Can owls be used to monitor the impacts of urbanisation?
A cautionary tale of variable detection

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Abstract

Context. Due to their important ecological roles, predators are increasingly being suggested as targets for biodiversity studies investigating how they respond to landscape change and transformation. But there is limited literature investigating our capacity to accurately monitor changes in their occupancy.

Aims. To test the efficacy of playback surveys for monitoring owls as a basis for investigating change in owl occupancy over time. We ask whether playback is an effective tool, and whether it can be optimised to improve its utility.

Methods. Using the urban–forest interface of Melbourne, Australia, as a case study, we used playback techniques to survey for the presence of three owl species: the powerful owl (*Ninox strenua*); southern boobook (*Ninox boobook*); and eastern barn owl (*Tyto javanica*). Sites were repeat surveyed at least 16 times throughout the year and occupancy models were developed to establish how season and temperature influence nightly detection probabilities of owls.

Key results. All three species of owl were detected through playback survey approaches, but the detection probabilities varied greatly between species and across seasons and temperature conditions. Eastern barn owls are poor candidates for playback surveys due to their low detection probabilities. The southern boobook and powerful owl are responsive to playback, but detection probabilities are influenced by season and/or temperature conditions. To optimise survey approaches, southern boobooks should be surveyed during spring and summer and the powerful owl should be surveyed on nights where the minimum temperature is near 20°C.

Conclusions. Although there is considerable interest in using predators such as owls to monitor biodiversity impacts associated with landscape change, poor detection rates can limit their utility. However, optimising survey approaches that consider shifting detection probabilities under different conditions such as time of year or temperature may improve the utility of predators as surrogates in biodiversity monitoring.

Implications. Optimising survey approaches for owls considerably reduces the window of opportunity in which to conduct surveys. To counter this, the intensity of survey effort needs to be increased during key periods. The use of highly trained citizen science teams may be one effective way of delivering such an approach.

Introduction

As species loss continues to occur at unprecedented rates globally, it is paramount that we adopt robust methods to monitor changes in species distribution over time (Isaac *et al.* 2014*a*). Different methods of species detection are well documented; however, optimising the efficiency of these methods is often less well understood, especially when monitoring predators that occur at low densities, are cryptic in nature and can be notoriously difficult to detect.

Top-order predators are thought to play vital roles in ecosystems and may have utility as umbrella species (e.g. Simberloff 1998; Sergio *et al.* 2006; Roth and Weber 2008) because they have large spatial requirements and are often sensitive to landscape-scale modification (Sergio *et al.* 2008),

making them one of the first groups of species lost from a system when conditions are not optimal. The literature is far from settled in regard to using predators as indicators of environmental health (see Sergio *et al.* 2008 for review). However, they are widely considered as having some utility as indicators of the health of an ecosystem. A major issue with using predators as indicators of environmental change is that they are difficult to monitor. Poor detectability can mean metrics such as change in occupancy (the species does or does not occur in a particular site or area) over time lack the precision necessary to confidently discern trends.

Raptors, like many predators, are considered difficult to detect (confidently establish they are in an area, by seeing or hearing them) and monitor, and most owls have the added logistical complication of being nocturnal. There are several survey

approaches, all of which depend on the landscape scale of the research question. For large-scale research, fixed-route surveys with listening stations is recommended (Takats *et al.* 2001). Site-specific occupancy and breeding data can be gathered through monitoring areas for occupancy of breeding pairs (Olsen and Trost 2015) and the use of call playback (Zuberogoitia and Campos 1998). In the present paper, we focus specifically on the use of call playback as a method for establishing occupancy in owls, which involves the broadcasting of owl calls through a speaker to elicit a response (e.g. an owl flying into the area or calling). Because owls often exhibit high territoriality, the theory is that any resident owl will respond to the playback as a defence mechanism (Redpath 1994). However, the level of success with call playback is highly variable and often species dependent (e.g. Ritchison *et al.* 1988; Galeotti 1990; Wintle *et al.* 2005).

