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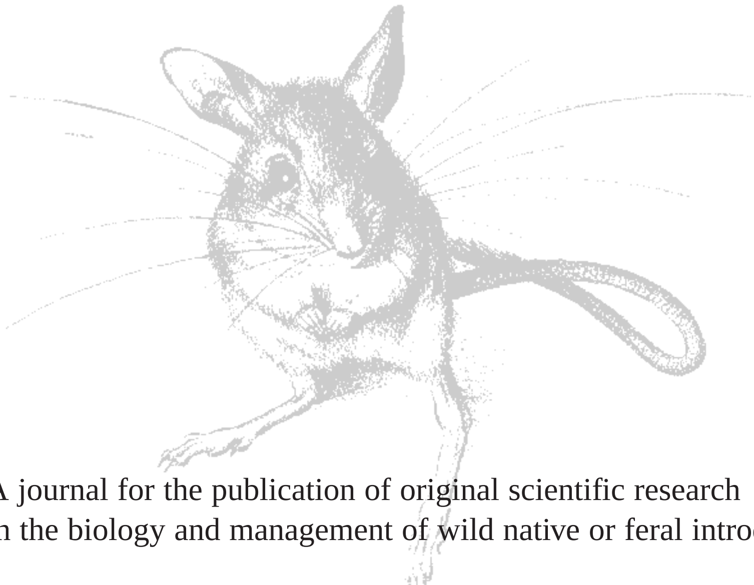

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Efficacy of Fox Control in Reducing the Mortality of Released Captive-reared Malleefowl, *Leipoa ocellata*

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Abstract

The effectiveness of localised, high-intensity fox baiting in reducing the incidence of fox predation was examined after captive-reared malleefowl were released and their survival monitored. Malleefowl released into baited areas survived longer than those released into nearby areas that had not been baited. Survival in both baited and non-baited areas was greater than that prior to any fox control. Of those malleefowl released, 29% were still alive three months later, whereas prior to fox control almost all were killed by foxes within a month of release. Despite the improvement in survival of malleefowl, fox predation remained the primary cause of malleefowl mortality. The number of baits taken by foxes indicated a large fox population and a high level of reinfestation. A more widespread, but less intensive, regime of baiting failed to further enhance the survival of malleefowl. Malleefowl were also particularly vulnerable to predation by raptors in habitats where the mallee was interspersed with areas of open woodland, and where the understorey was sparse. Fox baiting will need to be frequent, intensive and widespread to reduce fox density to levels where predation no longer threatens the survival or recovery of malleefowl populations.

Introduction

Malleefowl, *Leipoa ocellata*, roost in trees by night but by day they nest, forage and rest on the ground. Although capable of laboured flight, malleefowl take to the wing only when alarmed, preferring to evade danger by walking or running from any threat. Being well camouflaged, such evasive behaviour provides the malleefowl with an effective defence against avian predators that generally rely on sight to locate their prey. This strategy, however, is largely inappropriate against mammalian predators that possess a keen sense of smell.

Malleefowl have undergone a marked reduction in geographic distribution and a drastic decline in abundance within the last century (Blakers *et al.* 1984; Priddel 1989). The species previously occurred throughout the southern half of the Australian continent, from the Indian Ocean in the west to the Great Dividing Range in the east. An almost continuous distribution across this range has been replaced by scattered, isolated and contracting remnant populations.

Once found in a variety of habitats, malleefowl are now confined largely to semi-arid areas containing mallee vegetation communities (Marchant and Higgins 1993). The largest expanse of mallee reserved in New South Wales is contained within three contiguous nature reserves: Yathong (107 241 ha), Nombinnie (*c.* 70 000 ha) and Round Hill (13 630 ha). About 54% of the area protected by these reserves is mallee. This habitat contains only small numbers of malleefowl at very low densities ($<0{\cdot}04$ pairs km^{-2}; Brickhill 1985). Extant populations apparently survive as vestiges of much larger populations; inactive nests outnumber active nests by a factor of 64 : 1 (Brickhill 1985).

Previous studies examining the causes of malleefowl mortality involved the experimental release of young (3–5 months old) captive-reared malleefowl into Yathong Nature Reserve (Priddel and Wheeler 1996). From the first day after release, malleefowl were found dead, and mortality continued at a rapid rate until none remained alive. Half were dead within a week; 83% were dead within a month; and none survived beyond three months. Predation by foxes was the principal cause of mortality: 50–92% of young malleefowl fell prey to foxes (Priddel and Wheeler 1996).

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The European red fox, *Vulpes vulpes*, was successfully released in Victoria in the 1870s to provide sport for the hunting gentry (Rolls 1969). The species spread rapidly, largely following the spread of the rabbit (Long 1988). Foxes now occupy most of the Australian continent, and are particularly abundant in semi-arid areas of New South Wales (Wilson *et al.* 1992). This ubiquitous predator is believed to be a major factor in the demise of many native species (Finlayson 1961; Short and Smith 1994; Saunders *et al.* 1995).

Foxes prey on malleefowl eggs (Frith 1959; Brickhill 1987), chicks (Benshemesh 1992), juveniles (Priddel and Wheeler 1994, 1996), subadults (Priddel and Wheeler 1996) and adults (Booth 1987; Benshemesh 1992). Although foxes are a major cause of malleefowl mortality, the extent to which this introduced predator is responsible for limiting malleefowl abundance or distribution is difficult to ascertain. The situation is confounded by the effects of, and interactions with, other threatening processes such as habitat destruction and fragmentation (Frith 1962), degradation of habitat by introduced herbivores (Frith 1962), and altered fire regimes (Benshemesh 1990, 1992).

