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Indices for Measuring the Efficacy of Aerial Baiting for Wild Dog Control in North-eastern New South Wales

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Abstract

This study investigated the efficacy of aerial baiting with 1080 poison for the control of wild dogs in the temperate rangelands of north-eastern New South Wales. In each of three years from 1991 to 1993, two indices of the abundance of wild dogs, one a raw count of sets of footprints per kilometre of transect (SF) and the other a ln-transformed frequency corrected for sightability of signs (CI), were used to quantify the change in abundance of wild dogs caused by aerial baiting. The abundance of wild dogs at a nil-treatment site was estimated concurrently.

The SF index found the 1991 baiting to be efficacious. Both measures of abundance showed baiting to be efficacious in 1992 and 1993. Reductions of 66·3–84·5% in the abundance of wild dogs at the treatment site were found for the CI measure. The SF measure displayed abundance changes of 76·1–91·1%. The indices of abundance measured prior to the annual baiting in 1992 and 1993 were similar, indicating that populations returned to their initial abundance within one year.

Introduction

The predation of livestock by wild dogs [wild-living members of the species *Canis familiaris*, including feral dogs (*C. f. familiaris*), dingoes (*C. f. dingo*) and their hybrids] is regarded as a threat to the profitability of grazing enterprises situated where holdings are adjacent to or within terrain inhabited by wild dogs (NERDA undated; Fennessy 1966; Fleming and Korn 1989). Thomson (1984) indicated that most dingoes that moved into sheep-grazing areas killed sheep. The dingoes that did not kill sheep were observed to harass flocks of sheep. In a study of the stomach contents of trapped dingoes, Newsome *et al.* (1983) found that 94% of dingoes that had eaten sheep (n = 17) were trapped within 3 km of sheep-grazing lands. Fleming and Korn (1989) reported a significant positive relationship between sightings of wild dogs and the reported incidence of sheep predation.

Although individual dogs are often blamed for large numbers of sheep kills (Thomson 1984), logic would suggest that a lower number of dogs corresponds with a smaller likelihood of predation of livestock. The actual relationship between predator density and sheep predation is not known. Sheep graziers with land holdings adjacent to or within terrain inhabited by wild dogs attempt to reduce the abundance of wild dogs on the logical premise that fewer wild dogs equates with fewer depredations of livestock by wild dogs. Aerial baiting, with helicopters and 1080-poisoned meat baits, is one method that is used to achieve this.

Aerial baiting, with fixed-wing aircraft and 1080-poisoned meat baits, has been demonstrated to be an efficient and cost-effective method for controlling dingoes in the pastoral zone of north-western Western Australia (Thomson 1986). In three trials in 1980 and 1981, aerial baiting was shown to reduce the abundance of wild dogs by 100, 63 and 62% (Thomson 1986).

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A similar trial in 1985 reduced the number of radio-collared wild dogs by 85% (Thomson and Marsack 1992). Thomson and Marsack (1992) also recorded a range of changes to the abundance of wild dogs (6–80% reductions) in the Nullarbor area as the result of aerial baiting with 1080-poisoned baits. Bait type and the age and social status of the targeted dogs appeared to affect the efficacy of the baiting programme (Thomson and Marsack 1992). McIlroy *et al.* (1986) reported that a ground-baiting programme in south-eastern Australia reduced wild dog populations by 22%, and they questioned the efficacy of aerial and ground-based 1080-baiting progammes in eastern Australia.

Helicopters have been shown to be more suitable than fixed-wing aircraft for the accurate placement of baits in the temperate rangelands of north-eastern New South Wales (NSW) (Thompson *et al.* 1990). Aerial baiting with helicopters has been widely practised for controlling wild dogs in these lands since 1985 (A. Barnes, personal communication), and has been shown to be cost beneficial (Thompson and Fleming 1991). However, the effectiveness of aerial baiting in reducing the abundance of wild dogs in the temperate rangelands of north-eastern NSW has not been evaluated.

