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HOME-RANGE SIZE AND TERRITORIAL CALLING OF SOUTHERN BOOBOOKS (*NINOX NOVAESEELANDIAE*) IN ADJACENT TERRITORIES

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ABSTRACT.—Adjacent nesting home ranges of four radio-tagged Southern Boobooks (*Ninox novaeseelandiae*) were studied in a Canberra, Australia, woodland over 418 observation nights during four breeding seasons. Spatial locations and bouts of territorial calling (''boobook calls'') were recorded during each observation night. Home ranges and core areas were computed from the spatial locations using minimum convex polygons and characteristic hull polygons. Home-range sizes varied by individual owl, between breeding seasons, and by estimation method, ranging from 18.1 to 205.8 ha. Core-area estimates varied from 0.2 ha to 19.6 ha, indicating intensive use of core areas within much larger home ranges. Overall, about 26% of the boobooks' vocalizations occurred within core areas and about 56% within the home range but outside the core area, often near the border shared with the adjacent pair. Approximately 21% of boobook calls were observed on or outside home-range boundaries, which suggested that owls actively defended areas larger than their core areas.

KEY WORDS: *Southern Boobook*; Ninox novaeseelandiae; *Australia*; *calling*; *home range*; *owl*.

TAMAÑO DEL RANGO DE HOGAR Y LLAMADA TERRITORIAL DE *NINOX NOVAESEELANDIAE* EN TERRITORIOS ADYACENTES

RESUMEN.—Estudiamos los rangos de hogar de anidación adyacentes de cuatro individuos de la lechuza *Ninox novaeseelandiae* marcados con radiotransmisores en un bosque de Canberra, Australia, durante 418 noches de observación durante cuatro estaciones reproductivas. Las localizaciones espaciales y los eventos de llamada territorial (''llamadas boobook'') fueron registrados durante cada noche de observación. Los rangos de hogar y las áreas núcleo fueron computados a partir de las localizaciones espaciales usando el método de polígono mínimo convexo y polígono envolvente convexo característicos. El tamaño de los rangos de hogar varió para cada individuo entre las estaciones reproductivas y para cada modelo de estimación, fluctuando entre 18.1 y 205.8 ha. Los estimados de área núcleo variaron entre 0.2 ha y 19.6 ha, indicando un uso intensivo de las áreas núcleo dentro de áreas de hogar mucho más grandes. En total, cerca del 26% de las vocalizaciones boobook ocurrieron adentro de las áreas núcleo y cerca del 56% adentro del rango de hogar pero afuera del área núcleo, usualmente cerca del borde compartido con la pareja de lechuzas vecina. Aproximadamente el 21% de las llamadas boobook fueron observadas en y afuera de los límites del rango de hogar, lo que sugiere que las lechuzas defienden activamente áreas más grandes que sus áreas núcleo.

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Home ranges delineate the spatial extent inhabited by an animal during its usual activities, whereas core areas denote smaller regions within that range that are used much more intensely (Burt 1943). In practice, the home range is often considered the smallest area within which an animal spends 95% of its activity and the core area 50% (White and Garrott 1990). Together, home ranges and core areas provide the most fundamental information about the movements and space-use patterns of raptors and other animals. When individuals are tracked during subsequent breeding seasons, quantification of home-range overlap can lend insights regarding site fidelity. Likewise, measurements of home-range overlap among neighboring individuals during the same season can be used to understand the territoriality of species. Furthermore, when coupled with field observations of vocalizations and other agonistic behaviors, home-range analysis provides a useful approach for understanding the spatial and social structure of populations.

We used detailed location data and field observations to study space-use patterns and territorial behavior of two Southern Boobook (*Ninox novaeseelandiae*) breeding pairs in adjacent home ranges over four breeding seasons. Boobooks are monogamous, single-brooded owls that breed during the austral spring in southeastern Australia. Though widespread, the species is not well studied, and little is known about the spatial and social structure of their populations (see Olsen and Taylor 2001, Olsen et al. 2008). For each of the four individual owls, we computed their seasonal home ranges and core areas, quantified home-range overlap with other individuals, documented annual shifts in home ranges, and mapped bouts of territorial calling with respect to home-range boundaries.

