Malleefowl conservation in New South Wales: a review

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Together with land clearance, grazing by stock and inappropriate fire regimes, predation by the introduced European red fox *Vulpes vulpes* (Linnaeus, 1758) has decimated populations of malleefowl *Leipoa ocellata* Gould, 1840. The decline of the malleefowl has been most pronounced in New South Wales, where foxes prey so heavily on malleefowl that adult mortality exceeds recruitment of young into the breeding population. Although young malleefowl are particularly vulnerable to foxes, subadults and adults are also taken. Within New South Wales, heavy predation by foxes occurs both in the remnants of native vegetation within agricultural lands and in the large tracts of mallee that lie further inland. Foxes appear to be the prime cause of malleefowl mortality throughout much of the malleefowl's geographic range. Both fire and grazing by domestic stock reduce the carrying capacity of the habitat for malleefowl. In reserves where stock are excluded, there is no evidence that food resources are limiting malleefowl populations. Exotic herbivores, such as goats and rabbits, probably contribute to the demise of the malleefowl by reducing vegetative cover. Malleefowl are particularly vulnerable to predation by raptors in habitats where vegetative cover is sparse. Greater canopy cover, together with greater stocks of seeds within the soil seed-bank, can explain why old-growth mallee is optimal habitat for malleefowl. Malleefowl survival can be enhanced substantially by fox control. Fox baiting, however, needs to be frequent, intensive and widespread to reduce fox density to levels where predation no longer threatens the survival or recovery of malleefowl populations. Poisoning of foxes on surrounding properties, together with effective rabbit and goat control, is needed to maximise the effectiveness of any fox-control program. Without conservation action, the steady decline and loss of extant populations will continue unabated. Improved survival of malleefowl in habitat that has been intensively managed for their benefit is encouraging, but as yet there has been no definitive evidence of population recovery. In New South Wales, conservation efforts will need to focus on the expansive reserves of mallee in the west of the state. Conservation of malleefowl throughout its range is likely to be achieved only by the use of exclusion fencing to protect isolated populations in small remnants of native vegetation.

Introduction

Megapodes typically inhabit moist tropical forests where the physical environment is seemingly conducive to the characteristic mode of incubation adopted by this family, *viz*. the utilization of natural sources of heat. The malleefowl *Leipoa ocellata* Gould, 1840, is unique in that it is the only megapode to inhabit arid habitats (Frith, 1956a). The species has adapted to this relatively harsh environment by increasing the sophistication of both nest construction and temperature regulation (Frith, 1956b). Malleefowl go to extraordinary lengths to harness solar radiation to supplement the heat produced by vegetative decomposition.

Despite its apparent resilience, the malleefowl has not contended well with the myriad of environmental changes wrought by Europeans during the last two centuries. Contraction in the geographic range of the malleefowl (Blakers et al., 1984) has occurred through widespread clearing of its habitat (Priddel, 1989). The species once inhabited much of arid central Australia, as far north as the Tanami Desert (Mountford, 1950), but it has disappeared from much of this region (Kimber, 1985). The main effect of human-induced changes, however, has been to alter dramatically the distribution of malleefowl within its geographic range. Malleefowl once occupied an almost continuous distribution across the southern half of the Australian continent, from the Indian Ocean in the west to the Great Dividing Range in the east. Throughout much of this range the malleefowl now exists only as isolated, disjunct and scattered populations.

Within New South Wales, malleefowl formerly inhabited a diversity of habitats, but they are now confined largely to mallee — a range of plant communities dominated by multi-stemmed *Eucalyptus* species. These habitats generally are on soils of low fertility and receive less than 430 mm of rainfall annually (Rowley, 1975). Habitats containing the highest densities of malleefowl are old-growth mallee (Benshemesh, 1990) with a continuous well-developed canopy and a dense shrub layer (Frith, 1962a). In terms of food resources, the critical aspect of malleefowl habitat is the occurrence of a wide range of food-bearing shrubs such as *Acacia*, *Eremophila* and *Dodonaea* (Harlen & Priddel, 1996).

Malleefowl were once numerous and relatively common across much of their range, but their numbers have declined markedly. The decline, although ubiquitous, appears more pronounced in New South Wales than in other Australian states. Despite the demise of the malleefowl having been recognised as early as 1950 (Griffiths, 1954), it continues today unabated. Densities of malleefowl in central New South Wales have fallen to a fraction of those recorded earlier this century. This decline, although exacerbated by pastoral activities (Frith, 1962a), has also occurred in areas that have been set aside as conservation reserves. In Round Hill Nature Reserve, for example, aerial surveys conducted in the early 1980s located only 0.04 active nests per square kilometre (Brickhill, 1985). Ground surveys of similar habitat three decades earlier returned densities of 0.15 active nests km^{-2} in mallee grazed by sheep and 1.54 km^{-2} in mallee devoid of stock (Frith, 1962a). Brickhill (1985) found less than 2% of all malleefowl nests in Round Hill Nature Reserve to be in use.

The fertile arable lands of central New South Wales were once the stronghold of the malleefowl in this region. Today small, isolated populations of just a few individuals survive in remnant patches of native vegetation scattered throughout the wheatbelt (Brickhill, 1987a). One such remnant near Yalgogrin once contained the highest density of malleefowl known in New South Wales in contemporary times (> 3.5 breeding pair km^{-2}). Patches of eucalyptus (*Eucalyptus viridis, E. polybractea, and E. behriana*) within this remnant are harvested regularly to provide young leaves for the distillation of eucalyptus oil. This practice, occurring here since the 1940s, has created a structural mosaic of dense low regenerating mallee interspersed with areas of mature mallee. It is not known whether this modification of the habitat has been to the benefit or detriment of the local malleefowl population. Monitoring in recent times, however, has shown the population to be in decline, it having fallen steadily from 16 breeding pairs in 1986/87 to just seven in 1997/98. Although there has been some recruitment of young into the breeding population, this recruitment has not kept pace with adult mortality.