Previous assessments of how call playback can be optimised have recommended that survey effort should focus on the breeding season (Flesch and Steidl 2007), reduce ambient noise where possible (Ibarra *et al.* 2014) and consider external abiotic factors such as temperature, wind speed and moon phase (Takats *et al.* 2001; Braga and Motta-Junior 2009). However, the success of call playback is difficult to quantify. The obvious measure of success is a response from a resident owl but does no response actually mean there is no owl present? Determining an absence with certainty is as difficult as, if not more difficult than, determining a presence for many owl species. How many playback surveys are needed at a site to be confident in assigning a site as being unoccupied? Is our capacity to detect owls uniform throughout time and across species? In the present study, we investigated how call playback might be used as a tool for establishing occupancy of owls, and established a baseline to investigate long-term changes in occupancy in relation to urbanisation. We chose the urban fringe of Melbourne, Australia, as a case study, where we expected variable occupancy and a high likelihood of change through time. This is the type of landscape where data on long-term occupancy would be valuable. Urbanisation is one of the most dramatic land-use changes that can be made to a landscape (McKinney 2002) and, as such, the ideal type of landscape where monitoring of a predator could be utilised to understand modifications to ecosystem health. Focusing on three owl species, we used call playback surveys across multiple seasons to establish:

(1) The effectiveness of call playback for monitoring nocturnal owls;
(2) Whether detection rates for these species differ with time of year;
(3) Whether detection rates for these species are influenced by temperature; and
(4) Optimal survey approaches that reduce the number of site visits required to establish accurate estimates of site occupancy.

Methods

Study area

Melbourne is the second largest city in Australia, with a population of ~4.5 million people (Australian Bureau of Statistics 2016). Over the last 10 years, Melbourne has had the greatest population growth of all Australia's capital cities and consequently urban expansion and intensification has occurred in many outer suburban areas (Australian Bureau of Statistics 2016). In an attempt to constrain urban growth, an Urban Growth Boundary (UGB) has been developed to separate the urban landscape from the forested landscape (Department of Infrastructure 2002). The UGB designates that the Melbourne city side of the boundary contains the urban landscape and the opposing side remains undeveloped and primarily forested. The region between the highly urbanised landscape and forested environment (i.e. the urban–forest interface) is important for future conservation efforts as it is currently moderately disturbed and maintains remnant habitat vital for the survival of native species (Andrén 1994; McKinney 2006). However, as urbanisation intensifies in this area, it is critical to develop a clearer understanding of the ecological features that need to be protected to maintain ecological integrity of the urban–forest interface (Weaving *et al.* 2011).

To define the urban–forest interface for this research, a 3-km buffer was established either side of Melbourne's UGB. There is little sign of urbanisation 3 km out from the UGB (away from the city of Melbourne), with the majority of the landscape consisting of the natural environment and low-intensity agriculture (Fig. 1). Just 3 km in on the city side of the UGB, there is an increase in the extent and intensity of urbanisation (Fig. 1).

Study sites

After defining the urban–forest interface, several potential study sites were generated using ArcGIS 10.0 (ESRI 2011). A minimum of 2 km was maintained between each site to account for the large home ranges of the target species and to minimise the potential of recording the same individuals at multiple sites. A 2×2 km grid was overlaid using the fishnet tool in ArcGIS 10.0 (ESRI 2011), generating a set of potential points for site selection. From these points, 55 study sites were randomly selected for this research covering the entire urban–forest interface (Fig. 1). Highly urbanised areas with high proportions of impervious surfaces (above ~40%) and in close proximity to major roads were excluded because these areas were considered unsuitable due to ambient noise interfering with surveys and possible disruption to residents. Prior research also indicated that highly urbanised areas are not often utilised by owls (Weaving *et al.* 2011). Daytime visits were undertaken to each site to confirm that site conditions matched the geospatial layers and GPS waypoints were taken to record the exact location of each site.

