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CONTROL AND ECOLOGY OF THE RED FOX IN WESTERN AUSTRALIA

FOX POPULATION DYNAMICS AND CONTROL

INVASIVE SPECIES PROGRAM, PROJECT #4

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PRECIS

The Fox Threat Abatement Plan identifies the development of immunocontraception as a possible new method of controlling fox populations. As part of the development of this technique, research was undertaken to investigate the response of a fox population to a substantial reduction in the number of vixens breeding. Any significant population compensation for the reduced density would reduce the effectiveness of immunosterility control, and would have to be taken into account in predictive models.

The rates of fertility, fecundity and barrenness were compared between two populations: one population that was intact and one that had been reduced to approximately 20% of its original density using lethal baits. Potential compensatory increases in juvenile survival were also investigated by comparing the proportion of juveniles in each population. If proportionately more juveniles occurred in the reduced population, this would indicate that compensatory juvenile survival had occurred.

Both experimental populations were comprehensively sampled during August-December 1997 when vixens were pregnant or had recently whelped. The ovulation rate and litter sizes observed in the reduced population were significantly higher than in the intact population indicating that compensation had occurred. Results of age-specific fecundity investigations indicate that there was no significant age-related bias in the production of cubs and that vixens did not breed at a younger age in the reduced population. There were no significant differences in the number of barren vixens or in the number of vixens that resorbed their entire litters between the two sites.

An increase in juvenile survival was identified in the reduced population. This compensatory increase in juvenile survival and the observed increase in litter size were used to calculate the overall compensatory response of the reduced population. It was estimated that it would take approximately 4 years for the population to regain its original density in the absence of any density dependent changes in adult survival.

As part of the above experiment, the effectiveness of baited buffer zones in preventing recolonisation of depopulated areas was investigated. A 15 km wide buffer zone was established around the 1000 km^2 reduced fox density site. Population changes in both the buffer zone and the central core site were monitored by means of fox track counts on sandplots, by catch-per-unit-effort live-trapping, and by cyanide baiting indices. The outer 10 km of the buffer zone were periodically re-baited using lethal 1080 baits (3 mg 1080 per bait; 5 baits km^2). This buffer baiting proved to be very effective in preventing reinfestation of the entire baited area.

BACKGROUND

The research described in this document is part of the ecological work being conducted by the Vertebrate Biocontrol Co-operative Research Centre (VBCRC). This CRC aims to develop immunocontraception as a new method for controlling pests including foxes. The new technology is being developed in an attempt to reduce fox populations and thereby minimise fox predation upon threatened species. This aim is consistent with the objectives of the Fox Threat Abatement Plan. As part of the development of this technique, the dynamics of fox populations are being investigated to determine whether sterilising a large proportion of vixens will result in a substantial fox population decline, or whether fox populations will compensate for reduced density and thus overcome the imposed level of control.

The experiment was set up near Carnarvon WA in June 1995 (Fig. 1). Data were collected under two regimes: one where the fox population was left intact and the other where the fox population was substantially reduced (20-25% of original density) using aerially delivered 1080 baits.. The two populations were comprehensively sampled in August-December 1997 when the vixens were either pregnant or had recently whelped. The ovulation rates, litter sizes and proportion of barren vixens were compared between the two populations. The age structures of the two populations were also compared to determine if a greater proportion of yearling recruits occurred in the reduced population. If so, this would indicate that compensatory cub production and/or survival had occurred.

Other aspects of fox ecology were examined. Buffer zones were investigated to determine their usefulness in preventing reinvasion of large baited areas by dispersing foxes. This information is needed because sterility baits may reduce juvenile recruitment into a fox population in a specific area but unless recolonisation of the site is prevented there will be no effective reduction in fox density. A 15 km baited buffer was placed around the main treatment area to prevent immigration by foxes from higher density, unbaited areas nearby. This buffer zone was baited to coincide with the timing of dispersal of juvenile foxes. The timing and incidence of dispersal into site was determined by monitoring the presence of fox tracks on sandplots, by trapping and by cyanide baiting.

During 1995 and 1996 background data on the age structure, general condition and breeding performance of foxes were obtained from populations near to the two main study areas. Fox carcases were retrieved using cyanide baits and data on age-specific fecundity and litter size were obtained. During 1995, 257 foxes were collected and during 1996 151 foxes were obtained. The results obtained from these foxes were compared with those obtained from the experimental sites in 1997. This comparison ensured that breeding success was not atypical in 1997.

PROGRESS IN RELATION TO MILESTONES:
Determine changes in the relative density of foxes using sand plots in baited sites.

Counts of fox tracks on sandplots were used to determine the efficacy of the original population reduction and to monitor any changes to the reduced population. The original population reduction was imposed using aerially delivered 1080 baits across the core and buffer sites (Fig. 1). The baiting was more effective than anticipated and most of the foxes in the site were killed (Fig. 2). There were too few foxes left remaining in the site for the experiment to continue. It was decided that immigrants would be permitted to reinvade the site until the fox population had returned to 20-25% of its original density. Any further immigration would then be stopped by further baiting in the buffer zone (see below).

The density of foxes in the baited site returned to 25% of its original density by March 1996 (Fig. 3). The number of foxes indicated by the sandplot data may appear to be higher but this can be attributed to the shortcomings of sandplot monitoring. Sandplots are only useful when fox densities are low to moderate. At very low densities the activities of individual foxes can be identified. As density increases the foxes that are present encounter few competitors and increase their activity and encounter proportionately more sandplots. Consequently, a few foxes can incorrectly indicate a higher density of foxes. As actual density increases an asymptote occurs beyond which it is impossible to determine whether there are actually more foxes present or whether the foxes that are present are very active.