This study investigated the extent to which fox control by baiting could enhance the survival of captive-reared malleefowl released into Yathong Nature Reserve. Two different baiting regimes were tested to examine whether the human and financial resources available for control activities were best directed toward intensive localised control or toward less intensive but more widespread control. Besides clarifying the efficacy of fox control in enhancing the survival of captive-bred birds after reintroduction, the findings also have important implications for the conservation and recovery of remnant populations of malleefowl.

Methods

Study Site

The study, undertaken between 1990 and 1992, was conducted within Yathong Nature Reserve (32°40′S, 145°30′E) approximately 160 km south of Cobar. The study site, encompassing 19 200 ha of mallee in the north-west corner of the reserve, was partitioned into nine blocks by a network of access trails (Fig. 1). The three western blocks are hereafter referred to as the western sector. Similarly, the three central and three eastern blocks comprise the central and eastern sectors respectively.

The study site was characterised by low (10 m relief) linear dunes of red siliceous sands, and swales of deeper red sands and calcareous red earths (Mabbutt *et al.* 1982; Bradstock 1989). Vegetation was predominantly mallee of *Eucalyptus dumosa*, *E. leptophylla*, *E. gracilis*, *E. socialis* and *E. viridis*, interspersed, particularly in the north, with areas of open woodland of belah, *Casuarina cristata*. Most mallee contained a dense and diverse understorey of shrubs dominated by *Acacia rigens*, *A. wilhelmiana*, *Melaleuca uncinata* and *Eremophila glabra*. Interspersed amongst this habitat were expanses of mallee with an open understorey dominated by spinifex, *Triodia irritans*.

The local climate is characterised by cool, wet winters and hot, dry summers. Mean annual rainfall at Cobar is 344 mm (Weather Records Database, Bureau of Meteorology). Rainfall during the period of this study was below average. The region encompassing the study site was officially declared to be drought affected from September 1991 to August 1992 (Drought Area Declarations, Hillston Rural Lands Protection Board).

Experimental Design

The study measured and compared the survival of young captive-reared malleefowl released into both baited and non-baited areas following the commencement of a regime of localised, high-intensity fox baiting. During this baiting regime only the western sector of the study site (6400 ha; Fig. 1) was baited. This sector was selected because it appeared, from the relative frequency of fox tracks, to contain higher densities of foxes than either the central or eastern sector. The eastern sector was used as a non-baited control. The baited and non-baited areas, separated by 4 km, were similar in landform, vegetation and fire history. Survival rates of captive-reared malleefowl released into each area were compared to determine whether this particular baiting regime was sufficient to enhance malleefowl survival. Survival in both baited and non-baited areas was also compared with existing data on the survival of young captive-reared mallee-fowl released into the study site prior to baiting (see Priddel and Wheeler 1996).