Ground surveys conducted in 1989 found or confirmed that malleefowl were now absent from many small reserves in which they once occurred, including The Charcoal Tank Nature Reserve (86 ha) and Gubbata Nature Reserve (162 ha) (Priddel &

Wheeler, 1994). Old disused nests were found but there was no sign of any current or recent breeding activity. No breeding has been recorded in Pulletop Nature Reserve since the 1989-90 season when one nest was found to contain eight eggs, all of which were infertile. Pulletop Nature Reserve (145 ha) is all that remains of the mallee where Frith undertook his landmark studies of the bird's breeding habits in the late 1950s (see Frith, 1956a; 1956b; 1959; 1962a; 1962b).

These local extinctions give considerable cause for concern, as they have occurred within what is regarded as prime habitat in relatively pristine condition. The reserves which no longer support malleefowl have long been protected from all forms of clearing or harvesting of native vegetation and are subjected to little or no grazing by exotic herbivores. Moreover, with the exception of a small part of Pulletop Nature Reserve that was intentionally burnt in 1988, all these reserves are comprised entirely of old-growth mallee — the preferred habitat of the malleefowl. These local extinctions are stark evidence that, without well-focused conservation action to address the threatening processes which operate, the malleefowl is in imminent danger of extinction across much of its range. Without such action the decline and loss of extant populations will continue unabated.

A definitive understanding about the stability of most malleefowl populations is lacking because of the paucity of long-term monitoring. Routine census of the number, density and status of malleefowl at specific sites has recently been instigated in all states in which malleefowl still occur. Most monitoring programs involve regular ground-searching for nests within small areas of habitat (2-4 km^2) that have been surveyed and permanently marked (Benshemesh, 1989; Brandle, 1991). Monitoring has not been conducted for sufficient years for any definitive conclusions to be drawn. Preliminary results suggest that overall the number of breeding pairs in Victoria has declined by 16% since the early 1990s (Benshemesh, 1997; 1998). Contrary to the general trend, a few populations have remained stable (Benshemesh, 1997) and at least one may have increased in number (Benshemesh, 1998). The population in Bakara Conservation Reserve, South Australia, also appears to have increased in recent years (P. Copley, pers. comm.). Routine fox poisoning is carried out around this and many other populations currently being monitored.

The potential reproductive rate of malleefowl is among the highest of all bird species. Aside from a few clutches of small and infertile eggs in isolated remnant populations (Priddel & Wheeler, 1994), there is no evidence of any ubiquitous decline in malleefowl fecundity. Clutch size differs between pairs, fluctuating annually in response to rainfall and food availability. In drought years, few or no eggs are laid. Between 1987 and 1997, annual average clutch size for the population at Yalgogrin varied between 5.2 and 20.4 eggs per nest. Overall, an average of 13.9 eggs per annum were laid by each breeding pair (Priddel & Wheeler, unpubl. data). Similar clutch sizes have been recorded elsewhere (Frith, 1959; Booth, 1987; Brickhill, 1987b). Most malleefowl eggs are fertile, and unless nests become saturated by rain (Brickhill, 1987b) or are raided by foxes (Frith, 1959), most eggs hatch (Frith, 1959; Brickhill, 1987b; Booth, 1987; Benshemesh, 1992; Priddel & Wheeler, unpubl. data). Besides infertility, the only other significant causes of egg loss are breakage and incorrect placement outside the egg chamber. Eggs laid late in the season and still present in the nest during autumn may also be abandoned and lost.

On average, however, each breeding pair produces about 10 offspring each year they breed. Given that individuals may breed for a decade or longer, a single pair may produce more than a hundred offspring within their lifetime. Poor breeding success, therefore, is not implicated as a general cause of malleefowl decline. A mere 2% recruitment rate is all that is required to sustain a stable population (Frith, 1962a). Consequently, a high rate of natural mortality is expected, but in many populations the natural balance has been disrupted to the extent where current mortality exceeds sustainable limits.

Causes of decline

During the nineteenth and early twentieth centuries, European settlers hunted malleefowl (fig. 1). The birds featured regularly on the dinner table of many settlers, and recipes for their preparation can be found in cookery books of the day. The effect of hunting on malleefowl populations is unknown, but is thought to be inconsequential relative to other threats. The numbers killed by hunting parties, however, attest to the former abundance of the species. Today, malleefowl are protected and hunting no longer takes place.

The principal causes of malleefowl decline are: the destruction of habitat through the clearance of mallee lands for cropping and pastoralism (Frith, 1962a; Brickhill, 1987a), grazing of mallee understorey by stock, goats and rabbits (Frith, 1962a), the frequency and extent of wildfire (Benshemesh, 1990; 1992) and predation by foxes

Fig. 1. Malleefowl were hunted by early European settlers (photograph courtesy of the Cobar Museum; source unknown).

(Priddel & Wheeler, 1994; 1996; 1997). Many of these threatening processes operate in concert. Thinning of the vegetation by exotic herbivores, for example, reduces the protective cover available to malleefowl, thereby increasing their exposure and vulnerability to predators.

Land clearance

Vast tracts of mallee once extended across southern mainland Australia (Specht, 1981; Hill, 1989). Clearance of mallee lands for agriculture, principally for wheat cultivation and sheep grazing, has resulted in significant loss of malleefowl habitat. The only large tracts of mallee to remain intact are in low-rainfall areas largely unsuited to agriculture and of marginal quality for malleefowl (Frith, 1962a). Mallee on the more fertile soils in areas of relatively high annual rainfall have been extensively cleared; these areas were once prime habitat for malleefowl (Frith, 1962a). Only small, discontinuous and isolated remnants remain. Several patches of high-rainfall mallee have been spared the bulldozer and are now public reserves protected from future clearing and from any harvesting of native vegetation. These reserves, however, have not gone unscathed and populations of malleefowl within them have declined due to other threatening processes.

