

CHAPTER 6

FOX DENSITY AND DEN PREFERENCES

6.1 Introduction

Estimates of abundance of animal populations often form the cornerstone of ecological and wildlife management studies (Caughley 1977; Krebs 1989). Accurate and reliable estimates are especially important for the planning and assessment of pest management programs where the objective is to reduce population size (Wilson and Delahay 2001). Abundance may be either estimated in relative or absolute terms (Caughley 1977) using direct (counts of animals) or indirect methods (counts of field signs) (Sadler *et al.* 2004; Webbon *et al.* 2004). Most fox management programs only seek to obtain indices that relate to true abundance, since it is usually the direction (increase or decrease) and magnitude of the change (percentage) that is required. However, absolute estimates of abundance are inherently more useful for determining the need for and magnitude of management, especially for containment of exotic diseases or zoonotics, and to assist in the planning, cost and choice of strategies employed by management programs.

In Australia, actual density estimates are essential for determining the likelihood of spread and persistence of rabies in fox populations. Rabies is present on every continent except Australia and Antarctica (Blancou 1988) and would be a major concern if it ever became established here (Saunders *et al.* 1995). Rabies has two major epidemiological cycles; urban rabies with the dog as primary host, and sylvatic rabies with at least one wildlife vector involved (Saunders 1999). In Europe and North America foxes are the major host of sylvatic rabies (Geering 1992) and, as a result, considerable effort is made annually to reduce the density of susceptible individuals by immunisation of wild foxes against the disease (Wandeler 1988; Stohr and Meslin 1996; MacInnes *et al.* 2001; Vos 2003). Accurate estimates of fox density in Australian environments are needed to determine whether density is greater than the threshold required for sylvatic rabies to persist here (Marks and Bloomfield 1999a). Where the threshold is exceeded, these estimates would be invaluable for calculating the reduction in susceptible individuals required to stop this persistence.

There are many problems associated with estimating the actual density of foxes (Harris 1981). The use of direct counts to estimate the absolute abundance of foxes is limited, given the largely cryptic, nocturnal activity and relatively low density of the species compared to other animals (e.g. Newsome and Catling 1992). Estimates from distance techniques using line and point (spotlight) transect counts are promising but violations of sampling assumptions (particularly reduced encounter rates on the transect) suggest that additional refinement of the technique is necessary (Ruelle *et al.* 2003). Additionally, the distribution of foxes in a variety of habitats worldwide means that many direct count techniques, including distance sampling methods (Ruelle *et al.* 2003), cannot be applied consistently across different habitats and landscapes (Wilson and Delahay 2001). Counts of field signs are becoming favoured due to the greater cost, effort and observer skill required for direct counts of animals (Sadler *et al.* 2004). A well-chosen field sign index, such as faecal counts may be applicable across a range of habitats; early assessments of the technique suggest that it is an efficient means of estimating relative density across landscapes (Sadler *et al.* 2004; Webbon *et al.* 2004). The technique has the potential to yield estimates of absolute fox density (see Webbon *et al.* 2004) but requires further validation with reliable estimates of actual density (Sadler *et al.* 2004; Webbon *et al.* 2004).

Counts of natal den sites during spring are generally regarded as being the most reliable method to determine fox density (Trehwella *et al.* 1988). With knowledge of typical sex ratios, family group organisation, and litter size it is possible to determine the population size (Harris and Smith 1987). These estimates are normally labour-intensive and may require large areas to be searched to find sufficient dens. Since areas are often too large to survey completely, a representative sub-sample may be searched and the results extrapolated to a greater area (Krebs 1989; Wilson and Delahay 2001). With counts of natal den sites, developing an appropriate sampling strategy requires knowledge of the likely distribution of dens to determine the probability of detection (Wilson and Delahay 2001). Improving our knowledge of where dens are likely to be located should increase the search efficiency and therefore the use of the den-count technique for estimating density.

Understanding the factors that determine the location of fox dens is useful not only for estimating fox density, but may lead to improvements in fumigation and baiting programs. Fumigation with carbon-monoxide can be an efficient control technique (Anonymous 1995), but it again relies on being able to locate natal dens. If baiting campaigns are undertaken while the nightly ranging area of juveniles is small, animals may not be susceptible unless baits are distributed within these ranging areas (Robertson *et al.* 2000). During the whelping and initial cub-raising period den sites are a ‘focal point’ for fox activity, and may provide ideal sites for distributing bait (Robertson *et al.* 2000). This is confirmed by Bugnon *et al.* (2004) who found that presenting bait at dens increased the uptake of anti-rabies bait and resulted in high levels of vaccination in young foxes. Distribution of baits dosed with an abortifacient (cabergoline) at known den sites was shown to be effective in reducing the reproductive success of urban foxes (Marks *et al.* 1996). Spring baiting campaigns undertaken on agricultural lands are often timed to precede or coincide with periods of high prey susceptibility (see Chapter 5); these periods may be ineffective for targeting juveniles if bait is not laid within activity centres. Improving our understanding of where den sites are likely to be found should, therefore, improve the efficiency of spring baiting campaigns.

This chapter assesses the distribution and density of fox dens on one agricultural property on the central tablelands of New South Wales. The density and distribution of dens is used to estimate fox density and to determine if there are preferences shown by foxes in locating den sites. The implications of these findings for density estimation, rabies contingency planning and current fox management strategies, particularly poison baiting, are discussed.

6.2 Methods

6.2.1 Study site

This study was conducted on “Larras Lake North”, a mixed farming and grazing property on the central tablelands of New South Wales. This property was chosen because it was representative of a typical central tablelands agricultural enterprise with associated remnants of natural habitats and likely to undertake fox baiting (see Chapter 5). The 9.6 km² property is used primarily for sheep (wool) and cattle production but cereal (including wheat and oats) and pasture crops (lucerne, forage sorghum) are also sown. The site is composed

primarily of open pasture, with patches of open woodland and timbered riverbanks. The Bell River and adjacent habitat form part of the south-eastern boundary. Plant community associations are given in Chapter 5.

6.2.2 Den searches

An intensive search of the site was undertaken between August and early November in the years 2000, 2001 and 2002 by systematically traversing transects over the entire site. Dens are only usually active during the breeding season and searches were undertaken during the peak cubbing period (August to November) for eastern Australia (McIntosh 1963b; Ryan 1976; McIlroy *et al.* 2001). A four-wheeled motorcycle was used to search those habitats that could be easily traversed, with the remaining areas searched on foot. The distance separating each driven or walked transect depended on the sighting probability, which in turn reflected such factors as topography, habitat, and pasture height. Transects were spaced up to 40 m apart where visibility was high but decreased to be almost overlapping where habitat or terrain reduced visibility. The distance between transects therefore varied based on the judgement of the observer to ensure that the probability of sighting dens was high at all times.

All structures (e.g. tree stumps, tree bases, logs, rock piles, shrubs, fence posts, sheds) encountered were thoroughly checked for the presence of dens. Sites were considered to be dens when they showed obvious signs of construction and/or use by foxes. Dens were classified as natal if they showed obvious signs that cubs were present, such as the presence of adult and cub scats, hair or prey remains, digging and/or scratching, and fresh scent. This was confirmed in most cases by the visual sighting of cubs either during the day or at dusk/early evening. Active dens were those that showed signs of recent (i.e. the current season) preparation or use, including digging, the presence of scats and scent, but were not currently occupied. Inactive dens were older dens that had not been prepared for use in the current breeding season and showed no signs of being used. The location (GPS grid reference), habitat, den habit and form, evidence of activity, and number of entrances were recorded for each den.

6.2.3 Data collation and analyses

All data relating to den locations were collated and entered into a Microsoft Access[®] database, and location data then imported into ArcView[®] to facilitate spatial analyses. Once imported, den locations were plotted and checked for accuracy and the location and/or datum (AGD66, AGD84 or WGS84) modified if necessary.

A habitat map of the study site was constructed through selecting areas of each habitat from satellite imagery (Landsat) supplied by the New South Wales Department of Primary Industries. Areas were selected based on a combination of canopy intensity and density and were extensively ground-truthed during the den searches. Three habitat types were defined: open, open woodland and riverine. Open habitat consisted of areas of open grassland and crop areas with no canopy layer of trees or tall shrubs. Open woodland areas were those with a canopy of trees apart from those situated along the river. Areas immediately adjacent to the river (<10m) were classified as riverine and may or may not have had a canopy layer of trees or shrubs.