The focus of this research was to measure the reduction in the abundance of wild dogs achieved by aerial baiting with helicopters, in north-eastern NSW. The relative merits of two measures of the abundance of wild dogs are discussed.

Methods

Study Area

Two sites in the temperate rangelands of north-eastern NSW, east of Guyra (30°14′S, 151°40′E), were chosen, one where control of wild dogs by aerial baiting was routinely conducted (the treatment site) and one that was not baited (the nil-treatment site) (Fig. 1).

The Aberfoyle River gorge (treatment site) is 148·3 km^2 of privately held land where annual baiting to reduce wild dog populations occurs. The river basin has steep sides, dissected by steep ridges and gullies, a relatively flat bottom and is only accessible on horseback or foot, or by motorbike. The southern and western boundaries are delineated by a dog-proof fence, the eastern side is bounded by Guy Fawkes River National Park (GFRNP) and the northern side is the edge of the escarpment. The vegetation is typical of temperate rangelands (Lodge *et al.* 1984), being mostly dry open eucalypt woodland with a grassy understorey. River she-oaks (*Casuarina cunninghamiana*) grow along the river banks and on gravel beaches. Some of the river flats have been cleared and there are gravel and coarse-sand beaches on the insides of river bends. Cattle, feral horses and macropods have trodden paths along which wild canids [wild dogs and red foxes (*Vulpes vulpes*)] regularly travel. Aerial baiting from helicopters to control wild dogs has been conducted annually in late autumn or early winter since 1983. Prior to this, aerial-baiting programmes with fixed-wing aircraft had been conducted regularly from the mid-1960s.

The lower reaches of the Sara River and the upper Boyd River are within GFRNP. This area (139·5 km^2) provided the nil-treatment site. The terrain and vegetation are similar to those of the Aberfoyle River, although the valley floors are wider in the Boyd River basin and the weed lantana (*Lantana camara*) provides a shrub layer in some areas. Baiting with 1080 for the control of wild dogs had not been conducted in GFRNP since 1988, when 80 kg of meat baits (*c.* 350 baits) had been distributed along the Sara and Boyd Rivers, and no baiting occurred in GFRNP during the project (NSW Agriculture, aerial-baiting records). At the nearest points, the two study sites were 7·5 km apart and the valley floors were 12·7 km apart. Both rivers are fed by smaller creeks.

Indices of Wild Dog Abundance

For animals that are cryptic in their behaviour, as are canids, it is usually impossible to take counts of individuals in order to estimate their abundance. However, these animals leave behind signs of their passing, in the form of footprints, faeces, excrement and indicators relating to social organisation, such as scent posts (Vilá *et al.* 1994). Counts of these signs (as indices) are indicative of the activity and the relative abundance of a species (Caughley 1980). These indices are presumed to be related to the size of a population by a proportional constant of unknown dimension (Link and Nichols 1994). Seasonal differences in the activity of wild canids influence the quantity and distribution of signs (Peters and Mech 1975; Macdonald 1980). To account for this source of error, the time over which indices are taken should be compressed into a discrete period of the species' annual cycle. The movements of wild dogs are not

