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Does the integrity or structure of mallee habitat influence the degree of Fox predation on Malleefowl (*Leipoa ocellata*)?

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Abstract. Malleefowl (*Leipoa ocellata*) are in decline across their range. Previous studies have found that the survival rate of young Malleefowl is low, the single greatest cause of mortality being predation by the introduced Red Fox (*Vulpes vulpes*). Many of these studies, particularly those in New South Wales (NSW), were conducted in habitats that were heavily modified by fire, exotic herbivores or plant harvesting. In this paper, we examine the survival of Malleefowl in relatively undisturbed mallee habitats within two conservation reserves in South Australia (SA). Both reserves were long unburnt and free of large exotic herbivores, but differed greatly in understorey structure. Fifteen young captive-reared Malleefowl were released into each reserve. In all, 70% of these individuals were dead within 40 days. Fox predation was the prime cause of mortality, accounting for at least 30%, and perhaps as much as 96%, of all deaths. The extent and causes of mortality were similar in the two reserves. The overall level of Malleefowl survival was (1) better than that recorded in more disturbed habitat in NSW in the absence of any Fox control, but (2) substantially less than that in NSW after widespread Fox control was implemented. This study indicates that Malleefowl in SA are subject to significant levels of Fox predation, even in relatively undisturbed habitats. Also, for the two mallee habitats examined, evidence suggests that understorey structure had no influence on the degree of predation. Available data indicate that during the past two decades Malleefowl populations in SA have declined at about the same rate as those in NSW. Current densities in SA are typically about one-quarter of what they were 15 years ago. We conclude that habitat integrity and structure have little effect on the interaction between Foxes and Malleefowl, and suggest that Malleefowl populations across Australia are threatened by Foxes, placing the species at substantial risk of extinction.

Introduction

Malleefowl (*Leipoa ocellata*), once numerous and widespread across much of the southern half of mainland Australia, have undergone a substantial decline in abundance since European settlement of Australia (Brickhill 1987*b*; Benshemesh 2000). Before 1981, Malleefowl were recorded in a total of 166 1° grid-cells, but in the period 1981–99 they were reported in only 81 cells (Benshemesh 2000). Clearing of native vegetation, principally for cropping and pastoralism, has been the major cause of habitat loss and fragmentation (Frith 1962). In many of the patches of remaining habitat, populations have continued to decline, and several local extinctions have been documented (Benshemesh 2000; Priddel and Wheeler 2003).

Other factors believed responsible for Malleefowl decline, and identified in the *National Recovery Plan for Malleefowl* (Benshemesh 2000) include: (1) habitat degradation by introduced herbivores, including Sheep (*Ovis aries*), Goats (*Capra hircus*) and European Rabbits (*Oryctolagus cuniculus*) (Frith 1962); (2) altered fire regimes (Benshemesh 1992); and (3) predation by the introduced Red Fox (*Vulpes vulpes*) (Priddel and Wheeler 1994, 1996, 1997). Predation by the feral House Cat (*Felis catus*) may also have been a contributing factor (Priddel and Wheeler 2004).

In recent studies conducted in NSW, Priddel and Wheeler (1999) have found Fox predation to be the single greatest current cause of Malleefowl mortality. Foxes prey on Malleefowl of all ages: eggs (Frith 1959; Brickhill 1987*a*), chicks (Benshemesh 1992; Priddel and Wheeler 1994, 1996), juveniles (Priddel and Wheeler 1996), sub-adults (Priddel and Wheeler 1996), and adults (Booth 1985; Benshemesh 1992; Priddel and Wheeler 2003). Not only do Foxes prey on Malleefowl that inhabit small mallee remnants, they also affect those populations within at least some of the broader expanses of native vegetation that remain (Priddel and Wheeler 1994, 1996, 1997). On this evidence, Priddel and Wheeler (1999) have argued that Foxes are not only a major threat to Malleefowl survival but also a key cause of the species' decline across its range.

Earlier, Frith (1962) concluded that grazing by stock, rather than predation by Foxes, was the prime cause of Malleefowl decline in otherwise undisturbed habitats. Although the availability of plant-borne food (fruits and seeds) is largely determined by rainfall (Bradstock 1989), introduced herbivores such as Rabbits and feral Goats can change the structure and floristic diversity of the habitat (Friedel and James 1995) thereby reducing the amount of food available to Malleefowl. Lower food availability can translate into a lower carrying capacity.

