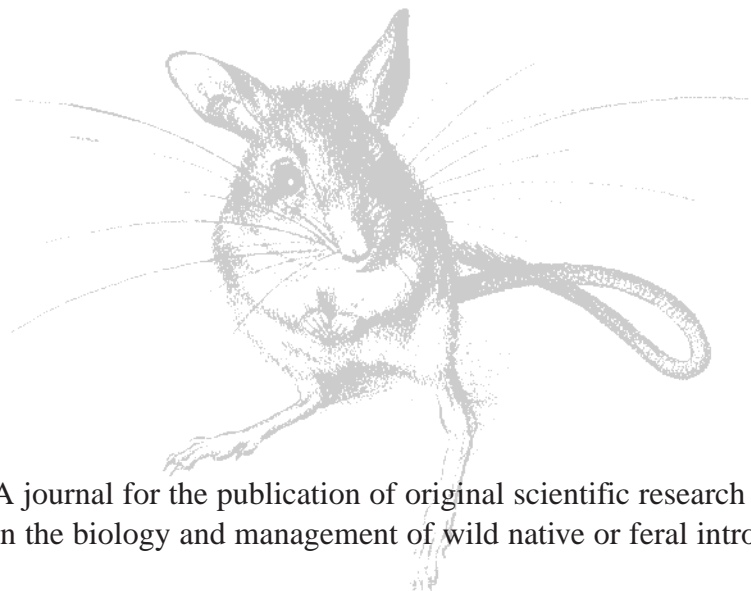

CSIRO PUBLISHING

Wildlife Research

Volume 27, 2000

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Home range and movement of foxes (*Vulpes vulpes*) in coastal New South Wales, Australia

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Abstract. Data on the home range and activity of 14 foxes was collected from coastal habitat in Jervis Bay, New South Wales during 1993–95. Radio-collared foxes had a mean home range of 135 ha and core activity areas of 23 ha (determined by the Minimum Convex Polygon method). There were no significant differences in the home ranges of male and female foxes. The home ranges of some foxes shifted throughout the study. Some animals went on long forays beyond their normal range. All animals displayed nocturnal activity patterns except during the breeding season or after long spells of wet weather when some foraging occurred during daylight hours. The information collected in this study is discussed in the context of fox control.

Introduction

Information on the areas used by foxes and the size of their home range is essential when planning programs either for disease control (Coman *et al.* 1991) or to mitigate environmental or agricultural impacts through population reduction. Understanding spatial distribution, areas of preference and avoidance, and activity and movement patterns are also important in formulating fox-control strategies and stratifying control effort (Kolb 1984).

The use of natural habitat by foxes in Australia is not well understood because although home-range utilisation by foxes has been widely studied overseas, with significant variation in home-range size between habitat types and locations (Saunders *et al.* 1995), few such studies have been conducted in Australia (Coman *et al.* 1991; Phillips and Catling 1991; Marlow 1992; Thompson 1994). Only one of these studies (Phillips and Catling 1991) was conducted in a coastal wilderness area similar to the habitat of this study. May and Norton (1996) believe that foxes rely heavily on roads and tracks to gain access to foraging areas, whereas Catling and Burt (1995) found that disturbance to vegetation in proximity to roads was a factor in the presence or absence of foxes. Phillips and Catling (1991) found that foxes in coastal New South Wales were infrequently recorded in heath and beaches and believed that foxes did not favour these habitats.

In this paper we report on the home range, movement and activity patterns of foxes living in Jervis Bay Territory on the south coast of New South Wales. Management implications resulting from this study are also discussed.

Methods

Study site

The study was conducted on Bherwerre Peninsula (35°13'S, 150°45'E), which is located on the east coast of New South Wales in Jervis Bay Territory. The study area included the residential areas of Jervis Bay Village, HMAS Creswell and Wreck Bay Community. The area consists of 13 vegetation categories, predominantly heath (Ingwerson 1976). The peninsula covers approximately 7700 ha, including Booderee National Park. The Wreck Bay Community is located on the south coast of the peninsula (Fig. 1). The average annual rainfall for Jervis Bay is 1150 mm, with May the wettest month and September the driest. Average maximum day temperature for winter is 15.1°C and for summer is 24.0°C.