As a consequence of the sandplot monitoring producing ambiguous results, trapping was undertaken to more accurately estimate the relative density of foxes in the site. At the commencement of the experiment, and before the population had been reduced, 52 foxes had been captured. The same trapping effort was used in June 1996 and fourteen foxes were captured, or 27% of the original number. This result indicated that the fox population was at the prescribed density for the experiment to continue. The density of the fox population during the breeding season of 1996 needed to be known accurately because this would greatly influence the extent of the compensatory breeding response.

A further density estimation using trapping was made in the baited site just prior to the final comprehensive population sampling in August 1997. This density estimation was necessary to ensure that the fox populations in the baited and unbaited sites had not changed appreciably during the experiment due to unforseen circumstances. Trapping in the baited site yielded 7 foxes, which was 13% of the original density. Although this result may appear to indicate a decline in fox density between 1996 and 1997, it is more likely that the trapping success rate was reduced because foxes had already been subjected to trapping in 1996 and thus were harder to catch. It is more appropriate in this case to compare the relative number of foxes trapped in the baited and the unbaited areas. Using this approach, and having identified that the capture success in the baited area was 32% of the unbaited site, this result indicates that no unexpected immigration into the site had occurred and that the populations were still at the prescribed densities. This conclusion is supported by data from radio-collared foxes in the site. Of the 14 foxes caught in 1996, only 2 were known to have died, suggesting that mortality was unlikely to have caused any apparent density decline.

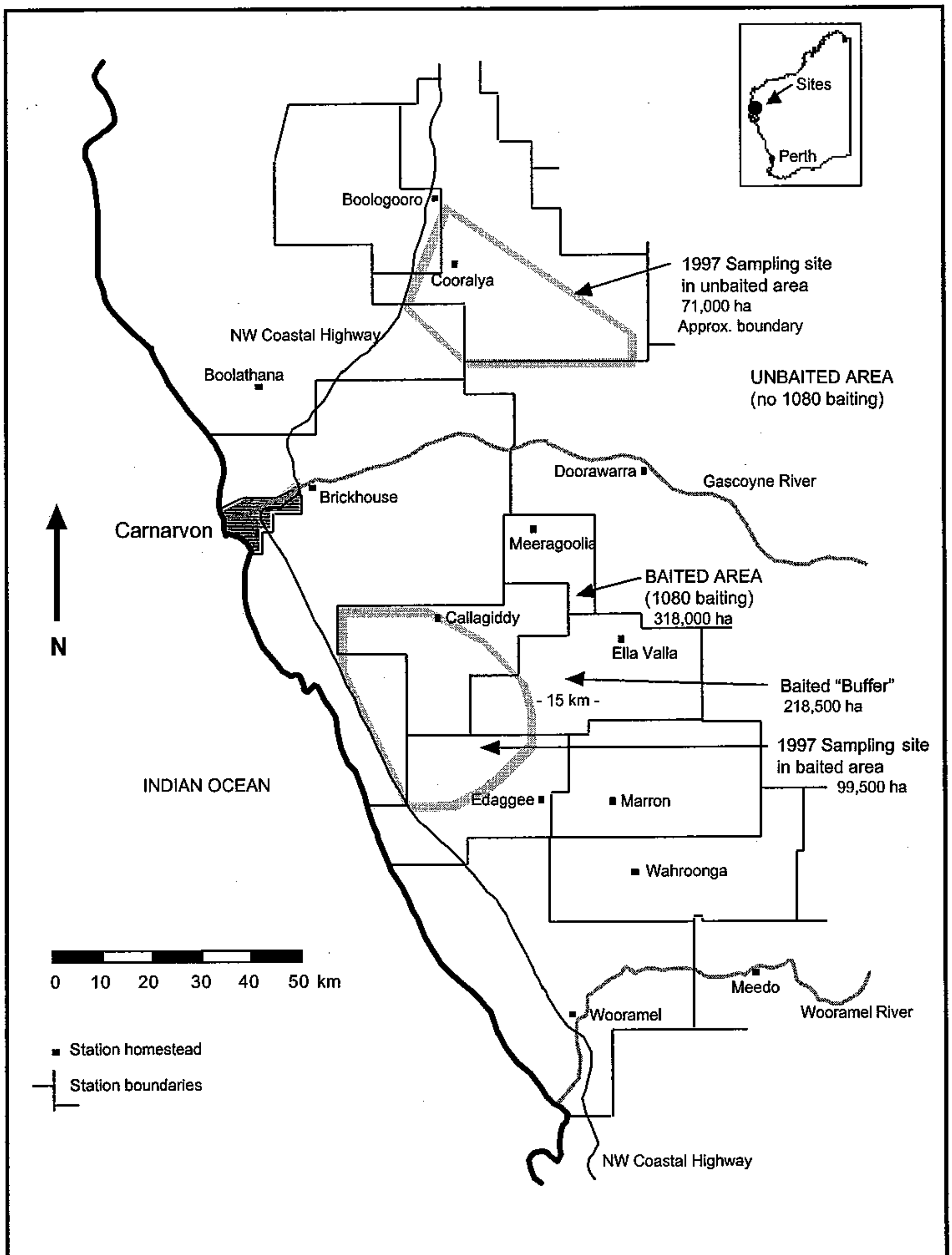

FIG. 1 CARNARVON FOX RESEARCH STUDY AREAS

A further index of fox density in the baited site was obtained by using CPUE cyanide indices (Algar and Kinnear, 1992). Cyanide indices were used to estimate density in the baited site before the final destructive sampling in August-December 1997. An average of 0.11 foxes per kilometre was recovered and this result was compared with 0.55 foxes obtained per kilometre in the unbaited site (see below). This comparison indicated that the density of the fox population in the baited site was approximately 20% of that of the unbaited site and is consistent with expectations.

