Trend Analysis of Malleefowl Monitoring Data

Milestone 3 report to the Mallee CMA, Victorian Malleefowl Recovery Group (VMRG), and multi-regional "National Malleefowl Monitoring, Population Assessment and Conservation Action Project" steering committee.

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Preamble

The multi regional "National Malleefowl Monitoring, Population Assessment and Conservation Action Project" is a two year NHT funded project that implements key components of the National Malleefowl Recovery Plan. The general aims of the project are to:

- Collate existing Malleefowl monitoring data for analysis
- Interpret breeding density trends in the light of management practises and environmental variables
- Develop a consistent national monitoring system and a national database, and foster on-going and self-sufficient monitoring that facilitates government, private and community monitoring programs.
- Develop the monitoring program in the future so that management actions that are most beneficial to Malleefowl conservation can be identified and demonstrated, and integrate this knowledge into outcomes for conservation on private and public land across Australia.
- Involve all stakeholders in this project and provide advice to regional NRM bodies on how best to promote Malleefowl conservation within their region.

The first phase of the project aims to tackle the first two points above. This document reports on the second of the above points and specifically deals with examining the data that has been collated from around Australia for trends in Malleefowl breeding populations. The central question addressed in this report is:

> *Are Malleefowl populations declining, and if so, what environmental factors might be responsible?*

Every effort has been made to represent data accurately. Malleefowl breeding count and fox baiting data used in the analysis of trends is provided in appendices at the back of this document. If you notice an error, or feel something has been misrepresented, please notify the first author.

Introduction

Declining Malleefowl distribution

The original distribution of Malleefowl was considerable, especially considering the species' peculiar and demanding nesting habits. Malleefowl once occurred over much of the southern half of the continent in all mainland states except Queensland. The species ranged from the west coast as far north as Shark Bay and the Gascoyne River in WA to the western slopes of the Great Dividing range in NSW, as far north as the Tanami Desert in the Northern Territory (Kimber 1985), and to within 60 kilometres of Melbourne in the south (Campbell 1884, Campbell 1901, Mattingley 1908). Indeed, the species was widespread and regularly occurred in more than a quarter of the 80 major biogeographic regions of Australia (Benshemesh 2005b).

Within the past century the range of Malleefowl has contracted, particularly in arid areas and at the periphery of its former range (see Benshemesh 2005b). The species may already be extinct in the NT, and its range has also contracted in the far north and south-west of WA, and from the south-east of its former range in Victoria. Severe

declines have occurred in southern agricultural areas due to the clearing of the mallee for wheat and sheep production. In the semi-arid zone where Malleefowl densities are highest, the clearing of habitat has been the major cause of the marked decline in the distribution of the species. Apart from removing much of the habitat supporting high densities of the species, this clearing has fragmented the distribution of Malleefowl, and over much of its range the species now persists in small patches of habitat that may be inadequate for its long-term conservation.

The Malleefowl is recognised as threatened in every state in which it occurs, is listed as Vulnerable nationally under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, and has been classified as Vulnerable under IUCN criteria (Benshemesh 2005b).

Monitoring

How Malleefowl are faring in reserves set aside for their conservation is less clear than the effects of clearing. In order to answer this crucial and fundamental question, monitoring programs were established in the late 1980s and 1990s in NSW, SA, Vic and WA. While often initiated by wildlife authorities, by the mid 1990s most of the Malleefowl monitoring was being undertaken by volunteers. Sites were usually selected for monitoring based on local concerns and focussed on counting the number of mounds used for breeding. Unlike most birds, Malleefowl build conspicuous incubators composed of sand and fuelled by the heat generated by decomposing leaf litter. The 'active' mounds are relatively easy to monitor, whereas the birds themselves are shy and so well-camouflaged that they are rarely observed. These data have been accumulating for as much as two decades in some cases but have rarely been reviewed or analysed. The few data that have been examined have suggested a variety of trends: declines have been reported at many sites, whereas apparently stable and even increasing populations have also been reported (Frith 1962a, Priddel 1989, Benshemesh 1997, Priddel and Wheeler 2003, Gates 2004, Benshemesh 2005a). The reasons for these trends are usually unclear.