Intuitively, many of the threatening processes affecting Malleefowl probably operate in concert. If, for example, grazing does lessen food availability it is also likely to increase the time that Malleefowl spend foraging, thus lengthening the period of their exposure to predators (Priddel and Wheeler 1990).

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Benshemesh (1992) suggested that the persistence of Malleefowl in areas where Foxes are common may be dependent on habitat quality, with Malleefowl secure in undisturbed habitats but unable to maintain population levels in habitats that have been extensively modified by fire or heavy grazing.

Short (2004) identified many parallels between the ongoing decline of the Malleefowl and the past demise of Australia's mammal fauna. For some mammals, habitat quality can temper the severity of Fox predation. For example, Foxes are believed to have been responsible for the extinction of three species of rat kangaroo –the Brush-tailed Bettong (*Bettongia penicillata*), the Burrowing Bettong (*B. lesueur*) and Eastern Bettong (*B. gaimardi*) – on the western slopes and plains of NSW, where habitats are relatively open (Short 1998). In contrast, another species of rat kangaroo, the Long-nosed Potoroo (*Potorous tridactylus*), persists in coastal regions of NSW, where Foxes are also present. Short (1998) attributed the persistence of this species to the protection afforded by the denser understorey in mesic habitats.

To date, much of the research on Malleefowl survival in NSW has been conducted in habitats that have been degraded by frequent fire and large numbers of feral Goats (e.g. Priddel and Wheeler 1996) or by grazing of stock, harvesting of Broombush (*Melaleuca uncinata*) and extraction of eucalyptus oil (e.g. Priddel and Wheeler 1994). We question whether in less degraded habitats survival would be as low, the impact of Foxes as great, or population decline as rapid. In this paper we explore the relationship between Malleefowl survival and habitat integrity and structure. First, we assess the survival of captive-reared Malleefowl released into two long-unburnt, relatively undisturbed habitats in South Australia (SA) and compare this with published information on Malleefowl survival within highly disturbed habitats in NSW. Second, we compare the recent population trends of Malleefowl in SA and NSW. Third, we compare the survival of Malleefowl released into two undisturbed habitats, which differed markedly in understorey structure.

Methods

Study areas

Fieldwork was conducted in two conservation reserves in south-eastern SA: Bakara Conservation Park (34°30′S, 139°56′E) and Ferries-McDonald Conservation Park (35°13′S, 139°08′E). At the time of this study, these reserves, separated by ~108 km, were both long unburnt and free of large exotic herbivores, but differed greatly in understorey structure. The understorey in Bakara was sparse and dominated by hummock grass whereas the understorey in Ferries-McDonald was more dense and dominated by shrubs (see vegetation association maps in Kinnear *et al*. 2000). At the time, neither reserve had a Fox-control program in place, and as far as we could ascertain there had been little or no Fox control undertaken on the surrounding properties.

Bakara Conservation Park is situated ~30 km east of Swan Reach. It encompasses an area of 1031 ha and was proclaimed in 1985 (Department of Environment and Heritage 2004). Adjoining the park to the south-east is a 608-ha area of remnant vegetation covered by a heritage agreement or conservation covenant. Another patch of contiguous native vegetation, of ~700 ha, adjoins the park to the north. The dominant land use of the region is wheat cropping and Sheep grazing. Mean annual rainfall for the area is ~250 mm (Brandle 1991). There have been no known fires in the area now covered by the park since early in the 20th century (Henry Short, pers. comm., cited in Brandle 1991).

Soils, landforms and vegetation on Bakara have been described more fully elsewhere (see Potter *et al*. 1973; Laut *et al*. 1977; Brandle 1991). The vegetation on the sandhills is characterised by an overstorey of mallee eucalypts, including Ridge-fruited Mallee (*Eucalyptus incrassata*), Summer Red Mallee (*E. socialis*), Red Mallee (*E. oleosa*), Congoo Mallee (*E. dumosa*) and Narrow-leaved Red Mallee (*E. leptophylla*). The understorey is dominated by spinifex (*Triodia irritans*), and, with <30% foliage cover (see Results), is classified as sparse (Specht 1972). The vegetation on the flats or swales has an overstorey of Red Mallee, Yorrell (*E. gracilis*) and Narrow-leaved Red Mallee, and a pre-dominantly open understorey of *Geijera linearifolia,* Tar Bush (*Eremophila glabra*) and Comb Spider-Flower (*Grevillea huegelii*). Also on the swales is the occasional isolated stand of Dryland Tea-tree (*Melaleuca lanceolata*).