Target species

Three non-migratory owl species were selected for this research, the southern boobook (*Ninox boobook*), the powerful owl (*Ninox strenua*) and the eastern barn owl (*Tyto javanica*). The southern boobook is a common, widespread species throughout Australia (Higgins 1999), surviving in a wide variety of habitats (Olsen and Taylor 2001). It has been shown to occupy remnant vegetation in urban environments, but requires tree hollows for nesting and will also regularly utilise them for roosting (Weaving *et al.* 2011). Powerful owls were selected because, although they display some tolerance
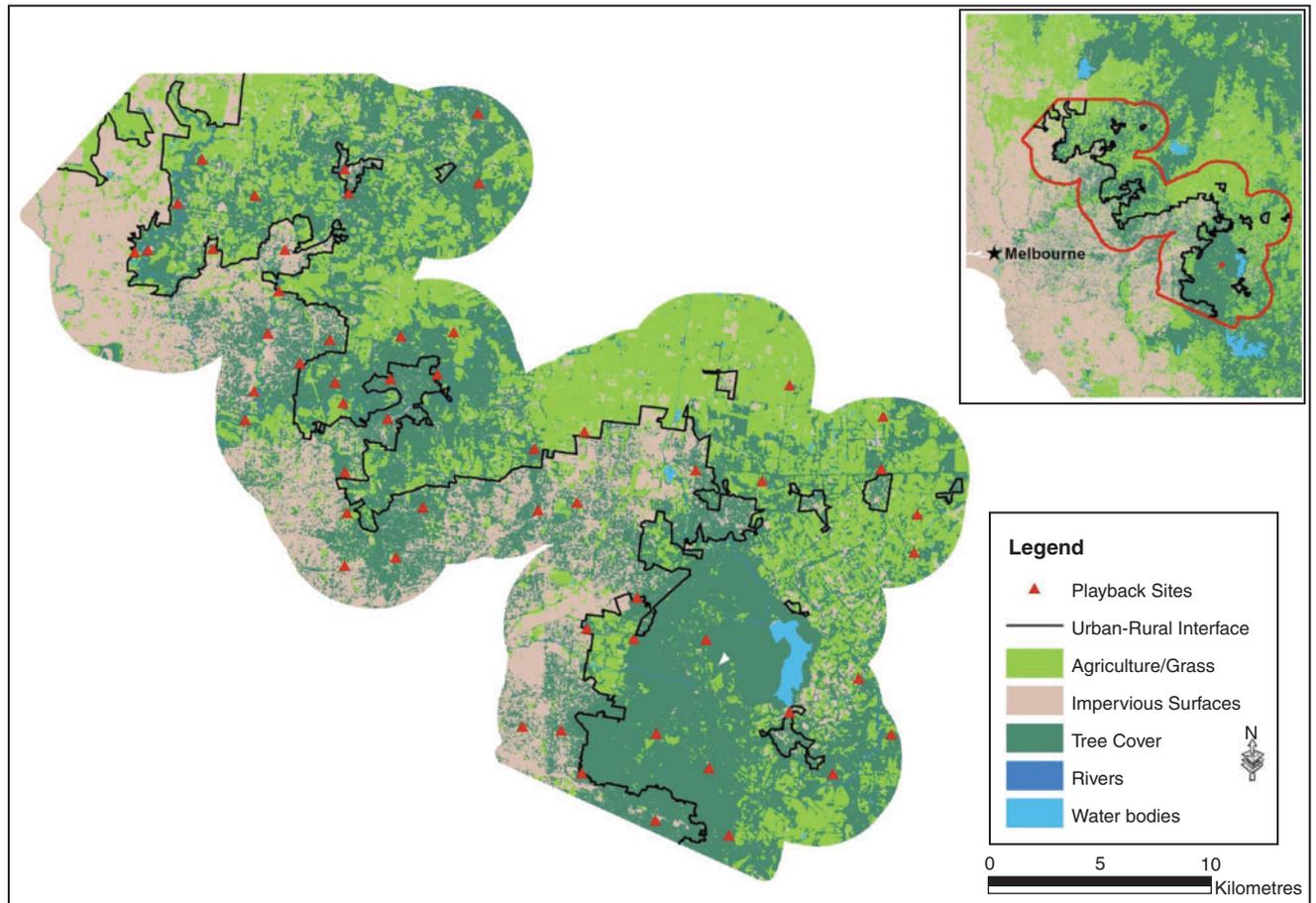
Fig. 1. Study site showing Melbourne Urban Growth Boundary (black) with a 3-km buffer applied to create the urban–forest interface. Triangles represent the 55 study sites selected throughout the landscape in relation to varying land uses.

to urbanisation, they require extensive tree cover, a prey base of arboreal marsupials and large tree hollows for breeding (Cooke *et al.* 2006; Isaac *et al.* 2013, 2014*b*; Bradsworth *et al.* 2017). The eastern barn owl was chosen because there has been very little research on aspects other than diet on this species in Australia. The barn owl is largely an open-country, hollow-nesting raptor that preys predominantly on small terrestrial mammals (Kavanagh 2003; Debus *et al.* 2008).

Survey approach

Call playback surveys were completed at all 55 sites to determine the presence of the southern boobook, the powerful owl and the barn owl. An iPod with specifically designed tracks of each species' calls and a megaphone were used to project the calls. The volume at which the calls were broadcast was tailored for each site to account for varying forest densities impacting the ability of the sound to travel (Grossman *et al.* 2008). Calls were projected at a volume sufficient to survey the site without calling individuals from other sites (Grossman *et al.* 2008). At each site, calls were played at a volume where another researcher could hear them from ~300 m away.