METHODS

Study Area. The owls tracked in this study were located in nature reserves within Canberra, Australia (149°5′E, 35°17′S) at elevations from 600 to 800 m. Owls were observed within the 80-ha Aranda Bushland, the northwestern corner of the 600-ha Black Mountain Reserve, the suburbs of Cook and Aranda, open grazing land to the south of Aranda Bushland and Cook, and occasionally the wooded north flank of Mount Painter. Except for Mount Painter and the grazing land, the area is primarily open forest and tall woodland (see Olsen et al. 2002a for details).

Radiotelemetry. We used wire bal-chatri traps (Olsen and Woollard 1975) baited with a house mouse (*Mus musculus*), a noose mounted on the end of a surf-casting rod, and fishing nets on extended poles, to trap four breeding adults. Adults with a brood patch were classified as females, those without a brood patch classified as males (Olsen and Trost 1997). We fitted each owl with a stainless steel, numbered Australian Bird and Bat Banding Scheme band, and a plastic color-band sealed with superglue.

We fitted each owl with a backpack style Sirtrack single-stage transmitter with a string harness and weak link designed to break if the bird became entangled by its transmitter and harness (Karl and Clout 1987). Radios weighed 5.4 g and harnesses 1.0 g, making a 6.4-g package on a 270 g male (2.4% of body mass) and on a 340 g female (1.9% of body mass) and habituated the owls to our presence so they would forage, mate, and call in our presence. We used a flashlight to view color-bands and identify individuals at night, and did not rely solely on radiotelemetry locations, because two or three owls could be present at one calling location and because the calls of males and females could not readily be separated by ear (see Olsen and Trost 1997, 2007, Olsen and Taylor 2001, and Olsen et al. 2002a, 2002b for details).

We tracked the owls during the breeding season from 15 August when courting began to 1 March, after young had fledged and achieved independence. We visited the area several nights per week at sundown and stood 10–30 m from a nest or roost until the owls first flew; this time is the period of peak activity for Southern Boobooks (Debus 1997). Then, we tracked the owls continuously for 1.2 hr, recording the spatial location of each owl twice per night at 60-min intervals. A relatively short tracking interval was chosen so that the spatial extent of each owl's movements could be more precisely documented. We tracked owls for a total of 418 nights over the course of the study duration (1994–2001).

Home-range Analysis. We computed home ranges and core areas from the telemetry data using minimum convex polygons (MCP) and characteristic hull polygons (CHP). MCP, the smallest polygon containing all points such that all outer edges are convex, is the oldest home-range technique (Mohr 1947). Numerous studies criticize the method for overestimating home ranges or not overlapping well the true home range (Barg et al. 2005, Franzreb 2006, Downs and Horner 2008), particularly when the true home ranges have non-convex edges. However, the method is so commonly applied for avian

species including owls (e.g., Baekken et al. 1987) and especially for Australian owls (Olsen and Bartos 1997, Kavanagh and Murray 1996, Kavanagh and Jackson 1997, Soderquist and Gibbons 2007) that we include it here to allow comparison to other studies. In addition to the full MCP, we constructed home-range and core-area estimates that included 95% and 50% of the densest points, which helped remove the effects of the most peripheral points. MCPs were constructed using ArcGIS v. 9.2 (ESRI, Inc.) with the Home Range Tools extension (Rodgers et al. 2007). We also applied CHPs to estimate home ranges. Characteristic hull polygons are constructed from the Delaunay triangulation of a set of points, where some set of triangles is removed to construct a hull that can have non-convex edges (Duckham et al. 2008). Here, we estimated home ranges and core areas using CHPs constructed by retaining the smallest 95% and 50% of triangles, measured in terms of perimeter (Downs and Horner 2009). CHPs were generated using standard functions in ArcGIS. These two methods were chosen because they are robust to autocorrelation induced by a frequent temporal tracking interval compared to statistical methods like kernel density estimation (Andersen and Rongstad 1989, Fieberg 2007).