Ferries-McDonald Conservation Park (843 ha) is located ~60 km south-east of Adelaide. It was proclaimed in 1956 but added to substantially in 1972 (Department of Environment and Heritage 2004). As far as is known, the last bushfire in the area now covered by the park occurred sometime during the 1950s (Department of Environment and Natural Resources 1996). Mean annual rainfall is ~375 mm (Commonwealth of Australia 2006).

The vegetation is characterised in most places by a canopy of mallee eucalypts with an understorey of tall shrubs. The understorey, with a foliage cover of 30–70% (see Results), is classified as mid-dense (Specht 1972). Overstorey species on the dunes include Ridge-fruited Mallee, Narrow-leaved Red Mallee and Summer Red Mallee. Understorey species include Broombush, Green Tea-tree (*Leptospermum coriaceum*), Desert Hakea (*Hakea muelleriana*), Blue Boronia (*Boronia coerulescens*), mat-rush (*Lomandra juncea*) and sword-sedge (*Lepidosperma concavum*) (Neagle 1995). The dominant overstorey plant on the swales is Narrow-leaved Red Mallee with an understorey of Green Tea-tree, Desert Hakea, Muntries (*Kunzea pomifera*) and sword-sedge. Other areas are dominated by Broombush, Silver Broom (*Baeckea behrii*) and cypress-pine (*Callitris canescens*) with an understorey of saw-sedge (*Gahnia deusta* and *G. lanigera)*, Clustered Sword-sedge (*Lepidosperma congestum*), Common Fringe-myrtle (*Calytrix tetragona*) and Horned Hop-bush (*Dodonaea hexandra*).

Malleefowl data from Bakara and Ferries-McDonald were compared with data from a series of similar studies undertaken at Yalgogrin and Yathong Nature Reserve in NSW. Whereas both study sites in SA were relatively undisturbed (i.e. long-unburnt, free of stock and Goats, with only low numbers of Rabbits), the sites in NSW had been subject to substantial ongoing disturbance. Yalgogrin (33°49′S, 146°46′E) is a 558-ha remnant of mallee vegetation on freehold land within the NSW wheatbelt. It is surrounded by agricultural crop and pasture lands, and is regularly grazed by Sheep. Since the 1940s, patches of eucalyptus (*Eucalyptus viridis*, *E. polybractea*, and *E. behriana*) have been harvested regularly to provide young leaves for the distillation of eucalyptus oil. Broombush has also been harvested for use in the construction of brush fences. These ongoing practices have created a structural mosaic of regenerating vegetation of various heights and densities interspersed with areas of mature mallee woodland. Yalgogrin once contained in excess of 3.5 breeding pairs km^{-2} (Brickhill 1987*b*), the highest density of Malleefowl known within NSW in contemporary times, but the population is in decline and is predicted to become extinct within the current decade (Priddel and Wheeler 2003). Yathong Nature Reserve (107241 ha; 32°40′S, 145°30′E) has a long history of frequent fires and heavy infestations of Rabbits and feral Goats. Most mallee habitats within the reserve were burnt by wildfire in 1957, 1974–75 and 1984; some areas were burnt again in 1994. When mallee trees are burnt the above-ground stems are killed and the plant resprouts from an underground lignotuber. Consequently, an outcome of these frequent fires has been the creation of a patchwork of habitats with greatly different vegetation structure.

Collection and incubation of eggs

Eggs were collected from active Malleefowl mounds in Bakara and Ferries-McDonald during November and December 1989, using methods similar to those described by Priddel and Wheeler (1994). Collected eggs were buried in sand-filled insulated boxes, and transported by vehicle to Monarto Zoological Park (35°06′S, 139°09′E), ~97 km from Bakara and 14 km from Ferries-McDonald. At Monarto, the eggs were incubated artificially and the resultant chicks reared in covered outdoor pens of ~12 m^2. Individuals from each reserve were housed separately.

Release of Malleefowl chicks

Malleefowl chicks (aged between 97 and 190 days) were transported back to the reserve from which they came and released. Fifteen chicks were liberated at Ferries-McDonald on the morning of 1 June 1990, and 15 at Bakara the next day. The chicks were released in twos at 200-m intervals along internal roads. Release locations were at least 200 m from the boundary of the reserve.

