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SURVEYS OF LARGE FOREST OWLS IN NORTHERN NEW SOUTH WALES: METHODOLOGY, CALLING BEHAVIOUR AND OWL RESPONSES

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Field surveys of large owls were undertaken in coastal, escarpment and tableland forests of north-east New South Wales in 1990–92. A combination of listening, playback of taped calls and spotlighting was used at 401 sites. Of these, 354 sites were surveyed at least twice each. Powerful Owls *Ninox strenua* were recorded at 76 sites (19%), Sooty Owls *Tyto tenebricosa* at 74 sites (18%) and Masked Owls *Tyto novaehollandiae* at 35 sites (9%). Owls called spontaneously throughout the night, but particularly in the early evening and before dawn. The effects of moon visibility and cloud cover on spontaneous calling rates were not significant. Precipitation and wind were the two most important factors affecting owl detectability: owls were vocal on calm, dry nights but were not heard on nights of strong wind or heavy rain. Playback more than doubled the detection rate for all species; owls responded with distant calls, approached and called from a concealed or unconcealed perch, or occasionally approached silently. From a subsample of 48 sites surveyed five times each, the probability of detecting owls on a single visit was 26 per cent for Powerful Owl, 21 per cent for Sooty Owl and 20 per cent for Masked Owl. The number of visits required in order to determine owl presence or absence at a given site, with 90 per cent confidence, is seven for Powerful Owl, eight for Sooty Owl and nine for Masked Owl. For greater than 50 per cent probability of detection, the required number of visits per site is three for Powerful and Sooty Owls and four for Masked Owl.

INTRODUCTION

In 1990–92 field surveys of the Powerful Owl *Ninox strenua*, Sooty Owl *Tyto tenebricosa* and Masked Owl *Tyto novaehollandiae* were undertaken in north-east New South Wales, in order to relate owl occurrence to forest type and management. The rationale for the study has been discussed elsewhere (Debus 1994; Debus and Rose 1994; Debus and Chafer 1994): these owls are uncommon or rare, and may be affected by logging through loss of roost/nest trees and den sites for arboreal prey. Furthermore, being predators of vertebrates, they may be useful indicators of the ecological integrity of their environment. The results of the study, in terms of the distribution, status and habitat requirements of the owls, will be presented elsewhere (Debus, Ferrier *et al.* ms; Debus, Ford and Recher ms). This paper describes the methods used, the calling behaviour of the owls, and their responses to the survey technique. Many of these aspects have been discussed by Kavanagh and Peake (1993) for large forest owls in south-eastern New South Wales. This paper also assesses the probability of detecting each of the owl species at survey sites on only one visit. These aspects may assist future surveys of these birds.

STUDY AREA AND METHODS

Field work was carried out from 1990 to 1992 inclusive in coastal, escarpment and tableland forests between Taree, Armidale and the Border Ranges. In 1990, I conducted surveys in the Tweed Volcano Region: Border Ranges National Park; Mebbin, Wollumbin, Mooball, Nullum, Whian Whian and Bungabbee State Forests; Stotts Island, Brunswick Heads, Broken Head and Uralba Nature Reserves; Devils Pulpit/Mororo State Forests and Bundjalung National Park. In 1991, I conducted surveys in (a) Chaelundi, Paddys Land, Warra, Oakwood/Glen Nevis/London Bridge and Brother State Forests (on both sides of the Guy Fawkes gorge); (b) Mt Boss/Bellangry/Ballengarra and Way Way State Forests (Wauchope-Kempsey); (c) Enfield/Doyles River/Bulga/Dingo/Knorrit, Kiwarrak, Coopernook/Lansdowne, Johns River and Middle Brother State Forests (Walcha-Taree). In 1992, I conducted surveys in Styx River, Lower Creek and Carrai State Forests (east of Armidale-Walcha), with repeat surveys in Chaelundi, London Bridge and Styx River.

A range of altitudes and forest structural types was sampled, from sea level to 1 000 m, in closed forest (rainforest), tall open (wet sclerophyll) forest and open (dry sclerophyll) forest. Survey sites were placed in a range of forest patch sizes from small remnants (<200 ha) to large blocks of greater than 20 000 hectares. Transects along forest roads and tracks were selected on the basis of accessibility to a four-wheel-drive vehicle in wet weather. Survey points were usually located at approximately 1 km intervals (minimum straight-line distance) along a transect, but were often extended slightly to the nearest landmark (e.g. track junction or creek crossing). Transects were placed in logged forests subject to routine management practices, and in unlogged ('old-growth') forests, where logging had been deferred pending the completion of environmental impact studies. Each transect usually encompassed seven to nine survey points, the number which could be completed in a night of favourable weather. In total, 401 such sites were surveyed over the three years.

Almost all (354, 89%) survey sites were visited twice, usually with approximately one month between consecutive visits to a site and usually within the same season. Surveys were conducted between March and August of each year, except that unfavourable weather caused some delay until October in 1991. Field trips were conducted in autumn and winter, on the assumption that all three species would be breeding or preparing to breed at this time and therefore at their most vocal and responsive to playback (cf. Schodde and Mason 1980). Forty-seven sites (12%) were surveyed only once, owing to time, access or logistical constraints, and of these, six were nearby substitute sites for those inaccessible on the second round. In addition, 48 sites in Chaelundi (20 sites), London Bridge (14) and Styx River State Forests (14) were resurveyed a further three times in 1992, giving a total of five visits per site, in order to test the repeatability of owl detections. These repeats were also at approximately monthly intervals within a year, and were standardized as far as possible for weather conditions over the five visits. In practice each of these three areas had four visits in favourable weather and one in unfavourable weather: it was wet at nine of 48 sites (19%) on the third round (London Bridge section only) and windy at nine sites (19%) on the fifth round (parts of Chaelundi and Styx River sections).