Study animals and radio-telemetry

In total, 21 foxes were trapped between July 1993 and October 1994 using #3 Victor Soft Catch Traps®. Eighteen adult foxes were radio-collared and three juveniles were ear-tagged and released. Movement data were collected from 14 of the radio-collared foxes. After being trapped the animals were sedated with an intramuscular injection (0.05 mL) of Zoletil 20® and fitted with Sirtrak® collars. The collars operated on frequency 151 MHz and varied in battery life (12–24 months). The collars were customised using reflective tape with colours and shapes assigned to each animal so that they could be identified under reduced lighting or with the aid of spotlighting. To expedite locating the foxes, a 7-element Yagi antenna was fitted to a 2-m aluminium mast attached to a vehicle so that signals could be received inside the cabin while driving. Once located, foxes were individually tracked on foot with a 4-element hand-held Yagi antenna.

Locations were estimated by manoeuvring (homing-in) as close to an animal as possible while causing minimal disturbance to its behaviour. The advantage of collecting radio-fixes on foot rather than relying on fixed towers was that actual animal locations were recorded rather than estimates within a triangulated polygon (White and Garrott 1990).

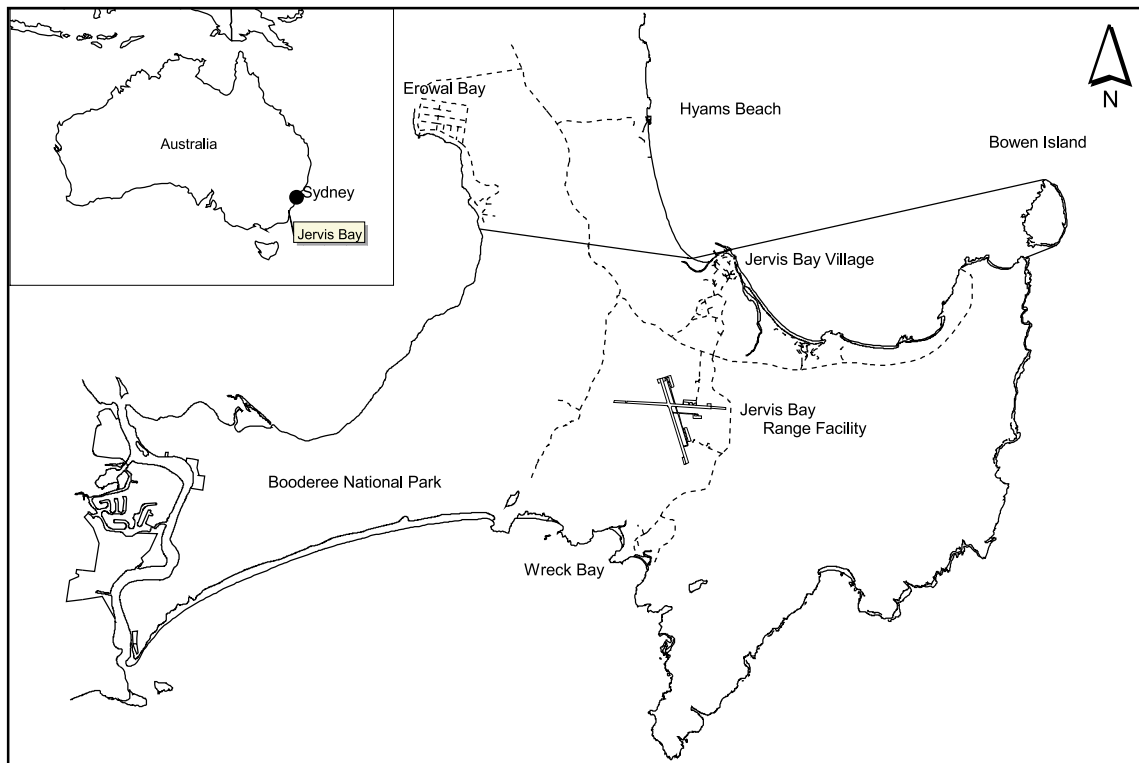


Fig. 1. The study site of Bherwerre Peninsula, Jervis Bay, New South Wales.