Radio-tracking of Malleefowl

Each Malleefowl was fitted with a radio-transmitter (AVM, type SB2) of unique frequency (150.84–151.95 MHz) 11–13 days before release. The duration between fitting and release enabled the birds to adjust to the presence of the transmitter while in captivity. Each transmitter incorporated a mortality sensor and was mounted on the bird by cotton straps passing under each wing. The average weight of the transmitters was 25 g, 2.8–4.8% of the weight of the chick at the time of release. Transmitter life was ~4 months. Efforts were made to recapture all surviving individuals to replace or remove the transmitter before the batteries expired.

Malleefowl were tracked daily on foot for the first 11 days after release, and then intermittently over the life of the transmitters. Attempts were made to sight the bird on each occasion it was tracked, but this was not always possible, especially at Ferries-McDonald where the denser understorey often obscured the birds from view. Transmitters emitting a ‘dead’ signal (a pulse rate of ~120 min^{-1} compared to the normal pulse rate of ~60 min^{-1}) were tracked and located. The transmitter, any Malleefowl remains and the surrounding area were inspected for indications as to the cause of death. Criteria used to determine the cause of death follow those described by Priddel and Wheeler (1994).

Malleefowl population trends

Gillam (2006) reported the results of surveys of Malleefowl mounds conducted within several SA sites (including Bakara and Ferries-McDonald) between 1989–90 and 2005–06. Malleefowl population trends within Bakara and Ferries-McDonald were examined by linear regression analyses of the density of active mounds. Similar analyses were conducted for all other surveyed sites in SA for which data spanning at least 10 years were available and counts of active mounds exceeded five in any one year (Cooltong and Pooginook Conservation Parks, and Cowell and Shorts Heritage Agreements). The overall population trend in SA was then compared with the trend at Yalgogrin, NSW (Priddel and Wheeler 2003), the only site in NSW for which long-term data are available.

Assessment of habitat structure

A rapid, non-destructive technique was used to collect data for a quantitative comparison of habitat structure at Bakara and Ferries-McDonald. Vegetation was sampled within quadrats (4 m^2) randomly located near where Malleefowl had been recorded during the study. Canopy cover, as a proportion of total area, was estimated using reference diagrams of foliage cover published by Walker and Hopkins (1984). Understorey cover was estimated similarly, except looking downward from above rather than upward from below. For this purpose, understorey was limited to any vegetation over 10 cm tall; anything lower than that was regarded as offering negligible cover for Malleefowl. Using the same technique, vegetative cover was estimated for two height-classes: 10–50 cm and 50–200 cm. Vegetation within the quadrat was then viewed in profile and an estimate made of the proportional vertical coverage of the vegetation within each height-class. The product of horizontal cover and vertical cover for each height-class provided an index of the density of vegetation within each three-dimensional space. Vegetation parameters were compared between reserves using single factor analysis of variance (ANOVA) on data transformed to arcsine.

Results

Malleefowl survival

Three (20%) of the 15 birds released into Bakara were killed by Foxes within 11 days. Another four individuals were killed (or scavenged) by predators 11–40 days after release (Table 1). Four birds went missing between Days 11 and 27, and the precise fate of these individuals is not known. It is unlikely that these birds moved out of range of the receiving equipment because: (1) the area of contiguous native vegetation is small, and (2) the species is reluctant to traverse open country. Similar studies conducted by the authors in a much larger study area (Priddel and Wheeler 1996, 1997) used aircraft to locate transmitters that could not be located from the ground. In no instance was a ‘missing’ transmitter located on a live animal. Thus, the Malleefowl that could not be located at Bakara were presumed dead. Four individuals (27%) survived longer than 100 days. One died on Day 101 (owing to capture trauma), the others were still alive when the batteries in their transmitters expired (up to 244 days; Table 1).

Four (27%) of the 15 birds released into Ferries-McDonald died within 11 days; all were killed by Foxes (Table 1). Another six birds were killed (or scavenged) by predators (one Fox, one Fox or Cat, and four unknowns) 11–31 days after release. Five individuals (33%) survived for longer than 100 days. One was killed by a predator 104–181 days after release. The other four were still alive when the batteries in their transmitters expired (up to 244 days after release; Table 1).