The survey technique was a modification of that described by Kavanagh and Peake (1993), and incorporated some of their recommendations where possible. Their basic procedure was followed, the main departures being a shorter listening period (15 min vs 1 hour except at sunset), no use of remote recording equipment, inclusion of Masked Owl playback calls, and spotlighting after each species' playback. At each site, a listening period of 15 minutes was followed by broadcast of tape-recorded calls of Masked, Sooty and Powerful Owl (in that order, i.e. according to size lest the largest species inhibited the others). Each species' calls were broadcast for five minutes, followed by 1–2 minutes of stationary spotlight-sweeping after each species' broadcast (total 5 min spotlighting per site). After the final broadcast/spotlight at a site, I listened for responses for up to a further five minutes then drove to the next site on the transect, spotlighting en route (>1 000 km of such spotlight-driving over 125 nights). Listening commenced at sunset, with the first playback an hour later when it was dark; I repeated the sequence until about 2300 hrs then resumed from about 0330 hrs until dawn. I camped on the transect, at the first pre-dawn site, and occasionally obtained incidental records of owls calling between 2300 hrs and the first pre-dawn count.

For playback I used a National Panasonic RX-CW26 twin-speaker, portable cassette player of 8 watts output at maximum volume. Broadcast calls from the vehicle bonnet or roof were audible, under optimal conditions, at c. 600 m for *Tyto* calls to c. 1 km for Powerful Owl, as determined by field testing and by the distances (some measured) at which owls replied. For maximum effect, the graphic equalizer was set at maximum on the three highest frequency bands (1, 3.3 and 10 kHz) and minimum on the two lowest bands (100 and 300 Hz) for *Tyto* screeching/screaming calls, and the opposite for Powerful Owl hooting calls (maximum setting for 100, 300 and 1 000 Hz, and minimum for 3.3 and 10 kHz bands; see sonagrams in Kavanagh and Peake 1993). This, equivalent to a treble setting for *Tyto* and bass for Powerful Owl on a machine with a 'tone' dial, matched the properties of the owls' calls and enhanced playback volume. During playback I moved to a stationary position sufficiently far from the vehicle (20 m or more) to avoid the interference effect and to detect simultaneous animal vocalizations. For spotlighting I used a 12 volt, 100 watt hand-held light.

At each site I counted the number of nocturnal birds and arboreal marsupials detected in the listening period, playback/spotlighting or both; whether they were seen, heard or both; and their estimated distances from the point. I also recorded the moon phase and whether the moon was visible or not, and weather details. Cloud cover was scored in eighths (pooled as two classes for analysis: greater or less than half). Precipitation was scored as dry (0), fog or mist (1), drizzle (2) or rain (3), pooled as two classes for analysis (0–1, 2–3). Wind was scored on the Beaufort scale: calm (0), light breeze (1: leaves moving), light wind (2: upper branches moving), strong wind (3: main branches moving), also pooled as two classes for analysis (0–1, 2–3). In practice, counts were often abandoned if rain consistently reached 3 for most of a night and/or wind frequently exceeded 3 (4 = gale, trunks moving). If drizzle was sufficiently intense to wet the cassette player under its umbrella shelter, playback was abandoned and the listening period was doubled, with intermittent imitations of Powerful Owl calls for about a minute at the end. This occurred at 38 sites, but 21 of these were visited more than twice in order to achieve two playbacks; only 17 sites received one effective and one abortive playback. Similarly, 17 sites were too windy for effective playback on one of two visits, but six of these were visited more than twice to compensate. Such sites in the Border Ranges required up to four or five visits in order to achieve two effective visits on nights of reasonably favourable weather.

The effect of environmental variables on owl calling was tested by χ^2, the expected frequency being calculated as n cases (for each species) × n counts in each class/total counts. The number of counts in each category was not evenly distributed, with relatively few counts in rainy weather. $P < 0.05$ was the criterion used for statistically significant differences.

Sooty Owl calls are defined as follows. *Scream:* the so-called 'falling bomb' whistle, varying in intensity from a shrill siren to a plaintive wail; a variant is a strident or 'urgent', harsher version. *Trill:* downscale, insect-like stridulations. *Harsh screech:* Masked Owl-like rasping but more prolonged, downslurred and menacing or 'churring', sometimes with 'hard', grating version of trill; apparently a high-intensity threat call. [This rarely heard call is not widely known or reported, but one clear view established the caller as an 'angry' adult Sooty Owl; this species does occasionally give a Masked Owl-like screech, e.g. Hyem in Debus (1993a), Chafer and Anderson (1994)]. *Juvenile begging:* long, descending, wheezing rasp. Masked Owl calls are defined as follows. *Screech:* rich, deep and loud version of Barn Owl *Tyto alba* rasping hiss (see Debus 1990, 1993b; Debus and Rose 1994). *Chatter:* rapidly repeated notes, sometimes with a squeaky quality, varying in intensity from a low rattle to a loud, petulant cackle. Sooty Owl calls broadcast were two sequences of screams (each note at about 5–10 sec. intervals), followed by two sequences of the trill. Masked Owl calls broadcast were intermittent loud screeches and subdued chattering, interspersed with 5–10 seconds of silence. Powerful Owl calls broadcast were two long hooting sequences (slow *woo-hoo* call), female followed by male (the sexes distinguishable by pitch and inflexion: male lower, slower and second note descending; female second note rising). See Kavanagh and Peake (1993) for sonagrams of Sooty and Powerful Owl calls.

Mark-recapture theory was employed to estimate detection probabilities, by assuming that an owl repeatedly detected at a given site (over five visits to 48 sites) was the same individual or member of a territorial pair. This analysis was performed using a non-parametric frequency-of-capture technique described by Overton (1971). Dr Simon Ferrier (NSW National Parks and Wildlife Service) performed the calculations on the survey data. This method enables estimation of the number of sites at which owls were present but missed, and hence an estimate of the total number of sites at which each species was potentially present. Simple probability theory was then used to calculate the probability of detecting an owl on a given number of visits. The probability of detection after n visits was calculated as $[1 - (1 - P)^n]$, where P is the probability of detecting an owl on one visit. The 48 sites were in optimal Powerful Owl habitat (tall eucalypt forest on the eastern edge of the tablelands), but more than half (28 in London Bridge and Styx River) were at the western edge of the Sooty Owl's range in the region, in possibly suboptimal habitat for this species. Some sites in Chaelundi (c. 10) may have been in suboptimal habitat (too wet or dense) for Masked Owls.