A Digital Elevation Model (DEM) was then constructed using ArcView[®] Spatial Analyst (ESRI, California USA) to derive slope and aspect surfaces. Slope class increments were chosen at 5 degrees, allowing for 7 classes ranging between 0 and 35 degrees. Eight aspect classes were chosen to represent the 360 degree aspect spectrum.

Each den location was then classified by aspect, stratum, and habitat through a spatial join of the respective data layers in ArcView[®]. These were then modified if necessary through comparison with the recorded details and/or ground-truthing. The area of each class within each stratum was calculated using functions in the extension Xtools[®] (M. Delaune, September 2003) to provide habitat availability. A chi-squared test of heterogeneity (Pearson's) with Yates' correction for continuity (Sokal and Rohlf 1995) was used to compare whether there was any preference in selecting den sites for habitat, slope and aspect and whether these were different for natal and active dens. A Students *t*-test was used to compare the number of entrances between active and inactive dens.

6.2.4 Den distribution

The nearest neighbour distances between the active and natal dens were calculated for each year to determine whether dens were distributed in an aggregated, regular or random pattern at $P < 0.05$ (Clark and Evans 1954; Krebs 1989; Berghout 2001). This was done using the index of aggregation,

$$R = \frac{ro}{re}$$

where:

ro is the mean nearest neighbour distance

re is the expected nearest neighbour distance.

This index is computed by comparing the distance to the nearest den (i.e. nearest neighbour distance) with the expected nearest neighbour distance (the Clark and Evans test: Clark and Evans 1954). The expected nearest neighbour difference is the distance between neighbouring dens assuming a random distribution of dens across the study site. The ratio (index of aggregation or R) of the mean observed nearest neighbour distance to the expected distance indicates den dispersion. If $R = 1.0$ the distribution is random, if $R < 1.0$ dens are clumped or aggregated. A regular pattern is evidenced by an R value exceeding 1.0. A z -test (Clark and Evans 1954) was used to indicate whether R significantly deviated ($P < 0.05$) from random:

$$z = \frac{ro - re}{se[ro]}$$

where:

z = standard normal deviate

$se[ro]$ = standard error of expected distance to nearest neighbour

$$= 0.26136/\sqrt{nD}$$

n = number of individuals in search area

D = density of individuals in search area

(Clark and Evans 1954; Krebs 1989).

The coded ArcView[®] extension ID Within Distance[®] (Jenness Enterprises, August 2003) was used to calculate the distance between the nearest neighbouring dens and the edge of the search area. Dens that were located closer to the edge of the search area than to another den were excluded from the analyses. This addition of a ‘boundary strip’ reduces the potential for bias in the Clark and Evans test towards a regular pattern by not including outermost dens that may have nearest neighbours outside the search area (Krebs 1989).

A low density of natal dens would potentially mean that use of a boundary strip to exclude outermost dens would drastically reduce the sample size and hence ability to determine den dispersion. Therefore, a correction of the expected nearest neighbour distance and standard error in the Clark and Evans (1954) test proposed by Donnelly (1978) was applied to reduce bias arising from including dens in the boundary strip in the analyses.

The corrected distance is re_c , where:

$$re_c = re + (0.051 + 0.041/\sqrt{n})(L/n)$$

$$se[ro] = (\sqrt{(0.07A + 0.037L\sqrt{A/n})})/n$$

A = search area

L = length of search area perimeter

n = number of individuals in search area

(Krebs 1989).

This shall be referred to as the Donnelly (1978) test.

6.2.5 Fox density

To estimate fox density accurately from natal den counts the social organisation of the population must be known (Trehwella *et al.* 1988). In Australia, the predominant social group consists of a pair of breeding adults with dependent and then dispersing juveniles (Saunders *et al.* 1995; McIlroy *et al.* 2001). However, social groups may contain additional

non-reproducing vixens and/or males; failing to account for these will underestimate true density (Sadlier *et al.* 2004). Previous studies on the central tablelands suggest that the proportion of non-reproducing vixens in the population is low (McIlroy *et al.* 2001; Saunders *et al.* 2002b). Given that the sex ratio of foxes does not differ from parity (Saunders *et al.* 2002b), there would also be few non-reproducing males.

Assuming monogamous pairing, each natal den will have a male and female fox with a litter of cubs (Harris 1981). Only a few litters were directly and accurately observed, so the mean litter size (4.0) estimated using placental scar counts from vixens collected on the central tablelands (Saunders *et al.* 2002b) was used.

Family groups may prepare and use several dens (classified here as active) during the breeding season. Each family group may use several active dens during the cub-raising period (Berghout 2001), such that, active dens only represent *potential* natal den sites. As a result, only active dens confirmed to contain litters (classified here as natal dens) each year were used to estimate the number of family groups, and hence estimate fox density.

An additional density estimate was calculated by dividing the total number of active dens located each year by the mean number of active dens used by vixens (estimated by radio-tracking) on the central tablelands of New South Wales (Berghout 2001).

6.2.6 Potential for persistence of rabies

To control a rabies outbreak, it is critical to reduce the number of susceptible individuals to below the threshold density needed to maintain rabies in the wild population (Saunders 1999). The density of susceptibles may be reduced either through vaccination or through the use of lethal control measures to reduce population density. The proportion of animals that must be immunised or killed to stop persistence of rabies is therefore determined by comparing the density of susceptible animals to the critical threshold density (Anderson 1986; Marks and Bloomfield 1999b). Adopting the approach of Marks and Bloomfield (1999b), published K_r values were compared to pre and post-whelping fox density estimates using the formula below to estimate whether fox density was sufficient to support the

persistence of rabies and estimate the proportion of the population that needed to be immunised to stop persistence.

$$\underline{P} > 1 - (K_t/K_{pr})$$

or

$$\underline{P} > 1 - (K_t/K_{po})$$

where:

\underline{P} = proportion of the population to be immunised

K_t = critical threshold density of animals to support rabies persistence

K_{pr} = pre-breeding density of susceptible animals

K_{po} = post-breeding density of susceptible animals

(Anderson 1986; Marks and Bloomfield 1999b).

Pre-breeding density estimates were calculated from the number of breeding adults; post-breeding estimates are calculated from the number of breeding adult pairs plus the mean number of cubs in each litter.

6.3 Results

6.3.1 Den locations

Totals of 79, 119 and 84 fox dens were found in the 9.6 km² search area in the years 2000, 2001 and 2002 respectively (Table 6.1 and Figures 6.1, 6.2, 6.3 and 6.4 respectively). The combined total of 282 dens recorded over this period included 231 individual dens comprising 19 natal, 112 active and 100 inactive dens.

Table 6.1: The number of inactive, natal and active fox dens located each year on “Larras Lake North”.

<i>Den activity</i>	<i>Number of dens</i>		
	<i>2000</i>	<i>2001</i>	<i>2002</i>
Inactive	34	56	38
Active	36	54	40
Natal	9	9	6
Total	79	119	84

6.3.2 Den persistence

The use of dens varied markedly from year to year with some dens used constantly while others were abandoned. The numbers of dens that were active or natal in each year that continued to be used in the following years are shown in Table 6.2.

Table 6.2: The numbers of active or natal dens in 2001 and 2002 that were active or natal in the previous year (Year -1) or two years prior (Year-2).