For both methods used, home ranges and core areas were computed for each season for each owl. The relative sizes of each were used to infer how intensely areas were used within an animal's range. For 1998–99, the only season where all four owls were tracked simultaneously, we mapped the home ranges to evaluate the amount of overlap between males and females of a given breeding pair, as well as among the two members of the neighboring pair. Finally, we overlaid the home ranges of individual owls for each season on top of one another to document how they varied among different seasons.

Territorial Boobook Calls. In addition to radio-tracking, we noted all detections of the two-note ''Territorial Boobook'' call. Territorial Boobook calls were usually given from a high perch to broadcast across the territory, often in long bouts of up to one hour, and sometimes in ''duels'' where two unmated owls from different territories faced each other in the same tree, or up to 50 m apart (Olsen et al. 2002a, 2002b). We scored each bout of vocalizations heard during each observation night, as well as the spatial location and identity of the caller. Locations of calls were overlaid with home-range and core-area boundaries for each owl in each breeding season. We computed the percentage of calling locations that occurred within the core area, home range (excluding core area), and on or outside the home-range boundary. We used CHPs for this portion of the analysis, since they generated more realistic home-range boundaries than the MCP (Downs and Horner 2009).

RESULTS

We caught four breeding adults: (1) White Male, trapped in 1993, radio-tracked during 1994–95 and 1998–99, and found dead in 2006; (2) White Female, trapped in 1993 while mated to Green Male. She switched to White Male in 1997, was radio-tracked during 1998–99, 1999–2000, and 2000–01, and found dead in 2001; (3) Green Male, trapped in 1993. By 1998 he had displaced the neighboring pair Red (color-banded 1993, not radio-tagged or included in this study) and absorbed Red's territory. Green Male was radio-tracked during 1997–98 and 1998–99, and was still alive in January 2010. (4) Green Female, trapped in 1997 when first mated with Green Male, was radio-tracked during 1997–98 and 1998–99, and disappeared in 2004.

Home-range Analysis. Home ranges varied for the individual owls, breeding season, and estimation method, ranging from approximately 20 to 200 ha (Table 1). Based on 9 estimates for each measure combined across individuals and years, unweighted mean home-range size was 145.1 ha (SE = 18.7) using 100% MCP, 69.0 ha using 95% MCP (SE = 12.0), and 59.1 ha for CHP (SE = 12.1). Mean core areas were 7.3 ha using MCP (SE = 2.0) and 2.4 ha for CHP (SE = 1.4). Although the estimates varied among individuals and methods, with 100% MCP generating the largest sizes, all of the results consistently document substantially smaller core areas within the home range.

Home ranges within pairs of males and females overlapped considerably in all cases, regardless of whether MCPs or CHPs were used to compute the estimates. For the White pair, home ranges of the male and female were similar in size and shape during 1998–99, the only year they were tracked simultaneously. For the Green pair, during the 1997–98 and 1998–99 seasons, the female's home range was larger, encompassing all or most of the male's range. All four owls were tracked during the 1998–99 breeding season, and the home ranges of neighboring pairs overlapped in the southwestern corner of the White territory, where the Green pair pushed into the southwestern corner of the White territory

Table 1. Home ranges and core areas (ha) of four Southern Boobooks estimated using minimum convex polygons (MCP) and characteristic hull polygons (CHP).

				MCP			CHP	
					HOME RANGE			
OWL	SEX	SEASON	*n*	CORE AREA	95%	100%	CORE AREA	HOME RANGE
White	M	1994–95	69	12.7	83.1	205.8	4.5	97.2
		1998–99	67	1.2	71.7	75.2	0.2	28.4
White	F	1998–99	56	0.3	32.4	73.4	0.3	18.1
		1999–00	197	7.3	90.4	191.6	0.5	53.1
		2000–01	69	3.4	23.9	180.3	0.2	28.6
Green	M	1997–98	195	4.9	55.3	172.9	0.5	58.5
		1998–99	112	11.8	38.9	70.6	1.9	45.3
Green	F	1997–98	82	19.6	137.9	150.1	10.7	131.7
		1998–99	204	4.7	87.8	186.0	2.7	71.0

(the Green Male first appeared in 1993 and progressively occupied parts of the adjoining territories that Red and White had occupied since at least 1991 [J. Olsen and S. Trost unpubl. data; Olsen et al. 2002a, 2002b]; Fig. 1).