Increased grazing pressure

An opportunistic feeding strategy enables the omnivorous malleefowl to exploit a diverse array of food items. Their diet includes: tubers, fungi, the foliage, buds, flowers, fruits and seeds of herbs and shrubs; as well as the invertebrates that these plants harbour (Frith, 1962b; Booth, 1986; Brickhill, 1987a; Barker & Vestjens, 1989; Benshemesh, 1992; Harlen & Priddel, 1996). Stock graze many of these plants, thereby reducing the food available to malleefowl (Frith, 1962a; 1962b). Grazing of mallee habitat by sheep greatly diminishes the carrying capacity of the habitat for malleefowl (Frith, 1962a). In mallee grazed by sheep malleefowl densities are only 9-16% of those in similar habitats free of stock. Grazing not only depletes the malleefowl's food supply, but also increases its vulnerability to predation by reducing vegetative cover and by increasing the amount of time spent foraging.

Although not grazed by stock, many mallee reserves in New South Wales contain significant populations of feral goats and rabbits. Presumably the added impost of these exotic herbivores also reduces the carrying capacity for malleefowl. Despite this potential depletion of food resources the habitat remains capable of supporting at least small populations of malleefowl (Harlen & Priddel, 1996). Food resources in the mallee are transient and patchily distributed, and composition and abundance fluctuate considerably, but food is never entirely absent. Malleefowl exploit the fluctuating availability of each of the various food resources by feeding opportunistically on whatever food items are locally or seasonally abundant. When plentiful, for example, malleefowl gorge on food such as *Acacia* seeds (Frith, 1962b) or lerps — starch deposits secreted onto the leaves of eucalypts by sap-sucking psyllids (Benshemesh, 1992).

The dense and continuous cover — characteristic of habitats containing high densities of malleefowl — provides greater concealment for malleefowl and, thus, greater protection from predators. Goats and rabbits have probably contributed to the demise of the malleefowl mainly by thinning the understorey, reducing vegetative cover and increasing exposure to predators.

Inappropriate fire regimes

Frequent or extensive wildfire is a significant threat to malleefowl populations. Comparison of densities of breeding pairs within different-aged stands of mallee coppice suggest a correlation between the density of malleefowl and time since last fire (Benshemesh, 1990; 1992). Breeding rarely occurs in habitats that have been recently burnt (Tarr, 1965; Benshemesh, 1992), and densities are greatest in mallee that has remained free from fire for at least 40 years (Benshemesh, 1990). Malleefowl may be unable to re-colonise burnt areas for many years, and population recovery thereafter is slow (Woinarski, 1989; Benshemesh, 1992).

Low densities of malleefowl in New South Wales may, in part, be attributable to recent fire history (Benshemesh, 1993). Broad-scale burning of unreserved mallee land has been widely practised in New South Wales to increase forage production, eliminate shrubs unpalatable to sheep, and for fuel reduction (Hodgkinson et al., 1984; Noble, 1984). This intentional burning, together with widespread wildfires in 1969, 1974 and 1984 (Pickard, 1988), has led to most of the extensive stands of mallee in western New South Wales being burnt within the last 30 years, many repeatedly. Large areas of old-growth mallee are now rare in New South Wales.

The threat of fire in small mallee remnants differs somewhat to that in the more extensive expanses of mallee. Due to their isolation, remnants may remain free from fire for long periods. Should a fire ever reach or break out within one, however, there is a high probability that the entire remnant will burn, rendering it unsuitable for malleefowl for many years. Even after the vegetation has re-grown it is doubtful that malleefowl could re-colonise these remnants because of the relatively vast expanses of cleared land separating remaining populations.

The abundance of herbs and food-bearing shrubs declines with increasing time since fire (Cheal et al., 1979; Noble, 1989; Bradstock, 1989), but stocks of large seeds within the soil seed-bank accumulate over time (Harlen & Priddel, in press). Enhanced food resources may explain, at least in part, why old-growth mallee appears to be the optimal habitat for malleefowl. Higher densities of malleefowl in old-growth mallee, however, may also result from lower levels of predation by foxes and raptors in vegetation that offers greater concealment for prey.

Raptors can inflict heavy mortality on cohorts of young malleefowl (Benshemesh, 1992; Priddel & Wheeler, 1990; 1994; 1997). Predation by raptors is particularly prevalent in areas where foxes have been heavily controlled, at times accounting for up to one third of all deaths. On Yathong Nature Reserve, most raptor attacks have occurred in areas where the canopy is open or discontinuous, particularly where the mallee merges with open woodland habitat or where the understorey is sparse (Priddel & Wheeler, 1997). In mallee less than 10 years old, the *Eucalyptus* canopy is low (< 3 m above ground) and scattered, with large expanses of open ground. As the vegetation ages, the canopy is raised and extended; after 35 years it can cover up to 70% of the habitat (Noble et al., 1996). Greater canopy cover affords malleefowl greater protection from raptors (Priddel & Wheeler, 1997). Although raptors are natural predators of malleefowl, their effect on malleefowl populations may have increased. Not only has thinning of the vegetation enhanced their ability to hunt, but their numbers may be artificially elevated by the ready-availability of introduced prey such as rabbits.

Predation by foxes

Introduced into Australia in the 1860s (Coman, 1983), the fox is currently the single greatest cause of malleefowl mortality. Foxes prey on malleefowl eggs (Frith, 1959; Brickhill, 1987b), chicks (Benshemesh, 1992; Priddel & Wheeler, 1994; 1996), juveniles (Priddel & Wheeler, 1996), sub-adults (Priddel & Wheeler, 1996), and adults (Benshemesh, 1992; Booth, 1985).