Detection probabilities from the 48 sites were used to estimate the number of owls missed at sites surveyed once or twice. Site data were culled where rain or wind exceeded 2 for one of two visits, to leave 247 sites surveyed twice in favourable weather and 98 sites surveyed once (with eight sites culled where rain or wind exceeded 2 on both visits). The total number of sites at which an owl species was present was calculated as n_1/P_1 or n_2/P_2, where n_1 and n_2 are the number of sites at which the species was recorded over one and two visits, and P_1 and P_2 are the probability of detection on one and two visits.

RESULTS

Powerful Owls were recorded at 76 sites, Sooty Owls at 74 sites and Masked Owls at 35 sites (19, 18 and 9% of sites, respectively): a ratio of 2:2:1. There was some overlap, with two or three owl species recorded at some sites. Overall, at least one owl species was recorded at 144 sites (36% or a third of total sites). One owl species was recorded at 113 sites, two owl species at 24 sites and three owl species at seven sites. Where two species were recorded, it was usually Powerful Owl with a *Tyto* species (14 cases with Sooty Owl, 7 with Masked Owl). The two *Tyto* species were recorded at three sites. Where three species were recorded, all three called spontaneously on the same night at two sites; at another two sites, all three species responded to playback on the same night; and at three sites the three species were detected over different nights.

Within the study area owls were encountered on 218 occasions, of which Powerful Owls contributed 90 (41%), Sooty Owls 89 (41%) and Masked Owls 39 (18%) detections. Virtually all detections were made by the stationary listening/playback technique. Only one Powerful Owl was seen, perching in a roadside tree, in over 1 000 km of spotlight-driving between sites, and no Sooty or Masked Owls were detected by this method during the survey. However, I have three incidental records of Masked Owls on low roadside perches, in or on the edge of forest, seen by spotlight or in vehicle headlights (not during this survey).

There were 910 counts on which the full playback technique could be used. On 82 (9%) of these, a forest owl called spontaneously before playback. On 106 (12%) of these, a forest owl was detected only by playback. Overall, at least one owl species was detected on 188 (21% or a fifth of) such counts. The use of playback accounted for 56 per cent of owl detections.

Maximum distances at which owls were heard calling were estimated at greater than 1 km (occasionally up to 2 km) for Powerful Owl and at least 500 m for *Tyto* species, particularly the Sooty Owl. Maximum distances at which they replied to tape playback (inferred as the maximum effective playback range in forest) were c. 1 km for Powerful Owl and c. 500 m for *Tyto* species. Sooty Owls' calls in the field seemed

TABLE 1

Spontaneous calling behaviour of owls in relation to environmental variables. SS = sunset, SR = sunrise. Cloud cover scored as eighths. Rain and wind scores explained in text. Numbers in parentheses are number of observed cases. Data from 401 sites (965 counts). Includes nine incidental observations (six Powerful Owl, three Sooty Owl) at survey sites outside count times, between 2200–2300 and 0300–0400 hrs. Significance level (χ^2, $P < 0.01$**) shown.

	h after SS			h before SR		Moon		Cloud		Rain		Wind	
Species	<2	2–4	>4	>2	<2	vis.	not	<5	>4	0–1	2–3	0–1	2–3
n counts (965)	259	308	165	129	104	405	560	599	366	856	109	732	233
Powerful:													
male (23)	2	7	5	6	3	11	12	14	9	22	1	22	1
female (11)	6	2	1	0	2	6	5	5	6	11	0	11	0
pair duet (11)	2	3	3	2	1	3	8	7	4	11	0	11	0
Total (45)	10	12	9	8	6	20	25	26	19	44	1	44	1**
Sooty (38)	13	6	6	4	9	21	17	23	15	33	5	33	5
Masked (17)	8	3	3	1	2	5	12	10	7	17	0	16	1
All owls (100)	31	21	18	13	17	46	54	59	41	94	6	93	7**

**Powerful Owl, wind: $\chi^2 = 10.7$, d.f. = 1; all owls combined, wind: $\chi^2 = 15.06$, d.f. = 1; all other cases, moon and weather classes: $\chi^2 < 3.84$, d.f. = 1, $P > 0.05$.

louder and more far-carrying, sometimes audible to perhaps 800 m or more depending on topography, than could be achieved by the playback equipment. Sooty Owl calls may have a range of up to 1 km (Kavanagh and Peake 1993).

Spontaneous calling

Spontaneous calling by all three species was infrequent: Powerful Owls were heard on 45 (5%) of 965 counts; Sooty Owls on 38 (4%) and Masked Owls on 17 (2%), in a region that supports relatively high densities of these owls (unpubl. data). Several trends are apparent in the calling behaviour of all three species, although in many cases sample sizes are small (Tables 1 and 2). For the Powerful Owl, male solo hooting was about twice as frequent as female solo calling or pair duetting. Males tended to call later at night, whereas females perhaps called more at dusk; duetting occurred throughout the night. Spontaneous calls of Sooty and Masked Owls were almost invariably the scream and screech respectively; both called commonly at dusk (roost departure), with perhaps a minor peak again at dawn just before going to roost, as well as throughout the night. All three species sometimes called between sunset and dark, or between first light and sunrise.

TABLE 2

Vocal behaviour of owls at survey sites. S = spontaneous calls during listening period only, no response to playback. B = called spontaneously then responded to playback. P = responded to playback only, no spontaneous calls during listening period. Number = n observed cases in each category (out of 965 counts, at 401 sites).

Species/call type	S	B	P	Total
Powerful:				
male	17	3	7	27
female	5	6	28	39
duet	6	3[a]	13	22
silent approach			1	1
juvenile beg			1	1
Total	28	12	50	90
Sooty:				
scream	23	7	27	57
trill	1	0	13	14
both		1	6	7
harsh screech			4	4
pair scream/ screech/trill		2		2
silent approach			2	2
juvenile beg			3	3
Total	24	10	55	89
Masked:				
screech	16		11	27
chatter			6	6
both		1	5	6
silent approach			0	0
total	16	1	22	39

[a]in two of the cases, only the female replied to the tape.

