

Nesting activity and demography of an isolated population of malleefowl (*Leipoa ocellata*)

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Abstract. Nesting activity of a population of malleefowl (*Leipoa ocellata*), isolated within a small mallee remnant in central New South Wales, was monitored annually between the summers of 1986–87 and 1998–99. A total of 148 nesting events was recorded. Only once was a new mound constructed rather than an old one reworked. Birds began and finished work on the mound progressively later each month (October to January). Nest-site fidelity was highly variable; some pairs persisted with the same mound for up to nine years while others relocated between a cluster of two, three or four mounds. Males displayed greater nest-site fidelity than females. After the loss of a partner, males tended to continue to use mounds they had used previously whereas females often relocated to a new mound. All individuals were monogamous. Pair bonds were maintained for life but, following the death of a partner, new bonds were quickly established with another unattached individual. Established pairs occasionally failed to breed, all such failures being coincident with years of low rainfall. Pairs that did not breed generally began construction of a nest but failed to complete the task. As far as can be ascertained, unpaired birds did not construct nests. The malleefowl population was characterised by a rapid turnover of breeding individuals, a high rate of adult mortality and a lesser rate of recruitment. The maximum longevity recorded for breeding adults was 12 years; average longevity was 7.5 years. Twenty-five adults were lost from the breeding population over a period of 9 years; meanwhile, 14 birds entered the breeding population. Thus, the ratio of adult mortality to recruitment was 1.79:1.00. Between 1986–87 and 1997–98 the population declined from at least 32 breeding adults to 14, at an average exponential rate of decrease of 0.075. Large population decreases were coincident with years of low rainfall. This population of malleefowl is predicted to become extinct by 2008.

Introduction

The malleefowl (*Leipoa ocellata*) has undergone a substantial decline in geographic range and population abundance since European settlement of Australia (Benshemesh 2000). An almost continuous distribution across most of southern mainland Australia has been replaced by scattered, isolated and contracting remnant populations (Blakers *et al.* 1984). The decline in abundance, although widespread, has been particularly severe in central New South Wales where much of the malleefowl's habitat has been cleared for cropping or pastoralism (Frith 1962*a*; Brickhill 1987*a*). Malleefowl populations within remaining remnants of native vegetation either persist at very low densities (Brickhill 1985) or are extinct (Priddel and Wheeler 1994). The prospects for the long-term conservation of small isolated populations of malleefowl are poor (Benshemesh 2000).

The malleefowl has been the subject of several ecological studies (see reviews by Jones 1989; Priddel and Wheeler 1999; Benshemesh 2000). These studies have identified several causes of malleefowl decline. They include land clearing (Frith 1962*a*; Brickhill 1987*b*), grazing by stock and other exotic herbivores (Frith 1962*a*), increased frequency and extent of wildfire (Benshemesh 1992), predation by the introduced red fox (*Vulpes vulpes*) (Frith 1962*a*; Priddel and Wheeler 1994, 1996) and, possibly, competition from increased numbers of kangaroos (Benshemesh 2000). The relative importance of each of these threats is not known.

Investigations into the survival of young malleefowl have found that the principal causes of chick and juvenile mortality are starvation and predation by foxes (Priddel and Wheeler 1990, 1994, 1996; Benshemesh 1992). In a population at Yalgogrin, in central New South Wales, the rate of mortality due to foxes was so high that it raised the

possibility of there being little or no recruitment into the adult breeding population (Priddel and Wheeler 1994). This population is the subject of the current study.

Malleefowl that do attain breeding age are thought to be long-lived (Benshemesh 2000). Thus, if recruitment was not occurring, the population would be heavily skewed towards a high proportion of old individuals. The inevitable demise of such an aging population is likely to be preceded by a decline in reproductive output and a rise in infertility as individuals within the population approach senescence. Incidences of low fecundity and poor hatchability of eggs have been observed in several small, remnant malleefowl populations prior to their extinction (Priddel and Wheeler 1994), adding weight to the hypothesis that, in some populations, recruitment may be absent or, at best, reduced to extremely low levels.

The adequacy of recruitment is fundamental to the conservation of the malleefowl (Benshemesh 2000). Currently, nothing is known about recruitment, including whether it occurs regularly, spasmodically or not at all. If recruitment does occur, it is not known under what conditions it happens, or whether current levels are sufficient to maintain present populations. There has been no study of malleefowl population dynamics, and virtually nothing is known about any aspect of malleefowl demography, including recruitment, adult mortality, longevity and the age structure of populations.

Recovery actions to address the known causes of malleefowl mortality and habitat degradation (Benshemesh 2000) have had to be developed in the absence of any demographic information. Several of these actions are currently being implemented, and the size of many populations is presently being monitored. The lack of basic demographic information, however, means that it is not yet possible to adequately model malleefowl population dynamics. Without such predictive modelling, it will be difficult to determine the long-term viability of populations or to assess how successful the recovery actions are in arresting the decline of the species.

This long-term study investigated the nesting activity and demographics of an isolated, remnant population of malleefowl in central New South Wales. By marking and monitoring the entire breeding population over many years the study aimed to determine the rates of recruitment and adult mortality, longevity, population trends, nest-site fidelity and mate fidelity. Fecundity, clutch size and hatching success were also investigated, but the findings of these studies are to be reported elsewhere.

Study site

This study focused on a population of malleefowl inhabiting a small (558 ha) remnant of native vegetation near Yalgogrin (33°49'S, 146°46'E) in central New South Wales. This mallee remnant was completely surrounded by large expanses of agricultural land, most of

which had been cleared in the 1920s (Hardinge and Payne 1989; Ryan 1990) and used chiefly for wheat and sheep production. This particular remnant had been left uncleared because its stony soils made it unsuitable for cropping. It served as shelter for stock, which were allowed to graze the paddocks (and the remnant vegetation) whenever the paddocks were fallowed. Throughout the study, sheep usually had access to a major portion of the remnant, and cattle could sometimes access an area of ~90 ha at the southern end.

Patches of mallee eucalypts (see below) within the remnant had been repeatedly harvested for the production of eucalyptus oil, a practice that began in the 1930s (Hardinge and Payne 1989) and which continues today. One form of harvesting involved removing, by hand, only the outermost branches and foliage of mature trees, but most harvesting was done mechanically and entailed the complete removal of all above-ground vegetation. The eucalypts regenerate from underground lignotubers. Nowadays, the processed plant material that remains after the eucalyptus oil has been extracted is returned as mulch. Approximately 40% of the remnant has been subjected to harvesting, creating a mosaic of mature vegetation (unburnt for more than 60 years) interspersed with patches of regenerating coppice of 1–10 years growth. Broombush (*Melaleuca uncinata*) has also been regularly and selectively harvested for sale as fencing material. Occasionally, small trees were felled for fence posts and dead trees taken for firewood.

At the commencement of the study, the remnant was at the juncture of three different freehold properties, but this increased to four in 1991 when the northernmost property was sold and subdivided. The properties were separated by 1-m-high stock fences that were of little impediment to malleefowl. As malleefowl do not fly or disperse across open country (Frith 1962*b*; Benshemesh 2000), the population within the remnant was considered to be a closed population with no immigration or emigration occurring. Aside from its isolation, this population was chosen because it was relatively large (>16 pairs) and some ecological information was available from a previous study (Brickhill 1987*a*, 1987*b*).