Habitat	Active		Natal	
	2001	2002	2001	2002
Number dens located	54	40	9	6
Number active Year – 1	9	4	2	4
Number active Year – 2	-	3	-	-
Number natal Year – 1	3	3	2	4
Number natal Year – 2		3	-	-

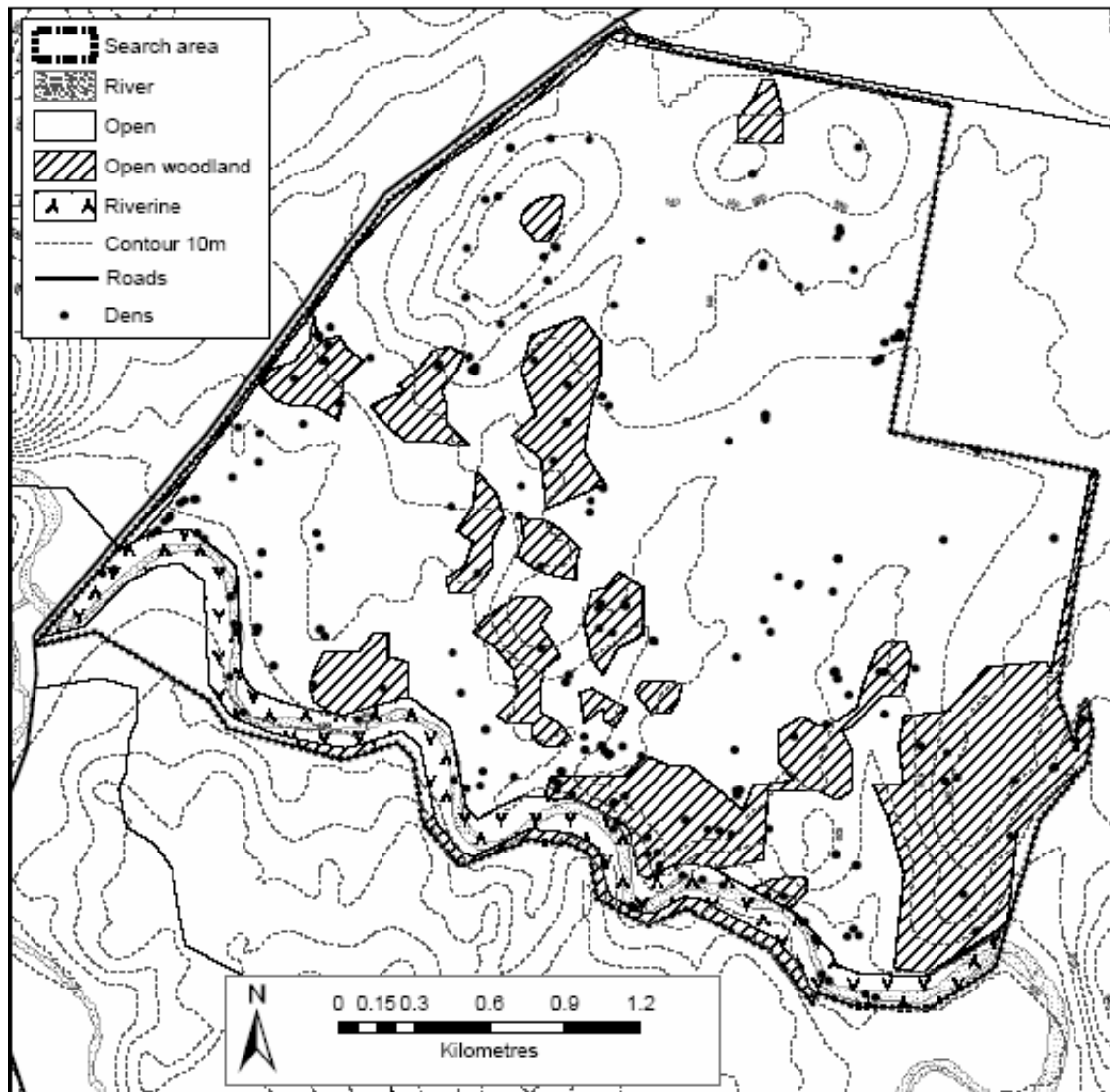


Figure 6.1: The locations of all active, inactive and natal fox dens found on the study site over the 3 year study period.

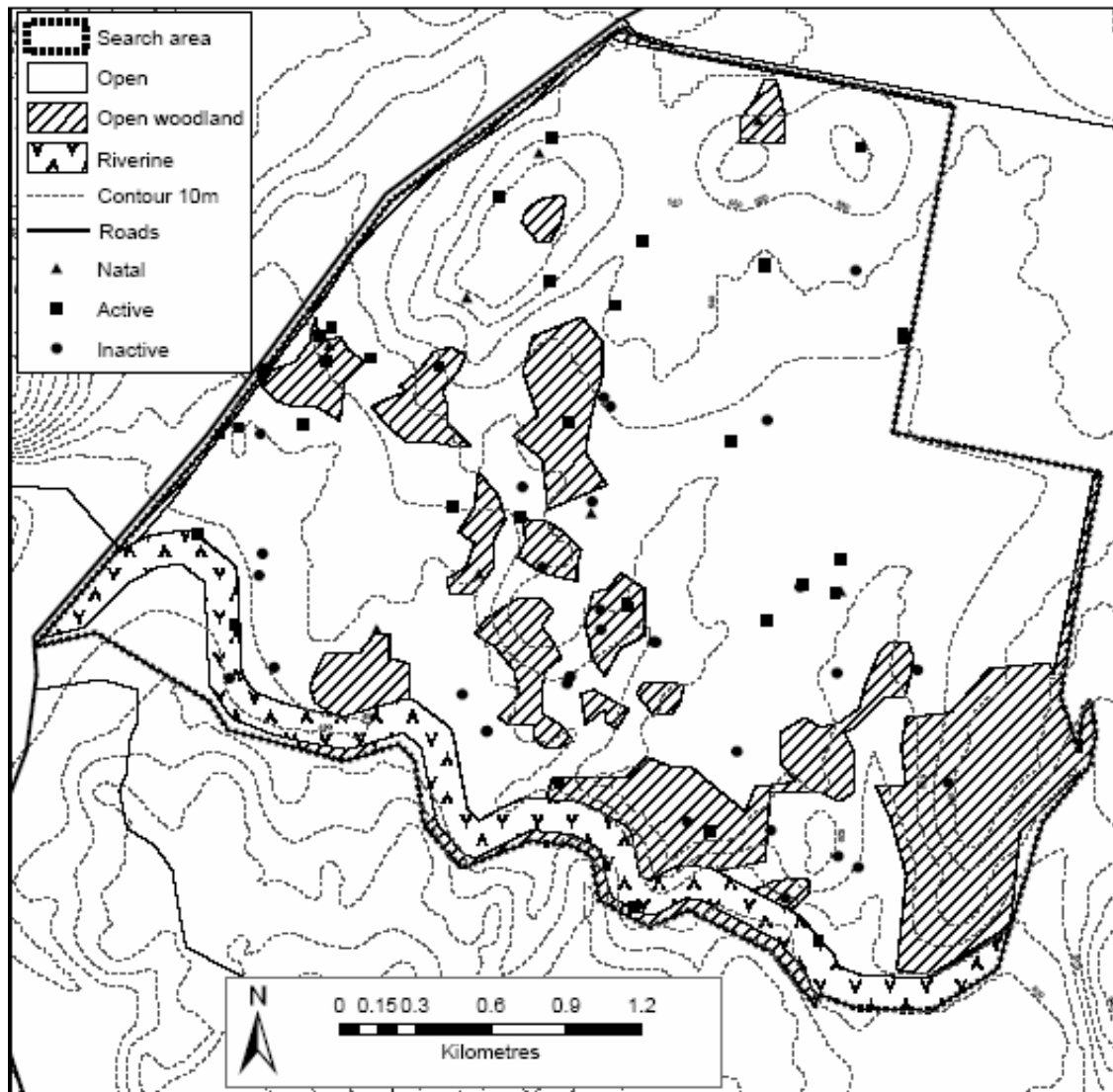


Figure 6.2: The locations of all natal, active and inactive fox dens found during 2000.