Fox predation was the prime cause of Malleefowl mortality, accounting for at least 30%, and possibly as much as 96%, of all deaths (Table 1). The cause of death could be determined reliably only during the first 11 days after release when each individual was located daily. All deaths during this period (n = 7) were attributed to predation by Foxes. The remains of three Malleefowl had wounds corresponding to the dentition of Foxes. Autopsies revealed that each puncture of the skin was accompanied by extensive haemorrhaging in the tissue below. This finding indicates that these Malleefowl were killed by Foxes, not simply scavenged after dying through other causes. Four additional Malleefowl deaths during this period were attributed to Fox predation on the basis of the remains being buried, fresh Fox prints or faeces found with the remains, or the transmitter casing showing signs of having been damaged by large teeth. We assume that these birds were killed by Foxes, and not scavenged because (1) all birds were observed the previous day and judged to be in good health, and (2) several remains were found with full crops.

A later death was also attributed to Fox predation (or scavenging) from the indentation marks left on the transmitter casing. Ten other deaths (Table 1) were also ascribed to predation (or scavenging), but there were insufficient remains or other evidence to be certain of the predator responsible. Previous monitoring of Malleefowl and Domestic Fowl *Gallus gallus* carcasses (Priddel and Wheeler 1996) found that most remains were rapidly consumed by fly larvae, ants, beetles and other invertebrates. Scavenging by vertebrates occurred only infrequently. Thus, in all likelihood most of these deaths were the direct result of predation.

The proportion of birds that survived in Bakara and Ferries-McDonald for 1 month was 33% within each reserve. Survival after 3 months was 27 and 33%, and did not differ significantly between reserves (χ^2_1 = 0.159, P = 0.690). Pooling data from both reserves gives a survival rate of 30% after 3 months.

Malleefowl population trends

Surveys of Malleefowl mounds within a permanently marked grid (400 ha) at Bakara have been conducted annually since 1989–90 (Gillam 2006). Up to 19 active mounds have been

Table 1. Weight on release, survival period and likely cause of death of Malleefowl chicks released at Bakara and Ferries-McDonald Conservation Parks, South Australia, in June 1990

Weight (g)	Survival (days)	Fate	Cause of death
Bakara			
675	0	Dead	Predation by Fox
952	2	Dead	Predation by Fox
651	5	Dead	Predation by Fox
813	11–26	Dead	Predation by unknown predator
733	11–26	Dead	Predation by unknown predator
952	11–26	Missing, presumed dead	Unknown
654	11–26	Missing, presumed dead	Unknown
503	11–26	Missing, presumed dead	Unknown
796	11–26	Missing, presumed dead	Unknown
634	11–40	Dead	Predation by unknown predator
685	27–40	Dead	Predation by unknown predator
804	101	Dead	Capture trauma
764	>109	Survived	
882	>190	Survived	
696	>244	Survived	
Ferries-McDonald			
477	1	Dead	Predation by Fox
900	1	Dead	Predation by Fox
665	3	Dead	Predation by Fox
715	10	Dead	Predation by Fox
835	11–31	Dead	Predation by Fox
739	11–31	Dead	Predation by unknown predator
690	11–31	Dead	Predation by unknown predator
883	11–31	Dead	Predation by unknown predator
873	11–31	Dead	Predation by unknown predator
716	11–31	Dead	Predation by Fox or Cat
591	104–181	Dead	Predation by unknown predator
890	>105	Survived	
922	>108	Survived	
924	>222	Survived	
723	>244	Survived	

Table 2. Results of linear regression analyses of the density of active Malleefowl mounds in SA reserves between 1989–90 and 2005–06

Data are from Gillam (2006). These analyses include only those reserves for which long-term data (≥10 years) were available and where counts exceeded five active mounds in any one year

Site	Size (km^2)	Sample period	Years	Number of active mounds (range)	Slope (b)	Intercept	r^2
Bakara	4	1989/90–2005/06	15	0–19	–0.1785	3.8732	0.3391
Ferries-McDonald	3.3	1990/91–2005/06	10	3–10	–0.0668	2.2923	0.3939
Cooltong	4	1993/94–2005/06	13	0–10	–0.1662	2.0096	0.6432
Cowell	4.8	1995/96–2005/06	10	3–13	–0.0698	1.933	0.1612
Pooginook	4	1990/91–2005/06	15	0–10	–0.1248	1.6904	0.5699
Shorts	2.3	1989/90–2005/06	13	0–8	–0.2327	4.1404	0.625
Combined					–0.1305	2.7053	0.8034