Perceived threats

Various detailed studies have hypothesized various causes for the declines of Malleefowl, although there is little strong evidence to confirm these. Apart from clearing of habitat, the four main threatening processes are considered to be predation by the introduced red fox (*Vulpes vulpes*) (Priddel 1990, Priddel and Wheeler 1990, 1994, 1995, Saunders et al. 1995, Priddel and Wheeler 1996, 1997, Short 2004), too frequent fires (Benshemesh 1990, 1992), habitat degradation due to over-grazing by domestic sheep (Frith 1962a) and probably feral goats (*Capra hircus*), and the effects of population and landscape fragmentation. Climate change has also been identified as a potentially devastating threat to Malleefowl in the longer term (Bennett et al. 1991, Benshemesh 2005b)

Foxes prey on all life stages of Malleefowl and predation is often identified as the leading cause of mortality of Malleefowl eggs, chicks, juveniles and adults (for reviews see Short 2004, Benshemesh 2005b). Despite these losses, others have questioned the effect of fox predation at the population level, arguing that the high fecundity of Malleefowl may make these losses tolerable at the population level (Frith 1962a, Benshemesh 2005b).

Fox predation is an especially important threat because foxes are ubiquitous in areas occupied by Malleefowl, and because fox abundance can be effectively controlled by baiting programs. Deliberately introduced into Australia in the mid to late 1800s, foxes have spread to occupy many habitats, especially woodlands and semi-open habitats (Saunders et al. 1995) such as mallee. Baiting programs are widespread in the mallee and are motivated by a desire to protect native species, particularly Malleefowl (Reddiex et al. 2004), and to protect lambs in agricultural areas. However, the benefits of fox control for Malleefowl have never been investigated at the population scale.

In contrast to fox predation which is likely to affect Malleefowl wherever they occur, most of the other threats occur at local scales. Fire in mallee is often very large and thorough, and thousands of square kilometres of mallee are often burnt each decade across the continent. Malleefowl are eradicated by these large fires and are typically slow to return: the species is usually absent for at least 10-15 years after fire (Cowley et al. 1969) and may not reach maximum breeding density for several decades later (Woinarski 1989a, Benshemesh 1990, Clarke 2005). Fire is a particularly potent threat in small and isolated populations because an entire population may be suddenly and permanently wiped out if there is no opportunity for recolonisation.

Fragmentation is believed to exacerbate other threats and, by reducing and isolating populations, makes them vulnerable to a range of stochastic processes. Moreover, fragmentation may also lead to greater exposure of Malleefowl to potential threats on agricultural land such as increased fox numbers, grazing by sheep and rabbits, and possible off-target affects of agricultural chemicals.

Grazing by sheep was a threat highlighted in Frith's (1962a) pioneering work on Malleefowl: Malleefowl breeding densities were reduced by 85-90% in grazed compared to similar ungrazed habitats. Other herbivores may also compete with Malleefowl for herbaceous foods and damage shrubs that are important as seed sources for the birds. Although rabbits are usually uncommon in mallee shrubland (Frith 1962a), feral goats are abundant in some areas (Pople et al. 1996) and their grazing/browsing affects may be as damaging to Malleefowl as those caused by sheep. High numbers of kangaroos may also be a problem where their numbers are artificially high due to access to permanent water sources, agriculture, and absence of predators such as dingos.

Finally, rainfall is a major determinant of the ecology of mallee habitats in general, and is expected to have profound effects on Malleefowl. Malleefowl respond to rainfall most conspicuously by not nesting in years of low winter rainfall (Frith 1956, 1959, Booth and Seymour 1983). Egg production is also determined by past rainfall (Frith 1959, Priddel and Wheeler 2003). Long term effects of declining rainfall would likely lead to a lowering of Malleefowl population sizes as the productivity across the landscape declines.

This study

In this study we examine the trends in Malleefowl populations using data collected in these monitoring programs in NSW, SA, VIC and WA by government agencies and community volunteers. This is the first time the results of different Malleefowl monitoring programs have been brought together, and our analysis is also the first detailed analysis of Malleefowl monitoring data involving multiple sites. The primary data comprise annual counts of mounds that were used for breeding each year and

provide a useful indicator of general population trends within well-defined areas. For each of these monitoring sites, we have also collated information regarding fox control efforts, rainfall, landscape fragmentation, and fire history, and examine the effects of these variables on Malleefowl breeding numbers. On the basis of previous observations and studies of Malleefowl ecology reported in the literature, we expect breeding densities to be negatively related to fox abundance and fragmentation, and positively related to fox baiting intensity, rainfall and increased time since sites were last burnt.

Most of the monitoring sites are within reserves, and none is believed to be routinely grazed by sheep. A few of the monitoring sites considered in this study were within landscapes that are known to have sizeable goat and/or kangaroo populations, but we were unable to obtain reliable information on the abundance of these grazers/browsers at many sites and were unable to examine the possible effects in our analysis.

