

Conservation of the Malleefowl: are there lessons from the successful conservation of native mammals by intensive fox control?

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Malleefowl and other ground-nesting birds have shown substantial contractions in range over the 200 years of European settlement and are believed to be at ongoing risk of further declines. One factor implicated in the decline of ground-nesting birds in general, and Malleefowl in particular, is predation by the introduced fox (Saunders *et al.* 1995: 126; Benshemesh 2000). However, these declines, as worrying as they may be, are dwarfed by the extent of decline among native mammals (Woinarski and Braithwaite 1990). At least eighteen species of mammal are extinct, many species that were formerly widespread now survive only on offshore islands, and many others persist only in small remnant populations. Recent management action to conserve mammals has been highly successful leading to substantial recoveries of local populations and the establishment of new populations by reintroduction. It may be that lessons learned in the conservation of mammals may be transferable to the conservation of the Malleefowl and other ground-nesting birds. This paper explores the historical parallels in the diagnosis of threatening factors in the decline of mammals and the decline of the Malleefowl, highlights recent successes in the conservation of mammals, and examines the evidence for and against a prominent role of foxes in the decline of Malleefowl.

Declines in ground-nesting birds and of mammals show many parallels. Declines in mammals, like declines in ground-nesting birds, have been particularly pronounced in the arid zone (Reid and Fleming 1992, Smith *et al.* 1994, Short and Smith 1994). Like mammals, ground nesting birds that occur on mainland Australia are often more abundant on offshore islands to which foxes have not gained entry (e.g. Bush Stone Curlews on Kangaroo Island: Ford 1979). There is also a similar tendency in species with a former extensive north-south range across continental Australia to contract northwards to areas where foxes are absent or rare (e.g. Australian Bustard: Grice *et al.* 1986; and the Nailtail Wallabies: Strahan 1995).

Benshemesh (2000) documented a contraction in the range of Malleefowl of about 50% within the past century, being most pronounced in arid areas and at the mesic peripheries of its former range. Habitat loss due to land clearing was a major factor in declines, particularly on the mesic margins of their former range, and grazing by sheep, goats and rabbits have played a significant part (Frith 1962a, b). The role of foxes was regarded as more controversial: “while some authors believe that fox predation is the main threat to Malleefowl populations and a major cause of their decline, others have considered Malleefowl populations resilient to high predation rates due to their life history and high fecundity.” (Benshemesh 1997: 25).

Fox – a brief profile

The European Red Fox occurs naturally throughout the continents of the Northern Hemisphere – Eurasia, North Africa and North America. It was introduced to

Victoria in 1871, spreading to South Australia by 1888, New South Wales by 1893, and Western Australia by 1912. Foxes colonised much of the southern part of mainland Australia but did not become established in parts of northern Australia and many offshore islands. Their spread from their initial release point was almost certainly facilitated by the prior spread of the European Rabbit. Foxes have a catholic diet ranging from insects, fruits, small to medium sized mammals, birds, reptiles and amphibian, carrion, and human rubbish (Saunders *et al.* 1995). Rabbits are a mainstay of their diet in many areas, typically followed in importance by house mice and sheep carrion. Foxes may surplus kill their prey (Short *et al.* 2002), often cache food for later consumption, typically occupy discrete territories, and are most active at night and at dawn and dusk. An important consequence of their catholic diet is that their numbers are not regulated by any one prey species; this factor makes them particularly effective at driving prey numbers of any particular species to low numbers or to extinction.

Foxes weigh up to 8 kg, with males slightly larger than females. Foxes breed once per year, with vixens typically coming into heat in mid-winter. Litter size varies from 4 to 10 cubs. Survival of cubs is often high and young become sexually mature from 10 months of age. Fox densities in rural areas vary from 0.2 to 7 per km² (Saunders *et al.* 1995), and tend to be abundant in the fragmented habitats of agricultural landscapes. High numbers (estimated at 2.5 per km²) have been recorded in semi-arid environments (Algar and Smith 1998) occupied by Malleefowl. Dispersal distances of cubs averaged 11 km in south-east Australia, with some movements up to 30 km (Coman *et al.* 1991). Dispersal distances in arid Western Australia averaged 43 km for males and 15 km for females (Saunders *et al.* 1995).