The nearby town of West Wyalong, 40 km to the east of the study site, receives a mean annual rainfall of 487 mm spread evenly between seasons (Commonwealth Bureau of Meteorology database). Mallee in such relatively high-rainfall areas is optimal habitat for malleefowl (Frith 1962*a*). The soils in the study site were stony, heavy-textured red-brown earths with copious calcrete nodules. Canopy vegetation was dominated by red ironbark (*Eucalyptus sideroxylon*), green mallee (*E. viridis*), blue mallee (*E. polybractea*), bull mallee (*E. behriana*), grey box (*E. microcarpa*) and white cypress pine (*Callitris glaucophylla*). The shrub layer was varied and included broombush, Wyalong wattle (*Acacia difformis*), golden-topped wattle (*A. tindaleae*), wedged-leafed hopbush (*Dodonaea cuneata*), shiny daisy bush (*Olearia tenuifolia*) and heath daisy bush (*O. floribunda*). Tangle vine (*Cassytha melantha*) grew in profusion in some areas. The herb layer was composed predominantly of perennial grasses with scattered forbs of the genera *Calotis*, *Helichrysum* and *Goodenia*.

Methods

Location of malleefowl nests

Malleefowl construct incubation mounds of soil and leaf litter, typically ~4 m in diameter and 1 m high, into which they lay their eggs. Heat generated by microbial decay of the central core of litter provides the warmth necessary to incubate the eggs (Frith 1959). In the latter part of the season the heat from microbial decomposition is supplemented by incident solar radiation. By regularly opening and closing the mound, malleefowl are able to maintain the internal temperature of the egg chamber to within a few degrees of the optimum required for incubation (34°C: Booth 1987*a*). Malleefowl nest mounds are prominent structures, typically comprising ~6 m³ of material, which persist for many years.

In October 1986, the study area was searched on foot to locate malleefowl nest mounds. The search was conducted by a line of 18 people, spaced 10 m apart, walking abreast along a fixed compass bearing. The precise position of each mound was plotted on an aerial photograph, and a numbered metal disc was nailed to the base of the nearest tree. In subsequent years, additional mounds were located by following birds that were observed repeatedly in an area where no active mound was known. The survey was repeated in 1989, 1992 and 1997 to locate any newly constructed mounds, or mounds that may have been missed previously. During the last two surveys, the extremity of each transect was delineated by the searcher at the distal end of the line trailing a thin biodegradable thread from a dispenser (Hip-chain, Topometric Products, Canada). This thread was used as a guide for the alignment of the next transect, thereby ensuring that no area remained unsearched.

Each spring between 1986 and 1998, all known mounds were visited and inspected for signs of recent activity. Active, fully formed mounds were subsequently revisited to capture, mark or identify the birds working the nest.

Trapping of birds

Breeding birds were trapped by placing a walk-in funnel-trap (custom-made by Mascot Wire Works, Sydney) directly over the nest. The trap, measuring 1.8 m long \times 1.8 m wide \times 0.9 m high, was collapsible and comprised six panels and two funnels (Fig. 1). Each panel (1.8 m \times 0.9 m) consisted of a galvanised steel frame covered with 25-mm galvanised steel mesh. The six panels were hinged together with wire rings for ease of transport and erection. A 25-mm steel tube running the entire length of one top panel served to strengthen the roof of the trap. Downward-sloping funnels (53 cm wide and 57 cm high at the entrance, 20 cm \times 25 cm at the exit, and 71 cm long) were positioned on two sides, offset from each other as shown in Fig. 1. An outward-opening door (62 cm wide \times 73 cm high) provided access to retrieve trapped birds.

Trapping was conducted during the nesting season (October–February). Traps were set in late afternoon, and removed by 1100 hours the following day. Traps were placed only on mounds that were fully formed. A shallow trench was dug around the base of the trap until it sat evenly on the mound. Once the trap was seated appropriately, the trench

was backfilled. A few handfuls of cereal grain were scattered around the entrances to the trap, with a trail leading in through each funnel to a small pile in the interior of the trap.

Traps were either monitored remotely or by observers watching from hides. Those that were monitored remotely were fitted with two trip-lines of cotton string stretched across the exit to each funnel, inside the trap (Fig. 1). One end of each trip-line was secured to the trap; the other end was attached to a magnet positioned on one of two radio-transmitters placed on the roof of the trap. The magnet functioned as a switch, turning the transmitter on when positioned correctly and turning it off when dislodged. Any disturbance to the trip-line immediately rendered the transmitter inoperative. While traps were set, transmitter frequencies were scanned remotely from a base camp that was up to 2 km from the trap site. Any loss of radio-signal was investigated immediately. Observers in hides were in radio-contact with the base camp.

Captured malleefowl were quickly removed from the trap, placed into a cloth bag and weighed. Where practicable, the following morphometric measurements were taken using vernier calipers: tarsus length (with foot), culmen length (exposed) and head–bill length. Measurements followed Lowe (1989). Each bird was then fitted with a numbered stainless steel leg-band plus three coloured plastic leg-bands. The colours and arrangements of these bands were such that each bird was individually identifiable. Once banded, birds were released at the place of capture, and the trap was removed. Birds were held no longer than 10 min.

Trapping was conducted at each active nest where at least one bird was known to be unbanded. Additionally, birds that lost colour bands were re-trapped and fitted with replacement bands.

Observations of banded birds

Each year, all active nests were visited and observed until the birds working each nest were identified. Observations were made from portable hides erected near each nest. Hides were generally put in place 1–3 days before watches commenced and removed as soon as the identity of both birds had been established. Mound watches were undertaken between first light and 1000 hours, and occasionally between 1700 hours and sunset. Records were kept of the time at which each bird arrived at the mound, the time it left the mound and its activity while at the mound. Opportunistic sightings of banded birds away from the nest were also recorded.

Malleefowl are sexually monomorphic. The sex of banded birds was determined by their position during copulation or by observations of egg laying or the male's territorial display or booming call (Frith 1962b). The sex of the partners of known-sex birds was inferred.

Results

Number of nest mounds

A total of 72 nest mounds were located during the first survey, conducted in October 1986. Over the next three years the number of known mounds increased to 87 (Table 1), the last being located in December 1989. Thereafter, no additional mounds were found. Surveys in 1992 and 1997 located only mounds that were known previously.

Of the 15 mounds first found after 1986, only one (No. 113) is known to have been newly constructed. The 14 other mounds to be found after 1986 are all believed to have been missed in the initial survey. Ten mounds were small, indistinct and had clearly not been used for many years. Of the four substantive mounds, one contained a fallen tree that had obviously been there for several years, two were

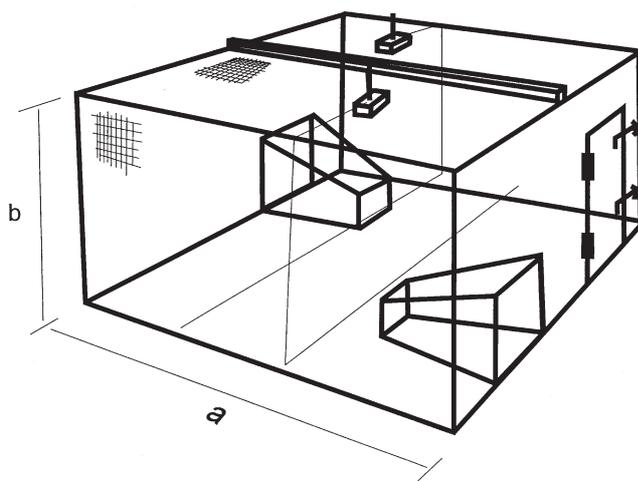


Fig. 1. Collapsible, walk-in trap used to capture malleefowl on the nest. The diagram shows a walk-in funnel on opposite sides of the trap, an access door on the right, a support beam across the roof, trip-lines running across the funnel entrances and two radio-transmitters placed on the roof. Dimensions: a = 180 cm, b = 90 cm.