Methods

Preparation of Malleefowl data before analysis

Data collection

Mound monitoring programs started in most states in the late 1980s and early 1990s, although some historical data from before this time have also been included where the historical sites could be closely matched to the monitoring sites.

Data were collected by a wide range of people and agencies. Nests were classified as 'active' (being used as an incubator) or inactive, and a range of additional data were usually also recorded for corroborating the activity status and to enable vetting of data.

In NSW, additional data were not collected as part of the monitoring program but the data were judged to be reliable as only a few experienced rangers inspected nests each year. Nests were typically inspected from a helicopter and nests that were thought to be active were also inspected on the ground.

Elsewhere, data were usually collected by volunteers and there was a greater need to vet records to ensure that nest activity was correctly classified. In SA and Vic the original datasheet protocols developed in the early 1990s were used consistently through to 2005 and provided various data fields that were used to vet data (datasheet appendix). In WA, community groups developed their own brief data sheets and these were of limited use for vetting. Records from WA over the past year or two have provided full nest descriptions, as in SA and Vic.

Collate data from all states

Issues arising from attempts to collate, enter and interpret monitoring data have been discussed in previous reports (Benshemesh 2006a, b). In short, invitations to provide data for this analysis were sent to government and community representatives in each state. Data custodians were generally willing to share data for this analysis; however even within states the data sets were often fragmented and were not readily accessible. Much of the data existed only on paper, and was entered onto databases for the current project by teams of volunteers.

Vetting Malleefowl breeding number data

An 'active' nest was defined as a nest that had been used as an incubator between October and December (manual), although it was apparent that this definition was not always followed. Other fields, where available, were used to check the reliability of the activity determinations. Key fields for vetting records and determining whether or not a nest was active are shown in Table 1. Apart from these standard fields, written notes were also considered in vetting records.

Table 1. Key features in the monitoring data that were used to vet records in regard to whether mounds were used for breeding. Features that are indicative of active and inactive mounds are shown for the typical mound monitored between Oct and Dec. Features may indicate different states at different times, for example a mound visited in winter that was partly filled with litter would probably be active later in the season, whereas a mound in this state in November would most likely have been abandoned early in the season. Asterisks show features that were most definitive.

Features	Nest is Active	Nest is Not active
Scraped	Yes*	No
Crust (in) or Herbs	No	Yes*
Mound Height	>30cm	<20cm
Profile	Dome (profile #4), or filling with sand (#5)	Dug-out (#2), or filling with litter (#3)
Radical change in shape between years	Yes	No
Xsticks in place from the previous year	No	Yes*

Records of allegedly active nests that did not conform to the typical pattern were scrutinised and in some cases changes were made if the activity status was considered to have been incorrectly recorded. For example, in some cases nests were recorded as active whereas it was clear from their descriptions that they had in fact been abandoned at an early stage of construction or in previous years, or were being prepared for the following season. In other cases, crust, herbs or cross-sticks over the centre of the mound indicated that the nest was not active, or notes in the comments clearly stated that the nest was not worked. In borderline cases where it seemed likely that a nest had been incorrectly classified, the record was given a score of 0.5 for activity rather than 1 (active) or 0 (not active). Occasionally, changes were also made where the activity status of a nest was not recorded but descriptions of the nest allowed a classification to be made with confidence. Where the monitoring data for a particular site and season were considered inadequate to provide a reliable count of active mounds, the data were excluded from further analysis (Appendix 3).

Changes to the recorded activity status were most common in SA where most records were detailed enough to allow cross-checking and vetting, and where there had been no previous scrutiny of data. However, even in SA, changes were uncommon and in the final dataset represented less than 7% of records classified as active, and about 0.1% of records classified as not active. Elsewhere, changes to whether nests were regarded as active or inactive were rare: in WA and NSW no additional nest descriptions were available with which to vet data, whereas in Vic the data had been vetted in 1997 (Benshemesh 1997) and annually since then as part of the routine management of monitoring data.

Dealing with new nests

The number of nests monitored at sites typically increased in time as nests that were encountered during searches of the site, or during monitoring, were added to the monitoring lists. To ensure that a set area was represented in the monitoring results through time, each newly added nest was checked against the original site boundaries and only nests that were within these boundaries were included in the monitoring

results reported here. Where site boundaries were not accurately defined, provisional boundaries of the appropriate dimensions were drawn to include the original nests, and any nests subsequently added to the site list were checked against these boundaries.