Accuracy of locations was to within 20 m. Some locations of animals were confirmed by sighting the reflection of individual collar markings. Records of behaviour and habitat were taken at each location.

Discontinuous tracking (Harris *et al.* 1990) was conducted over 4 consecutive nights on 12 occasions during 1994–95. The nature of the habitat made it difficult to locate animals that were in dune swales or on a foray, making continuous tracking impractical (intervals of less than 15 min, as discussed by Harris *et al.* 1990). Most tracking sessions were 18-h long although a block of 4 days (24 h) was conducted (July 1994) to collect data during the morning and afternoon when foxes were in lying-up sites and dens. Fixes on study animals were attempted every hour throughout the sampling periods.

At each radio-fix records were taken of the habitat; these were later used to quantify the number of fixes in each habitat type. Foxes were considered to be travelling along a road if they were within 15 m of the road edge. Seven habitat categories were selected to simplify recording and analysis:

1. Grassland (golf course and ovals)
2. Forest (woodlands and forests)
3. Riparian (swamps and creeks)
4. Heath (wet, dry and mallee heath)
5. Disturbed (roads, tracks, camp grounds, rubbish tips)
6. Coastal scrub, and
7. Beach

An eighth habitat category (Burnt heath) has since been included for the purpose of discussing the use of burnt habitat by foxes in this study.

Home-range estimations

Animal locations were identified on a map using Australian Map Grid co-ordinates (Zone 56). Each location was also digitised using a Graphical Facilities Information System (AUTOCAD-VQ). To test the accuracy of the AUTOCAD program, the distance between known points were ground-truthed using a Kaycee circular measuring wheel. The

program was accurate to <3 m on all field tests. Home-range area was determined using the program HOMERANGE (Ackerman *et al.* 1990). The Minimum Convex Polygon (MCP) (Southwood 1966) was selected as the preferred method of determining home range; this method produces a non-statistical home-range measure that is not affected by dependent data (Swihart and Slade 1985). Its simplicity also makes it the most popularly used method, in turn making it useful as an index of home-range size for comparisons between studies. Core activity areas (MCP 60% isopleth) were also derived to identify the size and location of areas of intense use (Woollard and Harris 1990).

Results

Approximately 700 h of tracking time resulted in 2410 fixes collected on 14 foxes. Four other foxes died or disappeared before any useful data could be collected and the ear-tagged juvenile foxes were not re-trapped or recorded after release.

Home range

Individual home-range data are presented in Table 1. Males had a mean home range of 138 ± 22.45 (s.e.) ha, compared with a mean home range of 132 ± 26.94 (s.e.) ha for females. There were no significant differences ($t = 0.85$, d.f. = 17, $P > 0.05$) between home-range sizes of males and females (Table 2). Three foxes displayed shifting home ranges (shifts by two foxes are shown in Fig. 2) so a mean home-range size was calculated from the different sites (Table 1). Core activity areas were small, with a mean area of 23 ± 4.30 (s.e.) ha (Fig. 3); although the core activity areas of females were marginally smaller (16 ± 5.49 (s.e.) ha) than those of males (28 ± 6.08

Table 1. Home-range estimates for individual foxes at Jervis Bay
Home ranges were estimated using the 100% and 60% minimum convex polygon method. n = number of locations

Fox	Sex	Weight (kg)	n	Home range (ha)	Core activity area (ha)
M70	M	6.0	134	270	74
F24 ^A	F	4.5	226	210	13
F30	F	4.0	295	210	48
M26 ^A	M	5.5	372	200	31
M22	M	6.0	151	160	40
M84	M	6.0	68	120	32
M18	M	5.0	251	110	24
M68	M	4.5	37	95	15
F28 ^A	F	3.5	333	91	10
F80	F	4.5	64	90	9
M82	M	4.5	78	85	10
M58	M	6.5	145	80	14
M60	M	5.0	127	63	10
F56	F	6.0	129	60	17

^AMean value where more than one home range was established.