located in any one year. Similar surveys conducted within a 330-ha grid at Ferries-McDonald since 1990–91 have recorded up to ten active mounds (Gillam 2006). Linear regression analyses of the data from these surveys (Table 2) show that the density of active mounds in each of these two reserves has declined, the decline being more pronounced in Bakara. Similar analyses of mound densities in other SA sites show that Malleefowl populations have declined within each site for which long-term data (≥10 years) are available (Table 2). Data from the six SA sites were combined and are shown together with data from Yalgogrin, NSW in Fig. 1. The rate of Malleefowl decline within SA between 1989–90 and 2005–06 (data from the six sites combined; linear regression: $b = -0.1305$, $r^2 = 0.8034$) and the rate of the decline at Yalgogrin, NSW during the period 1986–87 to 1998–99 ($b = -0.1241$, $r^2 = 0.7214$) were similar (t test between regression slopes; $t = 0.4682$, d.f. = 26, $P > 0.50$).

Habitat structure

Measurements of canopy and understorey cover at both Bakara and Ferries-McDonald are shown in Table 3. There was no difference in the amount of canopy cover between the two reserves ($F_{1,282} = 0.0417$, $P = 0.838$). However, understorey cover in Ferries-McDonald was more than twice that in Bakara ($F_{1,282} = 56.901$, $P < 0.001$; Table 3). Approximately 47% of quadrats at Bakara had < 10% understorey cover, whereas only 16% of quadrats at Ferries-McDonald were so bare. For both height-classes, the density of vegetation at Ferries-McDonald was greater than that at Bakara (10–50 cm: $F_{1,282} = 6.396$, $P = 0.012$; 50–200 cm: $F_{1,282} = 63.541$, $P < 0.001$; Table 3). The two reserves differed greatly in the amount of understorey present within the 50–200 cm height-class, reflecting the difference in the number of tall shrubs present. Approximately 91% of quadrats at Ferries-McDonald contained vegetation ≥50 cm tall, whereas only 53% at Bakara did so, and this vegetation comprised mostly hummock grasses, seldom exceeding 65 cm in height.

Discussion

Effect of habitat integrity

The survival rate of captive-reared Malleefowl released into NSW reserves has been shown to be dependent on the level of Fox control implemented (Priddel and Wheeler 1999). At the two sites in NSW where studies have been undertaken (Yalgogrin and Yathong), no birds survived to 3 months without Fox control (Table 4). When localised ground-baiting of Foxes was undertaken (see Table 4 for the area baited and baiting intensity) 33–50% of released birds survived for 1 month and 17–42% survived for 3 months. After the implementation of

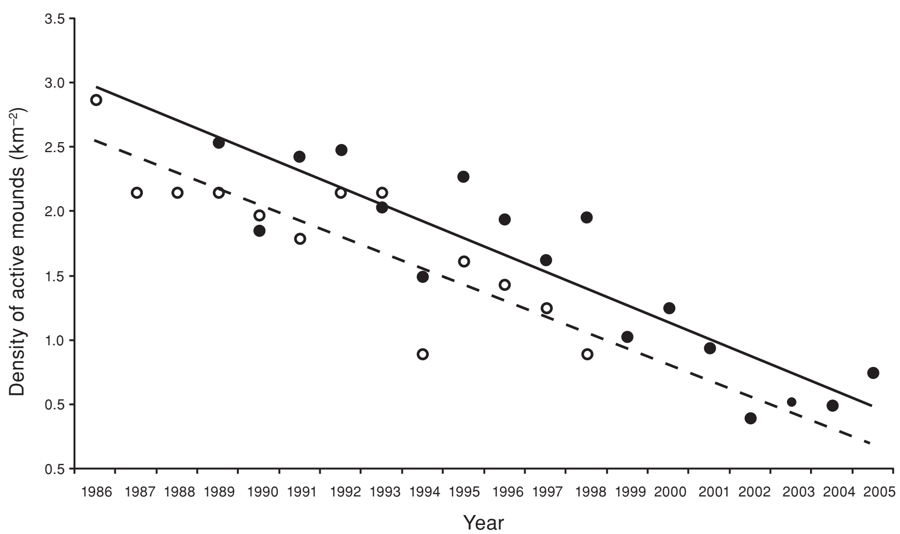

Fig. 1. The combined density of active Malleefowl mounds within six sites in SA (solid circles and solid line) between 1989–90 and 2005–06, and the density at Yalgogrin in NSW during the period 1986–87 to 1998–99 (open circles and broken line). Years on the x-axis refer to the beginning of the breeding season. The six sites in SA are Ferries-McDonald, Bakara, Cooltong, and Pooginook Conservation Parks, and Cowell and Shorts Heritage Agreements. Data for SA are taken from Gillam (2006); data for Yalgogrin from Priddel and Wheeler (2003).