The extent of predation of eggs by foxes, although usually low, can on occasion be severe. Whereas no loss of eggs to foxes occurred in a population of malleefowl near Renmark (Booth, 1987), 37% of 1094 malleefowl eggs laid near Griffith were dug up and eaten by foxes (Frith, 1959). At Yalgogrin, 5% of eggs were lost to foxes during 1982-84 (Brickhill, 1987b), in 1986 almost one third of all eggs were taken by foxes, but negligible loss occurred between 1987 and 1996 (Priddel & Wheeler, unpubl. data).

Predation of chicks and juveniles by foxes is more severe, particularly in New South Wales. Young captive-reared malleefowl experimentally released into areas of New South Wales containing small resident populations generally do not survive; most are killed by foxes (Priddel & Wheeler, 1994; 1996; 1997). Mortality is particularly high during the first few weeks after liberation. Typically, in habitat where fox control measures are not implemented, 50% of liberated chicks and juveniles die within the first week, 80% within two weeks, and survival beyond the first month is rare. A small percentage of birds die from metabolic stress or starvation, but most succumb to predation by foxes. Relying principally on camouflage, young malleefowl have no effective defence or escape behaviour to evade ground-dwelling predators, and consequently are easy prey for foxes.

Although young malleefowl are particularly vulnerable to foxes, sub-adults and adults are also taken (Priddel & Wheeler, 1996). The vulnerability of malleefowl to foxes, although protracted, does decline with age and is measurably lower in sub-adults (Priddel & Wheeler, 1996). Predation by foxes, however, remains the major cause of mortality among sub-adult malleefowl.

The extent to which foxes prey on adult malleefowl is not known. Of six adult malleefowl that were captured by Booth (1985) and subsequently radio-tracked, at least four were killed by foxes. Both Booth (1985) and Benshemesh (1992) reported adult malleefowl being killed by foxes after having been disturbed from their nocturnal roosts by abortive attempts to capture them. Adult mortality, however, appears low; banded individuals having survived for more than 13 years in an area where foxes are reasonably numerous. Of 23 adults radio-tracked for periods totalling more than 20 years, only two deaths occurred which could possibly be attributed to foxes (Benshemesh, 1992).

In New South Wales, heavy losses of malleefowl to predation by foxes occurs both in remnants of mallee vegetation within agricultural lands (Priddel & Wheeler, 1994) and in large expanses of mallee that are more remote from agriculture (Priddel & Wheeler, 1996). Although the decline of the malleefowl has been most pronounced in central New South Wales, heavy predation by foxes is not restricted to this region.

Where measured, the rate of mortality of malleefowl chicks in Victoria (Benshemesh, 1992) was similar to that observed in New South Wales, with foxes accounting for one third of all deaths. Two cohorts of captive-reared malleefowl experimentally released into reserves in South Australia survived longer than their counterparts in New South Wales, but foxes were again the prime cause of mortality (Priddel & Wheeler, unpubl. data). These findings suggest that the threat posed by foxes is present throughout much of the malleefowl's geographic range.

Predation by foxes is the major cause of malleefowl mortality, yet the extent to which this introduced predator has been responsible for the demise of the malleefowl is indeterminable. Foxes have been implicated in the disappearance of several species of medium-sized, ground-dwelling mammals from the arid and semi-arid regions of Australia (Burbidge & McKenzie, 1989). The malleefowl falls within the "critical-weight-range" of those mammals most severely affected and, because it is also essentially ground-dwelling, it is probably subjected to similar pressures. The detrimental impact of foxes is exacerbated by habitat fragmentation, inappropriate fire regimes and by the reduction in vegetative cover caused by exotic herbivores.

Efficacy of fox control

A comprehensive program of fox control can dramatically ameliorate the threat posed by foxes and can greatly enhance the survival prospects of young malleefowl. The high fecundity of the malleefowl (Frith, 1959; Booth, 1987; Brickhill, 1987b) 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.

Localised fox control on Yathong Nature Reserve (107,241 ha), involving fortnightly ground baiting of 6,400 ha at a density of 7.5 baits km^{-2}, was effective in reducing fox numbers in the immediate vicinity, and proved sufficient to enhance malleefowl survival (Priddel & Wheeler, 1997). Malleefowl released into the baited area (table 1; cohort C) survived longer than those released concurrently into nearby areas that had not been baited (cohort B). Survival in both the baited and the nearby non-baited areas was greater than in the same area prior to any fox-control (cohort A), when most malleefowl were taken by foxes within just a few days of their liberation. Despite the improvement in survival of malleefowl afforded by fox control, fox predation remained the prime cause of malleefowl mortality (Priddel & Wheeler, 1997).

Three months later, another cohort of captive-reared malleefowl (table 1; cohort D) was released under the same localised baiting regime but, this time, shortly after an emergence of herbaceous plants following rain. Herbs are a readily and easily obtainable food source for malleefowl (Harlen & Priddel, 1996), and malleefowl foraging at this time would have required only minimal effort to locate sufficient food. Despite the abundant food supply, malleefowl released in spring survived no better than those released in winter, three months earlier (cohort C). Similarly, a more widespread, but less intensive, regime of fox baiting (involving fortnightly ground baiting of 19,200 ha at a density of 1.5 baits km^{-2}) undertaken the following winter (cohort E) also failed to further enhance the survival of malleefowl beyond that achieved previously.

Widespread fox baiting, involving a combination of both broadscale aerial baiting and ground baiting, however, proved to be the most effective form of fox control. This baiting regime involved (i) fortnightly ground baiting of the core conservation area (19,200 ha) at a density of 1.5 baits km^{-2}, (ii) once-only aerial baiting of this core area and the surrounding mallee habitat within the reserve (50,000 ha) at a density of 5 baits km^{-2}, (iii) quarterly ground baiting of all boundary and internal roads of the reserve (other than those within the core conservation area) at a density of 1.1 baits km^{-2} (88,000 ha), and (iv) quarterly ground-baiting of neighbouring pastoral properties by the local community. Under this baiting regime, the proportion of captive-reared malleefowl (cohort F) that survived in the wild beyond the first month after liberation (88%) exceeded that of any other cohort released (table 1). Seventy-five percent of birds were still alive six months after their liberation. The relaxation in predation pressure and the resultant increase in survivorship under this baiting regime may prove sufficient to enable depressed populations of malleefowl to escape the "predator pit" (Kinnear et al., 1984) and recover to levels that are self-sustaining.