(s.e.) ha), the difference was not significant ($t = 0.17$, d.f. = 17, $P > 0.05$). Most core home-range areas were mutually exclusive, although many home ranges (100% MCP) did overlap; for example, foxes M22 and F28 lived within the home range of M26 for most of the study.

Movement patterns

Relocation of home ranges was also observed: one vixen moved home range twice and another moved three times.

Table 2. Mean home range estimates

Home ranges were estimated using the minimum convex polygon method. Includes shifting home ranges of 3 foxes (14 foxes = 18 home ranges). Home-range data are shown \pm s.e.

Method	Males ($n = 10$)	Females ($n = 8$)	Population
MCP (100%)	138 \pm 22.45	132 \pm 26.94	135 \pm 16.78
MCP (60%) core area	28 \pm 6.08	16 \pm 5.49	23 \pm 4.30

The reason for these moves was not apparent although they were possibly due to the departure of other foxes from neighbouring ranges. Three other foxes shifted home ranges during this study. M26 occupied a home range of 150 ha in one area and in February 1994 he completely shifted his home range to the north-west. Similarly, the death due to mange of M18 in November 1994 saw M84 take over the newly available home range: it was apparent that the home-ranges of these two males were very similar. F28 changed or adjusted her home range five times (Fig. 2). She moved a short distance (<1 km) east from her capture site into the Jervis Bay village where she occupied a small home range. In June 1994 she dispersed north out of the Bherwerre Peninsula, a distance of about 10 km, to a nearby crossroad. In October 1994 she moved south another 10 km back to the area where she was originally trapped. These three shifts were probably a result of her subordinate position in the population. She had not raised a litter during this time and occupied relatively small areas in all