Table 3. Estimates of vegetation cover and density in Bakara and Ferries-McDonald Conservation Parks

See text for explanation of methods used

	Bakara (mean ± s.d.)	Ferries-McDonald (mean ± s.d.)	*P*
n	101	183	
Canopy cover (%)	9.75 ± 10.80	10.21 ± 12.97	ns
Understorey cover (%)	21.22 ± 20.13	47.30 ± 33.06	<0.001
Index of vegetation density 10–50 cm	18.20 ± 18.83	22.20 ± 19.50	0.012
Index of vegetation density 50–200 cm	6.22 ± 11.61	19.11 ± 19.16	<0.001

widespread Fox control, involving both ground- and aerial baiting, 75% of birds were still alive 6 months after release.

Overall, the survival rate of captive-bred Malleefowl released into Bakara and Ferries-McDonald, in the absence of any Fox control, was 30% after 3 months. Thus, compared to a series of releases of captive-bred Malleefowl at two NSW sites where the habitat was far more disturbed, Malleefowl released at Bakara and Ferries-McDonald survived (1) better than those released in the absence of any Fox control, (2) about as well as those released when localised Fox control was undertaken, and (3) substantially less well than those released after widespread Fox control was implemented.

These findings should be treated cautiously because (1) they are based on small sample sizes and (2) comparisons between the various studies of Malleefowl survival are confounded by local differences in the densities of Foxes, grazing pressure, pastoral and fire history, habitat composition, annual rainfall, rainfall patterns before and after release, the timing of the release, and the ages of the birds released. All these factors can affect a Malleefowl's chances of survival (Frith 1962; Benshemesh 1992; Harlen and Priddel 1996; Priddel and Wheeler 1996, 1999, 2003).

Although the level of threat posed by Foxes clearly varies spatially, the threat is significant wherever Malleefowl occur. Fox predation is not restricted to fragmented remnants of mallee vegetation, but extends into and throughout the larger expanses of remaining habitat (Priddel and Wheeler 1994, 1996, 1997). Fox predation is not confined to habitats degraded by fire and exotic herbivores, but also occurs in relatively undisturbed habitats (this study). Foxes occur throughout the current and former range of the Malleefowl (compare Saunders *et al*. 1995 with Blakers *et al*. 1984) so it is likely that Foxes are a major factor in the decline of Malleefowl throughout the bird's range. Indeed, nowhere where Malleefowl survival has been studied has Fox predation not featured prominently, and wherever Foxes have been adequately controlled or eliminated (e.g. Priddel and Wheeler 1999; Morris *et al*. 2004), Malleefowl survival has increased substantially.

Using published data, this study has shown that Malleefowl populations have declined in each of the six SA reserves for which long-term population counts are available. Current densities are typically less than one pair per km^2, about one-quarter of what they were just 15 years ago (Fig. 1). This rate of decline is similar to that observed at Yalgogrin in NSW. Between 1986–87 and 1997–98 the population at Yalgogrin declined at an average exponential rate of decrease of 0.075 (Priddel and Wheeler 2003). The Malleefowl population at Yalgogrin once boasted the highest density of any population within NSW, but is likely to become extinct in the near future. Elsewhere in NSW, there are few populations of any significant size or density (Brickhill 1985), and in recent years many populations have either declined markedly or disappeared altogether (Brickhill 1987*b*; Priddel and Wheeler 2003). Unless remedial action is taken soon, populations within SA appear destined for the same fate.