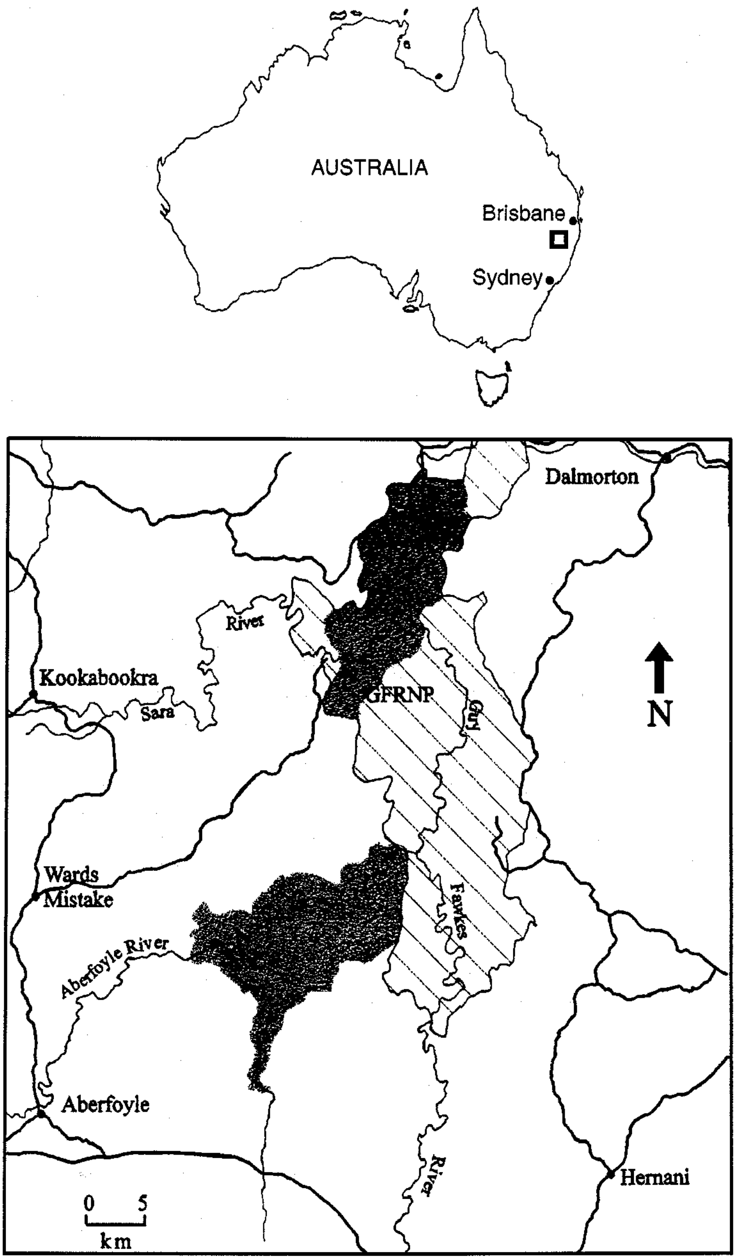

Fig. 1. Location of study sites (shaded) in north-eastern New South Wales. The northern site was the nil-treatment site and the southern site was the treated site. GFRNP, Guy Fawkes River National Park.

random and are concentrated along topographic features, including creeks, pads, paths, ridge-tops and roads (Harden 1985). To enhance the detection of animals that occur at low densities and have large home ranges and heterogeneous home-range use, it is best to systematically sample in areas where the animal is most easily detected. In 1991, surveys were walked along spurs and ridges (where the detection of sign was difficult), and along valley floors. Transects in 1992 and 1993 were walked only along the valley floors, where tracks were readily discernible and identifiable in the soil. The same paths and cattle pads were walked on each occasion. The width of the surveyed transects was equivalent to the width of a cattle pad ($\simeq$ 30 cm). Walking pace was kept as constant as possible (mean transect speed 2·04 km h^{-1}, s.d. = 0·18).

Signs of wild dogs were recorded as 'sets' of footprints per km (SF) or as a corrected frequency (presence/absence) per 100 m of transect. A 'set' of footprints was defined as a continuous trail of footprints made by one animal. These measures gave relative indices of the abundance of wild dogs. Intuitively, these sign indices are correlated with the mean density of a population (Caughley 1980) and, therefore, changes in density indices reflect proportional changes in population density.