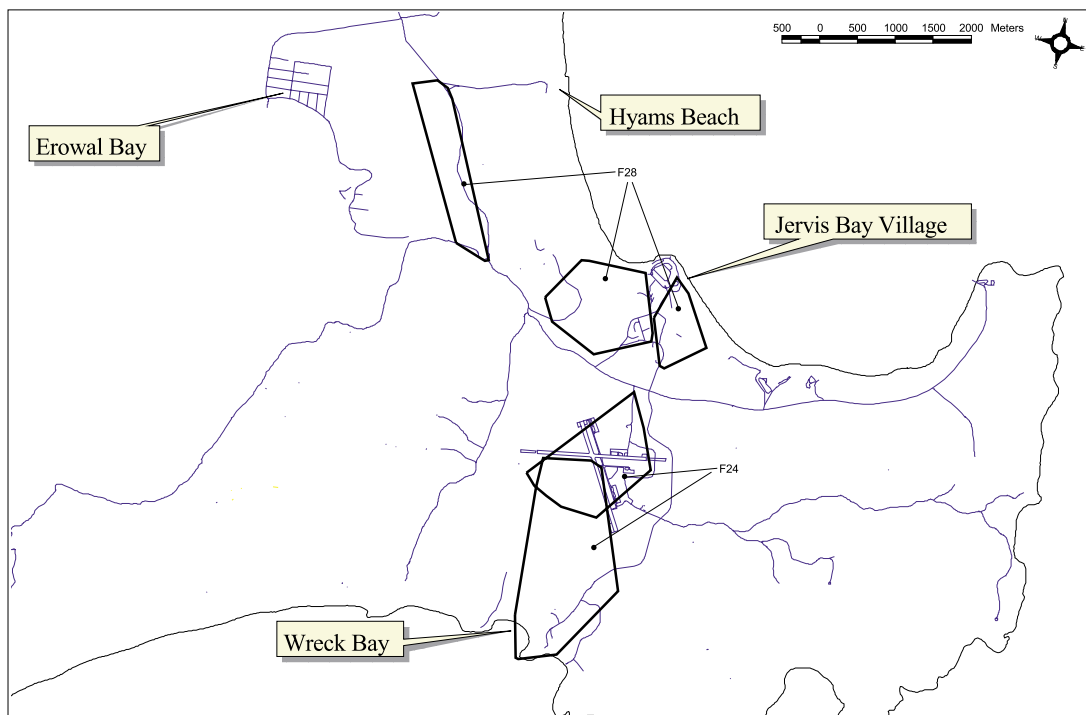


Fig. 2. The shifting home ranges of two foxes on Bherwerre Peninsula, 1994–95.

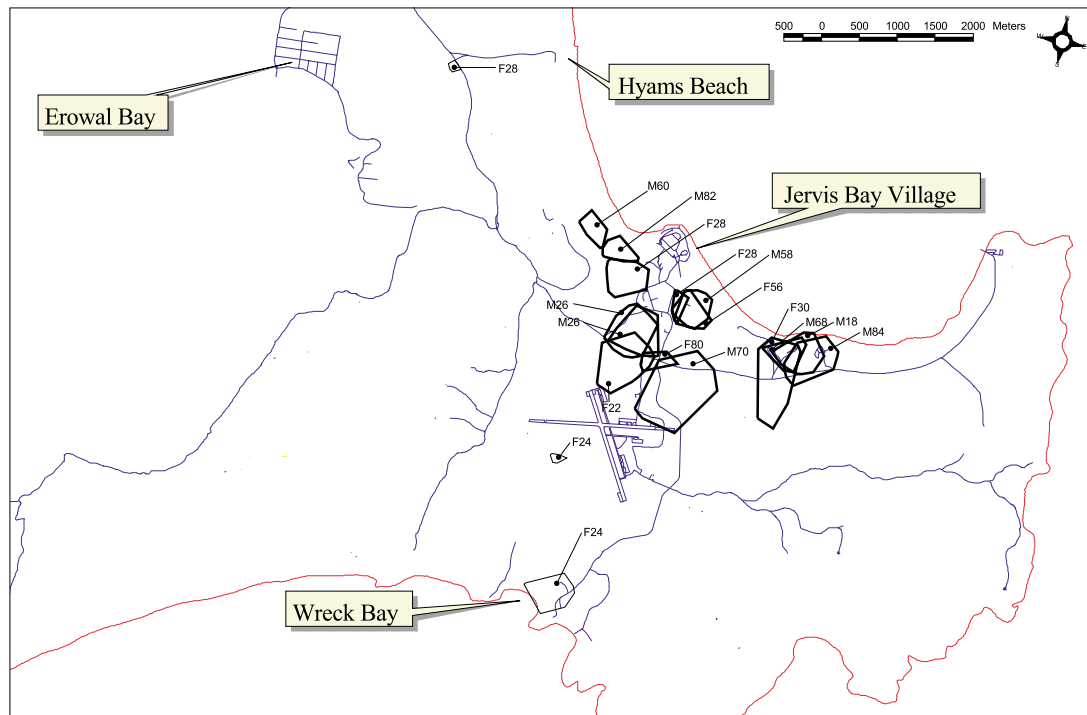


Fig. 3. Core activity areas of radio-tracked foxes on Bherwerre Peninsula, 1994–95.

Table 3. Mean percentage of time recorded in habitat types

Based on the number of radio-tracking fixes. n = number of radio fixes per habitat type

Habitat type	n	Mean percentile
Heath	686	28
Riparian	609	25
Forest	348	14
Disturbed	285	12
Burnt heath	214	9
Grass land	127	5
Coastal scrub	88	4
Beach	71	3

three locations. F30 also relocated her home range towards the end of the study although we were unable to determine the size and geographic location of her range

Habitat fixes

Foxes were recorded in all available habitat types although most radio-fixes were recorded in heath (Table 3), the most abundant habitat type in the study area. As in other studies, roads, beaches and creeks were used by foxes as thoroughfares and boundaries to their territories. On 33% of occasions foxes were recorded on or beside a road.