Dealing with missing data

Uncertainty about the number of active nests at a site during a particular season arises if not all nests are monitored, and this issue varied between states. In NSW virtually all nests were visited every year and there was little uncertainty. In Vic, previously recorded mounds were routinely omitted from monitoring if there was substantial doubt that they were in fact old Malleefowl nests, or if they could not be relocated despite thorough searches over 3 years. Omissions were explicit and the reasons were documented; apart from these deliberate omissions, only about one in 40 nests were classed as not-found. Elsewhere, nests were often dropped from the monitoring lists without explanation and it was not possible to distinguish justifiable omissions from those that were unintentional and due to oversight. In SA and WA, about one in seven nests were classed as not-found within the dataset used in the analysis.

To correct for missing data where nests were not found, the probability that a particular nest was active in a particular season was estimated as the proportion of years the nest was recorded as active in the past and subsequent four years:

$$\textit{Additional active} = \textit{(No. not-found)} * \frac{\sum \textit{No. active (past and subsequent 4 years)}}{\sum \textit{No. records (past and subsequent 4 years)}}$$

Thus, if none of the missing nests was active within four years of the season in doubt, no correction would be made, whereas if several nests that were usually active were missed, a correction would be made based on the number of missing nests and how frequently these nests were active within four years of the season in doubt. In a few cases several nests were not-found in the same season that a similar number of nests were newly added to the site, so that the total number of nests in the site remained constant, and it was concluded that the nests had most likely been re-labelled. In these cases, no compensation for missing data was made.

Corrections to the number of active nests at a site were rounded to the nearest 0.5. If more than 25% of the corrected total number of active nests at a site in a given year was due to compensation for missing nests, the data for the site were regarded as unreliable and excluded from analysis (Appendix 3).

Dividing sites

In a few cases, sites were divided and the different parts were treated separately in the analysis. Dividing sites simplified analysis where different parts of a site had different monitoring or fire history. For example, monitoring at Tarawi in NSW and at Wandown in Vic has been progressively expanded over a number of years as new areas were added to the monitoring program. Each of these areas has been treated separately in this analysis. Some monitoring sites were also split due to differing fire histories: several sites in Victoria (v01, v04, v07) straddle fire edges and were designed to equally sample different fire histories, and these parts were treated as separate sites.

Site selection

The distribution of the 64 sites that were included in the analysis is shown in Figure 1. We generally included all sites in the analysis for which there was reliable data from at least two seasons, but excluded sites several sites at which breeding Malleefowl had never been recorded since monitoring began (Appendix 3), and in a few other cases for historical or management reasons. We did not include data from Yalgogrin in NSW (Priddel and Wheeler 2003) because it is the only monitoring site that is extensively used for eucalypt harvesting and presents a unique example of this management practice. We did not include the limited Malleefowl data available from Kiata in Vic and Pulletop in NSW, even though sharp declines have been reported at these sites, because the original counts of breeding numbers occurred at a time of extensive clearing that may have artificially elevated breeding counts in these remnants (Frith 1962a, b, Keith Hately pers. comm.).

We excluded data from particular sites and years where the data on breeding numbers were considered unreliable, and where compensations for missing-mounds comprised more than 25% of the estimated breeding numbers (Appendix 3).