Corrected indices (CIs) were collected in the following manner:

1. Raw frequencies per 100-m section were transformed into densities (Caughley 1980) with the equation

$$\bar{x} = -\ln(1 - f),$$

where f is the mean frequency of detection of wild dog signs per 100-m section, and $\bar{x}$ is the mean density of detection of wild dog signs per 100-m section. Transformation was necessary because the relationship between frequency and density is asymptotic (Caughley 1980).

2. The densities were then corrected for relative sightability of sign. This was done by first estimating the percentage of each 100-m section that easily showed the footprints of the observers (i.e. a percentage of 'good tracking') after each 100-m section was walked. For each transect, a mean percentage of good tracking (%GT) was then calculated.

3. Indices for each transect were corrected by dividing the densities by the mean percentage of good tracking for the respective transect, that is, CI = $\bar{x}$/%GT. This accounted for differences in soil type, colour, surface structure and dampness, ground cover, rocky substratum, the angle of incident light, obliteration of tracks by cattle and difficulties imposed by dappled shadows, and enabled standardisation between transects, years and sites. Van Dyke *et al.* (1986) used a similar method to standardise road-track counts used to index the presence of mountain lions (*Felis concolor*) in Arizona and Utah.

All the indices of wild dog abundance were collected during the breeding period (Catling 1979; Thomson 1992), although the second walk after baiting in 1993 may have coincided with the birth and early lactation of some animals (Nursing Period I in Thomson 1992). As movements are less in Nursing Period I than in the breeding period, the effect of this would be to reduce the index for the second walk after baiting, at the nil-treatment site in 1993.

In 1991, the transects were walked once before and once after baiting, and the sign indices were recorded only as SF. The indices were not standardised for sightability of tracks. In the following two years, the abundance indices were taken as SF and CI.

D. Algar (personal communication) has found, in Western Australian studies, that removal of some foxes by ground baiting results in increased activity of survivors. The social disruption caused by the baiting of some wild dogs might increase the movements of the survivors. In that case, the indices taken after baiting would be higher than if the proportional level of activity did not change. This would result in the under-estimation of the efficacy of aerial baiting.

Efficacy of Aerial Baiting

The efficacy of each annual baiting programme was assessed by the index–manipulation–index method (Caughley 1980; Caughley and Sinclair 1994), where the CIs acquired before baiting were contrasted with those found after baiting. 'Efficacy' was taken as the proportional change in the indices of wild dog abundance, a greater reduction in index being more efficacious than a smaller reduction.

At both sites, CIs were collected twice before and twice after the baiting programme in 1992. The second index before baiting was taken three weeks after the first index; this allowed for rain, wind and cattle movements to erase the tracks recorded during the first transect. The same procedure was followed for the after-baiting indices. This procedure was repeated in 1993.

The first of the after-baiting CIs taken at the treatment site in 1992 was later discarded because one month had not elapsed after the baiting. Thomson (1986) indicated that dingoes in Western Australia were killed up to seven weeks after baits were distributed. However, in eastern Australia most baits are removed within a week of bait placement and 99% of baits are removed within one month of placement (McIlroy *et al.* 1986; Saunders and Fleming 1988). Therefore, one month was left between the end of baiting and the commencement of after-baiting indices.

The general hypothesis to be tested was H: $\mu_{after} < \mu_{before}$, that is, the abundance of wild dogs was lower after baiting than it was before baiting. To compare the impact of baiting on the wild dog populations in the treatment site with those in the untreated site, we used Randomised Intervention Analysis (RIA) of time-series data (Green 1977; Carpenter *et al.* 1989). In the general case, RIA compares changes in a manipulated ecosystem with an undisturbed reference system, and uses bootstrapping to estimate the probability of those changes occurring by chance. In this experiment, with a maximum of eight indices (four treated and four untreated), all possible differences were calculated and the exact probabilities determined. Serial autocorrelations, heterogenous variances and errors that are not normal do not affect RIA (Carpenter *et al.* 1989). Our CI data were expected to be serially and temporally autocorrelated because the 100-m sections used to determine the indices were contiguous, wild dogs are territorial (Harden 1985; Thomson 1992) and the movements of wild dogs tend to follow topographical features (Harden 1985).