History of changing ideas regarding the status of mammals and ground-nesting birds

Table 1 provides a chronology of changing ideas about the primary cause or causes of loss of medium-sized mammals. Typically, native mammals were perceived to be an unlimited resource to be intensively harvested as food or for skins or for their bounty as agricultural pests (Jarman and Johnson 1977, Short and Milkovits 1990, Short 1998). By 1910, concerns were being expressed about the rate of harvest of many species and some legislation was introduced or strengthened to protect many species (Ovington 1978). Marshall (1966) described an early contraction in the range of Malleefowl from the Bendigo area in Victoria at this time that he attributed to hunting.

By 1920, predation by foxes was considered a major factor in the decline of many species of medium-sized mammals, many of which had declined so precipitously that naturalists attempted to gather up the remnants to put on fox-free islands (Finlayson 1927, Wood Jones 1923-25, Short *et al.* 1992, Copley 1994). Foxes were considered a primary cause of loss of Malleefowl during this same period. North (1917) described the fate of the species at Coolabah on the northern slopes of New South Wales: “the introduced foxes were rapidly getting rid of Malleefowl in that district, and one was now rarely seen, where formerly they were numerous.” Similarly, Craig (1926) viewed the fox as a great destroyer of ground birds. Malleefowl, along with many species of mammal, were introduced to fox-free Kangaroo Island at this time with releases in 1911, 1923, 1924, and 1936 (Copley 1994). Over 20 birds were released but the population did not persist.

The 1950s – 1970s were the heyday of CSIRO Wildlife Research and the studies carried out by the scientists of this division were extremely influential in the debate on the reasons for the ongoing decline of Australia's fauna. Key scientists were Basil Marlow (who documented the loss of mammals from New South Wales, which was greatest from inland areas where sheep and rabbits had had greatest impact: Marlow 1958), John Calaby (the decline of the numbat in Western Australia attributed largely to habitat loss: Calaby 1960), Harry Frith (the decline of the Malleefowl due to habitat loss and the impact of grazing in remaining areas of natural habitats: Frith 1962a and b), and Alan Newsome (the decline of the desert mammals attributed to the impact of the pastoral industry: Newsome 1971).

All these scientists considered the role of foxes in the decline of native fauna and rejected them as a key factor. A typical quote for mammals comes from Calaby (1960): "It is the author's belief that the role of the predators in the Numbat's decline has been much over-rated. ...the fox is probably not important as it hunts mostly at night when the Numbat is not active and is confined to its hollow-log shelters. Foxes and cats are abundant in all areas where the Numbat is still fairly common."

Similarly, Harry Frith believed that the role of the fox was overstated: "It is concluded that the fox is not the main cause of the decline of Malleefowl in uncleared areas. It is more probable that sheep, and perhaps rabbits, enter into direct competition with the birds for food." (Frith 1962a: 33). "... the majority of mallee-fowl chicks are doomed to die young. ... foxes ... harvest only the surplus, and their depredations on eggs have no effect on the ultimate numbers of mallee-fowl." (Frith 1962b: 114).

They favoured the impact of grazing by domestic stock and rabbits and the effect of land clearing. They ushered in a major and important period of land acquisition for nature conservation (sites where grazing would be excluded and that were protected from clearing). However, it has become increasingly clear that this was a necessary, but insufficient step to conserve the biota (Short and Smith 1994).

The late 1980s and 1990s saw an increasing emphasis on management of the conservation estate, prompted by the dramatic decline or loss of fauna from many nature reserves and the failure of reintroductions of mammals to others. Examples of the former include losses from Tutanning Nature Reserve (Southern Brown Bandicoot and Numbat: Friend and Thomas 1994; Kinnear *et al.* 2002), loss of rock-wallabies from isolated granite outcrops in the central wheatbelt of Western Australia (Querekin Rock: Kinnear *et al.* 2002); and the dramatic reduction in the sightings of Numbats at Dryandra Forest in the late 1970s and early 1980s (Friend and Thomas 1994). These losses were believed to coincide with a period of high fox numbers resulting from the phasing out of use of 'one-shot' oats to control rabbits following the introduction of the European rabbit flea to Western Australia in 1969 (Christensen 1980, King *et al.* 1985). The flea provided a vector additional to the mosquito to transmit myxomatosis and led to a widespread reduction in rabbit numbers.