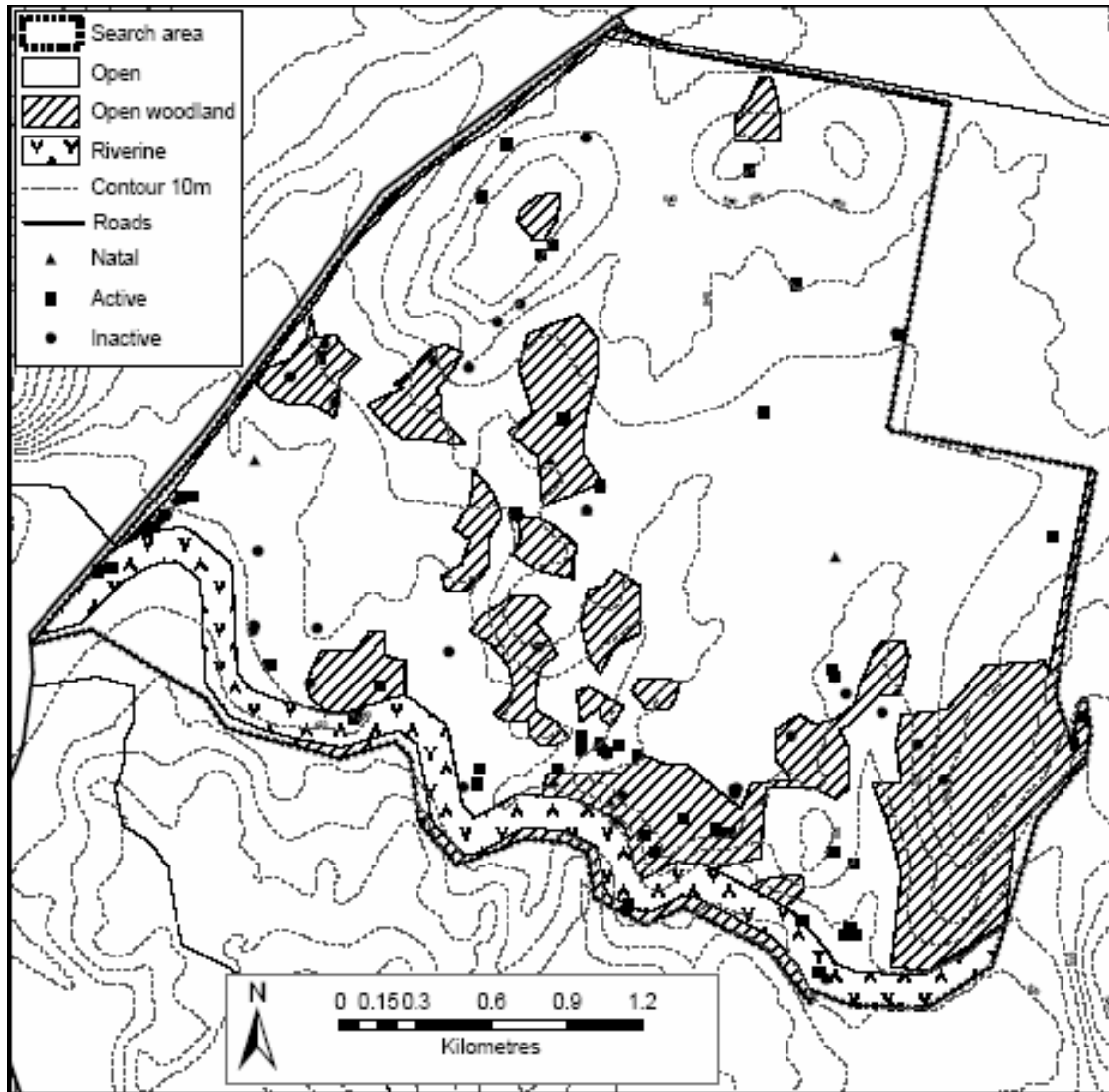


Figure 6.3: The locations of all natal, active and inactive fox dens found during 2001.

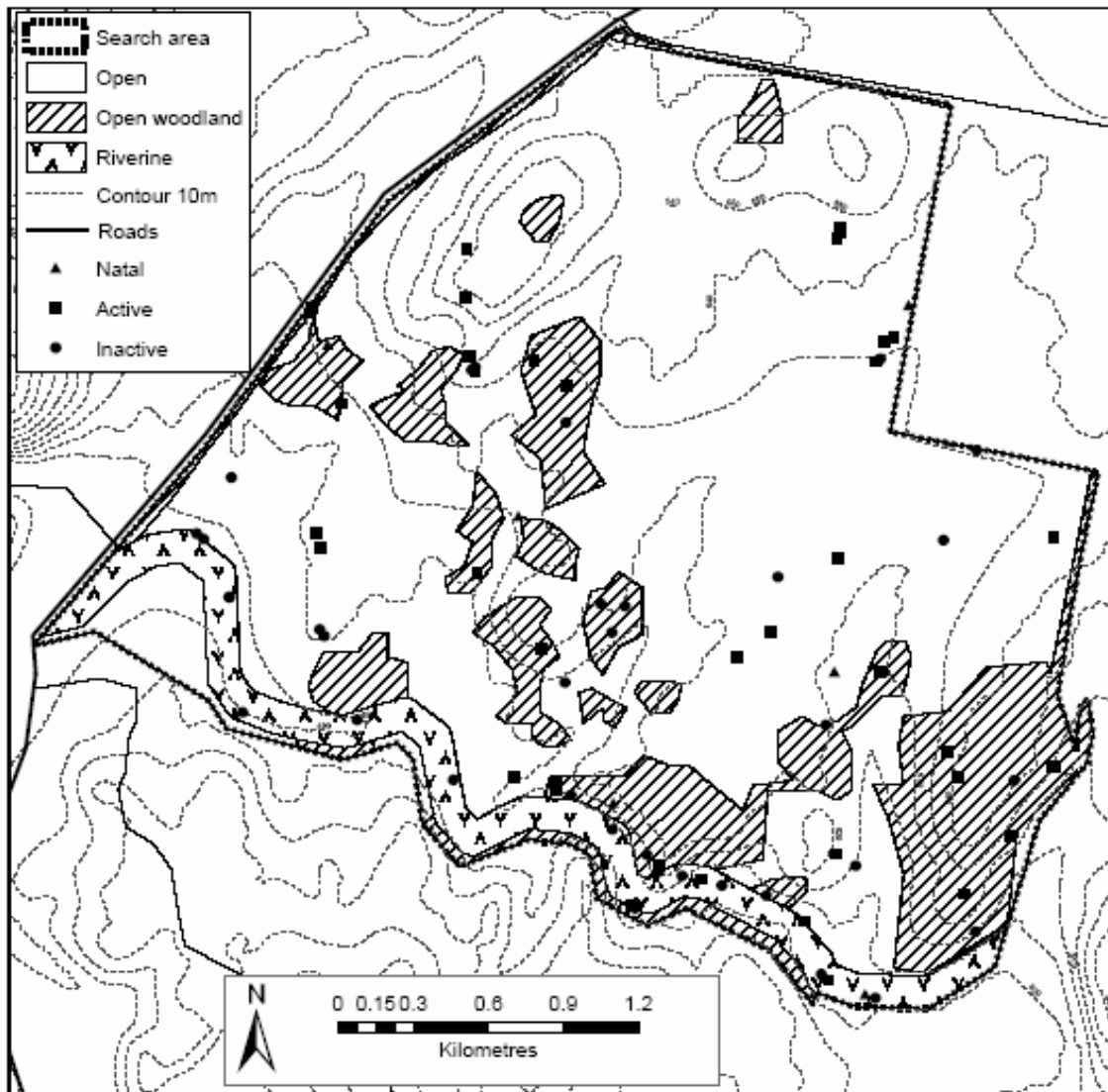


Figure 6.4: The locations of all natal, active and inactive fox dens found during 2002.

6.3.3 *Den microhabitat and form*

Most dens were dug into the ground (85.7%) with the remainder being located in logs (9.1%) or in the base of trees and/or between rocks (5.2%). The majority of dens (70.6%) were located adjacent to or within a physical structure, whether natural or man-made. Of these dens, 38% were predominantly under or near trees, 31.7% were in or near logs, 26.4% adjacent to or under rocks, and 3.9% were under or adjacent to a fence.

Due to the small number of natal dens located, both natal and active dens were pooled for comparisons against inactive dens. Relatively more active/natal dens were located within or adjacent to cover (0.771, 101/131) ($\chi^2 = 5.51$, d.f. = 1, $P = 0.018$) than inactive dens (0.62, 62/100). There was no significant difference between the proportion of active/natal dens and inactive dens situated above ground (24/131 and 9/100 respectively) ($\chi^2 = 3.29$, d.f. = 1, $P = 0.07$), although a slightly larger sample size may have returned a significant difference.

