	*Shrubland* is dominated by shrubs growing to greater than 2 m tall (Taws 1998). Three sub-types were recognised by Taws (1998). (1) Low shrubland occurs on coastal foredunes where it was planted for dune stabilisation in the 1960s and 1970s. It is dominated by *Leptospermum laevigatum, Acacia sophorae* and *Chrysanthemoides molinifera*. (2) Dry shrubland is dominated by shrubs growing to greater than 2 m tall. It is dominated by *B. serrata, L. laevigatum* and *B. integrifolia*. The understorey is often sparse due to the dense growth of the midstorey. The understorey is often sparse owing to the dense growth of the mid-storey. Typical understorey species are *Pteridium esculentum, Lomandra longifolia* and *Hibbertia scandens*. (3) In Wet Shrubland, soils are often waterlogged and the species composition is determined by the period of inundation and the saline content of the soils. More saline soils are dominated by dense post-fire regrowth of *Melaleuca ericifolia* with a sparse overstorey of *Casuarina glauca*. Less saline soils are dominated by *Melaleuca squarrosa* and *Leptospermum juniperinum*. Approximately 10% of the native vegetation cover of Booderee National Park is shrubland.
Sedgelands	*Sedgelands* are classified by Taws (1998) as herbaceous communities occurring on soils that are periodically or permanently waterlogged. Those sites not permanently waterlogged are dominated by *Baumea, Eleocharis* and *Schoenus* species. Those with permanent waterlogging are dominated by *Gahnia clarkei, Lepidosperma forsythii* or *Isolepis nodosa*. Sedgeland covers 2% of Booderee National Park.