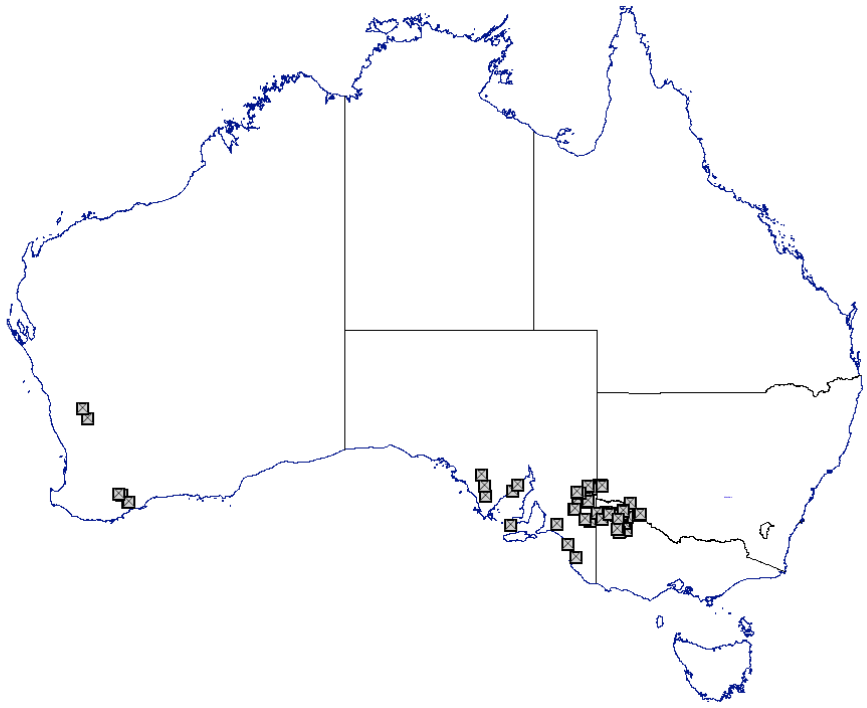

Figure 1. Distribution of the 64 monitoring sites used in the analysis of Malleefowl trends.

Independent variables

Fox bait data

Baiting using poison compound 1080 (sodium monofluoroacetate) is the most common method used for controlling fox numbers in Australia. In order to assess the affect of different baiting regimes on Malleefowl breeding populations, details on the fox baiting history at each site were sought from the relevant government agencies in each state, from community groups involved in fox control, and in some cases from

farmers whose properties adjoined monitoring sites. Baiting techniques varied enormously in terms of frequency, timing, intensity, extent and bait type. To provide a means of comparing baiting effort between sites that were baited to some degree, we estimated the total number of baits laid each year within a 100 km^2 area, with the monitoring site at its centre. This value combines frequency, extent and intensity into a single term that facilitates comparison between sites. We chose to estimate baiting over a 100 km^2 area because foxes are highly mobile and have large home ranges (Saunders et al. 1995) and because areas of this size are regarded as a minimum size suitable in the design of experiments for evaluating the effectiveness of fox control (Reddiex and Forsyth 2004).

Fox scats

As part of the monitoring process in both SA and Vic, observers were requested to state whether or not fox scats occurred on each nest visited. These data were used to provide an index of fox abundance at a site. Only inactive nests were used to derive an index of fox abundance. Active nests tend to be especially attractive to foxes and were excluded to avoid confounding this index of fox abundance with Malleefowl breeding density.

Rain

Monthly rainfall data were obtained from the Bureau of Meteorology for each site in the analysis. These data were modelled by the Bureau of Meteorology at a resolution of 5 km^2 using available climate information and provide the best available estimate of rainfall for sites. We used cumulative rainfall during the May-September period each year to estimate effective annual rainfall. Rainfall during this period has a strong influence on whether Malleefowl attempt to breed and on productivity in mallee ecosystems.

Site search history

The years that each site was searched for mounds was entered into the analysis for two reasons. Firstly, Malleefowl occasionally construct new mounds and these are unlikely to be detected unless the site is searched, which usually occurred only every few years. Thus it may be expected that monitoring may underestimate breeding numbers in the intervening period between searches and that this effect would increase with time since the site was thoroughly searched. Secondly, searching involves groups of people systematically walking through the site on a wide front (typically 200m). This activity may be disruptive to Malleefowl and might have a negative affect on breeding density, especially if searches are frequent. These potential effects are not mutually exclusive and have differing predictions (Table 2).

Table 2. Possible effects on apparent breeding numbers of the frequency of thoroughly searching monitoring sites in relation to the construction of new mounds by the birds, and in regard to possible deleterious effects of searches.

	Search frequent	Search occasional
New mounds added to the monitoring lists	None or slightly positive	Strong, positive
Possible detrimental effect of scaring birds	Strong, negative	None or slightly negative

Site variables

The landscape context of each site was examined using GIS (Arcview 3.2). Table 3 shows the main site variables that described sites in the analysis.

Table 3. Site variables estimated for this analysis, and those entered into the analysis (marked with asterisks).

Site variable	Definition
Patch size*	The size (km^2) of the patch of habitat in which the monitoring site was located. A patch was considered discrete if linkages with other patches were much narrower than they were long, and movement between patches was considered to be limited though not necessarily improbable.
Edge	The length of edge shared between the monitoring site and agricultural land.
%clr radius*	The proportion of cleared agricultural land within 2km, 5km and 10km of the centre of each site (3 separate variables).
fire@site*	The year of the last fire at the site
Fire%*	The proportion of the site that was burnt in the last fire
Proximity	Distances between sites were calculated from the latitude and longitude of each site centre using the spherical law of cosines. Where site boundaries were not available, the average latitude and longitude of nests within a site were used to estimate the site centre.