The mean number of entrances for each den was 1.9 (± 1.3 SD, $n = 231$). There was no difference in the number of entrances to natal dens (2.4 ± 2.1 SD, $n = 19$) compared to active dens (2.0 ± 1.2 SD, $n = 112$) ($t = 0.81$, $P > 0.05$). However, the number of entrances of inactive dens (1.8 ± 1.1 SD, $n = 100$) was significantly less than those dens showing obvious signs of activity (active and natal dens pooled) (2.0 ± 1.4 SD, $n = 131$) ($t = -1.67$, $P = 0.046$).

Habitat

The 960 ha search area consisted of 699.8 ha of open habitat (72.9%), 194.9 ha of open woodland (20.3%), and 65.3 ha of riverine habitat (6.8%) (Figure 6.5 and Table 6.3). From the total of 231 individual dens that were located, the majority (64.5%) were found in open habitat, 26.0% were found in open woodland, and the remainder were within riverine habitat (9.5%). When active, natal or inactive dens were pooled, foxes did not show a significant habitat preference for den locations ($\chi^2 = 3.84$, d.f. = 2, $P = 0.15$) despite proportionally more dens found in both riverine and open woodland habitats (Figure 6.5).

For active dens, there was no significant preference shown for locating dens within habitats ($\chi^2 = 2.33$, d.f. = 2, $P = 0.31$). Similarly, foxes did not show any habitat preference for the location of natal dens ($\chi^2 = 1.68$, d.f. = 2, $P = 0.43$), nor active and natal dens pooled ($\chi^2 = 3.66$, d.f. = 2, $P = 0.16$).

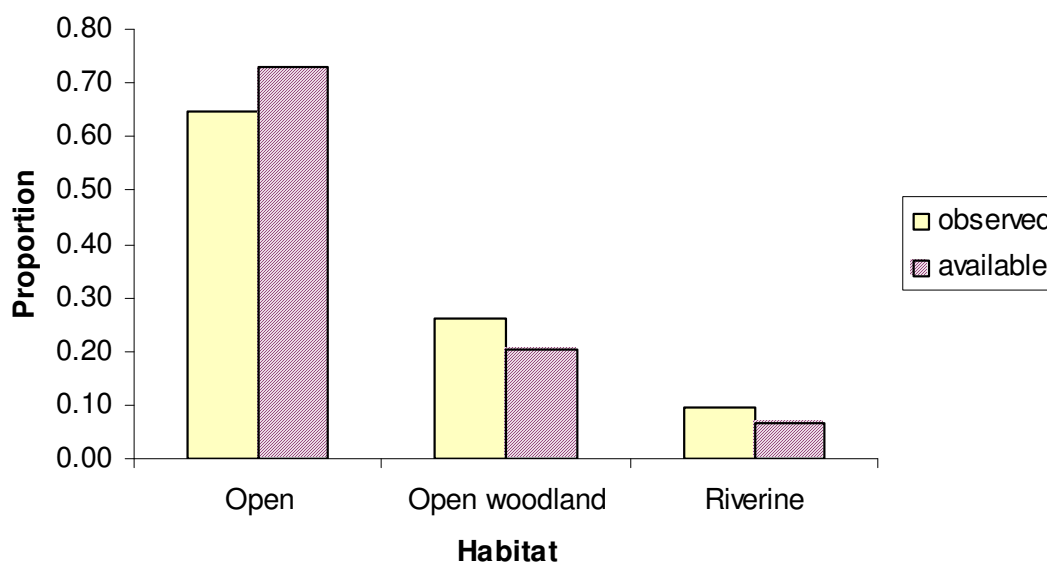


Figure 6.5: The proportion of all fox dens ($n = 231$) located in each habitat (observed) and the proportion of each habitat available within the search area (available).

Table 6.3: The percentage availability of habitat strata within the search area and the number of inactive, natal and active fox dens within each stratum.

Habitat	% available	Inactive			Active			Natal			Total
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
Open	72.9	27	43	14	23	38	20	5	5	3	178
Open woodland	20.3	6	11	12	10	10	17	3	4	2	75
Riverine	6.8	1	2	12	3	6	3	1	-	1	29
Total	100.0	34	56	38	36	54	40	9	9	6	282

There was a significant difference in the location of dens within habitats between years ($\chi^2 = 20.84$, d.f. = 4, $P < 0.001$). Foxes did not show any preference for locating dens within habitats in 2000 ($\chi^2 = 0.32$, d.f. = 2, $P = 0.85$) and 2001 ($\chi^2 = 0.02$, d.f. = 2, $P = 0.99$). In 2002, foxes showed a significant preference for habitat ($\chi^2 = 15.00$, d.f. = 2, $P < 0.001$), with a greater percentage of observed dens located in open woodland (36.9%) and riverine habitats (19%) relative to open areas (45%).

Slope

The majority of the study area was gently undulating, with over 90% of the site on slopes of 0-10 degrees. Dens appeared to be located within the slope classes (Figure 6.6). No significant preference for slope was detected ($\chi^2 = 0.305$, d.f. = 2, $P = 0.86$: Figure 6.6).

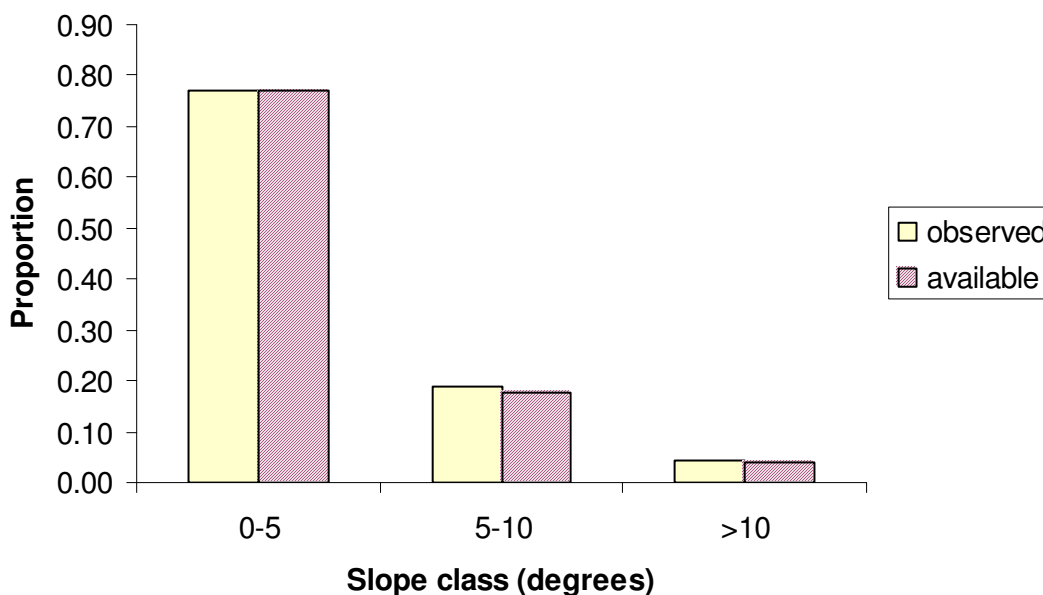


Figure 6.6: The proportion of all fox dens located ($n = 231$) in each slope class (observed) and the proportion of each slope class available within the search area (available).

Those dens that were active at some stage during the study period were assessed further. There was no evidence to suggest that these active dens were preferentially located in any particular slope class ($\chi^2 = 1.98$, d.f. = 2, $P = 0.37$). Similarly, foxes did not show any

preferences for locating active ($\chi^2 = 2.70$, d.f. = 3, $P = 0.26$) or natal dens ($\chi^2 = 0.39$, d.f. = 2, $P = 0.82$).

Table 6.4: The percentage availability of slope strata within the search area and the number of inactive, natal and active fox dens within each stratum.

Habitat	% available	Inactive			Active			Natal			Total
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
0-5	77.1	31	38	27	31	41	31	6	8	5	218
5-10	17.5	3	15	6	5	13	8	3	-	-	53
>10	5.4	-	3	5	-	-	1	-	1	1	11
Total	100.0	34	56	38	36	54	40	9	9	6	282

Aspect

The study area has a predominant southern to western aspect, with over 75% of the area facing this general direction (Figure 6.7).