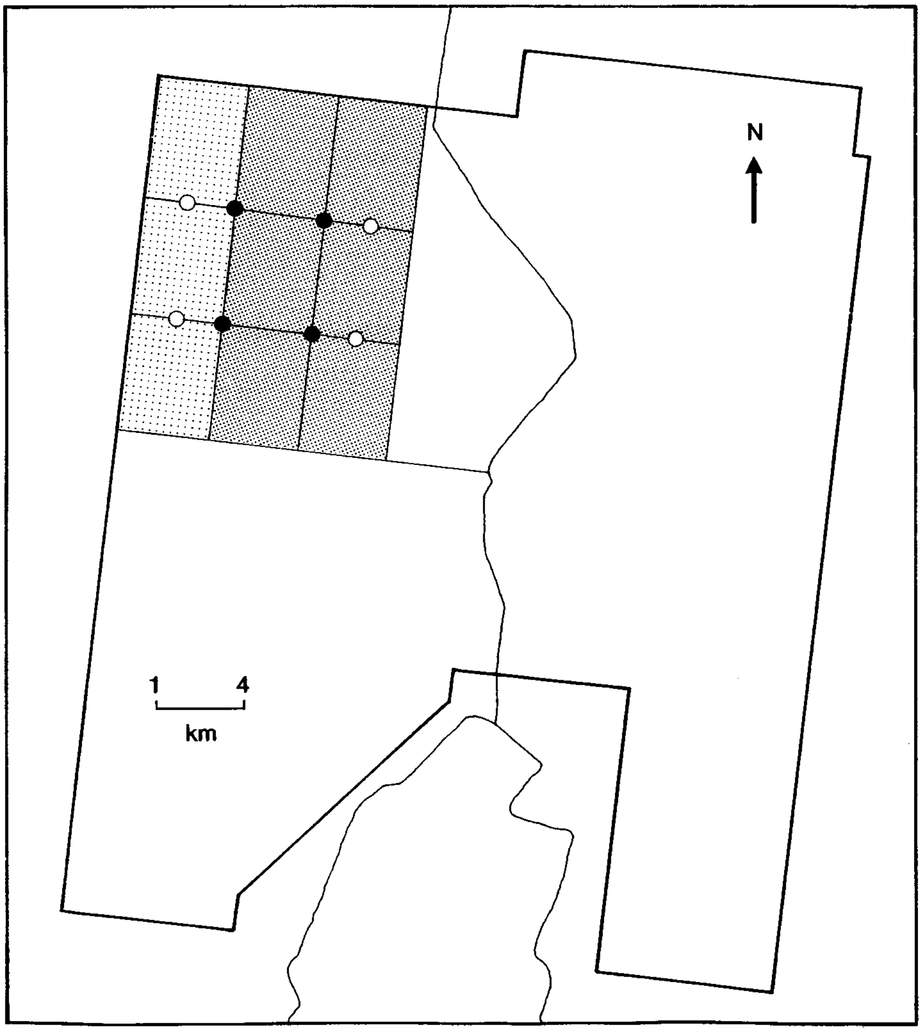

Fig. 1. Location of study site within Yathong Nature Reserve. Heavy line, boundary of Yathong Nature Reserve; light lines, roads and trails; light stippling, area baited during the first baiting regime; heavy stippling, additional area baited during the second baiting regime; ○, sites of first release of malleefowl; ●, sites of second release.

In the following year, the survival of another cohort of young malleefowl was measured during a regime of more widespread but less-intensive fox baiting. This time, baiting was conducted throughout the study site (19200 ha; Fig. 1). The human and financial costs associated with the control activities were similar for both regimes. Malleefowl survival was again compared with similar data obtained before fox control. Results from the two different baiting regimes were then evaluated to assess their relative efficacy in reducing the impact of foxes on malleefowl survival.

Fox Control

Foxes were baited with domestic fowl heads laced with 3 mg of sodium monofluoroacetate (Compound 1080). The poison was injected into the brain cavity through the eye. Baiting was undertaken at fortnightly intervals. A scent trail, intended to lure foxes to the baits, was laid by dragging a dead, disembowelled goat behind each 4-wheel-drive motor bike from which baits were laid. In total, 1125 bait stations were established at 100-m intervals along all perimeter roads and internal trails within the study site (Fig. 1). Each station was marked with a numbered cattle tag attached to a 1200-mm steel stake. Baits were buried 10 cm below ground next to selected bait stations.

The first baiting regime took place between July and December 1990. Baits were laid fortnightly at each of the 483 bait stations within the western sector, providing a coverage of 7·5 baits km^{-2}, or one bait per 13 ha. The second baiting regime started in April 1991 and continued for the duration of the study. Baits were laid at each alternate bait station (every 200 m) along each of either the four north–south or the four east–west trails (323 and 240 bait stations respectively). The trails to be baited were alternated fortnightly, such that each track was baited monthly. On average, baits were laid at a density of 1·5 km^{-2}, or one bait per 68 ha, per fortnight. No baits were laid during September 1991 because of the absence of appropriately qualified personnel.

Before each bait was deployed, the bait station was inspected to determine whether the bait laid previously had been taken. If present, the remains of the old bait were exhumed and removed. A fresh bait was then laid at the same bait station.

Egg Collection and Incubation

In the summers of 1989–90 and 1990–91, malleefowl eggs were collected from nests near Yalgogrin (33°49′S, 146°46′E), from Loughnan Nature Reserve (33°34′S, 145°48′E) and from Mallee Cliffs National Park (34°15′S, 142°40′E). These eggs were then transported to Western Plains Zoo, Dubbo, or Monarto Fauna Complex, Murray Bridge, where they were incubated artificially and where the resultant hatchlings were reared in captivity. Methods of egg collection, incubation and husbandry of chicks are described by Priddel and Wheeler (1994, 1996).

Release of Malleefowl

The first release of captive-reared malleefowl took place concurrently with the commencement of baiting. On the evening of 30 July 1990, 24 young malleefowl (6–9 months old), previously held captive at Western Plains Zoo, were placed in ventilated cardboard boxes. These birds were then transported overnight to Yathong Nature Reserve where they were liberated shortly after dawn the following morning. Six chicks were released at each of four release sites, two of which were within the baited area and two within the non-baited area (Fig. 1). Of the 24 chicks released, 17 originated from Yalgogrin, seven from Loughnan.

The second release of malleefowl took place three months after commencement of the second baiting regime. In the early hours of 1 June 1991, 24 young malleefowl (4–5 months old), previously held captive at Monarto Fauna Complex, were transported to Yathong Nature Reserve where they were liberated shortly after dawn. Six birds were released at each of four release sites (Fig. 1).

Radio-tracking of Malleefowl

A miniature radio-transmitter, incorporating a mortality sensor, was attached to each malleefowl several weeks before it was released from captivity. By periodically radio-tracking each transmitter after release, the fate of each individual could be ascertained. Radio-telemetry equipment and techniques are as those described by Priddel and Wheeler (1996).

Each malleefowl was located by aerial radio-tracking at least monthly after release. Once a radio-signal from a transmitter was received, the pulse rate of the signal was measured to determine whether the malleefowl carrying the transmitter was still alive. If a transmitter could not be detected readily, it was most likely that the malleefowl was dead (Priddel and Wheeler 1996). Aerial radio-tracking spanned two consecutive days during which time the location of the transmitter was determined only once, but the pulse rate was assessed twice, once each day. Transmitters emitting a ‘dead’ signal on either day were later tracked on foot to be retrieved along with any malleefowl remains. These remains, and where they were found, were examined to determine, where possible, the cause of death. Characteristics used to ascertain the cause of death are described fully by Priddel and Wheeler (1994) and include the following: puncture wounds; skeletal damage; evidence of feather plucking; the presence of prints, faeces, regurgitated pellets, and diggings; damage to the transmitter and harness; and the fullness of the crop and gizzard.