Determine changes in the relative density of foxes using sand plots in the unbaited sites.

The presence of fox tracks on sandplots was used to obtain an index of fox numbers in the unbaited area from July 1995 to March 1997. The results indicate that there were no significant changes in the numbers of foxes in this area and this is consistent with expectations (Fig. 4). A calibration of the sandplot index was undertaken using trapping. Half the trapping effort used to catch 52 foxes in July 1995, yielded 25 foxes in July 1996. Trapping was repeated in this site in August 1997 to further correlate sandplot and cyanide indices with actual fox numbers. In 1996 25 foxes were captured and when the same effort was used in 1997 eleven foxes were obtained. Although this result may appear to indicate that a decline in density had occurred we could still monitor 21 of the 25 foxes that had been originally radio-collared in the area. Therefore, it is more likely that trapping success was reduced because the foxes had already been subjected to trapping rather than an actual change in density occurring.

Cyanide indices were used to compare the final density of the unbaited site in August 1997 with that of the areas surrounding the experimental sites in 1995 and 1996. A t-test was used to compare the numbers of foxes retrieved and no significant difference in density between the years was observed. This result reveals that the density of foxes in the intact site in 1997 was not atypical.

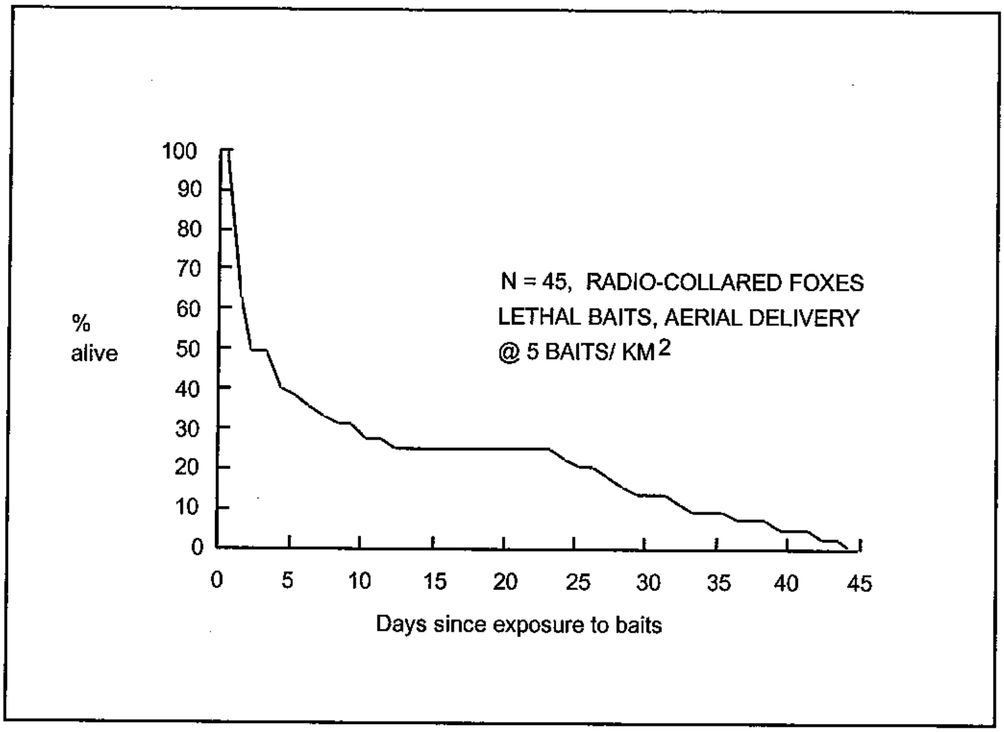

FIG. 2 TIMING OF LETHAL BAIT UPTAKE BY FOXES

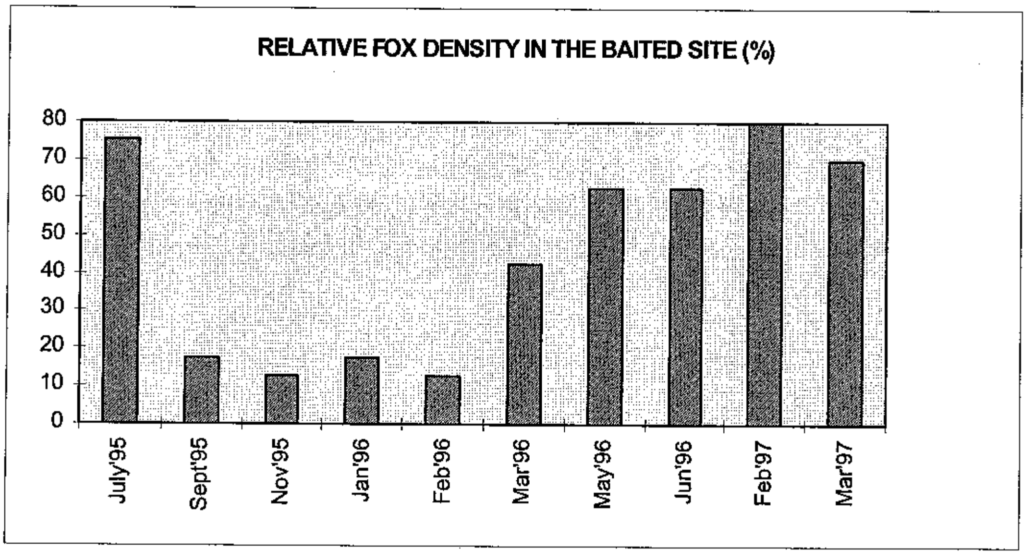

FIG. 3 TIMING OF REINVASION OF THE BAITED AREA

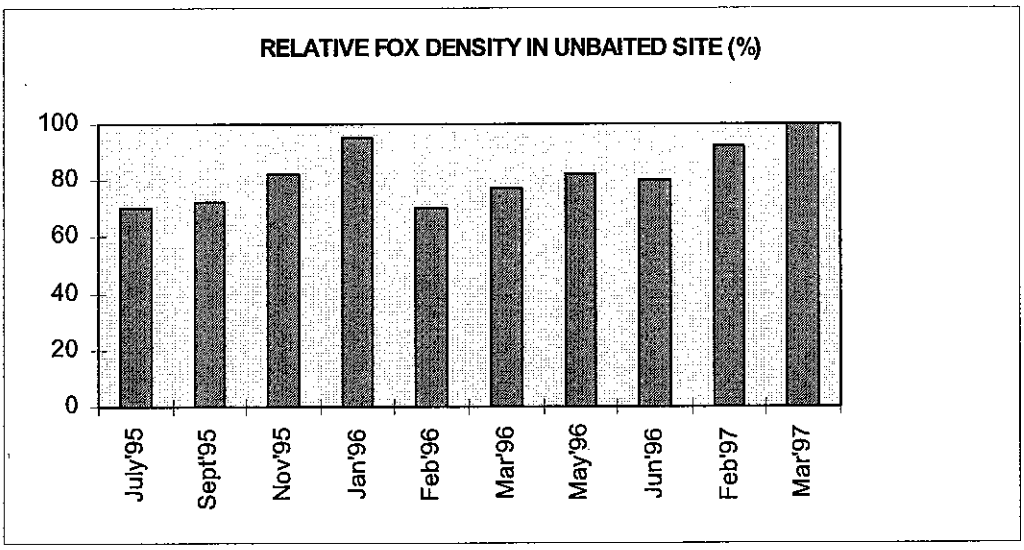

FIG. 4 SEASONAL FLUCTUATIONS IN FOX DENSITY IN AN UNBAITED AREA

Determine changes in the relative density of foxes using sand plots in the buffer zone.

The presence of fox tracks on sandplots was used to obtain an index of fox numbers in the buffer zone from July 1995 to May 1997.

A 15 km wide buffer zone was set up around the baited treatment site (Fig. 1) to minimise immigration into the site by foxes from higher densities outside the site. Following the greater than expected population reduction in July 1995, immigrants were initially permitted to traverse the buffer zone so that they could restore the treatment site to 20-25% of its original density. Once that density had been attained the buffer was rebaited to prevent any further immigration from higher density areas outside the treatment and buffer zones.