Home ranges were also mapped in order to compare individual changes over time, although they are not illustrated here. For the Green Male, home ranges estimated with CHP methods remained almost identical in size and shape over the two seasons he was tracked; they were somewhat variable with the MCP methods, as the boundary is only defined by the outermost points. The Green Female's home range was larger during 1997–98 than in the following season (Table 1) but still occupied the same general area. The White Male's home range

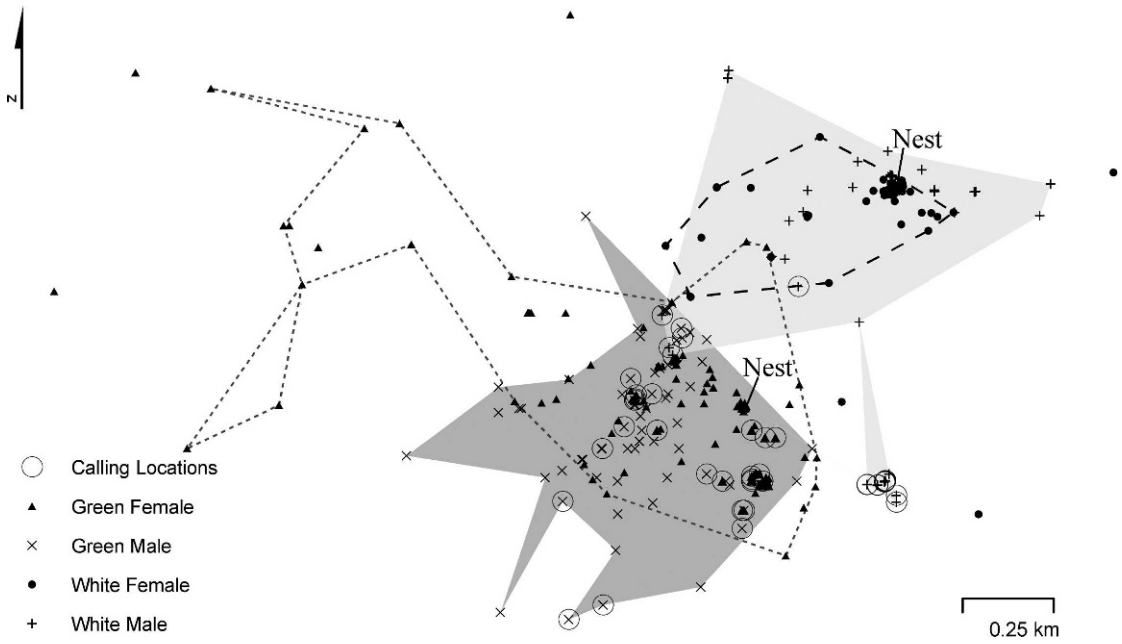

Figure 1. Home ranges of four Southern Boobooks during one breeding season (1998–99) estimated using 95% characteristic hull polygons. Female home ranges are dotted or dashed, while males are shaded. Locations of territorial calling are circled.

Table 2. Percentages of bouts of territorial calling by Southern Boobooks that occurred within their core areas, home ranges, (excluding core area), and on the border or outside of their home ranges, as estimated using 50% and 95% characteristic hull polygons.

				Location of Calling Bout (%)		
Owl	Sex	Season	*n*	Core Area	Home Range	Border/Outside
White	M	1994–95	5	60.0	40.0	20.0
White	M	1997–98	5	0.0	60.0	40.0
White	M	1998–99	16	37.5	25.0	37.5
White	F	1999–00	10	10.0	70.0	20.0
Green	M	1997–98	54	20.3	63.0	16.7
Green	M	1998–99	19	42.1	47.3	10.5
Green	F	1998–99	14	14.3	85.7	0.0

showed a much greater change, in terms of both size and location, being both smaller and shifted eastward.