Analysis

Data and Models

Hierarchical Poisson (loglinear) regression was used to model counts of active Malleefowl nests (Y_{ij}) recorded at different sites (indexed by i) each year (indexed by j) in Victoria, New South Wales, Western Australia, and South Australia. The hierarchical structure (Figure 2) resulted from the Poisson parameter λ_{ij} , the expected number of active nests at site i in year j being expressed as a function of covariates, some of which were random and some of which were missing. Where covariates were missing these were modelled using multiple imputation (Gelman et al, 2004).

Log-linear Regression Model:

It was expected that the number of Malleefowl active breeding nests observed at each site, would vary between sites (63 sites in total) and each yearly visit (43 years in total). Each state was expected to exhibit differing yearly effects. It was also expected that the number of Malleefowl active breeding nests observed at each site would be influenced by covariates that included the extent of non-cleared land within a site, the proportion of cleared land within a 5 km radius of the site centre, and effects due to fire history and the amount of winter rainfall in recent years. It is also P that counts are influenced by abundance of foxes within sites each year and in previous years. We indexed fox abundance by the probability that Malleefowl inactive nests contained fox scat.

Variables in the Model

Let y_{ij} be the observed number of Malleefowl active breeding nests in each site i on each yearly visit j. The observed counts y_{ij}, were modelled as independent Poisson random variables with parameter λ_{ij} representing the expected count of active Malleefowl nests. Covariate effects were expressed by modelling $\ln(\lambda_{ij})$ as a linear function of effects representing:

1. State expressed using indicator variables with $S_i = 1$ if nest i was located in South Australia, and zero otherwise, and similarly for N_i (New South Wales), and V_i (Victoria). Western Australia was the reference state.
2. Annual trend (X_j).
3. Patchsize (P_i), the size (km^2) of non-cleared land within a site,
4. C_i the proportion of cleared land within a 5km radius of site centre.
5. M_{ij} an indicator for whether site has a burn history before j.
6. L_{ij} the number of years since the last burn, if the site has a burn history.
7. O_{ij} the percentage of the site that was burnt in the most recent fire, if it has a burn history.
8. R_{ij} the total winter rainfall at each site between May and August each year.
9. Gij an indicator for whether the site was searched for fox scat.
10. Fij an indicator for fox scat presence.

The log-linear model expressed y_{ij} as the observed value of a Poisson random variable with parameter λ_{ij} modelled as:

$$\ln(\lambda_{ij}) = \alpha_i + X_j(\beta_1 + \beta_2 S_i + \beta_3 N_i + \beta_4 V_i) + \beta_5 P_i + \beta_6 C_i + M_{ij}(\beta_7 + \beta_8 L_{ij} + \beta_9 O_{ij} + \beta_{10} L_{ij} O_{ij})$$
$$+ \sum_{h=0}^{4} R_{ij-h}(\beta_{11+h} + \beta_{16+h} P_i) + \beta_{21} G_{ij} + \sum_{h=0}^{4} \beta_{22+h} \ln(\pi_{ij}/(1-\pi_{ij}))$$

where the parameters α_i are the site means. These were modelled as normal random variables with mean μ_{nest} and variance σ^2_{nest}

In this model, Mallefowl trends were modelled as state-specific ($\beta_1,\ldots,\beta_4$). The parameter β_5 represents the additive effect of patchsize and β_6 the additive effect of the proportion of cleared land within a 5km radius. The effect of fire, for those site that had a burn history ($M_{ij} = 1$), was modelled as a linear regression on number of years since the burn (β_8), extent of burn (β_9) and their interaction (β_{10}) with the intercept β_7 representing the effect of a burn in the current year (year j) of average size. The effects of rainfall were modelled by including up to 4-year lag effects ($\beta_{11},\ldots,\beta_{15}$) that interacted with patchsize ($\beta_{16},\ldots,\beta_{20}$).

The effect of foxes on the expected count of active Malleefowl nests was included by adding effects due to the log-odds of π_{ij}, the probability that a fox was present at the site, with lag effects up to five years ($\beta_{22},\ldots,\beta_{26}$). Given the number of inactive nests that were checked, the number of fox scats present on inactive nests (f_{ij}) was modelled as a binomial random variable with index n_{ij}, the number inactive nests that were checked, and probability π_{ij}. We modelled the log-odds of π_{ij} as:

$$\ln\left(\frac{\pi_{ij}}{1-\pi_{ij}}\right) = \gamma_{0i} + \gamma_1 B_{ij}$$

where γ_{0i} is the log-odds of scats on an inactive nest at site *i* with no fox baiting as a normally distributed random effect with mean μ_{fox} and variance σ^2_{fox}. The parameter γ_1 is the amount that the log-odds of fox presence changed by for a one-unit increase in the level of baiting.