Surviving malleefowl carrying transmitters that were due to expire within 30 days were recaptured and fitted with a new transmitter. Methods of capture follow those described by Priddel and Wheeler (1996). Radio-tracking of surviving birds continued until May 1992.

Results

Bait Removal: First Baiting Regime

Between July and December 1990, 10 baiting sessions were conducted and 4830 baits were laid, of which 1281 were taken (Fig. 2). Of the 483 baits laid in the initial session, 442 (92%) were taken. In the second session, two weeks later, 230 baits (48%) had been removed. Bait removal in subsequent sessions was much lower, reaching and maintaining a plateau of about 7–14% after three months.

The large number of baits taken by foxes during the first five months of baiting (1281) indicates that initial fox densities on Yathong Nature Reserve were high. One fresh bait contains sufficient poison to kill a fox, but footprints and tracks indicated that some foxes followed the scent trail, often consuming two or three baits, and on one occasion as many as seven baits, as they visited consecutive bait stations. The average number of baits taken by each fox is unknown as are the relative proportions of these that were eaten or cached; consequently, the number of foxes killed cannot be calculated. Notwithstanding, if we assume that an average of three baits or less were taken by each fox killed, baiting during the first five months alone removed at least 427 foxes, at a density exceeding 6 foxes km^{-2}.

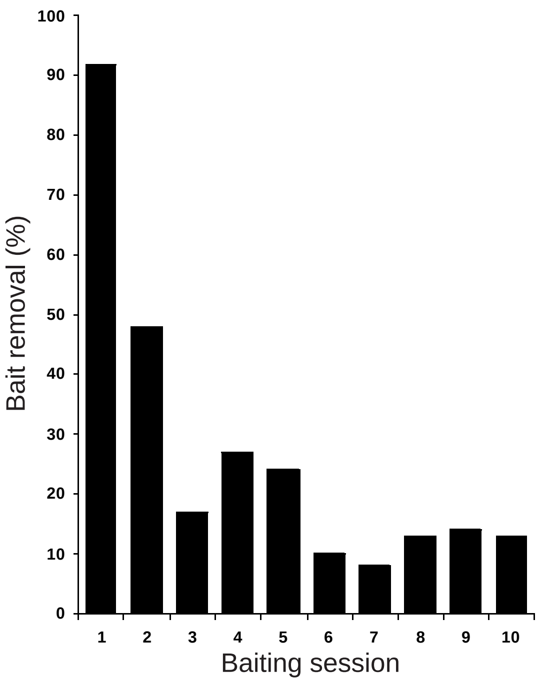

Fig. 2. Bait removal by foxes during the first baiting regime. Baits were laid fortnightly (July–December 1990) in only the western sector of the study site.

Bait Removal: Second Baiting Regime

The second baiting regime began in April 1991. The mean monthly bait removal was 35·5%. Bait removal was high (>40%) during the first five months (Fig. 3), fell to 31% in October and November, and thereafter remained relatively low (mean = 20·5%, range 14–26%). An unknown but relatively small proportion of this removal was attributable to a mob of little crows, *Corvus bennetti*, which had learnt to recognise the whereabouts of buried baits.

Despite all previous baiting being confined to the western sector, bait removal here was greater than that in the eastern sector throughout all months of baiting other than the first two (Fig. 3). During the period of heavy bait removal (May–August 1991), 62·1% of baits laid in the