By means of RIA, the changes in CI within the baited area were contrasted with changes at the similar nil-treatment site to determine whether a change in the abundance of wild dogs had occurred. Comparisons (within sites) between before- and after-baiting SF indices were also conducted by RIA. RIA could not be used to test whether the abundances of wild dogs before baiting (CIs) varied between years, nor could RIA be used to compare the abundances of wild dogs between sites. This was because the minimum probability of these contrasts occurring by chance was $P = 0{\cdot}16$ and therefore the traditional level of significance ($P < 0{\cdot}05$) was unattainable. To determine whether the magnitude and direction of the two measures of abundance changed simultaneously, the correlation between SF and CI values was calculated by GENSTAT5. Because the CIs and SFs were collected and analysed as a time series, it was inappropriate to use the before- and after-baiting indices for each year as replicates. Therefore, the magnitude of the changes in index is expressed as a range of percentage differences between before and after indices.

Bait Distribution

Baiting with 1080-impregnated meat baits (Table 1) occurred in late April in each year. Each bait [mean mass 203·5 g (s.d. = 39·4 g) (A. Barnes, unpublished data)] was injected with 6·0 mg of 1080 (sodium fluoroacetate).

In 1991, the valley floors, major ridges, dog-proof fencelines and the nine major tributaries within the Aberfoyle River gorge were all baited from a helicopter. The 1993 baiting was essentially the same, with minor variation in total bait quantity. In 1992, fewer baits were placed from the helicopter (*c.* 786 baits) and only the Aberfoyle River valley floor was baited from the air. The remainder of the baits used in 1992 were placed from motorbikes along some of the more accessible ridges and major tributaries. This took longer than aerial baiting and some areas were baited more than once. The 1992 baiting was not completed until one month after the aerial baiting.

Table 1. Bait quantities and estimated number of baits for baiting programmes of the Aberfoyle River gorge (1991–1993)
All baits in 1991 and 1993 were distributed from a helicopter. In 1992, only 160 kg (*c.* 786 baits) were aerially placed, the remainder being ground-placed over a 2-month period

Year	Bait quantity (kg)	Estimated No. of baits
1991	730	3587
1992	620	3047
1993	690	3391

Results

Indices of Wild Dog Abundance

The CI (Table 2) and SF (Table 3) measures fluctuated in the same direction and those fluctuations were of similar magnitude ($r = 0{\cdot}909$, d.f. = 14, $P < 0{\cdot}01$). The CIs taken before baiting were 16·1–54·2% higher at the nil-treatment site than at the treatment site, indicating a greater abundance of wild dogs at the nil-treatment site.

Table 2. Corrected density indices (CIs) of wild dogs before and after baiting with 1080 meat baits, in 1992 and 1993
n.r., no index recorded

Year	CI			
	Treatment site		Nil-treatment site	
	Before	After	Before	After
1992	1·579	n.r.	1·879	2·394
	1·707	0·281	2·238	1·054
1993	1·082	0·364	2·362	1·716
	1·774	0·314	2·935	1·728

Table 3. Density indices (SFs) of wild dogs before and after baiting with 1080 meat baits, in 1991–93
Indices are expressed as sets of footprints observed per km of transect.
n.r., no index recorded

Year	SF			
	Treatment site		Nil-treatment site	
	Before	After	Before	After
1991	0·804	0·084	1·050	1·289
1992	7·886	n.r.	5·629	7·969
	5·560	0·704	7·000	3·846
1993	6·122	1·462	8·390	6·560
	10·750	1·225	10·781	6·639

Efficacy of Aerial Baiting

In 1991 baiting was intensive and the density index (SF) for wild dogs in the treatment site was substantially reduced. Substantial reductions in the SF and CI indices were apparent in 1992 and 1993 (Tables 2, 3). In 1992, the changes in CI in the treatment site represented a reduction in the wild dog population of 82·3–84·5%. The change in CI at the treatment site in 1993 was 66·3–82·3%. The RIA (Table 4) showed that the differences between the CI indices at the treatment and nil-treatment sites were not the result of chance. Differences in the SF indices were large and nearly significant (Table 4). At the treatment site, the SF index was reduced by 89·6% in 1991, by 87·3–91·1% in 1992 and by 76·1–88·6% in 1993.