To account for the missing values for rain, we modelled standardized rainfall as a normal random variable with mean μ_{rain} and variance σ^2_{rain}. To account for missing values of fox baiting we modelled standardised bait as a normal random variable with mean μ_{bait} and variance σ^2_{bait}.

The model was fitted in WinBUGS (Speigelhalter, Thomas & Best, 2000), a program for Bayesian inference making use of Markov chain Monte Carlo. For priors on the parameters $\beta_1,\ldots, \beta_{26}$, μ_{nest}, μ_{rain}, μ_{fox}, μ_{bait} we used vague normal priors with mean 0 and variance 10000. For the parameters σ^2_{nest}, σ^2_{rain}, σ^2_{fox}, and σ^2_{bait} vague inverse-gamma priors with shape parameter 0.001 and scale 0.001 were used. The model was run twice using dispersed starting values to assess mixing. A sample was drawn from the joint posterior density of 200,000 values obtained from the two chains each run for a further 100,000 iterations after discarding a burn-in sample of 10,000 values.

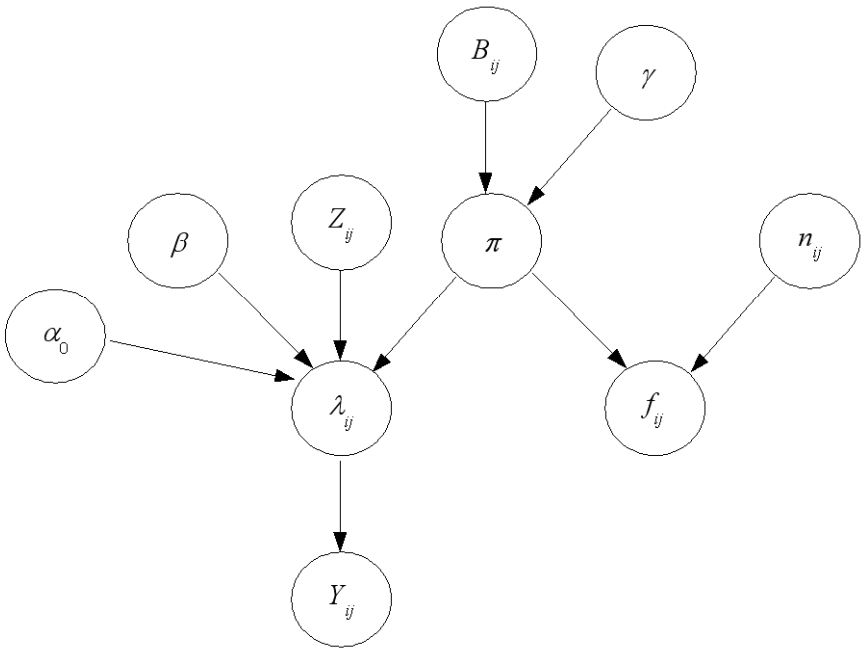

Figure 2. Directed acyclic graph representation of the hierarchical log-linear model for counts of active Malleefowl nests (Yij) modelled as a function of covariates (Z) and the probability of fox presence (π).

Results

Time trends

For the Western Australian sites there was evidence that average Malleefowl breeding counts have declined over time (posterior mean of $\beta_1 = -0.046$, 95% C.I. = –0.096, 0.004), although a minimal increase cannot be ruled out (Table 4). The parameters β_2 - β_4 represent differences between the trend for the particular state and Western Australia. After converting to state-specific trends, in South Australia there was evidence of an annual decline (posterior mean of $\beta_2 + \beta_1 = -0.054$, 95% C.I. = –0.075, –0.032) suggesting an annual decrease in active nests of between $100(1-e^{-0.032}) = 3\%$ and $100(1-e^{-0.075}) = 7\%$ Malleefowl nests per year. Evidence for Victoria was equivocal (posterior mean of $\beta_3 + \beta_1 = 0.005$, 95% C.I. = –0.012, 0.022) as we were unable to rule out either increases or decreases. Only in New South Wales was there evidence of an increase in active nests (posterior mean of $\beta_4 + \beta_1 = 0.101$, 95% C.I. = 0.063, 0.140) with evidence of an annual increase of between $100(e^{0.063}-1) = 7\%$ and $100(e^{0.140}-1) = 15\%$.