The first buffer only baiting campaign was undertaken in May 1996, covering the outer five kilometres of the buffer (Fig. 4). The number of foxes present at sandplots decreased after this baiting but the change was not significant. This result reflects the shortcomings of sandplot monitoring rather than indicating no change in fox numbers.

The outer 10 km of the buffer zone was aerially baited again in February 1997. The number of fox tracks on sandplots in March indicated a decline and it was concluded that the number of foxes had been sufficiently decreased. It was anticipated that the number of foxes recolonising the buffer could increase between March and May which is the peak time for juvenile dispersal. Therefore the buffer sandplots were monitored and another baiting was undertaken in April. This baiting involved hand laying cyanide capsules on the buffer sandplots to determine the number of foxes represented by the number of tracks observed. After three days of cyanide baiting, a single 1080 bait was left on each sandplot and left undisturbed for one week. The number of 1080 baits removed by foxes was determined and the number of foxes killed estimated. The number of foxes remaining in the site was then re-determined by sandplot monitoring. The number of foxes remaining was still be too high and so a further aerial baiting of the buffer zone was undertaken in May 1997. The outer 10 km of the buffer was baited.

Fox density was estimated in the buffer zone just prior to the final comprehensive destructive sampling in August- December 1997. Cyanide indices were used to compare the density of foxes in the buffer zone with that in the unbaited site and the baited site (see above). The density of foxes was revealed to be 0.05 foxes per kilometre in the buffer zone which is considerably less than the 0.55 foxes/km in the unbaited site and approximately half of that of the baited site (0.11 foxes/ km). This result is consistent with expectations and indicates that the buffer was sufficiently devoid of foxes to act as a dispersal sink and to protect the core site from reinvasion by dispersing juveniles.

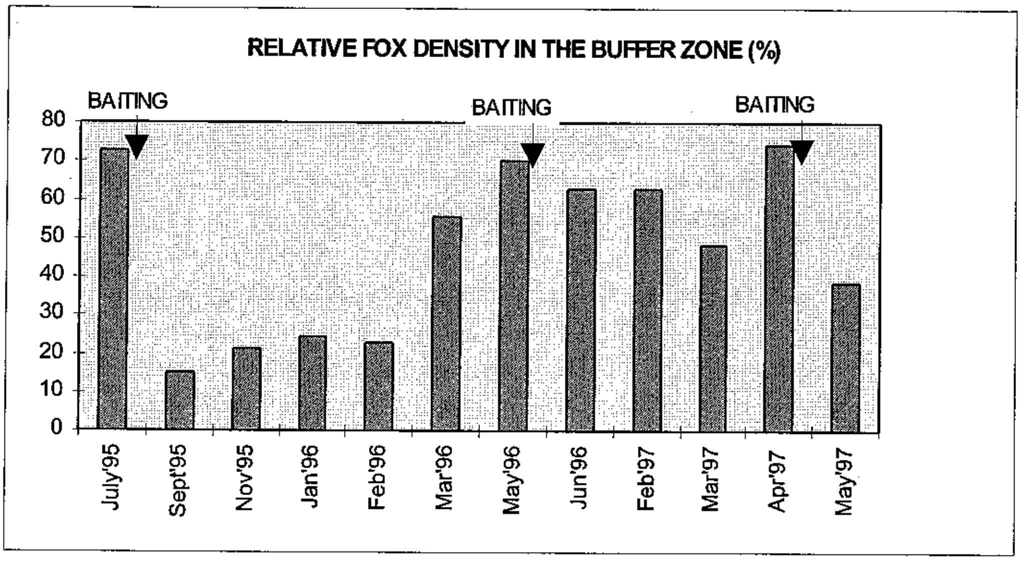

FIG. 5 CHANGES IN FOX NUMBERS IN THE BUFFER ZONE

Collate data from foxes collected to determine the proportion of yearling vixens breeding in baited and unbaited populations.