Seven foxes were recorded using burnt habitat (Table 3). For example, M26 was tracked in an area immediately after a bushfire had been extinguished. This animal sustained burns to its paws and was seen limping along the roads for days after

the fire. It was apparent that the animal had attempted to forage in the area and had burnt its feet on hot ash and coals. Despite his injuries, the burnt habitat became an important part of his home range for a number of weeks.

Discussion

The foxes studied at Jervis Bay had similar-sized mean home ranges to those of foxes of semi-urban Victoria (Coman *et al.* 1991) and of coastal areas in the Netherlands (Mulder 1985). The only foxes known to have smaller home ranges are those of urban areas (Doncaster and Macdonald 1991; Saunders *et al.* 1993). Given that a home range contains a 'finite potential energy resource that is proportional to its area, with habitats of greater productivity resulting in smaller home ranges' (Harestad and Bunnell 1979), it follows that the present study site must be relatively productive with respect to the requirements of foxes; in fact, Jervis Bay does have a rich mammal (i.e. prey) resource (Caughley 1993). Habitat richness has also been reported to influence home-range size of foxes in Italy (Lucherini and Lovari 1996).

In the only similar Australian study in natural coastal bushland (Phillips and Catling 1991), home ranges of foxes in Nadgee National Park were considerably larger (120–520 ha compared with 63–270 ha in this study). This result was unexpected as the two areas have similar vegetation communities, aspect and geography, although the availability of prey in Nadgee National Park was very low in some habitats (Phillips and Catling 1991). One minor difference between

the sites was that Jervis Bay had some level of residential development, although only a small percentage of observations were recorded in these areas so it is unlikely that urban influences affected home-range size in Jervis Bay. The differentiation in home-range size may be a reflection of the methods used to analyse the home-range data (P. Catling, personal communication) whereby these authors may have overestimated their home-range size by not excluding outliers, and estimates were for three foxes only.

There was a clear association between home range boundaries and the road and track network on the peninsula. Foxes were recorded within 15 m of roads on 33% of all fixes. Similarly, many European studies have found home-range boundaries of foxes to be defined by man-made features such as roads, playing fields and railway lines (Macdonald 1981; Kolb 1984; Doncaster and Macdonald 1991; Saunders *et al.* 1993). Range boundaries and size can also be affected by other factors such as land use: forestry activities and clearing for agriculture have been found to influence fox movements within their range (Catling and Burt 1995).

It has been suggested that foxes do not live entirely within closed-canopy forests but can penetrate some distance into them in search of food by using roads and tracks (Jarman 1986). May and Norton (1996) recommend that one of the most important fox-related research needs is to establish the relative impact that exotic predators may have under varying degrees of road construction in native forests. Foxes in this study consistently used roads and tracks for access but were also found living and foraging within dense coastal forest and heath. The use of roads by foxes may be a means of optimising foraging success, e.g. road-killed wildlife. Swamp wallabies are regularly killed on Jervis Bay roads and the prevalence of their hair in fox scats (Meek and Triggs 1998a) shows that they are a food resource. However, the presence of foxes off-road has obvious implications in the risk they pose to native fauna in these habitats. While some authors (Catling and Burt 1995; May and Norton 1996) suggest that roads may assist foxes in accessing dense habitat, we believe that further research is required before accepting this conclusion: records of foxes using dense heath and forests in Jervis Bay is evidence that all habitats were being used by foxes. It could be argued that foxes use roads and tracks for ease of movement rather than walking through dense vegetation; however, in the absence of roads, foxes will forage and move about their home range through dense vegetation.