Examples of management interventions to conserve native species included the manipulation of habitat by the creation of fire mosaics in the Gibson Desert (Christensen and Burrows 1994) and the control of predators, particularly foxes

(Kinneare *et al.* 1988; Friend 1990). The values of such interventions were tested by reintroducing native mammals – sometimes successfully, sometimes not. Almost all successes were linked to effective predator control (e.g. Brush-tailed Bettongs to 15 sites in Western Australia, mostly in the jarrah forest (Morris 2000); Burrowing Bettongs and Western Barred Bandicoots to Heirisson Prong in Western Australia: Short and Turner 2000, Richards and Short 2003). Almost all failures were due to ineffective predator management (e.g. Parma Wallabies to Robertson in New South Wales: Short *et al.* 1992; Golden Bandicoots and Burrowing Bettongs to the Gibson Desert: Christensen and Burrows 1994).

The Numbat has been a particular success story – responding to effective predator control at Dryandra – and being successfully reintroduced to seven other sites in Western Australia where predators were effectively managed (Friend 1990; Friend and Thomas 1994; Orell 2003). Reintroduction sites include Dragon Rocks, Boyagin, Tutanning, and Karroun Hill Nature Reserves, Batalling State Forest, Hills Forest and Stirling Ranges National Park. Clearly, the diagnosis of Calaby (1960) has not survived the test of time. The Numbat shares many life history attributes with Malleefowl (Table 2), perhaps suggesting the need for similar management regimes for both species to ensure their conservation.

Other successes linked to control of foxes and/or feral cats in the 1990s include:

- Isolated rock-wallaby populations in agricultural landscape have increased 5 or 6-fold in abundance following fox control (Kinneare *et al.* 1988, 1998);
- Official downlisting of the threat status of tammar wallaby, southern brown bandicoot, and brush-tailed bettong in Western Australia (Morris *et al.* 1998);
- Over 80 reintroductions in Western Australia of 24 species from 1990-9 (Morris 2000);
- Rediscovery of the ‘extinct’ Gilbert’s Potoroo in the south-west in an area managed to exclude foxes (Sinclair *et al.* 1996);
- A reintroduced population of Burrowing Bettong has been extant for > 10 years (Short and Turner 2000). The last museum record of this species on mainland Australia was in 1942, 50 years prior to the successful reintroduction.

Foxes and Malleefowl

Early observers such as Griffiths (1954) in New South Wales and Ford and Stone (1957) in Western Australia attributed the decline of Malleefowl to foxes. However, Frith (1962a, b), who conducted a detailed study of the species in New South Wales, assembled a range of arguments to suggest that foxes were not the primary cause of loss of Malleefowl. They included: the high fecundity of Malleefowl; a history of exploitation of eggs, with predation by foxes merely replacing earlier exploitation by Aborigines, dingoes and early settlers; the lack of evidence of high levels of consumption of Malleefowl, particularly chicks, from the examination of fox scats; and the abundance of Malleefowl in areas where foxes were also abundant.

Frith’s chief argument for dismissing a pivotal role for fox predation was a mathematical argument based on their high fecundity. He established that a pair of Malleefowl produced an average of 19 eggs per annum and that the female may breed for eight years (Frith 1962a). Thus the pair may produce as many as 160 eggs in their lifetime but require just two birds from these eggs to survive to reproductive age to

replace themselves. He established that fox predation on eggs was high, with 37% of eggs being lost (Frith 1962a). However, he considered that predation on chicks was low with a brief period of vulnerability immediately after hatching (Frith 1962b). He believed chicks rapidly acquired behaviours that made them less likely to be predated (roosting in trees at night and an escape response to terrestrial predators of flying into trees to hang upside down from a clump of leaves!).

Just as recent research on numbats has changed the perception of the relative importance on fox predation to that derived from research in the 1950s so recent work on Malleefowl has changed the perception of the impact of foxes from that of studies carried out in the 1950s. Priddel and Wheeler (1994, 1996, 1997, and 2003) reported fox predation on Malleefowl at all stages of their life cycle from eggs, newly-hatched, juveniles, sub-adults and adults.

Priddel and Wheeler have shown that predation on chicks is very high in the presence of uncontrolled fox populations – to the point that no reintroduced chicks survived (Table 3). Predation was particularly pronounced for younger birds and in the first days after release. Subsequent work has revealed some natural recruitment into populations, but insufficient to account for adult mortality (Priddel and Wheeler 2003). They also showed that adult deaths were very high, linked in part to drought.