In some populations of foxes, especially those at high densities, a significant number of juvenile vixens do not breed. If the density of a fox population with this characteristic is suddenly reduced, the population may compensate by an increase in the number of vixens breeding.

The number of barren, juvenile vixens in each of the populations was compared using chi-squared analysis and there was no significant difference between any of the sites. This result reveals that there was not a compensatory increase in the number of juvenile vixens breeding as a response to reduced density. This result is not unexpected because the level of barrenness in all populations was very low and so there was limited capacity for any compensatory change to occur.

Deduce life tables for baited and unbaited populations.

Samples of foxes were obtained in 1995, 1996 and in the reduced and intact sites in 1997. These samples were obtained during or just after the breeding season to maximise the reproductive data obtained. In 1995 and 1996 cyanide baiting was used to sample fox populations near to the experimental sites. In 1995 165 foxes were collected and in 1996 149 were obtained. These samples were used to ensure that breeding success in 1997 was not atypical.

Comprehensive population sampling was conducted in the baited and unbaited sites from August to December 1997. This involved using intensive cyanide baiting, trapping and shooting to obtain a large sample of foxes from both sites. In the unbaited site 237 foxes were recovered (110M: 127F). Of these 202 (85%) were cyanide baited, 19 (8%) were trapped and 16 (7%) were shot. In the baited site 64 foxes were obtained (39M: 25F). Of these 40 (63%) were cyanide baited, 19 (29%) were trapped and 5 (8%) were shot. Data from a population sampled in the Carnarvon area in 1992 indicated that cyanide baiting and trapping do not result in an age or sex biased sample but that shooting is biased towards young male foxes. To ensure that densities within the sites were comparable, standard cyanide indices were obtained for all sites. These were compared using t-tests and no significant differences between sites were found.

For life table analyses to be undertaken, the ages of individuals within each population need to be known accurately. Foxes were aged by counting the number of cementum annuli present in their canine teeth. To reveal the number of annuli, transverse sections were made through each tooth using a diamond bladed isomet saw. Sections were taken from the apical region of the root but the extreme tip was avoided. Six sections from the upper left canine tooth were examined. If that tooth was damaged, the upper right tooth was used. The sections were decalcified using EDTA decalcifier for 5 minutes. Sections were then stained for 21 minutes using toluidene blue (0.01% conc). The maximum reliable number of annuli observed was recorded as the age for the individual. The data obtained for foxes in each of the experimental populations were used to generate the age structures presented in Table 1.

Table 1: Age structures for fox populations sampled in 1995, 1996 and in both the reduced and intact sites in 1997.

	1995	1996	1997 Intact	1997 Reduced
Age class 1 (0-1 yrs)	43	60	50	19
Age class 2 (1-2 yrs)	12	8	59	21
Age class 3 (2-3 yrs)	44	24	41	16
Age class 4 (3-4 yrs)	38	35	37	7
Age class 5 (4-5 yrs)	18	12	21	0
Age class 6 (5-6 yrs)	10	10	29	1
Total	165	149	237	64

The analysis of life tables assumes that there is a constant annual mortality between consecutive age classes and that the ratio of numbers in any two particular segments is fixed (Caughley 1977). It is assumed that most individuals will be in the first age class and that there will be least in the oldest age class. If some factor influences the survival of individuals in any particular year, the age structure is not stable and this greatly complicates comparisons of life tables.

The age structures of the populations sampled during this experiment were highly anomalous (Table 1). In 1995 and 1996 there were considerably more third year individuals than two year olds, indicating that some factor in 1992 and 1993 had influenced cub production and/ or survival. These unusual patterns of survival occur throughout the life tables and make calculation of survival between age classes impossible. Age classes need to be extensively pooled to obtain a decreasing age structure.

As a consequence of these unexpected age structures, no hierarchical log linear analyses of between age class survival could be performed. Instead χ^2 analysis of the populations was undertaken. There were significantly fewer juveniles in the intact population than in the reduced population in 1997. This result indicates that a relative increase in compensatory juvenile survival had occurred in the reduced population. The increase in cub survival in the reduced population was 20.9%.

Productivity changes between years, rate of increase, and stability of demographic parameters in relation to rainfall.

The fecundity of each of the fox populations sampled in 1995, 1996 and for both sites in 1997 was obtained by examining the reproductive tracts of vixens and counting the number of embryos or recent placental scars. Scars were graded with reference to Lindström (1981) and were classified as resorptions or resulting in viable cubs accordingly. Ovaries were examined and the number of corpora lutea present in each was counted. The rates of ovulation, implantation, resorption and barrenness were calculated (Table 2) and differences analysed using t-tests. Differences in the rates of barrenness were examined using χ^2 analysis.