There was no significant relationship between den location and aspect ($\chi^2 = 12.48$, d.f. = 8, $P = 0.13$). Similarly, active ($\chi^2 = 10.7$, d.f. = 8, $P = 0.22$) and natal dens ($\chi^2 = 6.02$, d.f. = 8, $P = 0.64$) were not preferentially located to face any particular aspect. Those dens that were active at some stage during the study period (active and natal pooled) were assessed, but there was no evidence that these dens were located in any particular aspect class ($\chi^2 = 10.22$, d.f. = 8, $P = 0.25$).

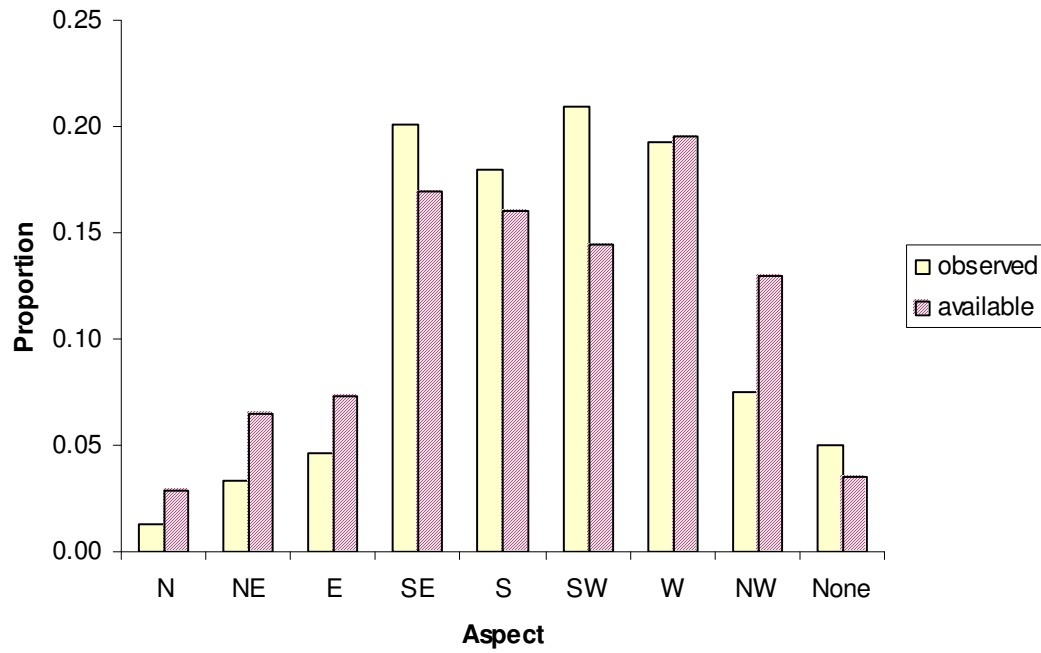


Figure 6.7: The proportion of all fox dens located in each aspect class (observed) and the proportion of each habitat class available within the search area (available) (n=231).

Table 6.5: The percentage availability of aspect strata within the search area and the number of inactive, natal and active fox dens within each stratum.

Habitat	% available	Inactive			Active			Natal			Total
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
N	2.9	-	1	-	-	-	-	1	-	1	3
NE	6.5	-	1	5	2	3	2	1	-	-	14
E	7.3	2	6	1	1	1	-	-	-	-	11
SE	16.9	10	9	7	8	8	10	2	2	2	58
S	16.0	4	8	11	6	11	7	1	3	-	51
SW	14.4	6	11	6	9	10	10	2	4	1	59
W	19.5	11	10	7	8	8	7	1	-	2	54
NW	13.0	1	4	-	1	10	4	-	-	-	20
No aspect	3.5	-	6	1	1	3	-	1	-	-	12
Total	100.0	34	56	38	36	54	40	9	9	6	282

6.3.4 Den dispersion

Removal of dens that were situated closer to the edge of the search area than the nearest neighbour den resulted in 11, 15 and 10 active dens being excluded from dispersion analyses in 2000, 2001 and 2002, respectively. The mean distance between neighbouring active dens was generally short, ranging between 89 m and 164 m, and analyses of nearest neighbour distances indicated that active dens in all years were significantly clumped or aggregated (Table 6.6).

Natal dens were spaced further apart than active dens, as expected due to their overall low density ($<1.0 \text{ km}^{-1}$). The mean nearest neighbour distances ranged between 375 m and 1140 m in 2001 and 2002, respectively (Table 6.6). The index of aggregation calculated for natal dens in 2000 and 2002 suggested that these dens were dispersed in a regular pattern, but only the distribution of natal 2002 dens was statistically significant different from random ($P < 0.05$). The aggregation index for 2001 natal dens was less than 1 (0.59), suggesting that dens were aggregated, but this did not deviate significantly from random ($P > 0.05$).

6.3.5 Fox density

A total of 9 natal dens was located in the search area in 2000 and 2001, but only 6 were located in 2002. Assuming that each den represents 2 adult foxes and the population sex ratio is 1:1, this equates to a pre-whelping population size of 18 foxes in 2000 and 2001, and 12 in 2002. Given that the mean number of cubs *in utero* is 4.0 (Saunders *et al.* 2002b) the post-whelping population size was calculated as 54 (18 adults and 36 cubs) in 2000 and 2001, and 36 (12 adults and 24 cubs) in 2002. These estimates equate to a pre-whelping density of 1.90 foxes km^2 for 2000 and 2001, and 1.25 foxes/ km^2 for 2002. Post-whelping density would be 5.60 foxes km^2 in 2000 and 2001 and 3.75 foxes/ km^2 in 2002.

Fox population size and density can also be calculated by using the number of active dens and an estimate of the number of active dens utilised by vixens. Berghout (2001) observed through radio tracking that each vixen utilised an average of 2.4 active dens ($n = 10$). In the current study, this translates to estimates of pre and post-whelping densities between 3.1 and 15.4 foxes/ km^2 (Table 6.7).

Table 6.6: The mean nearest neighbour distance (NND, km), expected nearest neighbour distance (NND, km), index of aggregation (R), deviation from randomness (z), test used, and significance (* $P < 0.05$; ^{NS} $P > 0.05$) for active and natal fox dens located during each search period.

<i>Den class</i>	<i>n</i>	<i>Den density (no/km²)</i>	<i>Mean NND (km)</i>	<i>Expected NND (km)</i>	<i>R</i>	<i>z</i>	<i>Suggested dispersion</i>	<i>Test and significance</i>
Active 2000	25	3.75	0.164	0.258	0.638	-4.15	Clumped	Clark and Evans*
Active 2001	39	5.63	0.089	0.211	0.422	-8.12	Clumped	Clark and Evans*
Active 2002	30	4.17	0.14	0.245	0.522	-5.41	Clumped	Clark and Evans*
Natal 2000	9	0.94	0.736	0.632	1.14	1.19	Regular	Donnelly ^{NS}
Natal 2001	9	0.94	0.375	0.632	0.59	-1.75	Clumped	Donnelly ^{NS}
Natal 2002	6	0.63	1.14	0.781	1.44	2.16	Regular	Donnelly*

Table 6.7: The number and density of active and natal fox dens during 2000, 2001 and 2002 and resultant estimates of pre- and post-whelping fox density (foxes/km²).

<i>Year</i>	<i>Active dens (density per km²)</i>	<i>Natal dens (density per km²)</i>	<i>Pre-breeding - post-breeding fox density (foxes/km²) from active dens</i>	<i>Pre-breeding - post-breeding fox density (foxes/km²) from natal dens</i>
2000	36 (3.8)	9 (0.94)	3.1 – 9.4	1.90 - 5.60
2001	59 (6.1)	9 (0.94)	5.1 – 15.4	1.90 - 5.60
2002	40 (4.2)	6 (0.63)	3.5 – 10.4	1.25 - 3.75

6.3.6 Potential for persistence of rabies

The most conservative estimate of K_t , or the threshold density required for rabies to persist in Australia, equals 1.0 (i.e. 1.0 foxes/km²) (Pech and Hone 1992). All the density estimates from natal den counts both pre and post-breeding for each year exceeded this minimum by at least 0.25 foxes/km². This suggests that fox populations on the central tablelands of New South Wales are at a sufficient density year-round to support the persistence of rabies.