Overall they believed Malleefowl were undergoing major decline, in both grazed and ungrazed sites, and in small fragmented sites surrounded by farmland as well as large areas of contiguous habitat. Declines occurred despite sites being long unburned, a factor known to have a major impact on Malleefowl densities (Benshemesh 1992).

Malleefowl have been introduced also to Peron Peninsula at Shark Bay in Western Australia (Morris *et al.* 2003). Peron is free of foxes, all having been eliminated by aerial baiting following the construction of a barrier fence across the narrow neck of the peninsula in 1995. It was a pastoral station but sheep were largely removed in the mid-1990s and the goat population reduced from *c.* 15,000 (15 per km²) to < 400 by 2001. Malleefowl were released in 1997 and 1998. Birds were raised to 6-12 months in captivity from eggs sourced from Wubin in the northern wheatbelt, Kalbarri National Park, and from Nanga Station at Shark Bay. Ninety percent of 67 birds released survived for greater than six months, far higher than that of birds released in a nature reserve in eastern Australia where foxes were still present (Table 3). At least six active mounds have been detected since the release and there have been some sightings of chicks (Morris *et al.* 2003).

The relevance of the results of Table 3 to the successful recruitment of Malleefowl in the wild has been questioned. Benshemesh (pers. comm.) has argued that mortality rates for released birds raised in captivity burdened with radio-collars may not reflect that of wild-born birds. Nonetheless, captive reared and radio-collared birds released to fox-free habitat have persisted; captive reared and radio-collared birds released in the presence of foxes have not.

Does the high fecundity of Malleefowl counter the impact of fox predation?

A key difference between the ecology of Malleefowl and that of many native mammals is the high fecundity of Malleefowl. This attribute of the life history of Malleefowl has been considered to provide substantial protection from the impacts of

foxes (Frith 1962a, b). Frith believed that losses of Malleefowl eggs to foxes was merely the loss of a “doomed surplus” – invoking Errington’s (1946) view that predators take only the excess production of a prey population. Errington conducted a 25-year study of predation of musk rats by mink in the marshes of Iowa and believed that the number of musk rats was determined by territorial behaviour with surplus animals excluded by such social behaviour doomed to die.

Banks *et al.* (1999) tested Errington’s hypothesis for the native bush rat in south-eastern Australia. This species has litter sizes of from 3-5 and can produce up to three litters in 93 days so has a fecundity considerably closer to that of Malleefowl than many of the mammals discussed above (Table 2). Banks *et al.* (1999) controlled foxes in two areas of 10-18 km² but not in two others. Rats were monitored in each to assess whether rats would increase in areas of fox control (and so be deemed predator limited) or remain relatively stable (foxes merely removing rats that were doomed to die from other causes). Rats failed to increase over two breeding seasons supporting the “doomed surplus” hypothesis. However, populations of Bush rats in south-western Australia have shown variable responses to broad-area control of foxes (Orell 2003). Populations were monitored at 14 sites, with seven showing an increase, three showing no trend, and four showing a decrease. It seems likely that factors such as vegetation density (linked both to annual average rainfall and immediate past fire history), inter-specific interactions with other species, and drought may have influenced the outcomes.

Malleefowl and bush rats share similar high fecundities, but differ in three important respects. Bush rats are likely to be buffered from fox predation by their choice of habitat and their short developmental period to sexual maturity. On the other hand, Malleefowl are long-lived relative to Bush rats and therefore have the opportunity to produce young over a greater number of breeding seasons. Bush rats have a preference for dense understorey in mesic locations around the coastal margins of southern and eastern Australia. Their density is strongly related to cover, with their numbers being greatly reduced by the opening up of habitat by fire and logging (Lunney 1995). In addition, they mature at 7 weeks of age and so are exposed to predation for a relatively short time before breeding (in contrast to the 3-4 years of Malleefowl: Benshemesh 2000). Bush rats have remained common in mesic parts of their range (such as in the dense vegetation of wet gullies and coastal scrub) but are now absent in drier sites on the inland margins of their former ranges. Malleefowl occupy a broad range of habitat densities but, like bush rats, appear to have persisted best in habitat which provides good cover. Malleefowl are potentially long-lived (cf. Priddel and Wheeler 2003), provided they survive to adulthood, and this means they can potentially produce young over many seasons and this may provide some protection from fox predation.