Table 2: Rates of ovulation, implantation, resorption and barrenness for each site

Site	Implantation rate (Viable scars or embryos/ vixen)	Ovulation rate (Mean # of corpora lutea/ vixen)	Resorption rate (%) (No of resorps/ total no implants)	Rate of barrenness (%) (# vixens not bearing live cubs)
1995	3.9	4.3	8.6	5
1996	3.8	5.1	12.9	20.5
1997 intact	3.9	4.7	16.7	6.5
1997 red'd	6.1	7.4	12.4	8

There was a highly significant difference in the number of implantations per vixen in the reduced site when it was compared with all other sites ($p<0.001$). Similarly there was a significant difference in the ovulation rate between the reduced site and all other sites ($p<0.001$). There was no significant difference in the resorption rate between any of the populations.

The rate of barrenness for 1996 was significantly higher than for all other years. Despite excellent body condition (when sampled) and a high ovulation rate, the implantation rate was very poor with 20.5% of the vixens being totally barren. The rates of barrenness for all sites and years other than 1996 were not significantly different.

The incidence of mange did not vary throughout the study except that male foxes in the reduced site in 1997 were significantly more mangy than others. This result may have occurred if some of the foxes that were permitted to recolonise this site in 1996 were outcasts from other fox populations. If this was the case they may have been generally less healthy and more prone to mange. Interestingly there was no correlation between the incidence of mange and body weight in any population.

There was no significant difference in the weights of male foxes in different years and sites. There was, however, a significant difference in the weights of vixens between years. This result can be explained by the fact that vixens were in different stages of pregnancy when sampling was undertaken in each of the sites. Therefore the observed differences in weight are more a reflection of the stage of pregnancy than an actual significant difference in weight.

Various factors that may have influenced litter size were investigated: weight of the vixen, incidence of mange, subcutaneous fat index, rainfall during the breeding season, and rainfall during the six months before the breeding season. There was no correlation between any of these factors and litter size except that there was a significant correlation between litter size and weight for vixens in the reduced site during 1997 (r^2=0.63).

The rate of increase for the reduced and intact populations for 1997 was calculated. The intact population was assumed to be stable. The rate of increase for this population was calculated by obtaining cyanide indices for the population for two consecutive years (see Caughley 1977). The resulting rate of increase was 0.07; a result that was consistent with expectations of a stable population. The rate of increase for the reduced population was calculated to be 0.43 which is not unexpected for a population that is increasing following a reduction. This result indicates that this population would double in size in 1.5 years (see Caughley 1977) which is consistent with the projected change in population density discussed above.

An analysis was undertaken to determine how long it would take the reduced population to return to its original density. A projection of the reduced population's increase in successive years is hampered by the anomalous age structure. Consequently, the data for each age class was pooled until a decreasing age structure was obtained (Table 3).

Table 3: Pooled age class data for vixens from the reduced and intact sites for 1997.

	Intact site	Reduced site
Age class 1 (0-2 yrs)	50	19
Age class 2 (2-4 yrs)	43	5
Age class 3 (4-6 yrs)	33	1
Total	126	25

The projected number of cubs produced by of the age classes of the reduced population was calculated by multiplying the age specific fecundity of each age class by the number of vixens in that age class and summing the results. A 1: 1 sex ratio at birth was assumed (Lloyd 1980) and so this result was halved to obtain an estimate of the number of vixen cubs born. The number of these cubs that would survive to be in Class 1 in the subsequent breeding season was then calculated. The cub survival rate was calculated by obtaining the relative difference in cub survival between the intact and reduced populations and subtracting this from the observed level of cub mortality for the intact population. The number of individuals present in the 2nd to 5th age classes of the projected population was then calculated using the same between age class ratios as those observed for the intact population.

It was recognised that changes in litter size would occur as population density increased. Therefore, the arithmetic relationship between litter size and population size for each age class was calculated. Similarly, changes in compensatory cub survival were adjusted for population density by assuming that there was a linear relationship between cub survival and population density.

These calculations were repeated to obtain the population structure for each subsequent breeding population. This process was continued until the number of individuals in the reduced population was returned to its original density (i.e 125 vixens). Using this technique it was calculated that it would take approximately 4 years for the reduced population to fully compensate for the initial reduction in breeding of 80% of its vixens (Table 4). It should be emphasised that no density related change in adult survival has been included in these calculations. It is reasonable to assume that there will be some increase longevity (and hence reproductive output) of vixens at lower densities. Thus the reduced population would be expected to take less than four years to regain its original density.

Table 4: Projected age structures as the reduced population returns to its original density.

Age	Ist year	2nd Year	3rd year	4th Year
0-2	18.62	30.12	45.05	58.74
2-4	16.01	25.90	38.74	50.52
4-6	12.28	19.88	29.73	38.77
Total	46.92	75.91	113.52	148.04

Sex ratios and cub-vixen ratios.

The sex ratios of the fox populations sampled during 1995 and 1996 are not significantly different to 1:1 (M: F). This result indicates that there is not a significantly higher proportion of vixens in the population as might occur if dominance hierarchies were the predominant social organisation. The social organisation of fox populations is an important factor to consider when the use of immunocontraception to is being considered. If dominance hierarchies are prevalent, and if there is some dominance related avoidance of baits, then it is possible (Caughley *et al.* 1992) that the reproductive suppression of subordinate vixens by dominant vixens may be reduced and the net result will be more rather than less cubs produced.

The sex ratio of the intact population (1:1.1 M: F) appears to be higher than that of the reduced population (1: 0.6). However, when these values were compared to the sex ratios observed in the fox populations sampled in 1995 and 1996 using analysis of variance they were not significantly different.

The cub to vixen ratios were calculated for all sites (Table 5). These values indicate that each vixen is producing a high number of cubs and this enhances the previous conclusion that the social organisation of these populations is probably a mated pair system rather than a dominance hierarchy. This conclusion is further supported by the fact that there are relatively few non breeding or barren vixens in each population and this parameter would be expected to be higher if dominant vixens were suppressing the reproduction of subordinate vixens. The cub to vixen ratios for 1995, 1996 and the intact site in 1997 were not significantly different but the cub to vixen ratio for the reduced population in 1997 was highly significantly different to the other sites.