Table 1. The number of active, incomplete, dormant and known malleefowl mounds, and annual rainfall (1986–87 to 1998–99) % incomplete, number of incomplete mounds as a percentage of the total number of active and incomplete mounds

	Year													Total
	1986–87	1987–88	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	
Active	16	12	12	12	11	10	12	12	5	9	8	7	5	131
Incomplete	2	1	0	1	1	4	1	0	4	1	0	2	0	17
% incomplete	11.1	7.7	0.0	7.7	8.3	28.6	7.7	0.0	44.4	10.0	0.0	22.2	0.0	
Dormant	54	60	64	74	75	73	74	75	78	77	79	78	82	
Known	72	73	76	87	87	87	87	87	87	87	87	87	87	
Rainfall (mm)	424	394	566	488	541	365	664	672	343	537	421	329	482	

concealed by dense broombush, and one was in an area of very low mallee regrowth that had not been searched in 1986.

Three of the mounds missed in 1986–87 were active when first found, one in 1987–88 (No. 94) and two in 1988–89 (Nos. 110 and 119). Each of these mounds may have been active during the years in which their existence was not known. Another missed mound (No. 126) was first found in 1989–90 and, although dormant when found, had been active recently. The number of active mounds present during the years 1986–87 to 1988–89, therefore, may have exceeded the number observed by as many as 4, 3 and 1 respectively.

In total, 148 nesting attempts were recorded during the period of this study (1986–87 to 1998–99, Table 1). Of these, 131 resulted in fully completed mounds, hereafter referred to as 'active'. Seventeen mounds were commenced but abandoned before being completed. These mounds are hereafter referred to as 'incomplete'. Mounds that were neither active nor incomplete are referred to as 'dormant'.

The number of active mounds ranged from at least 16 in 1986–87 to 5 in both 1994–95 and 1998–99 (Table 1). The low number of active mounds in 1994–95 coincided with a relatively large proportion of incomplete mounds (44.4%). This year was a period of particularly low rainfall (Table 1). Other years of low rainfall (1991–92 and 1997–98) were also characterised by a high proportion of incomplete nests (28.6% and 22.2% respectively) (Table 1). There was a significant negative, linear relationship between the proportion of incomplete nests and annual rainfall ($y = 540.7 - 5.442x$, $r = 0.632$, $F = 7.315$, $P = 0.02$).

Distribution of nest mounds

The 148 nesting events involved the use of 41 separate mounds. Forty-six mounds were not used at all during the study. Active mounds were distributed throughout the mallee remnant (Fig. 2), although expansive areas of tall forest that lacked undergrowth were generally void of mounds. Some active mounds were quite close together. Two particular mounds (Nos 2 and 3), for example, were separated by only 150 m yet both were used concurrently in five of the 13 years of observation. Another mound (No. 1) was only ~300 m from both these mounds, yet all three were used in 1986–87. Another three close mounds (Nos 24, 25 and 26) were also

used concurrently. The furthest distance between any two of these mounds was 240 m.

Some mounds were used regularly (up to 10 times during the 13-year study) whereas others were used only once. There appeared to be nothing particularly characteristic about those mounds that were used most frequently, or the habitat in which they were situated. Well used mounds were situated within ironbark forest (>10 m tall), whipstick mallee (~5 m) and mallee regrowth (1–3 m). Mounds were often sited at the interface between mature and regenerating mallee.

Only once was a new mound constructed. When first found, this mound (No. 113) was in the initial stages of construction. It was much smaller than other mounds and

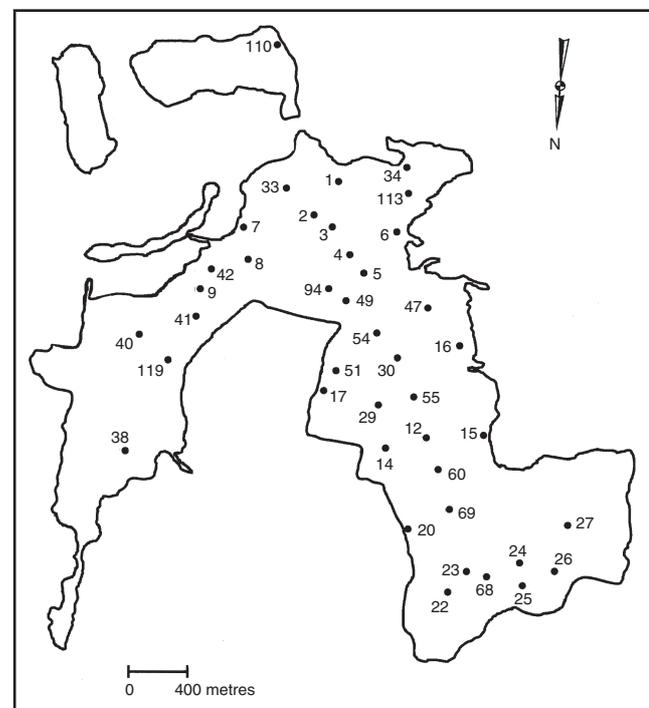


Fig. 2. Distribution of malleefowl nest mounds within the mallee remnant at Yalgogrin. Mounds shown are those that were used at least once during the study (1986–87 to 1998–99), including both active and incomplete mounds. Dormant mounds (those not used during the study) are not shown.

lacked sufficient soil to adequately cover the egg chamber. No eggs were laid into it during this first year (1989–90). The same mound was used again the following year and although substantially larger, it still did not have a sufficiently thick covering of soil to function effectively. Three eggs were laid into it, but none hatched. The mound was not used again. The identities of the birds that built this mound are not known. In the year following its construction (1990–91) the mound was worked by a pair of birds that had bred elsewhere during the previous year.

Trapping success

Trapping commenced in 1988–89. In total, 36 individuals were trapped, 34 of which were banded during this study, and two of which had been banded earlier by Brickhill (1987a). An additional four individuals were present within the population but were not trapped. Three did not require individual marking as they were readily identifiable from their characteristic plumage and size. The fourth individual, an unbanded female, bred in only one year and disappeared (presumably died) before it could be trapped.

Some birds entered traps readily, whereas others proved extremely difficult to capture, being reluctant to approach the nest when the trap was present. A single bird learnt that it could exit the trap through the entrance funnels. This bird was eventually caught after the addition of a one-way gate to each funnel. Once confined within the trap, most birds were content to feed on the scattered grain. Some birds attempted to excavate the mound and unearth the egg chamber despite the impediment of the trap. No entrapped bird appeared unduly stressed until humans approached the trap.

Measurements of culmen and head–bill were similar between sexes (Table 2). On average, males were 107 g heavier than females ($F_{1,35} = 7.2258$, $P = 0.0109$) and the tarsus was 3 mm longer ($F_{1,27} = 9.1001$, $P = 0.0055$). However, there was extensive overlap in these measurements between sexes (Table 2) so neither could be used as a reliable determinant of sex. Males tended to have thicker legs than females, many requiring bands with a 16-mm internal diameter rather than the 14-mm diameter bands used on all but one female. Comparable data from other studies are lacking, but measurements of small numbers of museum skins (Marchant and Higgins 1993) also show a tendency for males to be larger, particularly in the legs and feet.

Observations of banded birds

Most observations of birds on mounds were made between 0700 and 0930 hours, and 71% of all captures occurred during these times. Six birds (four males, two females) were trapped on the nest shortly before, or soon after, sunset.