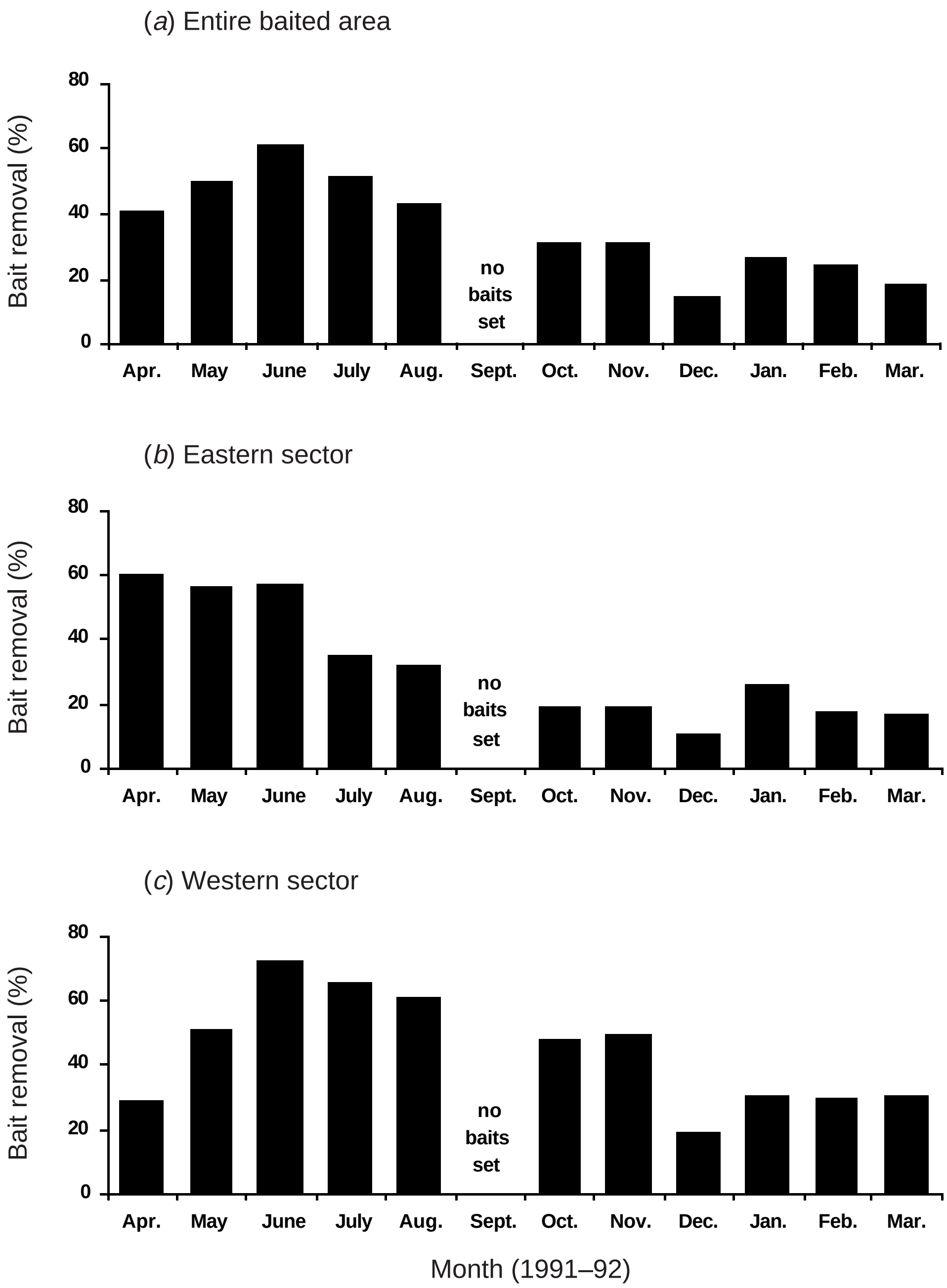

Fig. 3. Bait removal by foxes during the second baiting regime: (*a*) entire baited area; (*b*) eastern sector only; (*c*) western sector only. Baits were laid monthly throughout the study site.

western third were taken compared with 45·0% in the east. During the subsequent period (October 1991 to March 1992), the proportion of baits taken in the west was 35·3% compared with 18·3% in the east.

Malleefowl Survival: First Baiting Regime

Of the 12 malleefowl released into the baited area, three (25%) were dead and one missing, presumed dead, after 16 days (Table 1). By Day 34, two more were dead, but six (50%) survived for periods ranging from 66 to more than 581 days. The longest-surviving malleefowl was still alive when its transmitter was removed some 20 months after release. Survival time for this cohort was correlated with weight on release (Spearman's rank correlation, $r_s = 0{\cdot}745, P < 0{\cdot}02$), but was independent of age ($P > 0{\cdot}05$). All 10 individuals whose remains were recovered died as a result of predation by foxes.

Of the 12 malleefowl released into the non-baited area, seven (58%) were dead and one missing, presumed dead, after 16 days (Table 1). By the 34th day after release one more had died, the remaining three surviving for periods ranging from 64 to 251 days. A single individual (No. 694) was alive at the time of commencement of the second baiting regime seven months after release, but it died within 40 days thereafter. No significant correlation existed between survival time and age or weight on release. Of the 11 instances where remains were found, seven birds had been taken by foxes, two by raptors, one by a feral cat, *Felis catus*, and one left insufficient clues as to the predator responsible.

Table 1. Age, weight, survival and cause of death of malleefowl released concurrently with fox control under the first baiting regime

Age and weight are those at release

No.	Age (days)	Weight (g)	Survival (days)	Release site	Cause of death
			Released within the baited area		
771	176	672	0–?	NW	Missing
648	209	572	0–16	SW	Predation by fox
663	208	742	0–16	SW	Predation by fox
741	195	729	0–16	SW	Predation by fox
681	206	807	17–18	SW	Predation by fox
609	231	1112	17–34	SW	Predation by fox
742	209	786	66–104	NW	Predation by fox
611	248	1059	141–161	NW	Predation by fox
766	185	795	164–188	NW	Predation by fox
777	190	867	252–279	NW	Predation by fox
692	205	952	279–316	SW	Predation by fox
624	235	1262	> 581	NW	Survived
			Released outside the baited area		
723	227	840	0–?	NE	Missing
708	187	720	0–16	SE	Unknown predator
709	198	912	0–16	NE	Predation by fox
712	215	768	0–16	SE	Predation by fox
782	190	674	0–16	NE	Predation by fox
787	171	757	0–16	NE	Predation by fox
790	189	954	0–16	SE	Predation by fox
791	174	607	0–16	NE	Predation by fox
786	178	780	17–34	SE	Predation by fox
785	184	977	64–104	NE	Predation by raptor[A]
738	187	835	105–140	SE	Predation by cat
694	215	712	217–251	SE	Predation by raptor

[A]Remains found beneath the eyrie of a wedge-tailed eagle.