Table 4. Randomised intervention analysis (RIA) of the difference in the indices of the abundance of wild dogs at a site manipulated by baiting and an untreated control site
Tabulated values are the mean differences between the indices of the treatment site and those of the untreated control

Index	Mean difference before baiting	Mean difference after baiting	Difference between before- and after-baiting values	*P*
CI	0·887	1·626	0·739	0·029
SF	0·371	4·552	4·181	0·057

Discussion

Indices of Wild Dog Abundance

The indices of abundance (CIs) at the nil-treatment site were higher than those at the treatment site in both years, showing that the abundance of wild dogs was greater in the nil-treatment site. The abundance of wild dogs at the nil-treatment site in 1993 was 28·7% greater than that in 1992, but the difference was within the bounds of two standard errors, implying that the population had not changed significantly. The population abundance before baiting at the treatment site in 1993 was similar (−13·1%) to that of 1992, indicating that repopulation had occurred at some time after the 1992 baiting.

Both methods used to index the abundance of wild dogs in this study detected gross changes in abundance after baiting. The proportional changes in abundance in the CI index were mirrored in the SF index, although the SF gave slightly larger differences caused by baiting and were more variable (see Tables 2, 3). Although the changes in indices caused by baiting at the treatment site were large, the less-precise SF just failed to show significance under RIA (Table 4). A substantial biological change was not reflected as a statistically significant result (Carpenter *et al.* 1989). There is argument that the significance tests for changes to large-scale systems should be less stringent (e.g. Stewart-Oaten 1992) so that Type I errors are avoided.

Although useful indices of the abundance of wild dogs were provided by both techniques, the CI is potentially more useful. Because the CI accounts for variability in the tracking substratum and conditions, comparisons between sites by this method are more acceptable. Without standardisation, such comparisons rely on the untested assumption that tracking conditions at each site were uniform. In this experiment, the CIs were less variable and, as reflected by the RIA, were therefore more sensitive to changes in abundance than the SF method. However, between-season comparisons of any index reliant on the indirect detection of the activity of wild dogs are likely to be unreliable because wild dogs exhibit different levels of activity and movement in different seasons (Thomson 1992).

Standardisation of indices of the abundance of wild canids allows comparisons between sites and between years (Thompson and Fleming 1994; Fleming and Thompson 1995). Between-year contrasts of relative abundance at one site are possible if the indices are determined during the same time of year. Comparisons of the relative abundance of wild dogs between sites are possible only when the sites are topographically similar and if the surveys are done concurrently.

While the methods that were used here were able to detect gross changes in abundance, the exact relationship between actual density and indices of the abundance of wild dogs would require the experimental manipulation of a population of known size.

Efficacy of Aerial Baiting

The use of aerial baiting to reduce a wild dog population was found to be efficacious in 1991 and 1993. The reduction in SF index at the treatment site in 1991 was substantial and was not mirrored at the nil-treatment site. However, because the transect counts were not standardised in SF indices nor replicated, the real magnitude of the change would be uncertain without corroborating evidence. In 1992, the combined aerial- and ground-baiting programmes achieved a population reduction in SF similar to that in the other two years but took longer because of the greater time involved in ground baiting. The changes in abundance indices of wild dogs (SFs) in the nil-treatment areas in 1991 were small over the same period (22·8% increase). The observed change in SF in the treatment area was too large not to have reflected an actual change in the population abundance.