Hence, the impact of foxes is likely to be greatest in habitats of lower overall productivity for Malleefowl (in part, a function of lower rainfall) and where the frequency and impact of drought is greatest. In general terms, this means a greater impact in more arid habitat. Such an effect may be exacerbated by more open habitat in drier areas facilitating higher levels of predation. This may be why there appears to be a difference in scale of impact of foxes on Malleefowl between sites in New South Wales and Victoria (Priddel and Wheeler 1997 cf. Benshemesh *et al.* 2002). Detected trends in Malleefowl abundance over time tend to suggest relatively stable numbers at

some sites in Victoria, but a declining trend in New South Wales and north-western Victoria in relatively low rainfall areas of their range.

Predation interacting with other factors

A limitation of past studies of Malleefowl is that the effect of predation is not effectively separated from habitat quality. Grazing by sheep, goats and rabbits and harvesting of brushwood may have impacted the results of these studies, particularly studies in New South Wales (Benshemesh, pers. com.). For example, all experimental releases of Malleefowl to Yathong Nature Reserve detailed in Table 3 were prior to 1994 and apparently before effective control of goats was achieved by closing off watering points and by commercial harvesting (Priddel and Wheeler 1999, Benshemesh 2000). However, survival of released Malleefowl was greatly enhanced at Yathong with the expansion of the area of fox control, implicating fox predation as a primary cause of loss irrespective of the level of grazing (Priddel and Wheeler 1999). Similarly, there was low survival of released birds at Ferries-McDonald in South Australia in the presence of high fox numbers despite this site being long-unburnt and with dense impenetrable stands of mallee indicating few exotic grazers (Table 3 and D. Priddel, pers. comm.). Highest survival (at Peron in Western Australia) has come with the total elimination of foxes from a fenced peninsula of a 1000 km². This site is in a habitat of *Acacia* shrubland where grazing pressure from sheep had been largely eliminated and that of goats reduced.

Land clearing for agriculture has resulted in a major loss of habitat. Frith's study was conducted at a site north of Griffith, New South Wales with an area of 2200 ha in 1954. Three years later, this was reduced to just 180 ha (8% of the original area), resulting in a reduction of the Malleefowl population from 37 to 11 breeding pairs (Frith 1973). Malleefowl are likely to be subject to greater rates of predation in the small remnants of habitat that persist after clearing.

A range of factors other than predation are known or believed to be important in the persistence of Malleefowl. These include the impact of sheep grazing (Frith 1962a, b), altered fire regimes (Benshemesh 1992), drought (Priddel and Wheeler 2003), and avian predation (Priddel and Wheeler 1990, 1997). Predation by both foxes, other terrestrial predators (feral cats) and avian predators, appears strongly linked to vegetation density and this density is, in turn, linked to grazing, fire and drought. There is anecdotal evidence that predation by foxes on Malleefowl may also be intensified at times when there is a sudden reduction in their food supply, as has occurred with the loss of rabbits to diseases such as myxomatosis and caliche virus (Lloyd 1998, Benshemesh 2000). Benshemesh (2000) has cited evidence for a higher loss of Malleefowl eggs to foxes at these times.

Food shortage was a major factor in loss of birds released at one week of age into 1 ha pens of mallee habitat (Priddel and Wheeler 1990) and may also have been a factor in loss of juveniles released to the wild (Priddel and Wheeler 1996). The increased time spent foraging in the open when food was in short supply appeared to increase vulnerability to predation from both foxes and avian predators. Food availability is likely to be closely linked to grazing regime and fire history. Rabbits may also influence food availability as well as boosting numbers of both foxes and avian predators. Their control may be an effective way of reducing predation (Priddel and Wheeler 1997). Feral cats have been implicated in the loss of chicks in some

reintroductions. They are known to increase in abundance in semi-arid environments following the control of foxes (Risbey *et al.* 2000) – an effect known as a meso-predator release.