The baiting regimes used on Yathong Nature Reserve involved more frequent and more intensive baiting than that commonly employed elsewhere in the eastern States, either by pastoralists to reduce lamb losses or by conservationists to protect native fauna. Although such baiting regimes were successful in increasing malleefowl survivorship, they fell short of eliminating foxes as a major cause of malleefowl mortality. Many of those malleefowl that survived for relatively long periods in the wild were eventually killed by foxes before attaining breeding age.

The high fecundity of malleefowl (Frith, 1959; Booth, 1987; Brickhill, 1987b; Priddel & Wheeler, unpubl. data) suggests that this species may be able to tolerate a moderate level of predation. To reduce predation pressure to an acceptable level in New South Wales will require fox baiting to be frequent, intensive and widespread, and will require the use of aerial baiting techniques. The requirements for successful fox control and malleefowl recovery, however, are likely to vary between localities and between habitats. It is possible, for example, that in very dense or very old mallee malleefowl may respond favourably to more modest levels of fox control. Here the value of infrequent, low-intensity baiting as a means of conserving extant populations of malleefowl is not known, and remains one of the most vexing issues yet to be resolved.

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; Kinnear et al., 1988; Friend, 1990). Recovery of depressed malleefowl populations, however, may prove more difficult to achieve. Whereas control of foxes within Dryandra Forest has led to a marked recovery in the numbat, *Myrmecobius fasciatus* Waterhouse, 1836 (Friend & Thomas, 1995), there have been no indications of any increase in malleefowl numbers (J.A. Friend, pers. comm.). It has yet to be demonstrated that fox control, of any intensity, is capable of reducing predation pressure on malleefowl to a level sufficient to facilitate recovery of the species.

Experimental research on Yathong Nature Reserve concluded in 1994, but fox control continued along with new initiatives to control goats and rabbits. These actions form the basis of a malleefowl recovery program that aims to establish a self-

Table 1. Survival of captive-bred malleefowl released into the wild under different regimes of fox control. Survival estimates are based on the number of individuals known to be alive approximately 30 days and 180 days after release. P. & W. Priddel & Wheeler.

Cohort	A	B	C	D	E	F
Baiting regime	None	Nearby	Localised	Localised	Localised	Widespread
Ground baiting: area (ha)			6,400	6,400	19,200	a) 19,200; b) 88,000
Ground baiting: intensity (baits km^{-2})			7.5	7.5	1.5	a) 1.5; b) 1.1
Aerial baiting: area (ha)						50,000
Aerial baiting: intensity (baits km^{-2})						5.0
Community baiting	No	No	No	No	No	Yes
Release date	9 iv 1990	30 vii 1990	30 vii 1990	30 x 1990	1 vi 1991	14 x 1993
Sample size	23[a]	12	12	12	24	24
Age: range	101 - 145	171-227	176 - 248	238 - 328	111 - 136	183 - 223
Age: mean	113	193	208	288	125	210
% Survival: one month	4	25	50	33	42	88
% Survival: six months	0	8	25	17	21	75
Source of data	P&W 1996	P&W 1997	P&W 1997	P&W unpublished	P&W 1997	P&W unpublished

[a] excludes one individual removed from the experiment

sustaining population of malleefowl on the reserve. Since 1995 more than 90 captive-bred malleefowl have been liberated into Yathong Nature Reserve to bolster the small extant population. Thirty-five of these individuals were bred at Western Plains Zoo, Dubbo, the rest were the progeny of birds held captive on Yathong. The effectiveness of the recovery program is assessed by monitoring the number of malleefowl nests present within the Malleefowl Conservation Zone — an area of 19,200 ha within Yathong Nature Reserve managed specifically for malleefowl. Nests are surveyed by helicopter annually in spring. Five active nests were located in both 1996 and 1997. Malleefowl typically begin breeding when two to five years of age, so the success of the recovery and reintroduction program will not be known for several years.

Conservation strategies

Without prompt and well-focused conservation action, extant populations of malleefowl in New South Wales will continue to decline, and the species is destined to become extinct in this state within the next few decades. A suite of actions is needed to recover the species, including: control of foxes, goats and rabbits, management and suppression of wildfire, exclusion fencing, restocking, and reintroduction. Population monitoring is needed to assess the efficacy of recovery actions.

The malleefowl has a broad geographic range across Australia, throughout which there are variations in land tenure, the extent of fragmentation of remaining habitat, fire history, densities of foxes, rabbits, goats and raptors, natural tolerances to 1080, and varying risks to non-target species from poisoning programs. Consequently, any recovery action is unlikely to be universally applicable across the entire range of the species. The appropriateness of each recovery action will depend upon the geographic location of the population, the size of the habitat to be managed, land tenure and state laws. In New South Wales, two distinct strategies are proposed; one for small remnants of native vegetation within the wheat-belt, the other for the larger but more marginal expanses of mallee in the west.

Approximately 80% of all malleefowl remaining in New South Wales inhabit mallee lands in the arid west of the state (Brickhill, 1985). This region contains several large tracts of mallee (areas in excess of 10,000 ha) on public reserves (Yathong Nature Reserve, Mallee Cliffs National Park, Nombinnie Nature Reserve, Round Hill Nature Reserve and Tarawi Nature Reserve). These reserves are not threatened by clearing or prescribed burning (undertaken elsewhere to increase forage production), nor are they subjected to grazing by stock. They can also be managed solely for the conservation of the flora and fauna they contain. Consequently these reserves provide the best opportunity to establish secure self-sustaining populations of malleefowl in New South Wales. Conservation efforts, therefore, will need to focus on these reserves.