Birds began and finished work on the mound progressively later as the breeding season proceeded ($F_{3,130} = 9.6019$, $P < 0.0001$; $F_{3,80} = 8.8754$, $P < 0.0001$), with work commencing an average of 24 min later and finishing an average of 27 min later each month between October and January (Table 3). This, together with the seasonal changes in the time of sunrise, meant that in October birds were commencing work ~43 min after sunrise whereas in November, December and January, work on the mound commenced ~90, 115 and 128 min after sunrise, respectively (Table 3). The duration of work performed on the mound during the morning observation period remained unchanged between months (mean = 117 min, $F_{3,80} = 0.5618$, $P = 0.6418$).

Males tended to remain at the mound for long periods, often resting within sight of the mound. Females, on the other hand, spent very little time at the mound. Only when the mound was being fully opened did the female usually stay for long. It should be noted, however, that some birds (particularly females) appeared extremely wary of the hide and its presence may have affected some birds' behaviour.

Banded malleefowl were often observed foraging among wheat stubble in adjacent paddocks during late afternoon and dusk. While in these paddocks, the birds did not venture far from cover, usually remaining within the shadows cast by surrounding vegetation. They quickly retreated to cover when approached or disturbed. Occasionally, individuals were observed roosting at night; males were seen close to the mound (within 10 m), whereas females were seen roosting up to 300 m away.

Nest-site fidelity

Nest-site fidelity was highly variable between pairs; some pairs used the same mound each year, others moved between mounds. Of the 10 pairs that nested together for 5 or more years, two pairs used four different mounds, two pairs used three mounds, four pairs used two mounds, and two pairs used only a single mound (Table 4). The typical pattern of mound usage was for a pair to rotate between mounds within

Table 2. Mass and morphometric measurements of male and female adult malleefowl

Measurement	Females				Males				P
	Range	Mean	s.d.	n	Range	Mean	s.d.	n	
Mass (g)	1680–2235	2031	151	17	1895–2360	2138	118	20	0.0109
Tarsus (mm)	85.2–95.2	91.4	2.9	15	91.1–98.5	94.4	2.4	14	0.0055
Culmen (mm)	27.8–33.5	30.1	1.6	12	26.5–32.0	29.7	1.6	12	n.s.
Head–bill (mm)	75.2–82.1	79.2	2.4	12	76.6–86.5	80.8	2.9	11	n.s.

Table 3. Time of day and duration that malleefowl were observed working their nest mounds during morning observation periods (first light to 1000 hours)
 Sunrise, mean monthly time of sunrise; Sun-to-start, mean interval between sunrise and start time. All times are Eastern Standard Time (EST)

	Month				P
	October	November	December	January	
Start time					
Mean (EST)	0641	0700	0722	0754	<0.0001
s.d. (min)	22	48	34	40	
n	25	28	60	21	
Finish time					
Mean (EST)	0816	0836	0910	0940	<0.0001
s.d. (min)	34	37	38	42	
n	16	21	36	11	
Duration					
Mean (min)	99	140	113	110	n.s.
s.d. (min)	44	81	63	135	
n	16	21	36	11	
Sunrise (EST)	0558	0530	0527	0546	
Sun-to-start (min)	43	90	115	128	

a cluster of two, three or four mounds, often using the same mound for several years before moving on to the next (Table 5). Such movements occurred for no apparent reason. Each cluster consisted of mounds that were relatively close together (Fig. 3).

The most sedentary pair (band numbers: 25122 and 56126) used the same mound (No. 27) for nine successive seasons (1990–91 to 1998–99) (Table 5). Although this pair did not breed in 1994–95 they started constructing a nest at the same mound but abandoned it before completion. Another pair (25109 and 25110) used a single mound (No. 16) for 5 successive seasons (1988–89 to 1992–93) until the female of the pair died. The male then continued to use this particular mound for a further 3 years, during which time he nested with another two females, the first of these dying after just one year. The third partner died after two years, leaving the male unpaired in 1996–97. The following year the male, together with a new female, worked a different

Table 4. Number of mounds used by each pair of malleefowl relative to the number of years that the pair remained together
 Data are number of breeding pairs

Years	Mounds used							
	1	2	3	4	5	6	7	8
1	6	*	*	*	*	*	*	*
2	5	3	*	*	*	*	*	*
3	0	0	1	*	*	*	*	*
4	1	2	0	1	*	*	*	*
5	1	0	1	0	0	*	*	*
6	0	3	1	0	0	0	*	*
7	0	1	0	2	0	0	0	*
8	0	0	0	0	0	0	0	*
9	1	0	0	0	0	0	0	0

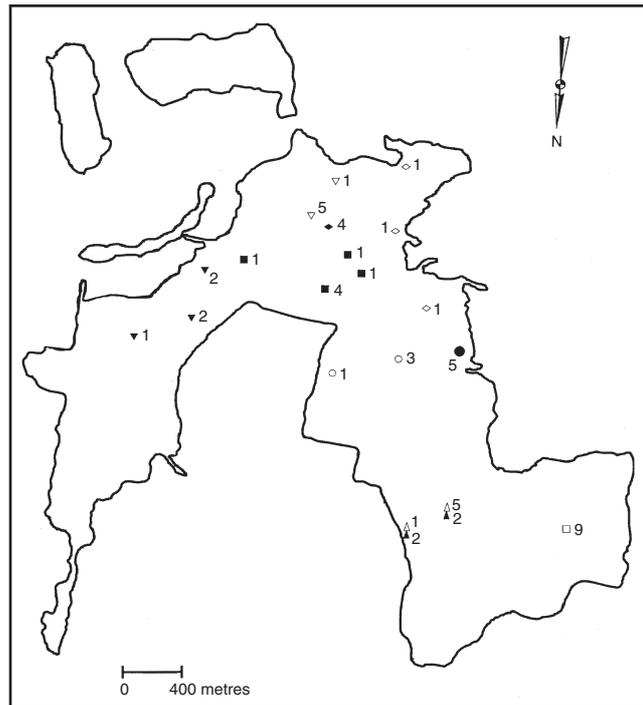


Fig. 3. Mound locations used by selected pairs of malleefowl showing how each pair used a single mound or a cluster of mounds that were relatively close together. Open square, birds 25122 and 56126; closed squares, 25111 and 25121; open triangles, 25114 and 25115; closed triangles, 25186 and 25187; open inverted triangles, 17222 and 56121; closed inverted triangles, 25125 and 25127; open diamonds, 17221 and 25102; closed diamond, 25107 and 56128; open circles, 56122 and 56125; closed circle, 25109 and 25110. Numbers next to the symbols indicate the number of years each mound was used by that particular pair. Closed and open triangles refer to the same mounds used by different pairs during different years.