Fox control and Malleefowl conservation

If foxes are a major threatening process for Malleefowl then we would expect broad-area fox control to result in an increase in the abundance and distribution of Malleefowl. In Western Australia, the Department of Conservation and Land Management launched the Western Shield program in 1996 to control foxes in 36,000 km² (= 3.6 million ha) of the south-west. Some 780,000 baits per annum are laid to control foxes. Baits are laid from the air at a density of 5/km² with a frequency of four times per year over the forest areas and larger reserves. Isolated wheatbelt reserves < 20,000 ha in area are baited monthly from the ground. The response of mammals to this baiting is assessed at forty monitoring sites scattered throughout south-west Western Australia (Orell 2003). Unfortunately, no such extensive monitoring program is available for assessing changes in abundance of Malleefowl. Sightings of Malleefowl are collated by community groups such as the Malleefowl Preservation Group (MPG) and the North-Central Malleefowl Preservation Group and by a limited number of grid searches by the MPG in the far south-west. An adequate assessment of changes in abundance of Malleefowl over time is likely to require the continued monitoring of active mounds on an expanded network of grids and this has been recommended in the Recovery Plan (Benshemesh 2000).

An example cited to suggest that fox control may not bring the same benefits to Malleefowl as to mammals is that of Dryandra Forest in the Western Australian wheatbelt (Priddel and Wheeler 1997: 480; Benshemesh 2000). This reserve has been the site of fox control since 1982 to benefit Numbats, Brush-tailed Bettongs, Tammar Wallabies and a suite of other mammals (Friend and Thomas 1994). There are occasional Malleefowl sightings at Dryandra but there has been no obvious recovery of the species. However, this site is neither mallee nor *Acacia* shrubland, being predominantly brown mallet, wandoo and powderbark wandoo woodlands with a lack of *Acacia* shrubs in the understorey. Hence it may be marginal or unsuitable habitat for Malleefowl. The most likely food plant for Malleefowl at Dryandra is sandplain poison *Gastrolobium microcarpum*, a legume which forms a dense understorey monoculture through much of the reserve. Malleefowl have an approximate lethal dose (ALD) of 100-125 mg/kg (King *et al.* 1996), and birds could plausibly exceed this if they feed extensively on the seeds of this species. The air-dried foliage of *G. microcarpum* contains up to 600 mg/kg of the poisonous compound sodium fluoroacetate in its leaves (Aplin *et al.* 1983) and this compound may be up to three times more concentrated in seeds (Twigg and King 1991). Hence a Malleefowl would need to consume about *c.* 10% of its body weight in seed per day to have a 10% chance of death. A variant of this hypothesis, if birds can limit their intake to reduce their exposure to the poison, is that birds may face critical food shortages in the midst of a surfeit of leguminous seed.

Typically, baiting programs in eastern Australia lack the scale, bait density and frequency of application required to effectively reduce fox numbers to a level likely to benefit threatened species. Benshemesh (1997) has described baiting regimes on two grids in north-west Victoria. The baiting regime of 15 baits per month in a 320 ha grid at Wathe Flora and Fauna Reserve (with a total area of 5900 ha), and a spring

baiting at “about a dozen bait stations around the reserve” at Wandown Flora and Fauna Reserve (2750 ha) are inadequate to effectively control foxes. This intensity and scale of baiting can be compared with baiting regimes for mammals in Western Australia (see above) and for Malleefowl in western New South Wales (Priddel and Wheeler 1997, 1999).

An example of an effective regime from Western Australia is the community baiting of Heirisson Prong at Shark Bay to protect a suite of threatened mammals (Short and Turner 2000). This involves a twice-yearly baiting of a 20-km deep buffer beyond the reserve at 5 baits per km² and monthly baiting of the actual reserve and the adjacent road corridors where foxes might approach the reserve. Dried meat baits are used that have a life of up to one month (resulting in baits being present at all times) and that have the bulk (120 g fresh meat dried to *c.* 40 g) to limit intake by non-target species.

There is an important role for fox control by rural communities to protect Malleefowl. Communities can enhance actions in existing reserves known to contain Malleefowl by greatly expanding the area of fox control. The effectiveness of control operations against foxes is greatly enhanced as the area subject to baiting increases. Such baiting programs are already being undertaken across the range of the Malleefowl and could profitably be greatly expanded.

Summary

Fox control has been demonstrated to be pivotal to mammal recovery in Australia, despite a 30+ year history of reservations from many scientists. The perceived primary cause(s) of decline of Malleefowl has varied over time in a pattern similar to that of mammals, with periods of scepticism regarding the role of fox predation. Foxes are known to impact on Malleefowl at all stages of their life cycle and effective fox control is a necessary part of any recovery program. Malleefowl differ from threatened mammals in their higher fecundity and some authors believe that this may buffer Malleefowl from fox predation in some environments. These appear to be sites with dense understorey, lower incidence of drought, and reliable food supplies on the southern margins of the species' range. High fecundity linked with utilization of dense habitat appears to confer some protection from foxes to mammal species such as Bush rats. However, even in such an apparently robust species, effective fox control results in increases in abundance at many sites. There are considerable opportunities for rural communities in both cropping and pastoral areas to supplement existing baiting programs in reserves or to initiate new programs in areas where there are remnant populations of Malleefowl. Their actions may greatly enhance the effectiveness of fox control by expanding the area subject to control.