The use of either pre or post-breeding density influences P , the critical proportion of population reduction or immunisation required to prevent rabies persisting (Table 6.8). For the years 2000 and 2001 it was estimated that >80% reduction would be required post-breeding as compared to less than 50% reduction before breeding. Similarly, only a 20% reduction would be required before breeding, compared to >70% following breeding in 2002. However, these values will vary since the mortality of yearlings is cumulative rather than instantaneous.

Table 6.8: Estimates of the critical proportion (P) of the fox population required to be immunised or made non-susceptible to prevent persistence of rabies both pre- (K_{pr}) and post-breeding (K_{po}) densities for each year of the study period. K_t values represent the minimum and maximum from the literature (Pech and Hone 1992).

Year	Pre-breeding (K_{pr}) - post-breeding (K_{po}) fox density (foxes/km ²) from natal den density	P ($K_t = 0.2$)	P ($K_t = 1.0$)
2000 / 2001	1.9 - 5.6	0.895 – 0.964	0.474 – 0.821
2002	1.25 - 3.75	0.84 – 0.947	0.2 – 0.733

The minimum K_t value of 0.2 proposed by Pech and Hone (1992) probably too low for rabies to persist and levels of reduction required to reduce the population to this density would be difficult. The K_t of 1.0 is probably the more realistic value; other assessments for Australian agricultural areas suggest that reducing fox density to <1.0 foxes/km² would be sufficient (Coman *et al.* 1991; Thompson and Fleming 1994).

6.4 Discussion

6.4.1 Caveat

Identifying fox dens was simplified in the study area since other animals likely to make similar burrows (e.g. common wombat (*Vombatus ursinus*) and the European rabbit (*Oryctolagus cuniculus*)) were not present. Where these and other burrowing species are present, additional care should be taken to confirm that the burrows are indeed fox dens. Foxes leave characteristic signs of occupation making this relatively straightforward. These should be checked to confirm their identification, especially where den destruction and fumigation is used as a management tool.

6.4.2 Den location and habit

The majority of the study site was open habitat, with less than 30% of the area open woodland and riverine habitats. Foxes located dens in all habitats, but did not show any consistent preference for locating dens in any specific habitat. However, in 2002 foxes showed preference for locating dens in open woodland and riverine habitats. Previous studies are also conflicting; Storm *et al.* (1976) found a significant preference for dens located in wooded areas, whereas other studies report that open areas are preferred (Henry 1986; Hewson 1986; Nakazono and Ono 1987). The results from the current study suggest that typical agricultural lands such as those on the central tablelands are suitable for dens, but preferences for locating dens within habitats may change from year to year.

This is most likely in response to seasonal conditions. A severe rainfall deficit occurred at the study site during winter and spring 2002 (see Figure 4.1) which severely reduced the growth, and subsequent coverage and density of pasture. During this period, visibility at ground level in open areas increased dramatically, particularly where grazed by stock. These areas may have become less preferred by foxes during this period since den sites would have been more visible, offering less protection from predators and/or the elements. This would explain the preference shown for riverine and open woodland areas, where visibility would have been relatively greater during this period.

Berghout (2001) suggested that this change in preference may be due to bias in the technique used to locate dens; Storm *et al.* (1976) radio-tracked foxes to locate dens, whilst the remainder of the studies relied on visual searches. It is unlikely that the visual searches undertaken in the current study resulted in a bias towards finding dens in open areas (due to greater sightability). Less dens were located in open habitats when sightability was high (i.e. 2002), suggesting that preferences at this time were not due to any visibility bias. Additionally, where sightability was reduced, the searching protocol was increased to ensure that the search effort expended while locating dens was directly related to the sightability within each habitat. Therefore, it is unlikely that the results were significantly affected through a bias towards any particular habitat or topography in the searching protocol.

There was no preference shown for den site selection on the basis of slope or aspect. This lack of preference is in contrast with the findings of other den studies. Eide *et al.* (2001) found that arctic foxes (*Alopex lagopus*) select steeper terrain for den sites. They also preferred a southerly aspect, which provides protection from winds and thermoregulation and microclimatic advantages (Arjo *et al.* 2003). No such preference was found in this study. In colder, arctic climates these sites may offer improved microclimate conditions suitable for raising cubs. The central tablelands does not suffer from extremes of temperature (see Chapter 3) like those found in the arctic (Prestrud 1992) or desert environments (Arjo *et al.* 2003) and therefore there may be little advantage in selecting sites to improve microclimatic conditions in 'milder' environments.

Swift foxes (*Vulpes velox*) preferentially select den sites on the top of hills, probably to assist in detecting the approach of predators such as the coyote (*Canis latrans*) or to avoid flooding in lower areas (Pruss 1999). Foxes in Australia generally lack a top-order predator, although raptors may take cubs (Corbet and Harris 1991) and the wild dog/dingo (*Canis familiaris*) is known to kill both cubs and adults (Saunders *et al.* 1995). Wild dogs/dingoes are not present on the study site and likely raptorial predators, such as the wedge-tailed eagle (*Aquila audax*) are sighted only occasionally (S. Brown, "Larras Lake North", pers comm. 2003). Additionally, foxes are not actively managed through either hunting or baiting on "Larras Lake North" so pressure from predators or man is unlikely to have been a major

determinant of den site location. The location of several dens close to roads, including a minor highway, also suggests that foxes appear to tolerate disturbance.

6.4.3 Den microhabitat and form

Despite there being no consistent preference for any specific habitat, slope or aspect by foxes in locating their dens, there were differences in where dens were located within habitats. Relatively more active and natal dens were situated within or adjacent to cover, such as fencelines, logs and rocks, than inactive dens. This is similar to the results of Meia and Weber (1992) who did not locate any breeding dens ($n = 14$) in bare earth alone, but found that all were located within root systems, rocks, or man-made dumping grounds. Other studies have noted a preference for covered areas that offer some protection from the elements (Storm *et al.* 1976; Weber 1982; Iokem 1985; Paqout and Libois 1986). Foxes may prefer to use dens that offer such protection; these sites may also be inherently more persistent and less prone to disturbance and/or destruction than those situated away from structures. Greater persistence would mean greater security and protection for the den-dwellers and an increased potential for the den to develop (i.e. through increased size, depth or complexity) into a more suitable environment for raising young.

Natal dens generally had more entrances than active or inactive dens, but this was not statistically significant. However, when pooled with active dens, natal and active dens had more entrances on average than inactive dens. Natal dens usually have more entrances than other dens (Weber 1983; Nakazono and Ono 1987). Dens with more entrances may offer cubs greater means of 'escape' into shelter (Meia and Weber 1992), may assist with ventilation and thermoregulation (Berghout 2001), or may simply be correlated to den size or age, and therefore suitability for raising cubs.

6.4.4 Fox density

The calculated densities of between 1.25 and 5.6 foxes/km² are similar to estimates from other den count studies undertaken in temperate grazing lands in Australia. Coman *et al.* (1991) recorded densities between 1.2 and 3.0 foxes/km² in temperate grazing land in central Victoria, and J. Tracey (NSW Department of Primary Industries, unpublished data) recorded

1.7 – 4.3 foxes/km² on the New South Wales central tablelands. It is also comparable to density estimates from similar habitats calculated by other methods; on the New South Wales northern tablelands (Thompson and Fleming 1994) visitation to sandplots both pre and post baiting (index-manipulation-index) yielded estimates of 4.6-7.2 foxes/km². All these estimates are generally greater than those found in other Australian habitats apart from some urban areas (e.g. city of Melbourne, 3.0-16.2 foxes/km²: Marks and Bloomfield 1999b). However, estimates from the current study are considerably greater than those from Berghout (2001) who calculated density at between 0.55 - 1.34 foxes/km² and 0.52 – 1.26 foxes/km² in 1995 and 1996 respectively on agricultural lands at Murringo, on the southern central tablelands of New South Wales. Despite enterprise (mixed grazing) and habitat (predominantly open) being similar to this study, fewer fox dens were located by Berghout (2001). This may, simply, have been a result of overall lower fox density during the period of the searches. Spotlight counts undertaken on both sites between 1995 and 1997 show that densities are broadly similar at Murringo and Larras, although they appear to fluctuate across years (see Saunders *et al.* 2002a). The relatively higher density of foxes on agricultural lands is also supported by studies in other countries; for example density of fox breeding dens in Scotland was greater on agricultural land compared to hill forest and heathland moorland (Hewson 1986). Since fox density is related to the productivity of the environment (Saunders *et al.* 1995), the relatively high densities found on temperate agricultural lands indicate that such habitats are highly productive and capable of sustaining high density fox populations.