Surveys were conducted over a 12-month period (September 2012–August 2013) to determine the presence of the target

species. Surveys were repeated at least 16 times (4 times each season) at each site to account for the expected low detection probabilities encountered when surveying owls (Wintle *et al.* 2005). On each survey night, up to five individual sites were surveyed provided weather conditions were satisfactory. No surveys were undertaken in the rain or on windy nights. At each site, surveys commenced with 2 min of listening before call playback was initiated, to determine whether any species were already calling (Weaving *et al.* 2011). If a species was calling, that particular species' call was not played during the survey as per our permit requirements.

The calls of each species were then played for ~2 min, with a waiting period of 2 min after each call to listen for a response. After each species was called once (sequence 1), the sequence was repeated, leaving out only the first step (listening for species calling). After the final species call was played in sequence 2, a final 2 min was spent listening. During the final 2 min listening period spotlight surveys were undertaken to determine if any owls had flown into the site undetected. Therefore, the total duration of a complete survey at a site was ~30 min.

The time each site was visited throughout the night (e.g. dusk as opposed to midnight) and the order the species' calls were played may have resulted in different responses (e.g. the powerful owl may respond better if called first opposed to second or last),

so these factors were randomised to avoid any bias (Weaving *et al.* 2011).

Climatic data was obtained from the Bureau of Meteorology's data services (Bureau of Meteorology 2016) with values averaged across all weather stations within the study area ($n = 4$) for each survey night. In the event of strong winds and/or rain, surveys ceased until weather conditions improved or surveys were abandoned and resumed on a different night.

Statistical analysis

Single-species single-season occupancy models (MacKenzie *et al.* 2002) were used to identify the factors influencing the detectability of southern boobooks, powerful owls and barn owls. Alternative models such as the multi-season model (MacKenzie *et al.* 2003) enable the consideration of colonisation and extinction probability between sampling periods. These additional parameters within this model were not considered to be of ecological significance within this study given the high site fidelity of raptor species (e.g. Newton 1979; Newton and Marquiss 1982; Jenkins and Jackman 1993) and the comparatively short survey period of 12 months. A set of candidate models were developed to test the influence of environmental variables on southern boobook, powerful owl and barn owl detectability. Site occupancy was held constant across all models with detection probability modelled against survey-specific covariates including season, minimum night time temperature and maximum day time temperature. Season was considered as either spring/summer or autumn/winter. Where model-selection uncertainty existed, the Akaike Information Criterion (AIC) was used to determine the most parsimonious model. Nagelkerke's (1991) *R*-squared index was used to quantify the proportion of variation explained by each model. Site occupancy for each species was estimated from each top model (i.e. accounting for detectability of the species), with naive site occupancy calculated as the total number of sites where a species was detected (i.e. not accounting for detectability). The number of survey nights required to confidently determine a site-specific absence of a species was determined at the 80%, 90% and 95% levels using the formula:

$$P = 1 - (1 - p_1) \times (1 - p_2) * (1 - p_3) \ldots (1 - p_n)$$

where P is the cumulative nightly detection probability, p_1 is the detection probability for night one, and n is the total number of survey nights. All analyses were run in R (R Development Core

Team 2015), with occupancy models run in the 'unmarked' package (Fiske and Chandler 2011).

Results

In total, 897 surveys were undertaken across the 55 sites (mean = 16.3, median = 16) within the urban–forest interface of Melbourne's eastern suburbs (Fig. 1). The southern boobook was detected on 22% of visits, representing a naive site occupancy of 80%. During spring/summer, they were detected on 30% of visits with a naive occupancy of 67%, compared with autumn/winter, when they were detected on 14% of site visits with a naive occupancy of 56%. The powerful owl was detected on 3% of visits, representing a naive site occupancy of 35%. During spring/summer, the powerful owl was detected on 4% of site visits with a naive occupancy of 20%, compared with autumn/winter, when they were detected at 3% of sites with a naive occupancy of 18%. The barn owl had poor detection throughout the survey and was only detected on 1.9% of visits during spring/summer and 2.5% during autumn/winter, representing site occupancy of 15% and 11% respectively. Over the entire year, barn owls had a naive occupancy of 27% and, due to poor detection, an estimated occupancy of 56%.

Consideration was given to whether the order that owl calls were played had any influence over the detectability of species within this study. Calling a more dominant species (i.e. powerful owl) before calling a smaller, less dominant species (i.e. southern boobook) may reduce the responsiveness of the smaller species when its call is played. Order of owl calls was included as a factor influencing the detectability of each species within a single-species single-season occupancy model. No support was given to the influence of order of calls on either eastern barn owl or powerful owl detectability with both models receiving less support than a constant model (AIC $\omega_i = 0.03$ and 0.12 respectively) (Table 1). The order of owl calls did have an influence on the detectability of southern boobooks (AIC $\omega_i = 0.58$) when compared with a constant model (AIC $\omega_i = 0.42$). This model predicted that southern boobooks are less responsive to call-playback when powerful owl calls are played beforehand, but this was not statistically significant. These results suggest the order of calls may have been a minor influence on southern boobook detectability, but this influence was consistent across sites and likely to result in a slight underestimate of detection probabilities. It was therefore not considered in subsequent models.