Table 5. Breeding activity of individual malleefowl, showing the mound used, unpaired birds, periods of non-breeding and deaths (1988–89 to 1998–99)

Numbers identify the mound used; Bird ID, band number (numeric) or identification code (alphabetic); M, male; F, female; UP, unpaired; NB, non-breeding; D, missing presumed dead; *, died in previous years; blank, not yet breeding

Bird ID	Sex	Year											
		1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	
17222	F	2	2	1	2	2	2	3	D	*	*	*	
56121	M	2	2	1	2	2	2	D	*	*	*	*	
25107	F	3	3	3	3	D	*	*	*	*	*	*	
56128	M	3	3	3	3	3	4	3	3	3	D	*	
25111	F	5	4	94	94	8	94	94	D	*	*	*	
25121	M	5	4	94	94	8	94	94	UP	94	3	M	
25108	F	7	33	UP	8	22	22	22	22	22	22	M	
56123	M	7	33	D	*	*	*	*	*	*	*	*	
25109	M	16	16	16	16	16	16	16	16	UP	60	60	
25110	F	16	16	16	16	16	D	*	*	*	*	*	
56124	M	23	23	25	NB	25	25	NB	25	25	D	*	
EEEE ^A	F	23	23	25	NB	25	25	NB	D	*	*	*	
25101	F	26	12	12	12	12	60	NB	D	*	*	*	
25112	M	26	12	12	12	12	60/D	*	*	*	*	*	
56122	M	30	51	30	30	D	*	*	*	*	*	*	
56125	F	30	51	30	30	3	4	D	*	*	*	*	
25120	M	55	15	54	D	*	*	*	*	*	*	*	
25124	F	55	15	54	54	49	49	NB	5	5	5	2	
25114	F	69	20	69	69	69	69	D	*	*	*	*	
25115	M	69	20	69	69	69	69	D	*	*	*	*	
25102	F	110	34	113	NB	6	47	16	16	D	*	*	
25113	M	110	D	*	*	*	*	*	*	*	*	*	
25119	F	119	119	UP	UP	UP	16	D	*	*	*	*	
56127	M	119	119	D	*	*	*	*	*	*	*	*	
17221	M	UP	34	113	NB	6	47	D	*	*	*	*	
25122	F			27	27	27	27	NB	27	27	27	27	
56126	M			27	27	27	27	NB	27	27	27	27	
25123	M				8	22	22	22	22	22	22	M	
25126	M				54	49	49	NB	5	5	5	2	
25125	M					41	42	41	40	42	D	*	
25127	F					41	42	41	40	42	38	42	
25128	M						60	NB	60	D	*	*	
UUUU ^A	F								60	D	*	*	
25141	F								3	3	3	M	
25142	F									25	25	60	60
25186	F									69	69	20	20
25187	M									69	69	20	20
XXXX ^B	F										94	D	*
VVVV ^A	F											38	42

^A Readily identifiable from characteristic plumage and size.

^B Bred in only one year and died before it could be trapped.

mound that neither bird had been associated with previously (Table 5).

After the loss of a partner, males acquired new partners and, in subsequent years, continued to use mounds they had used previously on eight out of ten occasions (80%), whereas females used mounds they had used previously only twice in ten occasions (20%). The difference between sexes was significant ($\chi^2 = 7.20$, $P < 0.025$), indicating that males had a stronger attachment to the mound than did females.

Several instances were observed of malleefowl (including both breeders and non-breeders) visiting mounds that were being worked by other birds, particularly towards the end of the breeding season (January onward). Occasionally these interlopers would stop to dig into the mounds they visited. Usually, the amount of digging was minimal, but on one occasion a male interloper (56122) dug for longer than an hour before being evicted by the resident male.

On another occasion an interloping pair created the appearance that two breeding pairs were working the same mound. On the morning of 14 January 1992, the interlopers (25102 and 17221) were observed to fully excavate a nest (No. 30) that was known to be worked by another pair. The interlopers dug into the mound purposefully for ~40 min, opening it sufficiently to expose the egg chamber. They left rather hastily just moments before the resident pair arrived at the mound. Seven eggs were laid into this nest during the 1991–92 season. Mean clutch size for that particular year was 8.2 (authors' unpublished data). Although not conclusive, these data suggest that only one female contributed eggs to this particular clutch. The interlopers had been together as a pair each year between 1989–90 and 1993–94 but failed to breed in 1991–92 (Table 5). The aberrant behaviour of this pair and their failure to breed in this year may have been related to disturbance of the area around the mound (No. 34) that these birds had prepared for breeding. The area had been mechanically harvested for eucalyptus leaves, the process removing all vegetation other than a few plants immediately surrounding the nest.

Mate fidelity

Pair bonds were maintained for life, with partners being replaced only after the death of the former partner. Each change in pairings ($n = 21$) was coincident with the disappearance (presumed death) of one of the original pair (Table 5). On no occasion was the original partner of a bird that changed mates seen subsequent to the new pairing. Consequently, a change of partner was a reliable indication that the original partner had died. Unpaired birds were never observed to construct or maintain a nest.

Following the loss of a partner, new bonds were quickly established with a replacement partner. At no time did two breeding birds of the opposite sex remain unpaired throughout an entire breeding season (Table 5). At least one bird (a female) lost and replaced her partner within the same breeding season. In October 1993 a long-established pair (25101 and 25112) were observed working a nest together. One month later, feathers near the nest suggested that one member of the pair had been killed. Observations at the nest in January 1994 revealed that the mound continued to be worked by a pair of malleefowl that comprised the female of the original pair (25101) together with a new male (25128). This male was not known to have bred previously but had been caught a few months earlier as an interloper on another mound ~300 m away.

Intermittent breeding

On six occasions, experienced breeding pairs failed to breed. Four of these instances occurred during the 1994–95 breeding season (Table 5) and were coincident with an

unusually high occurrence of incomplete nests ($n = 4$) (Table 1). The identity of the birds responsible for constructing incomplete nests could not always be determined because birds often abandoned their attempts to nest before observations commenced. However, three of the four incomplete nests present during the 1994–95 season had been used the previous year by pairs that failed to breed during the 1994–95 season (Table 5), and it is assumed that these failed breeders were responsible for beginning construction of these nests.

Rainfall during 1994 was particularly low (Table 1) and drought conditions prevailed throughout the 1994–95 summer. The lack of rain appears to be the reason why several pairs abandoned their attempts to breed. Of the eight experienced breeding birds that did not breed during the 1994–95 season, two died before the start of the next breeding season. The other six birds all bred the following season, two with new partners (Table 5).

The other two instances of non-breeding by established pairs occurred during 1991–92 (Table 5), again coincident with an unusually high occurrence of incomplete nests ($n = 4$) and a year of relatively low rainfall (Table 1). At least one incomplete nest (No. 25) could be reasonably attributed to an established pair that failed to breed during this year.

Longevity

Although this study spanned 12 years, it was not of sufficient duration to record the longevity of most of the individuals studied. Average longevity (L), however, can be estimated from the following relationship: $L = (\sum n_i)/D$, where n = the number of years over which each animal (i) was monitored, and D = the number of deaths observed. Based on this calculation, the average longevity of breeding malleefowl at Yalgogrin was 7.5 years.

The greatest recorded longevity of any individual was 12 years. This bird (17222) was banded as a breeding adult by Brickhill in January 1983 (Australian Bird and Bat Banding Schemes database) and was last seen working a nest in December 1994. It had bred in each of the intervening years in which monitoring was conducted (Table 5). Another bird (17221) banded by Brickhill in January 1983 (Australian Bird and Bat Banding Schemes database) survived 11 years until October 1993. Two birds banded in 1988–89 were still alive when the study concluded 10 years later (Table 5).

The recorded longevity of most birds, however, was much shorter. Of 25 adults known to be alive in 1988–89, 21 died during the following 10 years (Table 5). Two were known to be alive in 1998–99 and two survived to 1997–98 but were not sighted in 1998–89. The median survival time of these 25 birds beyond the year they were first sighted (1988–89) was 5 years. Of the 14 birds recruited into the population during the study, four are known to have died – one died after 4–5 years, one after 2–3 years, and the other two were seen during only a single breeding season.

Mortality

Sightings of banded birds were obtained from systematic observations at active mounds and from casual sightings of foraging or roosting birds. This information was used to track the number and identity of birds alive. Birds not seen for two consecutive years were presumed dead, and were recorded as having died in the first year in which they went missing. Individuals that died in the latter part of any breeding season would not have been recorded as dead until the following season. Only one individual that was not sighted for two or more consecutive years (25119) subsequently re-appeared. Unpaired for three seasons (1990–91 to 1992–93 inclusive) this female subsequently bred with a new partner in 1993–94 (Table 5). During the time that this female remained unpaired there were no excess males available for her to mate with. Two males lost partners during this period, but both paired with other unattached females.