Powerful Owl duetting invariably consisted of a bout of hooting by one sex followed by a bout of hooting by the other, unlike the antiphonal (alternate) hooting by male and female that is commonly used by duetting Southern Boobooks *Ninox novaeseelandiae* or Barking Owls *N. connivens* (pers. obs.). Duetting was heard by two Sooty Owl pairs that were moving through their respective territories. In the first case, the male (?) gave a scream, two harsh screeches and several short, 'urgent' screams, each call interspersed by a short trill from the female (?). In the second case, the female (?) screamed, the male (?) gave an 'urgent' scream, the female then male trilled, and the female screamed, the male meanwhile moving towards the female's position.

Moon visibility appeared to have little effect other than on Powerful Owl duetting, which was perhaps more frequent when the moon was not visible; results (χ^2, moon visible vs not) were not significant for any species (χ^2 = 0.03–2.29, d.f. = 1, P > 0.05). All three species called equally on clear and on overcast, dry nights (cloud <5 vs >4, χ^2 = 0.00–0.18, d.f. = 1, P > 0.05). Rain and wind had the most pronounced effect. Although trends were apparent, the only results to reach significance were wind on total Powerful Owl detections (0–1 vs 2–3, χ^2 = 10.7, d.f. = 1, P < 0.01) and on all owl detections (χ^2 = 15.06, d.f. = 1, P < 0.01). All three species were heard more on dry, calm nights, with Sooty Owl slightly more tolerant of wet or windy conditions. A Sooty Owl was heard once when rain rated 3, but owls were otherwise not heard when rain or wind exceeded 2.

TABLE 3

Owl response behaviour to playback. Distant reply = called more than 100 m away, did not approach. Approach = attracted to within 100 m (often <50 m) of tape. Number = n cases observed (401 sites; 965 counts). In cases of Powerful Owl duetting, male and female responses treated separately.

Species/sex	Distant reply	Approach: heard only	Approach: seen	Approach: both
Powerful:				
male	24	0	0	0
female	37	3	0	10[a]
?	0	0	1	1[b]
Sooty	36	22[c]	2	7
Masked	7	6[d]	0	10

[a]defended strongly; [b]begging juvenile with silent parent; [c]stayed hidden behind foliage although close, three of these were begging juveniles; [d]stayed out of sight although close.

TABLE 4

Owl response to playback in relation to weather. Number = n cases observed of pairs or single birds reacting to tape (401 sites; 965 counts). Includes cases of spontaneous calling before reply to playback. Rain and wind codes explained in text; playback abandoned but listening period doubled when rain >2. Significance levels (χ^2, P < 0.05*, P < 0.01**) shown.

Species	Rain 0–1	Rain 2	Wind 0–1	Wind 2–3
n counts (965)	856	109	732	233
Powerful Owl (n = 62)	62	0**	59	3**
Sooty Owl (n = 65)	58	7	59	6**
Masked Owl (n = 23)	22	1	22	1*

Powerful: rain χ^2 = 6.81, d.f. = 1; wind χ^2 = 11.63, d.f. = 1.
Sooty: rain χ^2 = 0.01, d.f. = 1; wind χ^2 = 7.11, d.f. = 1.
Masked: rain χ^2 = 0.53, d.f. = 1; wind χ^2 = 3.97, d.f. = 1.

Response behaviour

Three important conclusions from Tables 2–4 are: (a) that owls tended either to call spontaneously or to respond to playback, but seldom did both; (b) that use of playback more than doubled the chance of owl detection; and (c) that use of playback did not increase the detection rate in wind or rain.

There were many cases of owls calling spontaneously but then not responding to playback, or silence during the listening period then a response to playback. Comparing the number of owl detections before playback with the number obtained only by playback, the results for the three species were as follows: Powerful Owl 40 versus 50 detections (56% by playback only); Sooty 34 vs 55 (62%); Masked 17 vs 22 (56%).

Owls responded in calm, dry weather but not in wind or rain, again with an indication that Sooty Owls may be more tolerant of wet or windy conditions; no responses were heard when wind exceeded 2. Results reached significance for Powerful Owl in dry versus wet weather (χ^2 = 6.81, d.f. = 1, P < 0.01), and for all three species in calm versus windy weather (Powerful: χ^2 = 11.63, d.f. = 1, P < 0.01; Sooty: χ^2 = 7.11, d.f. = 1, P < 0.01; Masked: χ^2 = 3.97, d.f. = 1, P < 0.05).

Other trends are apparent from Tables 2–4. Powerful Owl males defended their territories weakly, from a distance, whereas females

TABLE 5

Owl vocal behaviour and response to playback by month. S = spontaneous calling. P = replied to playback (some overlap with S where calling birds also responded). Numerals are number of individual cases observed in each behavioural category in each month. Total = n cases of calling, responding or both. Mean ($\bar{x}$) = n responses per night, omitted where sample size too small (401 sites, 965 counts; mean 8 counts per night).

	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
N nights (125)	2	16	26	16	23	15	20	1	6
Powerful:									
S	1	8	7	10	8	0	6	0	1
$\bar{x}$		0.5	0.27	0.63	0.35	0	0.3		
P	3	8	14	12	11	1	10	0	1
$\bar{x}$		0.5	0.54	0.75	0.48	0.07	0.5		
total	3	15	18	21	15	1	14	0	1
$\bar{x}$		0.94	0.69	1.3	0.65	0.07	0.7		
Sooty:									
S	1	7	6	2	7	7	6	0	0
$\bar{x}$		0.44	0.23	0.13	0.3	0.47	0.3		
P	3	8	11	11	6	7	7	0	5
$\bar{x}$		0.5	0.42	0.69	0.26	0.47	0.35		
total	4	12	16	13	11	12	11	0	5
$\bar{x}$		0.75	0.62	0.81	0.49	0.8	0.55		
Masked:									
S	1	4	6	4	1	0	1	0	0
$\bar{x}$		0.25	0.23	0.25	0.04	0	0.05		
P	0	2	5	6	6	1	2	0	0
$\bar{x}$		0.13	0.19	0.38	0.26	0.07	0.1		
total	1	6	11	10	6	1	3	0	0
$\bar{x}$		0.38	0.42	0.63	0.26	0.07	0.15		