Table 1.   Influence of order of owl calls on detectability of southern boobooks, powerful owls and barn owls across Melbourne's urban–forest interface

Values represent the number of parameters (K), the Akaike Information Criterion (AIC), AIC differences (ΔAIC), Akaike weights (AIC ω_i) and Nagelkerke's *R*-squared index (R^2). Model parameters include: site occupancy (psi) and detection probability (*p*). Model covariates include: constant (.) and order of owl calls (order)

Species	Model	K	AIC	ΔAIC	AIC ω_i	R^2
Southern boobook	psi(.) *p*(order)	7	908.10	0.00	0.58	0.18
	psi(.) *p*(.)	2	908.74	0.64	0.42	0.00
Powerful owl	psi(.) *p*(.)	2	255.77	0.00	0.88	0.00
	psi(.) *p*(order)	7	259.69	3.92	0.12	0.11
Barn owl	psi(.) *p*(.)	2	193.87	0.00	0.97	0.00
	psi(.) *p*(order)	7	200.95	7.07	0.03	0.05

Southern boobook

A series of candidate models were run in which site occupancy was held constant. Model selection uncertainty existed, with the two top models having ΔAIC values <2. A seasonal influence on detectability was found to be the top model, with season and maximum daily temperature receiving some support (Tables 2, 3). The season in which surveys were conducted influenced nightly detectability with detections considerably higher during spring/summer than autumn/winter ($\beta = -1.066 \pm 0.18$, $P < 0.001$); overall, nightly detection probabilities in spring/summer were far more favourable than those in autumn/winter (Table 4). Although maximum daily temperature appeared in the second-top model, it had limited influence on boobook detectability ($\beta = -0.007 \pm 0.02$, $P = 0.670$). Our two top models had moderate explanatory power ($R^2 = 0.50$ and 0.51 respectively). Minimum nightly temperature was a poor predictor of southern boobook detectability (Table 2). The modelled site occupancy estimates were similar to the naive estimates, suggesting we can have reasonable confidence in

assigning absences for the southern boobook (Table 4). In context, these results suggest that three survey nights would be required to be 95% confident of a site-specific absence during spring/summer compared with a total of seven survey nights during autumn/winter (Fig. 2).

Powerful owl

Candidate models were run with site occupancy held constant. There was some model selection uncertainty, with two top models having ΔAIC values <2. Most support was given to minimum nightly temperature as a predictor for powerful owl detectability as the top model, with some support for a seasonal effect and minimum nightly temperature (Tables 2, 3). Minimum nightly temperature had a significant, positive influence on powerful owl detectability, with higher nightly temperatures increasing the likelihood of detection ($\beta = 0.106 \pm 0.05$, $P < 0.05$). A seasonal effect was also found to influence powerful owl detectability, with higher probabilities in summer than winter, but this was not significant ($\beta = -0.077 \pm 0.45$, $P = 0.87$). These models had

Table 2. Candidate models of the influences on detectability of southern boobooks, powerful owls and barn owls across Melbourne's urban–forest interface

Values represent the number of parameters (K), the Akaike Information Criterion (AIC), AIC differences (ΔAIC), Akaike weights (AIC ω_i) and Nagelkerke's **R**-squared index (R^2). Model Parameters include: site occupancy (psi) and detection probability (**p**). Model covariates include: constant (.), seasonal effect (season), minimum night time temperature (mintemp) and maximum day time temperature (maxtemp)