A total of 25 breeding birds died between 1989–90 and 1997–98, the annual number of deaths ranging from one to six individuals (Table 6). The causes of mortality are not known. However, the presence of large quantities of feathers near two nests (Nos 4 and 60) suggested that a predator may have taken at least two of the birds that died (25112 and 56125), but there were insufficient remains to establish the type of predator responsible. Mortality was greatest in 1994–95 (Table 6), coincident with a high incidence of incomplete nests (Table 1), a high incidence of breeding failure (Table 5) and a period of low rainfall (Table 1). Mortality has remained relatively high since 1994–95 (Table 6).

Recruitment

Fourteen recruits entered the breeding population in the 10 years between 1989–90 and 1998–99 (range = 0–5 birds per annum) (Table 6). The largest influx of recruits ($n = 5$) occurred in 1995–96. This year coincided with the end of a drought and followed a year of no recruitment and high adult mortality (Table 6).

Population size

Between 1986–87 and 1998–99 the number of active nests declined from 16 to five. Extrapolation of the linear regression ($y = 14.923 - 0.6923x$, $r^2 = 0.7214$, $P < 0.0005$) between the number of active nests (y) and years after 1985–86 (x) predicts that, if current trends continue, the population will be extinct by 2007 (Fig. 4). The overall pattern of decline and prediction of extinction remains little changed when incomplete nests are included in the tally of active nests ($y = 16.423 - 0.7198x$, $r^2 = 0.7539$, $P < 0.0005$, extinction by 2008).

Population estimates based on the number of active nests do not take into account the effects of intermittent breeding. Population estimates based on the number of adults known to be alive (Fig. 5), on the other hand, are unaffected by intermittent breeding and provide a more reliable estimate of population size. (For those years prior to 1988–89 the number of breeding birds was conservatively estimated as twice the number of active mounds.) Extrapolation of the polynomial regression ($y = 28.205 - 0.0642x^2 - 0.3299x$, $r^2 = 0.7882$, $P < 0.0005$) between the number of animals known to be alive (y) and years after 1985–86 (x) predicts that the population will be extinct by 2004.

The breeding population declined from at least 32 adults in 1986–87 to 14 in 1997–98, at an average exponential rate of decrease (Caughley 1977) of $r = 0.075$ (Table 6). No substantial population increase was recorded in any year ($r \leq 0.05$ for all years) (Table 6). The largest population decrease ($r = -0.29$) was recorded in both 1987–88 and 1994–95. Substantial decreases also occurred in 1996–97 and 1997–98 ($r = -0.11$ and -0.19 respectively) (Table 6). The exponential rate of increase was weakly associated with annual rainfall ($y = 6 \times 10^{-3}x^2 + 0.0041x - 1.1993$, $r^2 = 0.4874$, $P < 0.05$) (Fig. 6). All substantial population declines occurred during periods of low rainfall, although the converse was not always true (Fig. 6). In 1991–92, the rate of increase was positive (0.4) despite annual rainfall for 1991 (365 mm) being far below the long-term average. When this year is omitted from the regression analysis, the relationship between the

Table 6. Population size, rate of increase, deaths and recruitment (1986–87 to 1998–99)

–, insufficient data available to calculate this parameter in that particular year. Population estimates for 1986–87 and 1987–88 are based on the number of active mounds (16 and 12 respectively), those for 1988–89 onward are based on the number of individuals known to be alive

	Year												
	1986–87	1987–88	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99
Deaths	–	–	–	1	2	1	2	2	6	4	3	4	–
Recruitment	–	–	–	0	2	2	2	1	0	5	1	1	0
Population size	32	24	25	24	24	25	25	24	18	19	17	14	≥10
Breeding	32	24	24	24	22	20	24	24	10	18	16	14	10
Non-breeding	–	–	0	0	0	4	0	0	8	0	0	0	–
Unpaired	–	–	1	0	2	1	1	0	0	1	1	0	–
Exponential rate of increase		–0.29	0.04	–0.04	0.00	0.04	0.00	–0.04	–0.29	0.05	–0.11	–0.19	–

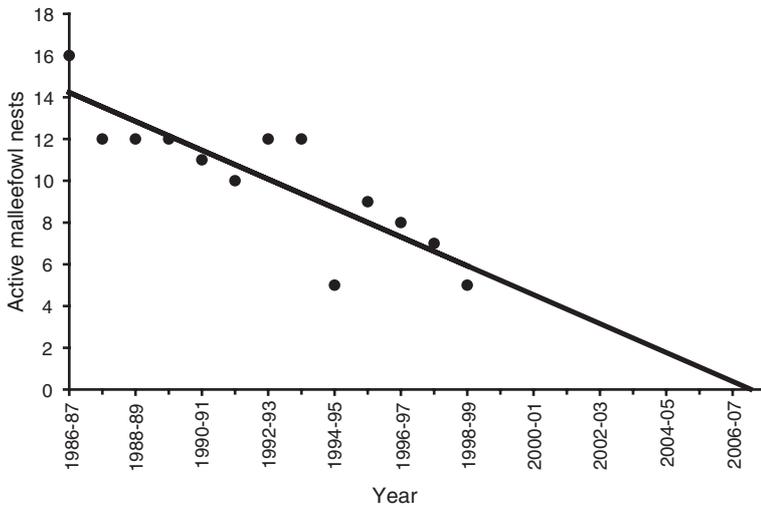


Fig. 4. Number of active malleefowl nests at Yalgogrin (1986–87 to 1998–99). The linear regression line ($y = 14.923 - 0.6923x$, $r^2 = 0.7214$, $P < 0.0005$) is extrapolated until $x = 0$.

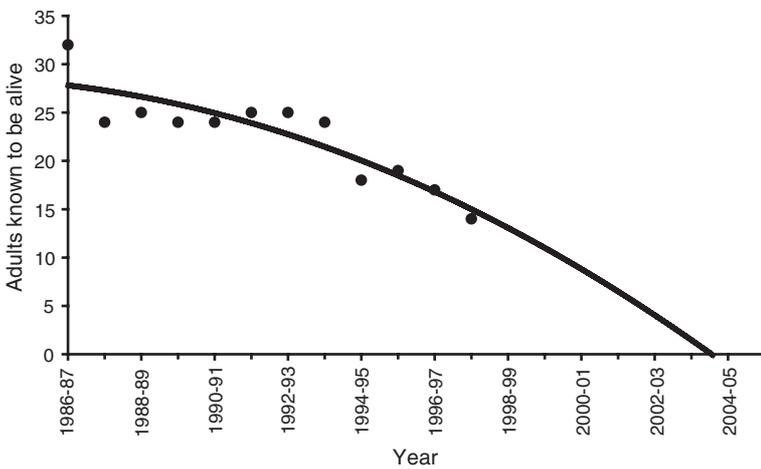


Fig. 5. Number of adult malleefowl known to be alive at Yalgogrin (1986–87 to 1997–98). The polynomial regression line ($y = 28.205 - 0.0642x^2 - 0.3299x$, $r^2 = 0.7882$, $P < 0.0005$) is extrapolated until $x = 0$.