defended strongly by replying more frequently, and sometimes by perching overhead, glaring and bristling, performing fly-overs, and once by swooping over and almost striking the observer who was imitating a female call. Duet responses often seemed to be initiated by females. One defending bird arrived silently, but was betrayed by a begging, fully plumaged yearling that accompanied it. Sooty Owls typically responded with a distant scream, and/or approached silently and trilled from a usually concealed perch. Two cases were detected where a bird arrived and departed in silence. Masked Owls responded with a distant screech or by approaching silently then chattering from an often unconcealed perch; in two cases a bird perched silently but departed with a screech when discovered by spotlight. Both *Tyto* species occasionally performed fly-overs, and one male Masked Owl circled above the tree canopy, chattering. Some *Tyto* replies were delayed until after the playback sequence had entirely finished (i.e. after Powerful Owl playback), and their first replies occasionally occurred during playback of their congener's calls (Sooty answered Masked and vice versa). That is, playback of other species' calls sometimes stimulated calling; Powerful Owl playback (at least sometimes) did not inhibit calling by *Tyto* species. Powerful Owls often took up to five minutes or more to reply, and in several cases did not reply until the start of the next count 1 km down the transect and 10 minutes after the previous playback finished (scored as a response at the previous site). Response times were not noted accurately, but a reasonable estimate of the mean response time for Powerful Owls is approximately 5 ± 1 minutes. There were also c. 5 cases where Powerful Owls were first heard calling within 1 km of a site 2–3 hours after playback at that site, i.e. they were not detected during the count or playback times at c. 2300 hrs but called much later, at around 0100 hrs.

Powerful Owls responded as a pair on 14 (23%) of 62 playback responses, with an additional case of a juvenile accompanying an adult. Sooty Owls responded as a pair on only two (3%) of 65 playback responses; in both cases the members had been calling to each other before playback. There were no cases of Masked Owls responding in pairs (n = 23 responses), but one case where two neighbouring males responded simultaneously on their mutual territory boundary. One remained perched while the other circled in flight 100–200 m away and retreated a further 100 m to a perch; both were chattering continuously. Once they had arrived, responding *Tyto* owls sometimes counter-called at the tape (trill/chatter, simultaneously with or immediately after each broadcast call). Powerful Owls waited for prolonged silence before giving a hooting sequence in turn.

Seasonality of calling and response

This study was confined to autumn-winter, within which some trends were apparent (Table 5). Powerful Owl calling and defence were strongest from March to June, coinciding with the pre-laying, laying and incubation periods of this highly seasonal breeder (cf. Schodde and Mason 1980). Sooty Owl calling and defence were consistently high, if somewhat variable, throughout autumn and winter: perhaps a slight bimodality, corresponding with the bimodal laying season of this species (autumn and spring, cf. Schodde and Mason 1980). Masked Owl calling and response were highest from March to June, with some inter-year differences: most of the strong responses occurred in 1992, at sites where Masked Owls were not detected during previous surveys in 1991.

Probability of detection

Powerful Owls were detected at 9–14 sites per round, out of 48 sites surveyed five times each (mean 12 per round, 25%: Table 6). Sooty Owls were detected at 4–7 (mean 5.4, 11%) sites per round. Masked Owls were detected at 1–6 (mean 3.6, 8%) sites per round. After five rounds of surveys, the cumulative number of sites at which Powerful and Sooty Owls were detected was apparently starting to plateau, but was still increasing for Masked Owl (respectively, recorded at 75, 40 and 31% of sites by the fifth round: Table 6, Fig. 1). Based on the mark-recapture analysis, the detection probabilities on a single visit were 26 per cent for Powerful Owl, 21 per cent for Sooty Owl and 20 per cent for Masked Owl (Fig. 2, Appendix 1). The resulting profiles reveal that the number of visits required in order to achieve 90 per cent probability of detection is seven for Powerful Owl, eight for Sooty Owl and nine for Masked Owl (Fig. 2, Appendix 1). For greater than 50 per cent probability of detection, the required number of visits is three for Powerful

TABLE 6

Number (proportion) of sites at which owl species were recorded during each of five visits (48 sites, each surveyed five times). Chaelundi State Forest (20 sites): high densities of all three species; London Bridge and Styx River State Forests (14 sites each): high densities of Powerful and Masked, but possibly suboptimal habitat for Sooty. Wet weather at nine sites (19%) on third round (London Bridge sites only); windy weather at nine sites on fifth round (some Chaelundi and Styx River sites).

	Round				
	1	2	3	4	5
Powerful:					
n sites	14 (0.29)	13 (0.27)	9 (0.19)	13 (0.27)	11 (0.22)
n new sites		9	3	8	2
n cumulative sites	14 (0.29)	23 (0.48)	26 (0.54)	34 (0.71)	36 (0.75)
Sooty:					
n sites	6 (0.13)	7 (0.15)	4 (0.08)	5 (0.1)	5 (0.1)
n new sites		5	4	1	3
n cumulative sites	6 (0.13)	11 (0.23)	15 (0.31)	16 (0.33)	19 (0.40)
Masked:					
n sites	1 (0.02)	3 (0.06)	4 (0.08)	6 (0.13)	4 (0.08)
n new sites		3	3	5	3
n cumulative sites	1 (0.02)	4 (0.08)	7 (0.15)	12 (0.25)	15 (0.31)