Control of foxes

Despite uncertainty as to the minimal level of fox control required across the range of the malleefowl, there is sufficient evidence to indicate that where fox control is not undertaken other recovery actions are likely to be futile. Large mallee reserves should be baited from the air and augmented with ground baiting around the perimeter. A community-based fox-control program should be developed to lower the density of foxes on surrounding properties and thereby reduce the rate of re-infestation. Baiting should take place on a regular basis (at least thrice annually) and should be timed to coincide with the onset of fox breeding (late spring or early summer) and the dispersal of young (autumn).

The risk posed to non-target species is greater for aerial baiting than for ground baiting as the baits remain exposed above ground (it is a legal requirement of ground-baiting operations in New South Wales that all baits be buried). In western New South Wales the risk to non-target species is minimal as those native species most likely to take baits have already been lost from the region. Those species that still exist locally are likely to benefit from the decrease in fox numbers resulting from aerial baiting programs (McIlroy & Gifford, 1991). To further minimize the threat to non-target species, the baits used in all aerial baiting operations should be too tough for small carnivorous mammals to chew and too large for them to swallow whole.

Work completed on Yathong Nature Reserve has demonstrated that the continual presence of viable baits does not render an area fox-free. Some resident foxes may not take baits, and re-infestation is a perpetual problem. Increasing the frequency of baiting, therefore, may not significantly enhance the effectiveness of the baiting program. Additional resources are better directed at expanding the area baited to create a broad buffer zone of low fox-density surrounding the core conservation area. Re-infestation of foxes into the conservation area is thereby dampened. Where sought, community participation in a widespread program of fox control on pastoral properties surrounding an area of high conservation concern has often been strong. For reasons of safety, community baiting programs are best done using commercially prepared baits. These baits are easy to handle, supplied with written instructions and warnings, and are readily biodegradable.

Aside from optimizing the frequency, intensity and extent of baiting, conservation managers need also to look at ways of improving the efficacy of the baiting program. For example, those foxes that have an apparent aversion towards poison baits are a major impediment to the success of any fox control program. These individuals should be targeted specifically. The use of a variety of bait media during the baiting program may minimize the incidence of bait aversion. The response to any fox sign should be immediate. The advent of commercially prepared baits that are pre-packaged and shelf stable provide the capacity for field operatives to achieve this.

Control of rabbits

An holistic approach to fox control is warranted. Foxes, and some raptors, are sustained at high densities by the abundance of their staple prey — the introduced rabbit (Coman, 1973; Croft & Hone, 1978). The control of rabbits, therefore, is an essential adjunct to effective fox control.

Rabbits should be controlled mainly through the judicious use of biological control agents such as myxomatosis and calicivirus (RCD). To aid the spread of the myxoma virus wild populations of rabbit fleas should be maintained and augmented where necessary. Supplementary methods of control, including poisoning, ripping and fumigation of warrens, should be used where appropriate. Baiting rabbits with 1080-laden carrots not only serves to control rabbits, but also provides a secondary means of killing foxes, as foxes will readily take dead and moribund rabbits.

Control of goats

Goats and all other exotic herbivores should be reduced to densities sufficiently low to facilitate the growth of a dense and diverse understorey. Reserves should be fenced to exclude goats and stock. A program of goat control should be established within each reserve using a combination of trapping at water holes and mustering. Working dogs should be muzzled to avoid the possibility of them inadvertently taking 1080-laced fox-baits. Aerial shooting should not be used as a long-term method of control. This technique is not cost-effective and the carcasses provide food for foxes. Ground shooting as a means of control should be permitted only if the carcasses are appropriately buried or removed from the reserve. As a long-term measure to reduce goat numbers all non-essential water reservoirs (earth tanks) should be destroyed, and all essential reservoirs should be fenced.

Management of wildfire

A fire management program should be developed and instigated with the major aim being to maintain much of the reserve as old-growth mallee. Given the high frequency and broad extent of wildfire in the past, this strategy will require a policy of fire exclusion and suppression for the foreseeable future.

Restocking

Recovery of depressed populations of malleefowl can be hastened by restocking rehabilitated habitat with translocated or captive-bred individuals. The publicity and educational opportunities associated with captive colonies can be beneficial in focusing public awareness on the environmental problems confronting malleefowl and mallee lands generally. Captive breeding, however, is expensive and should be undertaken only if populations have declined to such low levels that recovery of the extant population is unlikely to happen without it.

Captive colonies of malleefowl need not be intensively managed in the traditional sense. Large numbers of young malleefowl can be produced successfully by maintaining captive colonies *in situ* where they require only modest levels of maintenance and husbandry. On Yathong Nature Reserve, for example, breeding pairs are confined to large (1 ha) enclosures of native vegetation where their progenies are free to disperse into the surrounding natural habitat.

Monitoring of malleefowl populations

Regular monitoring is needed to track population trends and to assess the efficacy of recovery actions. In New South Wales, most malleefowl populations occur in such low densities that ground surveys are of only minimal value. Monitoring of malleefowl nests in these areas is best done from a helicopter. The high cost of such surveys restricts their widespread use, so priority should be given to those programs which aim to assess the efficacy of specific recovery actions. Global positioning systems technology (GPS) should be used to map nest locations and to relocate each nest during subsequent surveys. To facilitate ease of relocation, each nest should be marked with a numbered air cone marker.

Conservation strategy for small remnants

Although many small mallee remnants contain high quality habitat for malleefowl, i.e. old-growth mallee in high rainfall areas, these areas are logistically difficult and relatively expensive to manage. Nonetheless, the maintenance and recovery of malleefowl populations within these remnants are crucial if malleefowl are to be conserved throughout much of their former range.

All remaining stands of malleefowl habitat within the wheat-belt should be protected from further clearing. Much of this land, however, is freehold and the political reality is that regulations prohibiting clearance on land of this tenure have been difficult to impose or enforce. These areas are best protected through government acquisition and reservation or by conservation agreements established with the land-holder.