Table 5: Cub to vixen ratios for all sites

Site	Cub: vixen ratio
1995	3.0: 1
1996	3.5: 1
Intact 1997	3.9: 1
Reduced 1997	7.0: 1

Difference in age specific fecundity between baited and unbaited populations.

The number of cubs produced by each age class for each site and year was analysed using analysis of variance. The results indicated that there was no statistically significant difference in the number of cubs produced by vixens of any particular age. However, there was variability in cub production between age classes with 5 year old vixens having the largest average litter size and one and two year olds having the smallest litters (Table 6).

Table 6: Age specific fecundity

Age (years)	Number	Average litter size
5	31	3.9
3	50	3.8
4	57	3.7
6	30	3.4
1	70	3.3
2	56	3.1

The productivity of juvenile vixens between sites and between years was examined using t-tests. There was no significant difference in the productivity rate of vixens in 1995, 1996 and in the intact site in 1997. There was a significantly higher productivity of juvenile vixens in the reduced site in 1997. This result is consistent with the other results obtained in which all vixens in the reduced site increased their reproductive output as a compensatory response to the reduction in density.

SUMMARY

Effectiveness of buffer zones in preventing recolonisation of depopulated areas
The results of this trial confirm that aerial baiting in sections of the buffer zone was effective in producing a marked reduction in fox numbers in the buffer (cyanide indices). Immigration permitted in early 1996 apparently helped raise the population of the core area to about 27% of its former level. A year later, with the buffer baiting regime in place, the population was still 25-32% of its former level. This suggests that the baited buffer minimised further immigration. Any minor population increase in the core area could be explained by breeding. These results support the notion that a baited buffer zone can minimise immigration of foxes into protected areas such as fauna reserves, similar to the strategy for preventing dingo incursions into livestock grazing areas (Thomson *et al.* 1992).

Whether or not a buffer zone strategy would be appropriate in all situations needs to be considered. In the present study, a 15 km wide buffer of approximately 2000 km^2 (with the ocean acting as a barrier to immigration on one side), rebaited in up to 10 km of the periphery (1480 km^2), appeared to act as an effective 'dispersal sink' (sensu Thomson *et al.* 1992). Whether a narrower buffer would have been as effective is unknown. Clearly, if the width of the buffer remains constant but the size of the core protected area declines, the ratio of buffer to core area increases disproportionately. Depending on the frequency of baiting required, it may be economically and logistically more feasible to simply rebait small core areas more frequently, rather than bait over much larger areas in nominal buffer zones.

Population compensation
The fox population in the reduced density site could have compensated for the decrease in numbers in several ways. Increases could have occurred in the ovulation rate, litter size and cub survival. Decreases could have occurred in the rate of barrenness and resorption rate. Vixens could also breed at an earlier age.

The results indicate that there was a compensatory change in ovulation rate in the reduced population. This was accompanied by a significant compensatory change in the viable litter size. A similar increase in litter size in response to intense fox control measures was observed by Voigt and Macdonald (1984) where they recorded average litter sizes of up to 8.5 cubs. In the reduced population there was also an observed increase in cub survival. There was no significant difference in the number of resorptions observed in the two populations, although the rate was slightly lower for the reduced population (12%) than for the intact population (17%).

These data were combined to obtain an assessment of the ability of the reduced population to compensate for reduced density. The number of foxes that would occur in subsequent breeding seasons was projected and it was estimated that it would take approximately 4 years for the population to regain its original density. One factor that would need to be investigated before this projection can be viewed with conviction is the extent to which the longevity of adult foxes increases as density decreases. Nonetheless the results obtained in this study indicate that fox populations do compensate for reduced density but that it will take some time for them to reach their original density. The prognosis for the use of sterility baits as a management tool is therefore quite good.

CONCLUSIONS

The research described in this report has led to an increased understanding of fox ecology and has helped to identify and fill some gaps in our knowledge of fox control. The results of the research investigating the effectiveness of buffer zones in preventing reinvasion of depopulated areas are applicable to sites where lethal and/ or immunocontraceptive control is to be used. In either case a buffer area that is repeatedly baited with lethal baits will significantly reduce recolonisation of that area by foxes and thus will reduce fox predation upon desirable species therein.

The capacity of a fox population to compensate for fewer vixens breeding will influence the effectiveness of both lethal and immunocontraceptive control. The fox population observed in this study did compensate for reduced density by an increase in litter size and increased cub survival. When these data were used to project fox population structure and size into subsequent breeding populations, it was revealed that it would take approximately 4 years for the reduced population to return to its original density. This result suggests that immunocontraception could be a useful adjunct to lethal control in the management of fox populations in Australia.

REFERENCES

Algar, D. and Kinnear, J. E. (1992). Cyanide baiting to sample fox populations and measure changes in relative abundance. In 'Wildlife Rabies Contingency Planning in Australia'. (Eds P. O'Brien and G. Berry). pp. 135-8. (Bureau of Rural Resources Proceedings No. 11, Australian Government Printing Service: Canberra).

Caughley, G. (1977). 'Analysis of Vertebrate Populations'. Wiley and Sons. London.

Caughley, G., Pech, R., and Grice, D. (1992). Effect of fertility control on a population's productivity. *Wildlife Research* **19**, 623-628.

Lindström, E. R. (1981). Reliability of placental scars in the red fox *(Vulpes vulpes)* with special reference to fading of scars. *Mammal Review* **11**, 137-49.

Lloyd, H. G. (1980). 'The Red Fox'. (B. T. Batsford Ltd: London).