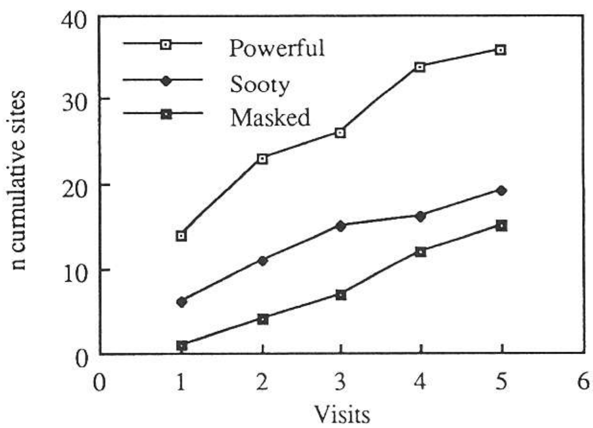

Figure 1. *Detection curves for owl surveys, as number of sites (total 48) at which a species was detected, against number of visits (total 5 per site).*

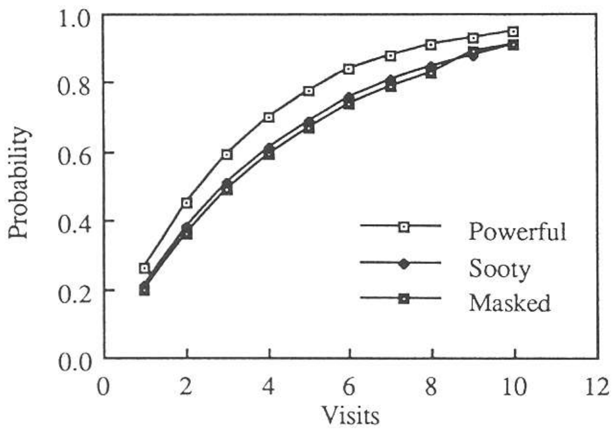

Figure 2. *Detection probability curves for large forest owls in north-east New South Wales: probability of detection versus number of visits per site.*

TABLE 7

An estimate of the number of sites at which owls were missed, at sites surveyed once (98 sites) or twice (247 sites) in favourable weather, calculated from detection probabilities based on 48 sites surveyed five times (Table 6, Appendix 1; total 393 sites surveyed at least once in favourable conditions). Percentages are calculated as the proportion of sites at which a species is expected to occur (i.e. detected + missed). The correction factor (expected/detected) estimates the total number of sites at which owls were present, for n visits per site. Expected number of sites at which a species is present (E, i.e. n sites at which owls occurred) = number of sites at which owls were detected (D)/probability of detection for n visits (P), i.e. E = D/P. Number of sites at which owls were missed (M) = (E–D). Therefore, %M = M/E; %D = D/E. Correction factor (C) = E/D, therefore C × D = E. Figures in parentheses are percentages.

Species	n sites owls detected	n sites owls missed	n sites owls expected	Correction factor
Powerful:				
1 visit	11 (26)	31 (74)	42	3.8
2 visits	28 (45)	34 (55)	62	2.2
5 visits	36 (78)	10 (22)	46	1.3
Total	75 (50)	75 (50)	150	
Sooty:				
1 visit	9 (21)	34 (79)	43	4.8
2 visits	44 (38)	72 (62)	116	2.6
5 visits	19 (68)	9 (32)	28	1.5
Total	72 (39)	115 (61)	187	
Masked:				
1 visit	9 (20)	36 (80)	45	5.0
2 visits	11 (35)	20 (65)	31	2.8
5 visits	15 (68)	7 (32)	22	1.5
Total	35 (36)	63 (64)	98	

and Sooty Owls and four for Masked Owl. Applying the probabilities to sites effectively visited once or twice shows that these owls were missed at 70–80 per cent of expected sites visited once, and 55–65 per cent of expected sites visited twice (Table 7). In other words, a single round of surveys detects these owls at only a quarter to a fifth of potential sites, and two rounds detect them at a third to a half of potential sites.

Overall, Powerful Owls were missed at an estimated 75 sites (19%), Sooty Owls at 115 sites (29%) and Masked Owls at 63 sites (16%) out of the 401 sites. From the detection probabilities, the correction factors that must be applied (Table 7) give an estimate of the total number of sites at which each species should have been present in the study area: Powerful Owl at 150 sites (37%), Sooty Owl at 187 sites (47%), Masked Owl at 98 sites (24%).

DISCUSSION

Calling, response and weather

The fact that low-frequency Powerful Owl hooting can be heard over a greater distance than high-frequency *Tyto* screeching/screaming is consistent with a general rule of acoustics. The lower the frequency, the farther the distance travelled by the sound; or, attenuation of sound over distance is greater at higher frequencies (Rossing 1990; J. Brettell, pers. comm.). The results of this study, in terms of the estimated audibility range of Powerful versus Sooty Owls, are consistent with the acoustic properties of their calls. It would be expected that, in humid conditions, Sooty Owl screaming at fundamental frequency c. 2 kHz is attenuated by at least twice the rate of that of Powerful Owl hooting at between 0.5 and 1 kHz (cf. Kavanagh and Peake 1993; Kaye and Laby 1978: 63).

It was not clear during this survey whether the owls reduced their calling rates during wind or rain, or whether they could not be heard as well under such conditions. Fleay (1968) noted that Powerful Owls were inactive during high wind or heavy rain. Sooty Owls were detected readily at close range (<200 m) during this survey when they did call (high-frequency scream) during wind or rain, suggesting that the lack of records during such conditions reflected a lack of calling by owls rather than poorer detection, at least over short distances. However, long-distance sound transmission is adversely affected by wind and rain. Atmospheric turbulence and rain are among the factors affecting sound propagation (Parker 1988; Rossing 1990); wind and air turbulence are also among the important ambient (background) sounds limiting the hearing of owls, through the interference effect (Martin 1990). Therefore, owls may not call under conditions unfavourable for long-distance sound transmission.

The results of this study, in terms of owl calling behaviour, response types and detection rates in relation to time of night, weather and listening versus playback, are generally similar to those reported for these species by Fleay (1968), Roberts (1983), Beruldsen (1986), Hollands (1991), Kavanagh and Peake (1993), Hyem (in Debus 1993a) and Chafer and Anderson (1994). The owls in this study gave a variety of response types to playback, and a variety of call types in the case of *Tyto* species. The Barred Owl *Strix varia* and Tawny Owl *S. aluco* give a similarly graded series of calling and behavioural responses, culminating in challenge or attack of the 'intruder' (human imitation or playback amplifier); males react faster but females are more aggressive (Bosakowski *et al.* 1987; Galeotti and Pavan 1993).