| Species	Model	K	AIC	ΔAIC	AIC ω_i	R^2
Southern boobook	psi(.) *p*(season)	3	872.21	0.00	0.56	0.500
	psi(.) *p*(season + maxtemp)	4	874.02	1.81	0.23	0.510
	psi(.) *p*(season + mintemp)	4	874.20	2.00	0.21	0.500
	psi(.) *p*(maxtemp)	3	895.27	23.07	0.00	0.250
	psi(.) *p*(mintemp)	3	901.37	29.16	0.00	0.160
	psi(.) *p*(.)	2	908.74	36.54	0.00	0.000
Powerful owl	psi(.) *p*(mintemp)	3	253.00	0.00	0.47	0.084
	psi(.) *p*(season + mintemp)	4	254.97	1.97	0.17	0.085
	psi(.) p(.)	2	255.77	2.78	0.12	0.000
	psi(.) *p*(maxtemp)	3	255.92	2.92	0.11	0.033
	psi(.) *p*(season)	3	256.27	3.27	0.09	0.027
	psi(.) *p*(season + maxtemp)	4	257.76	4.76	0.04	0.036
Barn owl	psi(.) *p*(.)	2	193.87	0.00	0.31	0.000
	psi(.) *p*(maxtemp)	3	194.63	0.76	0.21	0.023
	psi(.) *p*(mintemp)	3	194.79	0.91	0.20	0.020
	psi(.) *p*(season)	3	195.58	1.71	0.12	0.005
	psi(.) *p*(season + maxtemp)	4	196.53	2.66	0.08	0.025
	psi(.) *p*(season + mintemp)	4	196.79	2.91	0.07	0.020

Table 3. Beta coefficients for parameters included within models with a ΔAIC <2

Model formula and parameters are included with '*' identifying a parameter as significant at the 5% level. Coefficient values and standard errors (s.e.) are included

Species	Model	Parameter	Coefficient	s.e.
Southern boobook	psi(.) *p*(season)	Season*	−1.066	0.177
	psi(.) *p*(season + maxtemp)	Season*	−1.134	0.236
		Maximum daily temperature	−0.007	0.017
Powerful owl	psi(.) p(mintemp)	Minimum nightly temperature*	0.106	0.048
	psi(.) *p*(season + mintemp)	Season	−0.077	0.453
		Minimum nightly temperature	0.101	0.056

Table 4.   Seasonal nightly detection probabilities for southern boobooks, powerful owls and barn owls across Melbourne's urban–forest interface

Values represent the naive and estimated site occupancy (ψ), nightly detection probability (P) and standard errors (s.e. (P)) as well as the number of nights required to have 80%, 90% and 95% confidence of a site-specific absence. Detection probabilities were predicted between seasons where this was included within the top models. Nightly detection probability between seasons was estimated from the models psi(.)p(season) for each species (see Table 1)

Species	Season	Naive ψ	Estimated ψ	P	s.e. (P)	80%	90%	95%
Southern boobook	Spring/summer	0.800	0.804	0.637	0.060	2 (1.2–2.2)	3 (1.7–3.2)	3 (2.2–4.1)
	Autumn/winter			0.377	0.026	4 (2.9–4.1)	5 (4.1–5.8)	7 (5.4–7.5)
Powerful owl	Spring/summer	0.346	0.548	0.108	0.061	14 (5–46)	20 (7–66)	26 (9–86)
	Autumn/winter			0.070	0.022	23 (12–43)	32 (17–61)	42 (22–79)
Barn owl	Combined	0.273	0.563	0.039	0.016	41 (18–93)	58 (26–133)	75 (33–173)
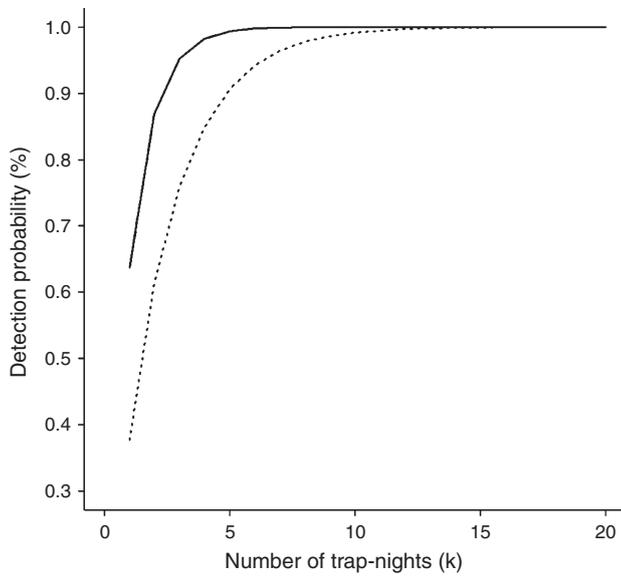
Fig. 2. Cumulative nightly detection probability for southern boobooks within spring/summer (solid line) and autumn/winter (dot line).
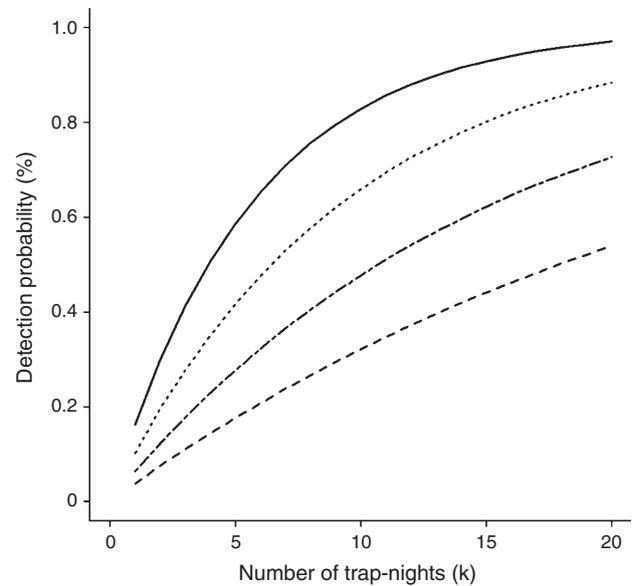
Fig. 3. Cumulative nightly detection probability for powerful owls with a minimum nightly temperature of 20 degrees (solid line), 15 degrees (dotted line), 10 degrees (dashed–dotted line) and 5 degrees (dashed line).