Malleefowl have been shown to be sensitive to a range of threatening processes in addition to fox predation. It seems likely that fox control alone will not be sufficient to permit recovery and is certainly not an alternative to good holistic land management. Malleefowl will benefit greatly from effective management of exotic grazers (sheep, goats, and rabbits) and of fire (to maintain substantial areas of long unburnt habitat).

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Table 1: Changing perceptions of mammal decline

Years	Status	Primary cause(s)	Sources
1860-80s	Over abundant	loss of Aborigines, dingoes	Jarman and Johnson 1977
1900-10s	Declining	excessive hunting	Lucas and Le Souef 1909
1920-30s	Declining	foxes, rabbits ...	Le Souef 1923; Troughton 1938, Short and Calaby 2001
1950-1970s	Declining	grazing stock, rabbits	Calaby 1960, Frith 1962a, b, Newsome 1971
1980s	Declining	lack of fire mosaic	Kitchener <i>et al.</i> 1980; Burbidge <i>et al.</i> 1988
1990s	Declining	foxes, cats	Kinnear <i>et al.</i> 1988; Friend 1990; Short and Smith 1994

Table 2: Comparative life history attributes of Malleefowl, Numbat, and Bush Rat

Species	Activity	Shelter	Reproductive output p.a.	Range	Susceptibility to aerial predation	Remaining strongholds
Malleefowl	Diurnal	Roost in trees, laboured flight	10-24 eggs	Semi-arid and arid woodland and shrubland	High	Uncleared areas towards mesic margins of former range
Numbat	Diurnal	Hollow logs	2-4	Semi-arid and arid woodland and shrubland	High	Mesic margins of former range
Bush rat	Nocturnal	Dense ground cover	c. 10 - 15	Forest and coastal scrub	Moderate	Mesic margins of former range

Table 3: Survival of reintroduced Malleefowl

Location	Foxes	Birds released	Age of birds	Food supplementation	Survival	Proportion lost to predation [^]	Proportion lost to food shortage or exposure	Source
Yathong, NSW	Absent	9	1 week	Yes	89% ^{##}	0%	11%	Priddel & Wheeler 1990
Yathong, NSW	Absent	20	1 week	No	0% ^{##}	30% [^]	50%	Priddel & Wheeler 1990
Wyperfeld, Vic	Abundant?	21	< 1 week	No	<25% [#]	48%	14%	Benshemesh 1992
Yalgogrin, NSW	Abundant	17	0-5 months	No	0% ^{**}	88%	6%	Priddel & Wheeler 1994
Yalgogrin, NSW	Abundant	15	3-6 months	Yes	0% ^{**}	93%	7%	Priddel & Wheeler 1994
Yathong, NSW	Abundant	24	3-5 months	No	4% ^{**}	87%	0%	Priddel & Wheeler 1996
Yathong, NSW	Abundant	12	14-28 months	No	25% ^{**}	58%	0%	Priddel & Wheeler 1996
Bakara, SA	n.d.	15	n.d.	No	13% [*]	100%	n.d.	Williams 1995
Ferries-McDonald, SA	n.d.	n.d.	n.d.	No	36% ^{##}	100%	n.d.	Williams 1995
Yathong, NSW	Low	24	6-9 months	No	29%	88%	0%	Priddel & Wheeler 1997
Yathong, NSW	Low	24	4-5 months	No	25%	96%	0%	Priddel & Wheeler 1997
Yathong, NSW	Ext. low	24	6-8 months	No	75% ^{***}	21%	4%	Priddel & Wheeler 1999; Priddel, pers. comm.
Peron, WA	Eliminated	67	6-12 months	No	90% ^{***}	0%	n.d.	Morris <i>et al.</i> 2003

[^] includes birds lost to avian predators; [#] survival to 10 days; ^{##} survival to 30 days; ^{*} survival to 2 months; ^{**} survival to 3 months; ^{***} survival to 6 months; n.d. no data