Secure remnants of mallee containing extant populations of malleefowl should be fenced to exclude foxes, and thereafter managed as sanctuaries for enclosed populations. A low-intensity program of fox control should be instigated to maintain the enclosed area fox-free. A community-based program of fox control should be developed to lower the density of foxes on surrounding properties and thereby reduce the incidence of foxes challenging the perimeter fence. Feral goats should be eradicated and rabbits should be controlled.

Where practicable, an area of agricultural land should be incorporated within the fenced area and regularly cropped so that malleefowl can feed on cereal stubble without moving outside the safety of the fence. Remnants in which malleefowl have become locally extinct should be fenced and managed in the same way once they have been repopulated with translocated or captive-bred individuals.

Conservation agreements should be negotiated with land-holders for the management of remnants on freehold land, and for the inclusion of arable land within fences surrounding reserves. It would be preferable to cease any ongoing commercial practices such as stock grazing, or the harvesting of timber, firewood, mallee leaf (for eucalyptus oil) or broombush *Melaleuca uncinata* (for brush fencing). This, however, need not be a mandatory requirement, and extractive practices could be allowed to continue provided there was evidence of at least moderate levels of population recovery.

A management program should be established to maintain and enhance genetic variability through the regular exchange of eggs between adjacent populations. Monitoring of population size and nesting activity can be done by regular ground-searching. GPS technology should be used to determine and map the location of each nest, and nests should also be marked with numbered tags. In addition, each nest should be dug up to confirm that the birds tending the nest are producing viable eggs.

Conclusions

The malleefowl is arguably the most studied of all megapodes. Despite some uncertainties, the mechanisms and threats responsible for the decline of the species are well understood. The challenge now is to implement a suite of recovery actions to halt the decline of this revered icon of Australia's arid lands and to successfully recover a number of populations. The recovery of malleefowl populations in New

South Wales will be difficult, but it is not beyond our capabilities. Fox control, the most demanding recovery action, is achievable, but only with the use of broad-scale aerial baiting in the west and exclusion fencing in the east. The control of other exotic pests to acceptable numbers can be achieved using conventional techniques provided efforts are adequately resourced and sustained. The long-term exclusion of wildfire is the one objective for which there exists the greatest degree of uncertainty in our ability to deliver. Well-developed fire management plans and policies, backed up by adequately resourced capabilities to prevent and suppress fires, will help reduce this uncertainty.

Recovery actions proposed for New South Wales may prove applicable elsewhere, but it is equally likely that somewhat different actions will be required to address different situations that exist elsewhere. Wherever recovery programs are undertaken their implementation will be reasonably costly, and success will be forthcoming only if there is a strong and sustained commitment of both will and resources.

References

Barker, R.D. & W.J. M. Vestjens, 1989. The Food of Australian Birds. I: Non-passerines.— Melbourne.

Benshemesh, J., 1989. Report on the establishment of sites for the monitoring of malleefowl populations: Operation Raleigh 1989.— Unpubl. Rep. Depart. Conserv., Forests & Lands, Melbourne.

Benshemesh, J., 1990. Management of Malleefowl with regard to fire: 206-11.— In: J.C. Noble, P.J. Joss & G.K. Jones, eds. The Mallee Lands: a Conservation Perspective. Melbourne.

Benshemesh, J., 1992. The conservation ecology of the malleefowl, with particular regard to fire.— Thesis, Monash University. Clayton.

Benshemesh, J. 1993. Recovery Plan Research Phase for the Malleefowl in Southern Australia.—Rep. to the Austr. Nat. Parks & Wildl. Endangered Species Program. Depart. Conserv. & Nat. Res., Mildura.

Benshemesh, J., 1997. Victorian update.— Around the Mounds 2: 1.

Benshemesh, J., 1998. Victorian update.— Around the Mounds 2: 2.

Blakers, M., S.J.J.F. Davies & P.N. Reilly, 1984. The Atlas of Australian Birds.— Melbourne.

Booth, D.T., 1985. Ecological physiology of Malleefowl (*Leipoa ocellata*).— Thesis, University of Adelaide, Adelaide.

Booth, D.T., 1986. Crop and gizzard contents of two Mallee fowl.— Emu 86: 51-53.

Booth, D.T., 1987. Home range and hatching success of Malleefowl, *Leipoa ocellata* Gould (Megapodiidae), in Murray mallee near Renmark, S.A.— Austr. Wildl. Res. 14: 95-104.

Bradstock, R.A., 1989. Relationships between fire regimes, plant species and fuels in mallee communities: 218-223.— In: J. Noble & R. Bradstock, eds. Mediterranean Landscapes in Australia: Mallee Ecosystems and Their Management. Melbourne.

Brandle, R., 1991. Malleefowl mound distribution & status in an area of the Murray Mallee of South Australia.— Unpubl. Rep. Nat. Conserv. Soc. South Australia Inc., Adelaide.

Brickhill, J., 1985. An aerial survey of nests of Malleefowl *Leipoa ocellata* Gould (Megapodiidae) in Central New South Wales.— Austr. Wildl. Res. 12: 257-261.

Brickhill, J., 1987a. The Conservation Status of Malleefowl in New South Wales.— Thesis, University of New England, Armidale.

Brickhill, J., 1987b. Breeding success of Malleefowl *Leipoa ocellata* in Central New South Wales.— Emu 87: 42-45.

Burbidge, A.A. & N.L. McKenzie, 1989. Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications.— Biol. Conserv. 50: 143-198.

Cheal, P.D., J. Day & C. Meredith, 1979. Fire in the national parks of north-western Victoria.— Melbourne.

Coman, B.J., 1973. The diet of red foxes, *Vulpes vulpes* L., in Victoria.— Austr. J. Zool. 21: 391-401.

Coman, B.J., 1983. Fox.— In: R. Strahan, ed. The Complete Book of Australian Mammals. Sydney.