Table 4. Survival of captive-bred Malleefowl released into the wild in SA, and in NSW under different regimes of Fox control

Location	Fox control	Area baited (km^2)	Baiting intensity (baits km^{-2})	Number of birds released	Age of birds (months)	Survival after 1 month (%)	Survival after 3 months (%)	Mortality from Fox predation[A]	Source
South Australia									
Bakara	None			15	3–6	33	27	27–100	This study
Ferries-McDonald	None			15	3–6	33	33	50–100	This study
New South Wales									
Yalgogrin	None			17	0–4	24	0	18–59	Priddel and Wheeler (1994)
Yalgogrin	None			15	3–6	7	0	73	Priddel and Wheeler (1994)
Yathong	None			23	3–5	4	0	52–96	Priddel and Wheeler (1996)
Yathong	Localised	6.4	7.5	12	6–8	50	42	86–100	Priddel and Wheeler (1997)
Yathong	Localised	6.4	7.5	12	8–11	33	17	70–80	Priddel and Wheeler (1999); unpubl. data
Yathong	Localised	19.2	1.5	24	4–5	42	25	45–56	Priddel and Wheeler (1997)
Yathong	Widespread	107.2	3.5	24	6–7	88	75	33–50	Priddel and Wheeler (1999)

[A]Based on mortality during the first 3 months after release.

Effect of habitat structure

Bakara and Ferries-McDonald contained mallee canopies of similar species and density. The understorey, however, differed greatly between reserves. In Bakara, the understorey was open and consisted mostly of scattered clumps of spinifex. The area was easy to walk through and Malleefowl could generally be seen from at least 20 m away. In Ferries-McDonald the understorey was more dense, dominated by tall, woody shrubs, and was difficult to negotiate. It was often impossible to glimpse sight of a radio-tagged Malleefowl walking just a few metres ahead.

There was no discernible difference between the survival of captive-reared Malleefowl released into Bakara and the survival of those released into Ferries-McDonald. Predators probably killed 73% of birds released into Ferries-McDonald and 47–73% of those released into Bakara. Although the denser understorey in Ferries-McDonald helped conceal Malleefowl from view, it seems it did not afford Malleefowl any significant level of increased protection from predators. It may be that denser vegetation also helps obscure the predator from its prey. Although dense understorey (>70% foliage cover; Specht 1972) in mesic habitats may help protect some prey species from Fox predation (Short 1998), it seems that the moderately dense understorey of Ferries-McDonald is not sufficiently dense to provide Malleefowl a similar level of protection. It should be noted, however, that this study was not replicated and examined only two habitat types. To more fully address the interaction between habitat structure and Fox predation on Malleefowl would require a replicated study involving both baited and non-baited sites across a range of habitats that differ in vegetation structure.

Conclusion

Predation by Foxes has been identified as a significant cause of Malleefowl mortality in conservation reserves in NSW (Priddel and Wheeler 1994, 1996, 1997), Victoria (Benshemesh 1992) and SA (Booth 1987; this study). We suggest that Foxes are likely to pose a threat to all Malleefowl populations.

The survival of young captive-reared Malleefowl released into SA reserves was marginally better than that reported from more disturbed habitats in NSW, but long-term population trends were similar. Although young captive-reared Malleefowl released in SA survived comparatively longer than those in NSW, most still died before reaching breeding age. Thus, the eventual outcome – declining populations – was similar. The level of habitat disturbance may have had a minor effect on Malleefowl survival, but no effect on the overall rate of population decline. Also, habitat density had no influence on either Malleefowl survival or the level of Fox predation, at least for the two mallee communities studied. We conclude that, to date, there is no evidence to suggest that any Malleefowl population (other than those few protected by predator-proof fences) is not threatened by Foxes. We suggest that this places the species at substantial risk of extinction.

Monitoring of nest densities has revealed steep declines in Malleefowl populations in NSW, Victoria and SA over the two past decades (Priddel and Wheeler 2003; Benshemesh 2005; Gillam 2006). Despite the high fecundity of Malleefowl (Frith 1959; Booth 1987; Brickhill 1987*a*; Priddel and Wheeler 2005) the current recruitment rate is generally inadequate to offset adult mortality and maintain stable population numbers (Priddel and Wheeler 2003). The distribution of the Malleefowl continues to shrink and population numbers Australia-wide continue to fall.

The rate of decline in SA (~75% in 15 years, or approximately three generations) is particularly ominous, and on a par with the decline in NSW, where the species is now absent from much of its former range. These declines exceed the current IUCN criteria for listing as an Endangered species: ‘at least 50% reduction in population size over the last three generations where the cause of the reduction has not ceased’ (IUCN 2007). The Malleefowl is currently classified as Endangered under conservation legislation in NSW (*NSW Threatened Species Conservation Act 1995*), but as Vulnerable in both SA (*National Parks and Wildlife Act 1972*) and Australia (*Environment Protection and Biodiversity Conservation Act 1999*). We suggest that each of these latter two classifications are in need of review.

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