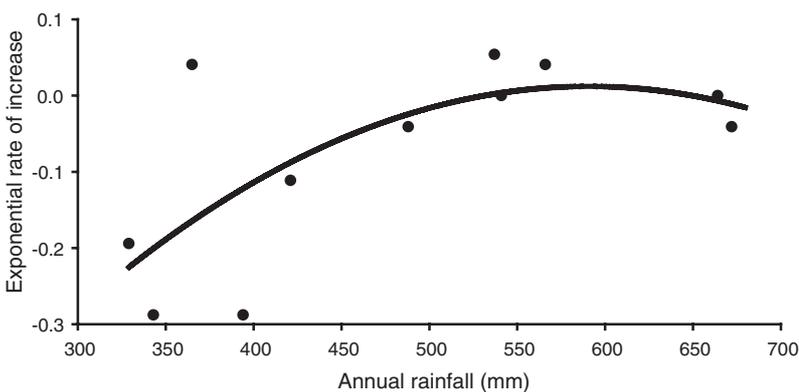


Fig. 6. The relationship between the exponential rate of increase and annual rainfall ($y = 6 \times 10^{-3}x^2 + 0.0041x - 1.1993$, $r^2 = 0.4874$, $P < 0.05$). The long-term average annual rainfall at West Wyalong is 487 mm.

exponential rate of increase and rainfall is much stronger ($y = 6 \times 10^{-4}x^2 + 0.005x - 1.4772$, $r^2 = 0.7893$, $P < 0.005$).

Discussion

Mound use and nest fidelity

Monitoring known mounds to assess long-term changes in malleefowl abundance is now undertaken routinely in all

States in which malleefowl occur (Harold and Dennings 1998; Benshemesh 2000; NSW NPWS 2001). Correct interpretation of the data collected is dependent on knowing the relative frequencies with which new mounds are constructed and old mounds reworked. Periodic re-searching of the areas surveyed, therefore, is an important component of these monitoring programs (Benshemesh 2000).

Although long suspected, this study has provided the first empirical evidence that malleefowl tend to reuse existing mounds rather than construct new ones. New mounds at Yalgogrin were extremely rare – only one in 148 nesting events, and none in the nine years between 1990–91 and 1998–99. Such a low incidence of new mounds (<1% of nests overall), however, may not be typical of all malleefowl populations. The profusion of calcrete nodules at Yalgogrin, and the incorporation of these into malleefowl mounds means that, over time, these structures can become quite large and may persist for many decades, perhaps even centuries. Mounds built from sandy soils, on the other hand, are likely to be smaller and erode much more quickly. Consequently, the incidence of new mounds in other areas may be considerably greater. Also, the malleefowl population at Yalgogrin has declined substantially in recent times and inactive mounds currently far outnumber active mounds. In malleefowl populations that are stable or increasing, the construction of new nests may be more common.

Each active nest was worked by a single pair of birds, and there was no evidence that breeding birds began construction of more than one nest. Nests without eggs (authors' unpublished data) were attributed to the failure of the female to lay rather than the absence of a female. Although breeding malleefowl commonly visited the mounds of other birds, particularly late in the breeding season, there was no instance of a male maintaining more than one nest or pairing with more than one female. Polygyny, such as that described by Weathers *et al.* (1990), in which two females laid eggs into separate mounds both worked by the same male, did not occur.

Many experienced pairs that failed to breed in any one year generally began construction of a nest. They filled the core of the mound with leaf litter, but then stopped short of adding the covering of soil needed to complete the construction process. The number of incomplete nests was inversely proportional to rainfall, supporting earlier assertions that the trigger for malleefowl to abandon attempts to breed is the lack of rain (Frith 1959; Booth and Seymour 1984). Rain is essential to moisten the litter and initiate the process of rapid decomposition.

Not all partially constructed mounds could be explained as abandoned breeding attempts by established pairs, as incomplete mounds occurred at times when all established pairs were successfully working other mounds. There was also no evidence to suggest that unpaired adults with previous breeding experience began construction of a nest. In 1995–96 there was an incomplete mound (No. 14) that could possibly be attributed to an unpaired male, but in two other years when unpaired males were present (1988–89 and 1996–97) (Table 5) there were no incomplete nests, and all active nests were worked by pairs. A single female was unpaired for three consecutive years, and at least one

incomplete mound was present each year, but there was no evidence to link this bird with the incomplete mound. It is likely that the incomplete mounds were built by young, pre-breeding birds, as has been observed in a captive population held at Western Plains Zoo, Dubbo (Kevin Brumby, personal communication).

Social organisation and mating system

This study confirmed that malleefowl are monogamous and mate for life (Frith 1959, 1962*b*). No separations occurred, and all new pairings followed the death of one of the established pair. Although pair bonds were maintained for as long as both partners were alive, new bonds were quickly established following any deaths. Males appeared to have the dominant role in the selection of the nest site, with unattached females generally relocating to the mound used previously by their newly acquired male partners.

Monogamy is common among the megapodes: 19 of the 22 extant species share this particular trait (Jones *et al.* 1995). Monogamous males vigorously defend females and, in all species other than the malleefowl, there is a high degree of behavioural synchrony, with paired birds remaining in close contact almost permanently. Generally, monogamous pairs tend to separate only when the female visits naturally heated incubation grounds (geothermal areas and solar-heated beaches) alone to lay. Males of the three polygamous megapodes defend incubation mounds, mating with any female attracted to the mound (Jones *et al.* 1995). For the Australian brush-turkey (*Alectura lathami*), the only polygamous species studied in detail, construction and defence of the mound is undertaken solely by the male, while the female exhibits a high degree of independence (Jones 1990).

Malleefowl employ a mating system that is different from all other megapodes (Jones *et al.* 1995), being the only species in which individuals of a monogamous pair remain separated from each other for extended periods. While males attend and defend the incubation mound, females forage away from the mound in search of the nourishment needed to sustain egg production (Frith 1962*b*; Booth 1987*b*). In all other species, as far as is known, either the paired birds remain together permanently, or no pair bonds exist (Jones *et al.* 1995). Jones *et al.* (1995) suggest that the environmental conditions associated with the malleefowl's semi-arid habitat constrain populations to such low densities that these mound-building birds have no option but to form pairs and mate monogamously.

Recruitment and mortality

This study found that, contrary to our own predictions (Priddel and Wheeler 1994), recruitment into the breeding population at Yalgogrin is occurring. Moreover, the rate of recruitment is not inconsequential. Over the 10 years in which recruitment could be assessed, a total of 14 new

recruits entered the breeding population. Clearly, despite an extremely high rate of predation of young birds at Yalgogrin, mostly by foxes (Priddel and Wheeler 1994), juvenile survival has not been reduced to the extent where recruitment is no longer possible. If recruitment were not occurring, the population at Yalgogrin would be heavily skewed towards old individuals. This was not the case. Instead, this study found that many breeding birds were relatively young, and there was a rapid turnover of breeding individuals. Although some individuals were long-lived (>10 years beyond the commencement of breeding), most individuals died younger – average longevity once attaining breeding age was 7.5 years.

Despite a significant number of recruits entering the breeding population, recruitment failed to keep pace with adult mortality. Mortality of breeding adults exceeded recruitment by a ratio of 1.79:1.00. Clearly, this imbalance between recruitment and adult mortality must lead to population decline. Poor juvenile survival has been flagged previously as a likely process by which malleefowl populations are declining (Priddel and Wheeler 1994), but this is the first strong evidence that high mortality of breeding adults may also be a significant factor driving populations downwards.