Croft, J.D. & L.J. Hone, 1978. The stomach contents of foxes, *Vulpes vulpes*, collected in New South Wales.— Austr. Wildl. Res. 5: 85-92.

Friend, J.A., 1990. The numbat *Myrmecobius fasciatus* (Myrmecobidae): history of decline and potential for recovery.— Proc. ecol. Soc. Austr. 16: 369-377.

Friend, J.A. & N.D. Thomas, 1995. Reintroduction and the numbat recovery programme: 189-198.— In: M. Serena, ed. Reintroduction Biology of Australian and New Zealand Fauna. Chipping Norton.

Frith, H.J., 1956a. Breeding habits in the family Megapodiidae.— Ibis 98: 620-640.

Frith, H.J., 1956b. Temperature regulation in the nesting mounds of the Mallee-fowl, *Leipoa ocellata* Gould.— CSIRO Wildl. Res. 1: 79-95.

Frith, H.J., 1959. Breeding of the Malleefowl, *Leipoa ocellata* Gould (Megapodiidae).— CSIRO Wildl. Res. 4: 31-60.

Frith, H.J., 1962a. Conservation of the Mallee Fowl, *Leipoa ocellata* Gould (Megapodiidae).— CSIRO Wildl. Res. 7: 33-49.

Frith, H.J., 1962b. The Mallee-fowl: the Bird That Builds an Incubator.— Sydney.

Griffiths, F.J., 1954. Survey of the Lowan or Mallee-fowl in New South Wales.— Emu 54: 186-189.

Harlen, R. & D. Priddel, 1996. Potential food resources available to Malleefowl *Leipoa ocellata* in marginal mallee lands during drought.— Austr. J. Ecol. 21: 418-428.

Harlen, R. & D. Priddel, in press. Relationship between time since fire and food resources for Malleefowl *Leipoa ocellata* in marginal habitat.— Austr. J. Ecol.

Hill, D., 1989. Mallee eucalypt communities: their classification and biogeography: 93-108.— In: J.C. Noble & R.A. Bradstock, eds. Mediterranean Landscapes in Australia: Mallee Ecosystems and Their Management. Melbourne.

Hodgkinson, K.C., G.N. Harrington, G.F. Griffin, J.C. Noble & M.D. Young, 1984. Management of vegetation with fire: 141-156.— In: G.N. Harrington, A.D. Wilson & M.D. Young, eds. Management of Australia's Rangelands. Melbourne.

Kimber, R.G., 1985. The history of the Malleefowl in Central Australia.— R.A.O.U. Newsl. 64: 6-8.

Kinnear, J., M. Onus & B. Bromilow, 1984. Foxes, feral cats and rock wallabies.— Swans 14: 3-8.

Kinnear, J.E., M.L. Onus & R.N. Bromilow, 1988. Fox control and rock wallaby population dynamics.— Austr. Wildl. Res. 15: 435-50.

McIlroy, J.C. & E.J. Gifford, 1991. Effects on non-target animal populations of a rabbit trail-baiting campaign with 1080-poison.— Wildl. Res. 18: 315-325.

Mountford, C.P., 1950. Brown Men and Red Sand.— Sydney.

Noble, J.C., 1984. Mallee: 223-240.— In: G.N. Harrington, A.D. Wilson & M.D. Young, eds. Management of Australia's Rangelands. Melbourne.

Noble, J.C., 1989. Fire regimes and their influence on herbage and mallee coppice dynamics: 168-180.— In: J.C. Noble & R.A. Bradstock, eds. Mediterranean Landscapes in Australia: Mallee Ecosystems and Their Management. Melbourne.

Noble, J.C., D.J. Tongway, M.M. Roper & W.G. Whitford, 1996. Fire studies in mallee (*Eucalyptus* spp.) communities of western New South Wales: spatial and temporal fluxes in soil chemistry and soil biology following prescribed fire.— Pacific Conserv. Biol. 2: 398-413.

Pickard, J., 1988. Analysis of stocking records from 1884 to 1988 during the subdivision of Momba, the largest property in semi-arid New South Wales: 245-253.— In: D.A. Saunders, A.J.M. Hopkins & R.A. How, eds. Australian Ecosystems; 200 Years of Utilisation, Degradation and Reconstruction. Sydney.

Priddel, D., 1989. Conservation of Rare Fauna: the Regent Parrot and the Malleefowl: 243-249.— In: J.C. Noble & R.A. Bradstock, eds. Mediterranean Landscapes in Australia: Mallee Ecosystems and Their Management. Melbourne.

Priddel, D. & R. Wheeler, 1990. Survival of Malleefowl *Leipoa ocellata* chicks in the absence of ground-dwelling predators.— Emu 90: 81-87.

Priddel, D. & R. Wheeler, 1994. Mortality of captive-raised Malleefowl, *Leipoa ocellata*, released into a mallee remnant within the wheat-belt of New South Wales.— Wildl. Res. 21: 543-552.

Priddel, D. & R. Wheeler, 1996. Effect of age at release on the susceptibility of captive-reared Malleefowl *Leipoa ocellata* to predation by the introduced fox *Vulpes vulpes*.— Emu 96: 32-41.

Priddel, D. & R. Wheeler, 1997. Efficacy of fox control in reducing the mortality of released captive-reared Malleefowl, *Leipoa ocellata*.— Wildl. Res. 24: 469-482.

Rowley, I., 1975. Bird Life.— Sydney.

Specht, R.L., 1981. Major vegetation formations in Australia.— In: A. Keast, ed. Ecological Biogeography of Australia. The Hague.

Tarr, H.E., 1965. The Mallee-fowl in Wyperfeld National Park.— Australian Bird Watcher 2: 140-144.

Woinarski, J.C.Z., 1989. The vertebrate fauna of broombush *Melaleuca uncinata* vegetation in north-western Victoria, with reference to the effects of broombush harvesting.— Austr. Wildl. Res. 16: 217-238.

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