Table 5.   Survey effort required to detect powerful owls given modelled parameter estimates for minimum nightly temperatures of 5°C, 10°C, 15°C and 20°C

Values represented estimated nightly detection probability for each temperature and the number of nights required to be confident of a site-specific absence

Minimum nightly temperature	Estimate P	80%	90%	95%
5°C	0.038	42 (21–88)	60 (29–125)	78 (38–163)
10°C	0.063	25 (14–45)	36 (21–64)	47 (27–83)
15°C	0.102	15 (8–32)	22 (11–46)	28 (14–59)
20°C	0.162	10 (4–27)	14 (5–39)	17 (7–50)

limited explanatory power ($R^2 = 0.08$ and 0.08 respectively) (Table 2). Powerful owls were shown to have been under-detected throughout the study, with an estimated site occupancy of 0.55 compared with a naive site occupancy of 0.35 (Table 4). To determine the seasonal effect on powerful owl detectability, nightly detection probability was predicted across each season. Nightly detection probability varied with season, with higher likelihood of detection in spring/summer compared with autumn/

winter. The number of nights required to be confident of site-specific absences reflected the species' poor detectability, with 26 nights required during spring/summer compared with 42 nights required during autumn/winter (Table 4). Parameter estimates were predicted from the top model to determine the nightly detection probability for survey nights with differing minimum temperatures. The number of nights required to be confident of a site-specific absence was determined for temperatures of 5°C, 10°C, 15°C and 20°C (Table 5, Fig. 3). Given 20 survey nights, 95% confidence in absence is only obtainable should these be on evenings with minimum temperatures above 20°C.

Eastern barn owl

Candidate models were run with occupancy held constant. Model selection uncertainty existed, but the null model was the top model, reflecting data deficiency and an inability to discern trends from these data. Site occupancy was estimated from a constant model and was considerably higher than our naive occupancy estimate (Table 2). No attempt to determine seasonal effects of detectability was made. In order to be 95%

confident in a site-specific absence, a total of 75 survey nights would be required; 41 survey nights would be required for 80% confidence (Table 4).

Discussion

The use of call playback as a detection method for establishing site occupancy for non-migratory nocturnal raptors certainly has merit; however, the level of success varies both between species and across different times of the year and different temperatures. This has significant implications for the utility of owls in studies investigating change in occupancy through time or simply the establishment of occupancy for any study.

We found playback was a useful method of detection for both the southern boobook and the powerful owl, as has been reported in the detection of other owls, including spotted owls (*Strix accidentalis*; Rinkevich and Guitierrez 1966), screech owls (*Otus asio*; Carpenter 1987) and tawny owls (*Strix aluco*; Redpath 1994). Playback as a detection method for eastern barn owls was ineffective in our study, supporting previous research such as Sara and Zanca (1989) on barn owls (*Tyto alba*). Zuberogoitia and Campos (1998) supported the use of playback as a detection method for barn owls to some extent, but they found that playback on barn owls was seasonal and weather dependant –very good results could be obtained during the breeding season but the method was ineffective in the winter or bad weather conditions. We found eastern barn owl detection via playback to be very low at all times of year, including during the breeding season. Playback for eastern barn owls was likely to have been ineffective if their behaviour is similar to the barn owls (*Tyto alba*) in Britain, which are not considered to be territorial and the areas they occupy are vast (Barn Owl Trust 2012).