The predominant cause of mortality among juvenile malleefowl is predation, principally by foxes, raptors and feral cats (Benshemesh 1992; Priddel and Wheeler 1994). The causes of adult mortality are less well understood. Adults are vulnerable to impact from motor vehicles (Booth 1986), and possibly to wildfire (Benshemesh 1992), but there are no public roads and very little traffic at Yalgogrin and there have been no recent fires. Quantities of feathers found at two nests suggested that predators killed at least two adults, although the predator responsible could not be determined. Known predators of adult malleefowl include foxes (Booth 1987*b*; Benshemesh 1992) and raptors (Korn 1986). Malleefowl appear particularly vulnerable to predation while working mounds. On three occasions during the study, observers watching from hides witnessed a fox come to a mound where birds were digging. The recurring presence of fox scats on malleefowl mounds indicates that foxes regularly visited these structures.

Population trends

Like many other small, remnant populations of malleefowl, the population at Yalgogrin has declined substantially, from at least 16 breeding pairs in 1986–87 to 5 pairs in 1998–99. This equates to an average exponential rate of decrease of 0.075. An earlier estimate of population size (20 active nests in 1983: Brickhill 1987*a*) indicates a similar decline in the population between 1983 and 1986 ($r = -0.074$).

Predictions based on extrapolation of current population trends indicate that malleefowl will become extinct at Yalgogrin before 2008. This finding is specific to the

population at Yalgogrin and any applicability to other malleefowl populations is yet to be tested. For a broader prediction of future population trends similar studies are needed at several other sites, particularly at less disturbed sites and at sites where fox control is being implemented. Notwithstanding, local extinctions of isolated malleefowl populations within the New South Wales wheat belt are not unusual. Malleefowl have already disappeared from several mallee remnants in the vicinity of Yalgogrin, including pastoral properties such as Arcadia (~1989) and Nature Reserves such as The Charcoal Tank (pre-1989), Pulletop (~1989), and Buddigower (~1991). Although many of the causal factors are known, the mechanism of these extinctions is not fully understood.

Effects of drought

Malleefowl have been reported to breed annually except in years of drought (Frith 1959; Booth and Seymour 1984). A similar pattern of behaviour was evident at Yalgogrin. Two instances of breeding failure occurred in 1991–92 during a year of relatively little rainfall. In 1994–95, following a period of drought, four established pairs failed to nest. This drought appears to have been particularly testing for malleefowl as not only did four experienced breeding pairs abandon their attempts to nest but at least six adult birds were permanently lost from the population.

It has long been recognised that drought can cause some malleefowl to abandon breeding, and lead to reduced clutch sizes among those pairs that do manage to breed (Frith 1959). It was, however, always presumed that the effects of drought were transitory, with reproductive output returning to former levels in subsequent non-drought years. This study has shown that by causing high mortality among breeding adults the effects of drought can be long-lasting. Combined with a background level of recruitment that is insufficient to offset any sizeable loss of breeding individuals, significant drought-induced mortality must result in a direct population decline. Over time, it is conceivable that the population would decrease through a series of stepwise reductions that coincide with the occurrence of drought, the magnitude of each reduction possibly reflecting the severity of each drought.

Threatening processes

The widespread destruction of habitat through the clearance of mallee lands for cropping and pastoralism is a key factor in the decline of the malleefowl (Frith 1962*a*; Brickhill 1987*a*). In New South Wales, almost all the prime habitat for malleefowl has been cleared. The small remnants of high-quality habitat remaining are severely fragmented. This fragmentation also appears to be highly detrimental to malleefowl, but the mechanics of this process are not fully understood.

Frequent fires or otherwise inappropriate fire regimes can be detrimental to malleefowl populations (Benshemesh 1992). However, neither the study site at Yalgogrin, nor any of the nearby mallee reserves (with one exception), show any evidence of having been burnt within the last 50 years. (A portion of Pulletop was deliberately burnt in 1986 to introduce some variation into a reserve that consisted entirely of long-unburnt mallee.) None of the harvesting activities conducted at Yalgogrin involve the use of fire.

Harvesting of mallee eucalypts for eucalyptus oil, broombush for fencing materials, and timber for firewood and fence posts all took place in the study site both before and during this study. These longstanding practices have created a mosaic of natural old-growth mallee interspersed with areas of dense regrowth. The impact that such habitat modification has had on the malleefowl population at Yalgogrin is unknown. Intuitively, such severe disturbance could be highly detrimental, but direct evidence of any significant impact is lacking other than the occasional displacement of breeding birds by harvesting operations. Given that the malleefowl population at Yalgogrin has persisted longer than those in nearby reserves where harvesting is prohibited, modification of the habitat may have been beneficial for malleefowl. One possible advantage of the change in habitat structure is that areas of dense regrowth provide malleefowl with increased protection from predators. Dense thickets of vegetation have been shown to be particularly important for the survival of young Australian brush-turkeys (Göth and Vogel 2002, 2003).

Observations of malleefowl feeding in crops could be interpreted as suggesting that the modified habitat at Yalgogrin was inadequate. However, feeding in wheat stubble is common practice among malleefowl populations that inhabit isolated remnants of native vegetation (Frith 1962b). Malleefowl feed on the leaves, buds, flowers, fruits and seeds of numerous shrubs and herbs, and also on the many invertebrates that these plants harbour (Harlen and Priddel 1996). Stock graze these same plants, thereby reducing the food available to malleefowl. Densities of malleefowl in habitat grazed by sheep are only 9–16% of those in similar habitats that are free of stock (Frith 1962a). Presumably, cattle and other introduced herbivores have a similar effect, as may the increased abundance of kangaroos brought about by land clearing and the provision of permanent water. Grazing by stock has almost certainly diminished the quality of the habitat at Yalgogrin, and may be a key factor in the decline of the local population of malleefowl. Stock, however, are absent from nearby reserves where malleefowl have also disappeared. A more ubiquitous threat is needed to account for the widespread declines and extinctions observed.

The only known threatening process which is ubiquitous across the entire geographic range of the malleefowl is the introduced red fox. Fox predation is the greatest single cause

of malleefowl mortality. Foxes prey on malleefowl eggs (Frith 1959; Brickhill 1987b), neonates (Benshemesh 1992), chicks (Priddel and Wheeler 1994, 1996, 1997), juveniles (Priddel and Wheeler 1996) and adults (Booth 1985; Benshemesh 1992). The impact of the fox is likely to be exacerbated by habitat fragmentation and the thinning of vegetative cover by introduced herbivores. 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 and 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. Fox densities at Yalgogrin are unknown, but no fox control, other than casual shooting, has ever been undertaken there.

Conservation implications

Most land-holders at Yalgogrin were delighted that malleefowl were present on their properties. Yet, whilst the birds were not persecuted, no specific actions were taken to conserve them. Fox control is an obvious potential conservation action. However, to be effective, fox control would need to be frequent, intensive and widespread (Priddel and Wheeler 1997). The current land tenure, small property size, and perceived threats to non-target species (including domestic and working dogs) makes broad-scale baiting in this vicinity a difficult proposition. Conservation of malleefowl at Yalgogrin, and in similar mallee remnants, would benefit from a reduction in grazing pressure. The exclusion of stock from these areas would incur a significant financial cost to the land-holder, and may necessitate some form of financial compensation.

The malleefowl is a threatened species, listed as *vulnerable* nationally (Australian Commonwealth Government 1999) and *endangered* in New South Wales (NSW Government 1995). The continued loss of small isolated populations is of grave conservation concern as ~20% of the New South Wales population of malleefowl is located in small mallee remnants within the wheat-belt (Brickhill 1987a). Conservation of malleefowl in fragmented agricultural landscapes will require change to established agricultural practices. This will need to be encouraged through land-holder incentives, conservation agreements and by fostering the concept of land-holder and community stewardship (NSW NPWS 2002).

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