Movement outside of normal activity areas by seven of the collared foxes in this study was a regular phenomenon. Similar forays lasting for 1–3 days and over distances up to 16 km have been recorded elsewhere (Lloyd 1980; Kolb 1984); it is thought that these irregular movements are influenced by food availability (Niewold 1974), the mating season (Zimen 1984) or foxes seeking new territories (Mulder 1985).

In this study foxes displayed normal activity patterns (Saunders *et al.* 1993), usually leaving their daytime lying-up

sites on dusk. Their initial movements were short and mostly within vegetated areas. On nightfall foxes would increase their activity and begin to use the roads to patrol their home range. At about 0200–0300 hours they would often rest for about an hour. Foxes usually reached their daytime resting sites, mainly riparian habitat and heath, by sunrise (0500–0600 hours). Occasionally they would make very small diurnal movements, but usually they rested in the shade of vegetation.

Many forays, by both male and female foxes, were recorded throughout the tracking period. The purpose of these forays is not known since movements were random and not always in the breeding season. The longest foray was undertaken by a male (M18) about 3 km (straight line) from the most outer limits of his normal home range. In most cases forays lasted only a few hours, although F28 sometimes disappeared for one or two days at a time.

Three foxes relocated their home range during this study. Zimen (1984) has recorded similar shifting of home range by foxes, and Doncaster and Macdonald (1991) and White *et al.* (1996) have discussed home-range drift at length. These observations of shifting and relocation of home range have implications for pest control in that foxes can quickly recolonise vacant territories after control if pressure is not maintained to reduce fox abundance (Bogel *et al.* 1974).

The importance of timing and intensity for controlling foxes has not been fully recognised in Australia and there are differing views on when to implement control according to the desired outcome, e.g. protection of lambs or endangered species (Saunders *et al.* 1995; Fleming 1997; Meek 1998). For example, the increased activity of foxes during dispersal provides an ideal opportunity for baiting and trapping. Dexter and Meek (1998) successfully used this approach in the Jervis Bay region during 1995 where protection of native species was the aim. In their study baiting was conducted in March to coincide with dispersal of yearlings and bait uptake remained low after poisoning for the remaining seven days of the program. Bait takes by foxes have remained low in comparison to the 1995 bait takes over subsequent annual baitings and *Perameles nasuta* have started to increase in abundance across the Peninsula (S. Moore, personal communication).

A control method that has not been explored is to bait, trap and shoot foxes in areas after bush fires. Observations in this study and those of Macdonald (1987) indicate that foxes are attracted to recently burnt habitat which provides an ideal opportunity for an intensive control effort. The open habitat is ideal for fox foraging and there are fewer native species that could be threatened by non-target poisoning. Threats to native species can be minimised by adopting a mound-baiting technique for poisoning (Thompson and Fleming 1994) and by using soft-jaw traps. Baiting at this time may also reduce predation on the early native mammal colonisers of the burnt habitat (Meek and Triggs 1998b).

Acknowledgments

This study was funded by the Bureau of Resource Sciences under the auspices of the Aboriginal Rural Resource Initiative Program, and by the Mainland Territories Section of the Department of the Environment, Sport and Territories (special thanks to Linda Hodges and Peter Lawler). Research was conducted under Booderee National Park Permit No. JBLA 22. Animal ethics approval was obtained from the University of Canberra Animal Experimentation and Ethics Committee (AE 93/5).

We thank Athol Ardler and Richard Hawksby for field support, sometimes under very unfavourable conditions. Kevin Lay and David Ward provided invaluable radio-tracking technical assistance. Thank you also to the many people who helped collect tracking data (Janelle Meek, Yvonne Brown, Ursula Moore, Teresa Thies, Rachael Dimasi, Vivina Sinnamon and Phil Borchard). Arthur Georges, Martin Fortescue and David Jenkins provided support and advice during this study. Finally, thank you to Rob Kirwood for assistance with producing the GIS maps and figures.

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Manuscript received 22 April 1998; accepted 24 November 1999