Nine breeding dens were found in 2000 and 2001, declining to six in 2002. Variation in pregnancy rates appears to be the primary source of changes in reproductive output of carnivores (Clark and Fritzell 1992). Therefore, the number of breeding vixens, and hence natal dens should be consistent in a stable population (Nakazono and Ono 1987), suggesting that the population at the study site is fluctuating. The decrease may be due to a decline in food abundance or prey availability (Hewson 1986; Meia and Weber 1992). A severe rainfall deficit occurred at the study site during winter and spring 2002 (see Figure 4.1), and this may have reduced the abundance of food resources, and hence reproductive performance (e.g. McIlroy *et al.* 2001). There is little evidence that mean litter size is

dependent on food supply (see review by Newsome 1995), indicating that the methodology is likely to be robust in detecting changes in density even without estimates of litter size for the consecutive breeding seasons.

6.4.5 Den dispersion

Analyses of den dispersion using nearest neighbour distances revealed that natal dens were regularly distributed across the study site in 2002, but were not significantly different from random in 2000 and 2001. This generally supports the findings of other studies; natal dens in the southern central tablelands of New South Wales (Berghout 2001), urban Melbourne (Victoria) (Marks and Bloomfield 1999b) Scotland (Hewson 1986) and Japan (Nakazono and Ono 1987) were all regularly distributed. However, natal dens in a mountainous area of Switzerland were randomly distributed, probably as a result of the limited number and random dispersion of suitable sites (Meia and Weber 1992). In the current study there was no preference shown for locating dens for any habitat or terrain features (slope and aspect), suggesting that suitable sites were available across the study site. The regular spacing of natal dens is probably a result of the territorial nature of foxes (Hewson 1986), and may act to ensure resource security and/or to avoid neighbouring foxes encountering cubs (Berghout 2001).

Active dens in all years were distributed in clusters. Foxes often prepare multiple dens for use (Berghout 2001) and it is likely that the clumping of active dens represents dens sustained by each vixen for this purpose. The lack of differences between natal and active dens in this study is not surprising given the similarities of the habitats across the study site. Additionally, the potential for active dens to be used at some stage during the whelping season means that these sites, like natal dens, would be suitable for raising cubs and therefore would be likely to have similar characteristics. The likelihood that cubs were shifted between dens is unlikely to be a confounding factor for estimating density and determining habitat differences given that large areas were searched within short periods, minimising the likelihood that litters were encountered multiple times. Regardless, it indicates that a large number of den sites in the study area are suitable for raising cubs,

providing further evidence that agricultural lands on the New South Wales central tablelands are highly suitable for foxes.

6.4.6 Management implications

Results from this study and others indicate that temperate agricultural lands like those on the central tablelands are highly suitable for foxes and support high-density populations. The lack of consistent preference by foxes for locating dens in any particular habitat and the dispersion of dens suggest that most habitats in these areas would be suitable for foxes to locate dens. Preferences shown by foxes for locating active and natal dens in proximity to cover means that particular attention should be paid to structures such as logs, rock piles and fencelines during searches within all habitats. Despite this, many dens, including both active and natal dens were located in open areas with no structure nearby. Therefore, undertaking searches for natal dens as a means of estimating fox density or to undertake fumigation /destruction should be done systematically to encompass all available habitats and landforms. This will ensure that the probability of detecting dens is greatest and will be less prone to under or over-estimation.

The regular distribution of natal dens on the study site suggests that there would be no benefit in laying bait in any specific habitat to 'target' natal dens sites. Rather it suggests that, to increase the probability of targeting potential activity 'focal points', baits should be laid systematically across all habitats.

The clumped dispersion of active dens indicates that, once an active den is located, the likelihood of locating additional active den/s nearby is increased. Since foxes may prepare multiple active dens for use during the cub-raising period, these dens represent likely areas to raise cubs. The mean nearest neighbour distance between active dens ranged between 86 and 164 m. Therefore, once an active den is located, searches for subsequent active dens should be concentrated in the area relatively close (less than a few hundred metres) to the location of the active den.

Foxes have been recognised as a potentially important host of rabies in southern Australia (Geering and Forman 1987; Pech and Hone 1992; Saunders 1999). If rabies were ever to be introduced into Australia, fox density on the central tablelands of New South Wales at any time of year (i.e. pre and post-breeding) appears sufficient for rabies to be maintained within the populations. Therefore, operations to reduce the proportion of susceptible individuals in the population would be required to halt the persistence of the disease.

The estimated proportion of the population to be either vaccinated or killed to stop rabies persisting (at $K_t = 1.0$) ranged from 0.2 to 0.82 depending on the year (2000/2001 and 2002), and density estimate (pre or post-breeding). A lethal rabies control strategy is probably oversimplified since it fails to account for any compensatory changes in fox reproduction, behaviour or movements that are likely to occur following culling operations (e.g. Marlow *et al.* submitted). Regardless, these figures demonstrate that a considerably smaller proportion of the population needs to be targeted to reduce the persistence of rabies pre-breeding (i.e. winter) than post-breeding (spring). Therefore, strategies to reduce the persistence of rabies in the fox population may prove to be more efficient when they are timed to coincide with pre-breeding compared to post-breeding.

Greater understanding of fox density, such as that provided in the current study may assist in understanding the impact of foxes on prey. Knowledge of fox diet (e.g. Coman 1973; Croft and Hone 1978; Palmer 1995) and nutritional requirements (see Winstanley *et al.* 2003) can be used to provide estimates of the quantity of food consumed per individual. Knowing the density of individuals can therefore assist in providing estimates of fox predation through calculating the amount of prey consumed (e.g. McLeod 2004). This technique is likely to significantly underestimate the true cost of fox predation since it fails account for surplus killing of prey (see Kruuk 1972; Chapter 3). Regardless, such assessments are valuable in highlighting the relative impact of foxes since they provide a means to quantify, economically assess, and compare the damage caused by foxes and other pests.

Assessments of fox density can be used to improve the efficiency of fox management strategies through determining if/where management is required and the appropriate level

needed through objective means such as cost-benefit analyses. This is critical for the responsible and strategic management of pest animals (Braysher 1993). Accurate estimates of abundance are required for pest management programs where the progress and ultimately success or failure of the program is measured in reductions of population size (Wilson and Delahay 2001). Such measures are also important in developing strategies that are sensitive to changes in the abundance of the species to be managed (e.g. baiting strategies – see Chapter 3). Additionally, evaluating the success of such strategies in terms of the prey response relies on understanding predator-prey interactions, especially the relationship between species abundance and damage (Hone 1994; Moberly *et al.* 2004). This is difficult for species such as the fox due to deficiencies in the techniques for monitoring fox abundance. Spotlight counts are inherently inaccurate but still remain widely used (see Ruetten *et al.* 2003); new techniques such as genetic fingerprinting show potential (see Kohn *et al.* 1999) but remain relatively inefficient and expensive (M. Piggott, Monash University, pers. comm. 2002). Density estimates from den counts are limited to the breeding season but remain an accurate and reliable means of estimating fox density (Trehwella *et al.* 1988). These estimates could be used to calibrate other techniques rather than comparing between abundance indices, which should be undertaken only with caution (Smith *et al.* 1984).

6.5 Conclusion

Estimating fox density through counts of natal den sites appears to be a successful technique to use in agricultural lands on the central tablelands of New South Wales. More importantly, the successful application of the technique may improve currently unreliable indices of abundance, critical to the improvement of fox management. However, factors including the coverage of baiting operations (Chapter 5), bait caching (Chapter 3) and bait longevity (Chapter 2) may influence the effectiveness of baiting operations. Additionally, other issues, such as the preparation, handling and the economic cost of using each bait type may be equally important and therefore should be considered in assessing baiting strategies.