The detectability of both the southern boobook and powerful owl were influenced by the time of year and the temperature when surveys were undertaken. We also showed a weak influence of order in which species calls were played, with slightly lower detection if powerful owl calls were played before the smaller southern boobook. Although both species were detected throughout the year, detection was much greater in the spring/summer period, particularly on warmer nights. The southern boobook was the most responsive to playback and required only three nights of playback to be 95% confident of a site-specific absence in spring/summer, compared with seven nights in autumn/winter. These findings support previous studies by Olsen *et al*. (2002), who found that calling behaviour varied with season, although their study used unsolicited calling behaviour to establish occupancy. This seasonality to responsiveness may reflect the species' breeding cycle, during which individuals may display more territorial behaviour (Olsen *et al*. 2011). Similar observations have been made for the ferruginous pygmy-owl (*Glaucidium brasilianum cactorum*), for which detectability during the breeding season approached 100% (Flesch and Steidl 2007). Conversely, Kavanagh and Peake (1993) found no seasonal differences in detectability of southern boobooks but did experience higher detection rates on nights with little or no wind, no visible moon and clear skies.

Detection of the powerful owl varied primarily with temperature and season. Higher detectability was observed in the spring and summer months compared with the autumn and winter, but the low detectability of this species means caution is required when interpreting these results. The number of nights required to be confident in an absence was 26 in the spring/summer and 42 in the autumn/winter. These results are consistent with Wintle *et al*. (2005), who found that 18 site visits were required to be 90% confident of a powerful owl absence in average survey conditions in forest environments. The trend of increased detectability throughout spring and summer, the species' non-breeding season, would seem counter intuitive but may reflect a period where pairs spend less time together and therefore naturally use calls more to maintain contact. The heightened responsiveness of powerful owls when the minimum nightly temperature is high is interesting, and suggests that surveying on nights with minimum temperatures around 20°C may reduce the survey effort required to be confident in site-level absences. Similar trends have been observed in the tropical screech owl (*Otus choliba*), which was found to respond more when temperature and humidity levels were higher (Braga and Motta-Junior 2009).

So, does playback have utility for surveying owls to measure the influence of land degradation processes such as urbanisation? It is clear from our results that a certain degree of caution needs to be taken if this is the ultimate goal. Detection probabilities of eastern barn owls were extremely low using playback, and we suggest they would not be a suitable candidate for such studies. In the case of both the southern boobook and the powerful owl, we have demonstrated that nightly detection probabilities are influenced by the time of year and/or temperature based metrics. Given this, how can we optimise survey approaches to improve the efficiency and utility of southern boobooks and powerful owls for assessing landscape change or other studies requiring estimates of occupancy? As a starting point, we suggest that there is limited value in conducting surveys for both species during the cooler times of the year (autumn and winter). Targeting survey effort towards the spring and summer would improve the survey efficiency for both species. While there is an operational attraction in conducting surveys in winter, when the nights are long, presenting longer potential survey periods, low detection probabilities negate this benefit. Further, we have also demonstrated that powerful owl survey success improves with increased minimum nightly temperatures. We therefore suggest that an ideal approach would be to limit survey effort to the spring and summer months on nights where minimum nightly temperatures are likely to be near or above 20°C. This poses several significant challenges. First, nights are shorter when these conditions are present, and second, there are a limited number of nights a year that will meet these criteria. During our research, we limited surveys to five sites a night, but it may be necessary to conduct surveys throughout the night to take better advantage of the optimal conditions. Although this might present a significant operational challenge, this could be achieved through the utilisation of a coordinated, well-trained network of citizen scientists conducting simultaneous surveys at predetermined locations throughout the study area. The co-ordination of surveys and citizen science teams is time consuming, but if it allows for the majority of surveys to be conducted under the best conditions for maximising detection, the benefits should outweigh the organisational requirements.

It is also worth having a consistent order for playing owl calls for different species. In the present study, we randomised the playback order, but we have demonstrated weak evidence to suggest order may influence detection of the southern boobook. Interspecies aggression and predation is well documented in owls (Sergio *et al.* 2007) and, as such, careful consideration should be given to whether multiple species need to be surveyed. In situations where there is likely to be aggression from larger species on a subordinate, it is desirable to only survey for one species at a time at a given location.

This research presents a cautionary tale to all researchers and organisations trying to monitor predators such as owls for various reasons, including pre-logging forestry assessments or the impacts of land-use change such as urban expansion. It is critical to understand the constraints of survey tools and use that knowledge to optimise the detectability of the target species.

Conflicts of interest

The authors declare no conflicts of interest.

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