Thomson, P. C., Rose, K., and Kok, N. E. (1992). The behavioural ecology of dingoes in northwestern Australia. VI. Temporary extraterritorial movements and dispersal. *Wildlife Research* **19**, 585-95.

Voigt D. and Macdonald, D. (1984). Variation in the spatial and social behaviour of the red fox, *Vulpes vulpes*. *Acta Zoologica Fennica* **171**, 261-5.

EVALUATION

1. Outcomes:

1.1 The degree to which the Project has achieved the outcomes as specified in Schedule 1.

The milestones against which the progress of this project is measured are listed in Annexure 1 of Schedule 1. All of these milestones have been fully met and detailed descriptions of the work undertaken and the results achieved are provided in the main text of this report. Each milestone has been addressed in the order in which it is listed in Annexure 1.

2. Appropriateness:

2.1 The appropriateness of the approaches used in the development and implementation of the Project.

The techniques and methodologies employed in this Project were relevant and appropriate.

Sandplot monitoring did prove to be less informative than anticipated but alternative census techniques (eg trapping and cyanide indices) were employed where appropriate. These alternative techniques, although more labour intensive, did enable adequate monitoring of changes in fox density to be undertaken.

The project has received some criticism because the experimental sites were not replicated. For replication to have occurred, the resources needed would have doubled. This level of resource support was not available from any of the funding agencies. External advisers to the VBCRC (eg Prof. C. Krebs, Uni of British Columbia) stated that the experiment was sufficiently robust with its current design and due to its large scale, concerns about within site variability confounding the results were unfounded.

The higher-than-expected bait uptake during the initial fox population reduction may have caused the experiment to be delayed but it also highlighted the effectiveness of this technique for controlling foxes. During the additional year that was then used to complete the project, data on the effectiveness of buffer zones in reducing reinvasion of protected areas was obtained. This information will used to develop management strategies which will enhance the long-tern effectiveness of sterility and/ or lethal baiting campaigns.

The ageing technique was painstakingly improved and developed from the methods described by other authors. Changes were made to the fixatives, to the staining protocol and to the interpretation of annuli. The final methodology will be written up as a short techniques paper and submitted for publication in the near future.

3. Effectiveness:

3.1 The degrees to which the Project has effectively met its stated objectives

The stated objectives of the Project were to determine

i) if fox populations could compensate for reduced population density; and

ii) if baited buffer zones were effective in reducing recolonisation of areas of high ecological or economic value.

Both of these objectives were met and conclusions about the management of foxes populations were made *viz*

i) Fox populations can compensate for reduced population density by an increase in ovulation rate, litter size and cub survival. Calculations revealed that despite these compensatory changes, it would still take a reduced population approximately 4 years to return to its original density. This result indicates that it is still feasible to use sterility baits in the management of fox populations. This conclusion indicates that the development of sterility baits as another tool in the arsenal to control foxes is justified.

ii) The results of this project indicate that lethally baited buffer zones are effective in reducing the immigration of foxes into protected areas. Buffer zones will therefore be useful in lethal fox management plans and in the implementation of sterility baits as a management tool.

By providing the data to address both of these objectives, the Project has been successful in meeting its obligations.

4. Transferability:

4.1 The degree to which the approach used to establish, implement and administer the operations of the Project could be applied to other Councils/ regions.

The results obtained that indicate that litter size and cub survival increase in response to lowered density are applicable to much of the Australian mainland. These results are directly applicable to all semi-arid areas within Australia and this forms a large part of the continent. There are many native species occurring in the semi-arid areas of Australia that would benefit from reduced fox predation.

It may not be possible to undertake such large scale trials in areas where lethal baits cannot be aerially delivered and where there numerous small landholdings and a greater risk to domestic dogs. However, the results obtained in this experiment are still applicable to most of these areas. Certain modifications to the experimental protocol may need to be made in areas where fox density is high. These may include the need to increase the rate of lay of baits (either sterility or lethal) because it is obvious that if the density of foxes is very high (e.g. 7/ km^2) then 5 baits km^2 will be insufficient.

In areas where fox density is very high the compensatory response to lowered density may be more rapid. The extent of this response would need to be investigated before the potential effectiveness of sterility baiting in those areas could be determined. In areas where fox densities are very high and /or where foxes are commensal with humans, a different fox social system may occur and the population response to lowered density may not occur in the same way. However, these are relatively small areas when the applicability of the technique is considered in relation to the continent as a whole.

The use of buffer zones is directly applicable to all semi-arid areas within Australia. The width of buffer zones may differ in other areas where fox density is higher but the observed 10 km wide buffer would probably be applicable to most areas. At higher densities the dispersal distance of foxes is shorter and this may suggest that only a narrow buffer zone is required. However because the density of foxes is higher there would be more pressure applied to the buffer zone. These two factors would probably balance each other and so a 10 km wide buffer may well be appropriate in virtually all cases.

4. Communication:

4.1 An outline of any demonstration/ communication activities undertaken as specified in Schedule 1

The project design and data obtained during this experiment have been presented at many seminars/ information exchange venues.
These include several presentations at VBCRC annual meetings, and their 3rd year and 5th year reviews. A presentation was given to the Australasian Wildlife Management Society in Christchurch (NZ) in December 1995. Two papers based upon this work were presented to the Vertebrate Pest Control Conference in Bunbury in May 1998. Other seminars have been given to CALM, CSIRO, and to CALM field staff.

Several manuscripts are being prepared that will report on the data obtained from this experiment. These include:

The population dynamics of red foxes in the pastoral zone of Western Australia.

Effectiveness of a baiting campaign for red foxes, *Vulpes vulpes,* in the pastoral zone of Western Australia.

Compensatory breeding in an artificially reduced population of red foxes in the pastoral zone of Western Australia.

A refined methodology for determining the ages of red foxes from cementum annuli.