Territorial Calling Results. Territorial calling, including dueling bouts, were detected for all four owls, although only males could be compared for multiple seasons. From 5 to 54 episodes were recorded for an individual during a single season. Females accounted for about 20% of bouts, and males 80% (Table 2). Overall, the unweighted mean indicated 26% of vocalizations occurred within an owl's core area, as delineated using CHP methods. About half of all bouts occurred within the 95% home range but outside the core area, and 21% were located on or outside the 95% home-range boundary. Mapping the calling locations for the owl with the largest sample size (Green Male) revealed that 17% of 73 detections of calling occurred near the home-range boundary, with several of these located along the border shared with Pair Red (not in this study) who were displaced in 1997–98. In 1998–99 Male Green duelled six times with Male White (Fig. 1).

Discussion

Regardless of whether MCP or CHP methods were used, the home-range estimates we obtained were larger than those commonly reported for boobooks in Australia. Early estimates of home-range size for boobooks were 8–10 ha (Schodde and Mason 1980, Loyn 1980) but these owls were unmarked. A study of one radio-tagged male boobook noted a maximum home range of 37 ha with a more restricted core area of 7.9–10.3 ha (Olsen and Bartos 1997). Olsen and Trost (1997) reported larger home ranges, approximately 100 ha for one radio-tagged male and at least 50 ha for another color-banded male, and Olsen and Taylor (2001) reported 122 ha and 91 ha for 100% MCP and 95% MCP over 12 observation nights for one radio-tagged wintering female. Our current results suggest that boobook owls may occupy areas larger than previously reported, and this has implications for conservation of these owls in terms of the amount of habitat they may require.

The results of both MCP and CHP analyses showed that during the breeding season, male and female boobooks made intensive use of small core areas within a much larger home range, spending most of their time near their roosts and nests. All four individuals made a number of flights distant from these core areas, although many of the habitats visited appeared to be used very infrequently and the function of these visits remains unclear. Female boobooks normally desert their fledged young and leave care to the males (Olsen and Trost 1997, Olsen et al. 2008), and may range more widely to prospect for future mates (Olsen and Trost 2007). Our results also showed that males and females of the same pair occupied roughly the same home range as one another and inhabited the same general area during consecutive seasons, suggesting they display a high degree of site fidelity. These color-marked owls stayed on these territories for 7 to 17+ years, although one female switched mates, from Green Male to White Male (J. Olsen and S. Trost unpubl. data). Additionally, home ranges of neighboring pairs overlapped slightly or not at all during seasons when they were tracked simultaneously. These findings suggest the boobook pairs displayed a high degree of site-specific dominance and territoriality.

Boobook owls actively defended both their core areas and home ranges throughout the breeding season. Approximately 20% of their vocalizations

and dueling occurred directly on the home-range borders, sometimes outside the delineated home range as determined by 95% CHP. For example, Green Male and White Male called in an area of overlapping home ranges (Fig. 1), and White Male traveled to prominent trees east of the Green home range and called there. These vocalizations over territorial boundaries may serve important ecological functions for breeding and maintaining quality territories, and may help male boobooks expand a territory (Olsen et al. 2002a, 2002b, Olsen et al. 2008, Olsen et al. 2010). Prominent call posts are used by many owls (Johnsgard 2002) and are said to surround ''core areas'' (Samuel et al. 1985) containing nests, refuges, or the highest availability of food (Delgado and Penteriani 2007). However, Linkhart et al. (1998) found that calling posts made up about 30% of nocturnal point locations of seven male Flammulated Owls (*Otus flammeolus*) and these were not necessarily close to nests or foraging areas. The results of our study suggest that boobooks often call in locations distant from core areas used for nesting and foraging.

Due to lack of monitoring and research on their biology, two Australian subspecies, *N. n undulata* and *N. n. albaria* are now extinct (Garnett and Crowley 2000). Researchers learned, too late, that *N. undulata* nesting habitat had been destroyed, and that *N. albaria* had apparently been eradicated by introduced Masked Owls (*Tyto novaehollandiae*). As little is known about the space-use and social behaviors of boobooks and other small *Ninox* species and subspecies present throughout Australasia (König and Weick 2008, Olsen et al. 2002), further home-range studies are needed to expand our knowledge and enhance our capacity to conserve these owls.

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