The proportion of individuals known to be alive on any given day after release was consistently greater for those released into the baited area (Table 2). This difference was due almost entirely to the events that took place during the first month after release. It was during this initial month when mortality in both cohorts was greatest. After the first 34 days, survival within the baited area was twice that outside the area (50% and 25% respectively). This ratio continued until Day 66; thereafter, the disparity increased. Mortality within the non-baited area continued until only one individual remained alive on Day 140. Mortality over the same period was significantly less within the baited area, where five individuals survived beyond 140 days.

Some malleefowl moved between the baited and non-baited areas. Of the 21 malleefowl found dead, 14 (67%) were found outside the baited area. Of the 12 malleefowl released into the baited area, three died outside this area. During the aerial-tracking phase of the study, malleefowl were radio-tracked and found alive on 51 occasions; 34 locations were within the baited area and 17 were outside.

Table 2. Proportion known to be alive of the malleefowl cohort released concurrently with fox control under the first baiting regime

No. of days after release	Proportion of individuals released outside the baited area	Proportion of individuals released within the baited area
17	0·33	0·67
34	0·25	0·50
66	0·25	0·50
104	0·17	0·42
141	0·08	0·42
164	0·08	0·33
188	0·08	0·25
217	0·08	0·25
252	0·00	0·25
279	0·00	0·17
316	0·00	0·08
581	0·00	0·08

Malleefowl Survival: Second Baiting Regime

Of the 24 malleefowl released into the study site after the commencement of the second baiting regime, 11 (46%) were dead after 11 days, and 14 (58%) were dead after 38 days (Table 3). The remaining 10 individuals survived for periods ranging from 39 to more than 338 days. The longest-surviving malleefowl was still alive when the transmitter was removed 338 days after release. No significant correlation was found between survival time and age or weight on release. Of the 11 individuals that died in the first 11 days, six (55%) were killed by raptors, two (18%) by feral cats, two (18%) by foxes and one (9%) by an unknown predator.

The cause of death of the 12 individuals that died during the subsequent months was more difficult to ascertain as most of the remains were extensively decomposed. One bird had clearly been killed by a raptor, eight appeared to have been killed or scavenged by foxes, and the remaining three had been consumed so completely that there were no clues as to the predator responsible.

Analysis of survival time grouped according to each of the four release sites indicated that survival was dependent on release location (Kruskal–Wallis single-factor ANOVA by ranks, $H_c = 13{\cdot}96$, $P < 0{\cdot}005$). Malleefowl released at the two southern sites survived considerably longer (nonparametric multiple comparison based on Newman–Keuls test; Zar 1974) than those released at the two northern sites (medians: 140 days and 5 days respectively). Most of the early mortality in the north was due not to foxes, but to raptors and cats (Table 3).

Table 3. Age, weight, survival and cause of death of malleefowl released concurrently with fox control under the second baiting regime

Age and weight are those at release

No.	Age (days)	Weight (g)	Survival (days)	Release site	Cause of death
1038	123	482	1–2	NE	Predation by raptor
1048	131	653	2–3	NW	Predation by cat
1046	124	598	3–4	NW	Predation by raptor
1050	126	677	3–8	NW	Predation by fox
1023	122	684	4–5	NW	Predation by cat
995	121	598	5–6	NE	Unknown predator
1018	118	537	5–6	NE	Predation by raptor
1051	133	706	7–8	NW	Predation by raptor
1052	128	736	7–8	SW	Predation by raptor
1020	120	596	9–11	NW	Predation by raptor
1039	125	623	9–11	NE	Predation by fox
975	111	724	12–38	SW	Predation by fox
1044	129	635	12–38	NE	Predation by fox
1054	134	876	12–38	SE	Predation by fox
1016	120	635	39–65	SW	Predation by fox
1049	130	696	39–65	SE	Predation by fox
984	120	593	39–93	NE	Unknown predator
1042	127	579	66–93	SE	Predation by fox
977	119	640	94–122	SW	Unknown predator
1043	136	854	186–221	SE	Unknown predator
1047	135	953	186–221	SE	Predation by fox
1003	116	600	220–247	SW	Predation by raptor
994	119	755	313–338	SE	Predation by fox
1053	132	598	>338	SW	Survived

No difference in survival was found between those malleefowl released at the two eastern release sites and those released at the two western sites (Mann–Whitney test for data with tied ranks, $U_{2,12,12} = 87{\cdot}0$, $P > 0{\cdot}05$). These areas received the same baiting effort under the second regime, and there is no evidence to suggest that either area was more conducive to malleefowl survival. This finding validates the use, during the first baiting regime, of the eastern sector as a control for the treatment (baiting) conducted in the western sector.

Comparison between Baiting Regimes

The comparative survival of the three cohorts of captive-reared malleefowl released into Yathong Nature Reserve, each under a different baiting regime, is shown in Table 4. The proportions of individuals known to be alive one month and three months after release were substantially greater for both cohorts released concurrently with fox control. Overall, no difference in survival was discernible between the two cohorts each released during the two different baiting regimes. Under the first baiting regime, 29% of individuals survived for at least three months, and 25% survived for that long under the second. Within each baiting regime, however, there were two levels of survival. Survival was low for birds released in the non-baited area of the first regime because of the high incidence of fox predation. Survival was also low in the north during the second regime owing largely to the high incidence of predation by both foxes and raptors. Survival was highest for those birds released within the baited area under the first baiting regime and for those released at the southern release sites under the second regime (42% and 50% after three months respectively).