While the RIA does not demonstrate causality, there were no ecological explanations for the significant and rapid changes to the indices of abundance of wild dogs at the treatment site other than aerial baiting. The CIs for 1992 and 1993 showed reductions in the abundance of wild dogs at the treatment site of similar, but slightly smaller, magnitude to those of the SF index. The untreated site also showed a small and insubstantial reduction in CI and SF at the after-baiting surveys. The magnitude of the changes in both abundance indices at the treatment site was similar for each year and was attributable only to the perturbation caused by the baiting. Spatial replication of the aerial-baiting treatment would be necessary in order to generalise the results of this experiment to other sites.

The use of a treatment site that had previously been baited may have influenced the results. Previous baitings might have changed the age structure of the population and thereby affected the relative susceptibility of the population to baiting. However, given that aerial baiting in north-eastern NSW is tightly controlled, most baitings occur in areas that have a history of baiting.

The proportional reductions in the abundance of wild dogs achieved in our experiment were similar to those found in the Fortescue region by Thomson (1986) ($\bar{x}$ = 75%, s.d. = 21·7%) and Thomson and Marsack (1992) (85%). The reductions in the abundance of wild dogs were greater than those recorded by Best *et al.* (1974) or McIlroy *et al.* (1986) with ground-baiting programmes. However, fewer baits are used in ground-baiting programmes than are commonly used for aerial baiting. For example, McIlroy *et al.* (1986) used 6·3 baits km^{-1} in their ground-based baiting programme, whereas aerial-baiting programmes in north-eastern NSW use 40 baits km^{-1} (NSW Agriculture, unpublished records).

Newsome *et al.* (1983) and Best *et al.* (1974) suggest that the availability of alternative prey may affect bait uptake by canids and hence affect the success of baiting campaigns. In our study, the abundance of macropod prey was significantly higher in the treatment area than in the nil-treatment area [RIA of wallaroo abundance between sites, P = 0·029 (Fleming and Thompson, unpublished data)], while the relative abundance of wild dogs was the reverse. This would imply that prey abundance was not limiting at the treatment site and that the uptake of baits by wild dogs was independent of prey abundance.

The CIs of the treatment site were similar between years, indicating that the abundance of wild dogs before baiting was similar between years. Given that a substantial reduction in the wild dog population had occurred because of the baiting programmes, the re-establishment of the population by the following year's baiting indicates that baiting programmes in north-eastern NSW should be conducted at least annually.

Knowledge of the relationship between the density of a vertebrate pest and the agricultural damage caused by the pest is useful when deciding upon a strategy and options for management. The relationship that best describes predation of livestock by wild dogs is not known and requires further research.

The timing of repopulation is unknown and was not investigated in this experiment. However, dingoes generally whelp during late winter and spring (Catling *et al.* 1992) and the young are weaned in mid-summer, 3–6 months later (Corbett and Newsome 1975). The increasing trend from January to May in the predation of livestock by wild dogs (Fleming and Korn 1989) could be explained by the increased movements of wild dogs corresponding with dispersal and mating that occur in autumn (Catling *et al.* 1992; Thomson *et al.* 1992). These activities may account for the return of before-baiting CIs in 1993 to the before-baiting levels of the previous year and could indicate that repopulation occurred largely by dispersal into the baited area between mid-summer and autumn.

Not all wild dogs were killed by the aerial-baiting programme. This result was expected, because not all carnivores will take baits (Thompson and Fleming 1994) and because of the high number of baits that would have been taken by foxes or removed by birds (Allen *et al.* 1989). Quolls (*Dasyurus* spp.) may also take baits on rare occasions (Fleming, unpublished data). As quolls are the non-target animals most at risk from 1080-poisoned meat baits (McIlroy 1986; Fleming and Parker 1991), further study is required to determine the effect of aerial baiting on the abundance of quolls.

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