The results of this survey, in relation to environmental and temporal variables, are also broadly similar to those for owls on other continents. Wind, in particular, and precipitation are the factors most affecting owl detectability and response. Wind may obscure owls' calls, render them difficult to distinguish, reduce their audibility range by a factor of up to 10, limit the range of playback, and reduce the observer's ability to see or hear responding owls; it may also cause reduced owl activity through difficulties in flight or foraging, or in hearing prey (Palmer 1987; Smith and Carpenter 1987; Gerhardt 1991).

Seasonality

It is apparent from Table 5, from incidental records elsewhere in November and January (pers. obs.), and from other owl survey work in July-December 1991 (with R. Kavanagh for the NSW Forestry Commission), that all three species call or can be induced to call in virtually all months of the year. However, the intensity of spontaneous calling or response may vary seasonally. There may also be annual variation in breeding activity by *Tyto* owls, reflected in calling and response rates (e.g. Schodde and Mason 1980). This is suggested by the sudden upsurge of Masked Owl records in this study in 1992, compared with 1990 and 1991; perhaps autumn 1992 was a good laying season for Masked Owls in the study area. A similar effect, of annual variation in calling intensity with fluctuations in populations of small mammals (and hence in the likelihood of successful owl breeding), has been recorded in some Northern Hemisphere owls (Palmer 1987; Smith and Carpenter 1987). Overall, this study detected little effect of season (within years) on owl calling or response, a result consistent with other owl survey work in Australia (Kavanagh and Peake 1993; Hyem in Debus 1993a; R. Kavanagh, unpubl. data). This contrasts with the highly seasonal owl calling and breeding, and harsh winters, in the Northern Hemisphere (e.g. Bosakowski *et al.* 1987; Palmer 1987).

Detectability and abundance

The survey results suggest that within the study region Powerful and Sooty Owls are similar in abundance and about twice as numerous as Masked Owls. However, some caution is needed, as the detection radii for Powerful Owl versus *Tyto* differ. Powerful Owls can be heard over at least twice the distance, and there were some cases of the same bird(s) being heard at two sites 1 km apart. Powerful Owls, therefore, may occur at lower density and have a larger home range than Sooty Owls. Furthermore, the probability data (Table 6, Fig. 1) support a field impression that the Masked Owl is less detectable than the others. There are several possible reasons: (a) Masked occurs at lower density in the region and/or individuals range more widely; (b) dense forest is not its prime habitat; (c) its calls are less distinguishable above background noise; (d) it may call less or sometimes respond less strongly to playback (i.e. it may be less territorial; see also Debus 1993b). The Masked Owl's detection curve may also have been biased by annual variation in breeding activity (response), with an increase in the detection rate (i.e. new sites) towards the end of the study, perhaps associated with greater breeding activity than in 1990–91.

Because over half the Sooty Owl detection sites were in possibly suboptimal habitat, the probability profile for this species may be a slight underestimate. This owl may occur at a higher proportion of sites in prime habitat, with a higher cumulative total, where its detectability profile may approach that of the Powerful Owl. This may also apply to the Masked Owl, when the characteristics of its prime habitat are known and surveys are carried out in sample areas within a single year. The detectability profiles apply to the region surveyed, and may be different elsewhere; this requires study in other regions/habitats.

The detection probabilities suggest that sites surveyed only once or twice will greatly underestimate the owl population in a given region, and that at least three rounds of surveys are required for greater than 50 per cent probability of detection of these species at given sites.

Survey implications

The survey results are generally in agreement with those of Kavanagh and Peake (1993). The combined results of both studies, and additional records of calling or responding owls (pers. obs.; Hyem in Debus 1993a; Kavanagh, unpubl. data), allow some conclusions on the technique:

(1) Owls call and respond in all months, therefore surveys may be conducted at any time of the year.

(2) The one-hour listening period at dusk, and surveys during the early part of the night and pre-dawn, are important times for detecting spontaneously calling owls.

(3) Powerful Owl calls apparently do not inhibit the other two species. Given the sometimes delayed response of owls, Powerful Owl calls could be placed earlier in the playback sequence and a ten-minute listening period built in at the end of playback/spotlighting (as is the procedure of R. Kavanagh). Similarly, Masked Owl calls could be broadcast last in the sequence because the less dramatic response will not be obscured by ensuing playback of other species (P. Peake, pers. comm.).

(4) Playback more than doubles the detection rate (56% of Powerful, 62% of Sooty, 56% of Masked Owl records in this survey), and is therefore an important component of owl surveys. This need not mean that if observers arrive at a site and only do playback, they will miss 44 per cent, 38 per cent or 44 per cent, respectively, of detections (i.e. they would detect those birds already calling on arrival).

(5) Spotlighting is important for detecting owls that approach silently, but random spotlight-driving is of no use in surveying these large owls.

(6) Wet and/or windy nights should be avoided.

(7) At least three visits are required if the aim is better than 50 per cent confidence of determining the presence of an owl species at a given site. For 90 per cent confidence, more than six visits are required (seven for Powerful, eight for Sooty and nine for Masked Owl). Kavanagh and Peake (1993) drew attention to the requirement in North American owl surveys of six visits to a site within a given breeding season in order to confirm owl occupancy.

(8) An inter-site distance of 1 km is suitable for Sooty and Masked Owls, but is too close for Powerful Owls. In order to avoid detecting the same bird(s) at two sites, Powerful Owl survey sites should be 2 km apart. The 1 km interval for Sooty and Masked Owls assumes that double-counting should not be a problem for these species, on the grounds that their calls are probably audible (to humans) at less than 1 km or tape playback is audible to them at less than 800 m in forest. This does not mean that their territories are 1 km apart or closely spaced.