Table 4. Survival of captive-reared malleefowl released into Yathong Nature Reserve under two regimes of fox baiting and prior to any baiting

Data are numbers of individuals known to be alive; *n*, size of cohort

Treatment	*n*	Time after release	
		1 month	3 months
No baiting[A]	24	1 (4%)	0
First baiting regime	24	9 (38%)	7 (29%)
Area not baited	12	3 (25%)	2 (17%)
Baited area	12	6 (50%)	5 (42%)
Second baiting regime	24	10 (42%)	6 (25%)
Northern release sites	12	1 (8%)	0
Southern release sites	12	9 (75%)	6 (50%)

[A] Data from Priddel and Wheeler (1996).

Discussion

Fox Numbers

The magnitude of the initial bait removal indicated a dense resident fox population. Bait removal in both baiting regimes declined from the initial high levels and stabilised after several months, but the continual removal of many baits suggests either a significant residual population or a substantial level of reinfestation or both.

Despite the earlier programme of baiting in the western part of the study site, bait removal in the west was usually greater than that in the east. The reason for the apparent higher density of foxes in the west is unclear, but is consistent with earlier observations. The area designated for baiting during the first baiting regime was selected on the basis that it probably contained the greater fox density. Any improvement in malleefowl survival in this area could then be attributed directly to the baiting programme rather than to naturally occurring differences in fox densities.

Some baits were exhumed by foxes but not eaten. In a few instances, baits were dug up and then urinated, or defecated, upon by foxes. Such behaviour was focused on a few specific bait stations, suggesting that some foxes resident within the control area were bait-wary, perhaps after having received a sublethal dose of poison. Baiting with cyanide capsules at the conclusion of the study, according to the procedure described by Saunders *et al.* (1995), confirmed the continued presence of mature foxes within the study site. Instances of foxes ingesting a bait of sufficient potency to induce sickness but not cause death can occur when the fox consumes a bait in which the 1080 has denatured substantially, or when it manages to eject the bait by vomiting. Microbial breakdown of 1080 occurs as a result of bacteria that occur naturally in bait media (Wong *et al.* 1991) and in most soils (Wong *et al.* 1992).

Impact of Fox Control on Malleefowl Survival

Captive-reared malleefowl released into fox-baited areas survived longer than birds released into areas not subjected to baiting. If malleefowl remained within the baited area, they had a higher probability of survival; if they ventured outside the baited area, the risk of predation by foxes increased.

During the first baiting regime, malleefowl in the nearby non-baited area survived better than those released prior to baiting (Table 4). Presumably, the baiting programme improved the prospects for malleefowl surviving in nearby areas by lowering fox populations locally. Extending the area baited to encompass the entire 19200-ha study site did not further enhance the survival of malleefowl. Conditions were more arid during the second baiting regime and, although there is no evidence, it is possible that differences in aridity affected the comparative efficiency of the two baiting regimes.

Survival of those birds released into the baited area under the first baiting regime was positively correlated with weight at release. This is the only instance of such a correlation, and no causal relationship has been established. For all other releases involving cohorts of similar-aged birds (this study; Priddel and Wheeler 1994, 1996), survival was independent of age and weight at release. Minor differences in age and weight on release, and the environmental conditions prevailing at the time of each release, cannot be ruled out as potential factors contributing to the differential survival of each cohort. Nonetheless, it appears reasonable to deduce that the better survival of malleefowl in the baited areas was due predominantly, if not entirely, to the lower density of foxes in these areas as a result of the baiting programme.

Fox control clearly slowed the rate of predation by foxes, and therefore went some way toward restoring the natural balance to that which might have existed before the arrival of the fox. Despite fox control, predation by foxes continued to be the major cause of malleefowl mortality. The high fecundity of the malleefowl (Frith 1959; Booth 1987; Brickhill 1987) suggests that the species may be able to tolerate a moderate level of predation, but it has yet to be established that fox control of any intensity is capable of reducing predation to a level sufficient to facilitate the recovery of the species.

Interaction between Habitat and Predation

During the second baiting regime, malleefowl released at the two southern sites survived much longer than those released in the north (medians: 140 days and 5 days respectively). Mallee surrounding the southern release sites was largely unbroken and contained expansive areas of dense understorey. The habitat surrounding the two northern release sites was more open than that in the south, and contained large expanses of mallee with little or no understorey. Mallee in the northern part of the study site was also discontinuous, being interspersed with open woodland of belah.

Although malleefowl have been recorded in a variety of habitats, Frith (1962) found that those habitats containing the highest densities were all characterised by a well-developed canopy and a dense shrub layer. A dense and diverse shrub layer can provide malleefowl not only with a continual source of food (Harlen and Priddel 1996), but also with protection from predators. Presumably, predators hunt less effectively in dense unbroken habitats, which offer greater concealment for prey species. After comparing the densities of malleefowl in areas of differing fire history, Benshemesh (1992) highlighted the importance of a dense and continuous canopy. The greatest densities of malleefowl occurred in mallee that had not burnt for at least 40 years, and these habitats were generally characterised by a greater preponderance of overhead cover. Optimal habitat for malleefowl, therefore, would appear to be characterised by an unbroken canopy and a dense understorey.

Predation by Raptors

At least nine young malleefowl, 19% of all birds released, fell prey to raptors. Raptor predation was most prevalent during the second release, particularly within the first 11 days after release, when no fewer than six birds were killed by raptors. This high incidence of raptor predation, relative to the first baiting regime, appears to be due to the vegetation structure in the vicinity of the release sites rather than to any factor related directly to the baiting regime or foxes *per se*. All but one of the kills made by raptors occurred in areas where the mallee was broken and the understorey sparse. As discussed, vegetation structure appears to be an important determinant of habitat quality for malleefowl.

Predation by Feral Cats

At least three young malleefowl fell prey to feral cats. Two birds, released during the second baiting regime, were killed by cats within five days of their liberation. This unusually high incidence of cat predation appeared to be due to the close proximity of a rabbit warren frequented by cats. Rabbit warrens, relatively uncommon in the mallee, occur mostly in the small dispersed patches of open woodland.

The extent of cat predation on malleefowl was substantially less severe than that of predation by foxes. Evidence, however, suggests that in some circumstances cat numbers may increase greatly once fox numbers have been reduced by baiting (Christensen and Burrows 1995). If this phenomenon is widespread, the potential exists for cats to become more-significant predators of malleefowl in many areas subjected to intensive fox control. If cats do replace foxes as a significant predator of malleefowl, then appropriate control programmes may need to be implemented.

Implications for the Conservation of Malleefowl

Fox control in areas of Western Australia has proven successful in reducing the predation pressure on several species of native mammals, which has, in turn, stimulated the recovery of these depressed populations (Kinnear *et al.* 1984, 1988; Friend 1990). Recovery of depressed malleefowl populations, however, may be relatively more difficult to attain. Control of foxes within Dryandra Forest has led to a marked recovery in the numbat, *Myremecobius fasciatus* (Friend and Thomas 1995), but as yet, there are no indications of any increase in malleefowl numbers (J. A. Friend, personal communication).

This study has demonstrated that fox control can increase the survival of young malleefowl and has shown, therefore, that it would be prudent to include fox control as an essential component of any malleefowl recovery programme. Certainly, releasing captive-bred malleefowl into areas where fox control is not undertaken is likely to be a futile exercise. However, it is still not known what intensity of fox control is needed to ensure the maintenance of populations of malleefowl or to allow the recovery of depressed populations. The two baiting regimes undertaken in this study involved more frequent and more intensive baiting than that commonly employed by agriculturalists. Although both baiting regimes enhanced the survival of malleefowl, neither managed to eliminate fox predation as a major cause of malleefowl mortality. Many of those individuals that survived for relatively long periods were eventually killed by foxes before attaining breeding age. The value of infrequent, low-intensity baiting as a means of conserving extant populations of malleefowl is, therefore, highly questionable. The requirements for fox control, however, are likely to vary between habitats or localities. It is plausible that in dense mallee, for example, malleefowl may respond to more-modest levels of fox control.

Baiting at fortnightly intervals on Yathong Nature Reserve exposed foxes continuously to viable baits. Increasing the frequency of baiting to more often than fortnightly is, therefore, unlikely to enhance the effectiveness of the baiting programme. Additional resources would be better directed at expanding the area baited to create a broad buffer zone of low fox density surrounding the core conservation area. The problem of rapid reinfestation would then be reduced. In Yathong Nature Reserve, this would entail initiating fox control on neighbouring pastoral properties.

In all releases of captive-reared malleefowl, the highest rate of mortality occurred in the first few weeks following liberation. A major goal of any recovery programme involving the release of captive-bred malleefowl should be to ensure that fox numbers are reduced to minimum levels immediately prior to the chicks being released. In any attempt to conserve or bolster extant populations it would be equally prudent to ensure that fox numbers were low during the period when chicks were likely to emerge from nests.

Aside from optimising the frequency, intensity and extent of baiting, conservation managers need also to look at ways of improving the efficacy of the baiting programme. For example, those foxes that have an apparent aversion towards poison baits are a major impediment to the success of any fox-control programme; these individuals should be targeted specifically. The use of a variety of bait media during the baiting programme may minimise the incidence of bait aversion. The recent advent of specially prepared commercial baits such as Fox-off® may reduce the incidence of foxes surviving after vomiting partially digested baits. These commercial baits are made from a highly soluble base that readily breaks down in the stomach and is difficult to expel. Fox-off® baits have proven to be more attractive to foxes than fowl heads (Applied Biotechnologies 1994). The use of these baits, therefore, may also improve the efficiency of the baiting programme by increasing the uptake of baits.

A more holistic approach to fox control is also warranted. Foxes, and some species of raptor, are sustained at high densities by the abundance of their staple prey—the introduced rabbit, *Oryctolagus cuniculus* (Coman 1973; Croft and Hone 1978). The control of rabbits, therefore, is an essential adjunct to effective fox control. Rabbit control has proven to be an effective means of reducing the abundance of other predators of rabbits such as cats and ferrets (Norbury and McGlinchy 1996).

No matter what regime of fox control is employed, fox control alone will not ensure the conservation of the malleefowl. Additional action must also be taken to mitigate the other threatening processes, namely loss and fragmentation of habitat, habitat degradation by exotic herbivores, and inappropriate fire regimes.

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