The mean detection radii, from the audibility of spontaneous calls versus playback and the approximately equal number of detections in each category, are assumed to be 1.5 km for the Powerful Owl and 800 m for the *Tyto* owls. This is consistent with conclusions on the audibility of Powerful and Sooty Owl calls (Kavanagh and Peake 1993) and the use of 800 m inter-site distances for Sooty Owl playback surveys (D. Milledge, pers. comm.). These values are used elsewhere to estimate the area sampled, and hence to estimate population sizes of these owls, in northern New South Wales (Debus, Ford and Recher ms).

Some caution is required in the use of playback. It is possible that frequent playback in the vicinity of occupied territories or active nests may inhibit breeding or have an adverse effect on breeding success, if it causes owls to devote excess time and energy to defence against 'intruders': time otherwise spent in courtship, nest preparation, food provisioning, or attendance of eggs or nestlings.

Habituation may also be a problem, where owls reply on initial playback attempts but refuse to answer playback on subsequent visits (Powerful Owl: pers. obs.; R. Kavanagh, pers. comm.), if the aim is to monitor occupancy over time. Observers should be alert to owls arriving and observing them silently on these later visits. Galeotti and Pavan (1993) found that for the Tawny Owl, which has individually recognizable calls, response intensity is higher when playback is of a stranger's calls than when a known neighbour's calls. Also, that the intensity of response to a stranger decreases with repeated playback of that call; response to neighbours remains weak. Furthermore, these owls have long memories for the calls of known individuals; Galeotti and Pavan used playback intervals of a month in order to minimize habituation. The explanation given for this neighbour-stranger discrimination is that it minimizes needless aggressive acts and prevents escalated contests between settled territory-holders. The contestant roles are presumed to be established from the first contest, hence the declining response to 'known' strangers (i.e. playback amplifiers, which retreat after a response). Therefore, repeated visits to confirm occupancy could profitably use different playback sequences, from various sources, on each visit or at least rotate two or three tape sequences over several visits. Intervals between playbacks should also be long, e.g. a fortnight to a month. Nevertheless, habituation did not occur with frequent playback in one study (Mottled Owl *Strix virgata:* Gerhardt 1991), and this may be the case with forest *Tyto*; this aspect requires study.

Behavioural aspects

Many of the survey results can be explained or interpreted in the light of the owls' social behaviour, habitat, sensory capacities or acoustic properties of their calls (e.g. Schodde and Mason 1980; Martin 1986, 1990; Hollands 1991; Kavanagh and Peake 1993). Much owl calling appears to be 'call and answer', with spontaneous (long-range) territorial calls being answered by neighbours but little prolonged counter-calling other than duetting by members of a pair (Table 2). It appears that neighbours or 'floaters', at least of these territorial, low-density forest species, can monitor each other sufficiently by calling occasionally and listening for a response, or by replying to another's call. However, prolonged counter-calling at close range can be artificially induced by playback, where the observer simulates a persistent intruder.

It appears that male Powerful Owls passively advertise their territories to conspecifics by calling, often in the middle hours of the night, and that females defend their territories strongly against other females by frequently reaffirming ownership with dusk and dawn calling, and by vigorously expelling 'intruders' (i.e. strongly responding to playback; Tables 1–3). Duetting on moonless nights (Table 1) may enable male and female Powerful Owls to maintain contact in conditions of low visibility. The resonant nature of Powerful Owl hooting carries for long distances (1–2 km: pers. obs.) in still conditions, but has no carrying power in wind (i.e. it is strongly attenuated by wind, as determined by field testing of playback in windy conditions; cf. Rossing 1990). Therefore, it is not surprising that the owls cannot be heard or do not call on windy nights.

Sooty Owls, similarly strongly territorial, also appear to reaffirm occupancy by frequent dusk and dawn calling (Table 1). Drizzle and rain are frequent in escarpment rainforests and Sooty Owls must therefore be active to some extent in such conditions (in fact it was rare to achieve a survey night of 0 rain in prime Sooty Owl habitat). This is reflected in the number of records when rain rated 2 or 3 and in the nature of their piercing, high-pitched calls which are audible above the sound of wind or light rain on foliage. Sooty Owls responding strongly to playback often remained invisible in cover (Table 3); this may have been related to their dense habitat but also seemed partly a reluctance to perch in the open.

The calling behaviour of Masked Owls is similar to that of Sooty Owls, and at times Masked respond as strongly to playback, although they may be generally less responsive. The calling behaviour of the Masked Owl in relation to weather, and its greater willingness to perch in the open when responding to playback, are consistent with its drier, more open habitat; it also seems bolder than the Sooty Owl (Debus 1993b). The Masked Owl's screeching calls are drowned out by wind or rain on foliage (the interference effect), hence it does not call or cannot be heard during wind or rain.

Finally, the results of 40 playback trials on 12 pairs of Tawny Owls by Galeotti and Pavan (1993) provide some perspective on the present survey results, in terms of response rates. They found that 50 per cent of playbacks in known territories produced no reply. There was some individual variation: some birds in known territories never replied (four males and four females, including two pairs and four members of other pairs). Nine individuals responded in only one trial, and only seven responded in more than one trial. These data support the impression in this study that owl surveys are time-consuming and labour-intensive, for rather low detection rates, and that some owls will inevitably be missed even with optimal survey techniques.

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APPENDIX 1

Detection probabilities for large forest owls in north-east New South Wales. Calculated from the raw data of Table 6, using the method of Overton (1971) to estimate the detection probability for a single visit. Probability at n visits = $[1 - (1 - P)^n]$ where P = probability on a single visit.

Visits	Powerful	Sooty	Masked
1	0.26	0.21	0.20
2	0.45	0.38	0.36
3	0.59	0.51	0.49
4	0.70	0.61	0.59
5	0.78	0.69	0.67
6	0.84	0.76	0.74
7	0.88	0.81	0.79
8	0.91	0.85	0.83
9	0.93	0.88	0.87
10	0.95	0.91	0.89

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Late note: a recent paper by Redpath (1994, *Bird Study* **41**: 192–198) is highly relevant.