Rainfall effects

There was strong evidence of a positive effect due to the amount of winter rain (β_{11}), and also lag effects for 2-4 years ($\beta_{13\text{-}15}$). Our estimates indicate that each one-standard deviation increase (approximately 63 mm) in the cumulative rainfall between May and September (henceforth 'winter-rain') for an average sized patch resulted in an increase in the average number of active nests of between $100(e^{0.247}-1) = 28\%$ and $100(e^{0.451}-1) = 57\%$. Lag effects after one year (β_{12}) were equivocal, but each one-standard deviation change in winter-rain after 2, 3 and 4 years ($\beta_{13\text{-}15}$) for an average sized patch led to an increase in the average number of active Malleefowl nests of between approximately 15%-40%, 0%-20%, and 2%-27% respectively (in each case obtained by $100(e^{x}-1)\%$ where x denotes the C.I. endpoints). There was also strong evidence of a positive interaction between patchsize and cumulative winter rainfall (β_{16}), and between patchsize and winter rainfall at lags of 2 and 3 years ($\beta_{18\text{-}19}$) indicating that responses to increased winter rainfall was stronger for larger patches than smaller ones (Figure 3).

Fire effects

There was also strong evidence of a negative effect due to previous fire history (posterior mean of $\beta_7 = -0.896$, 95% C.I. = –1.473, –0.310). Sites with fire history (ie. sites known to have been burnt at some time in the past) tend to have between $100(1-e^{-0.310}) = 27\%$ and $100(1-e^{-1.464}) = 77\%$ fewer active Malleefowl nests than sites with no fire history. There was strong evidence of an interaction (β_{10}) between the number of years since a site was burnt and the percentage area that was burnt. Evidence for the effect due to the number of years since the site was burnt (Table 5) was equivocal when just 10% of the site was burnt (95% C.I. = –0.532, 0.246) and when 50% of the site was burnt (95% C.I. = –0.134, 0.378). However, if 90% of the site was burnt there was strong evidence that the average count of active Malleefowl nests increases with the number of years since burning (95% C.I. = 0.135, 0.626). The effect of years since burning was expressed in decade units; that is, for each 10 year interval since burning, the number of active Malleefowl nests increases by

between $100(e^{0.135}-1) = 15\%$ and $100(e^{0.626}-1) = 87\%$ when 90% of the site had been burnt.

Fox effects

Our evidence for effects due to foxes (β_{22}), and for lags for one to four years ($\beta_{23\text{-}26}$) were all equivocal (Table 4), however there was strong evidence for an effect of fox control on fox abundance (posterior mean of $\beta_{\text{fox}} = -1.529$, 95% C.I. = −1.842, −1.212). Sites with fox control tended to have fewer scats on inactive mounds: each one-standard deviation increase in fox control led to a decrease in fox scats on nests approximately between $100(1\text{-}e^{-1.212}) = 78\%$ and $100(1\text{-}e^{-1.842}) = 84\%$ fewer.

Other effects

Our evidence for effects due to searches (posterior mean of β_{21} =0.131, 95% CI = −0.008, 0.268) and the percentage of land within a 5km radius that had been cleared (posterior mean of $\beta_6 = 1.288$, 95% CI = −0.179, 2.781) was equivocal. That is, in each case we are unable to rule out moderate negative or positive effects and effect means were not significantly different from zero.

Table 4. Posterior summaries for model parameters describing effects on the natural logarithm of the average number of active Malleefowl nests.

Parameter	Effect	mean	sd	0.025	median	0.975	
β_1	Trend - W	-0.046	0.025	-0.096	-0.046	0.004	
β_2	Trend - (S-W)	-0.008	0.025	-0.057	-0.008	0.041	?
β_3	Trend - (V-W)	0.051	0.025	0.003	0.051	0.100	?
β_4	Trend - (N-W)	0.147	0.031	0.087	0.147	0.207	?
β_5	Patchsize	0.058	0.252	-0.427	0.058	0.558	
β_6	5kRcleared	1.288	0.754	-0.179	1.289	2.781	
β_7	Burn	-0.896	0.295	-1.473	-0.899	-0.310	✳
β_8	Yearssince	-0.191	0.218	-0.640	-0.186	0.221	
β_9	Burnsize	-0.287	0.467	-1.211	-0.284	0.617	
β_{10}	Yearssince*Burnsize	0.635	0.252	0.164	0.630	1.146	✳
β_{11}	Winterrain	0.348	0.052	0.247	0.348	0.451	✳
β_{12}	Winterrain lag1	0.044	0.048	-0.049	0.044	0.137	
β_{13}	Winterrain lag2	0.238	0.049	0.143	0.238	0.334	✳
β_{14}	Wtnterrain lag3	0.097	0.047	0.004	0.097	0.190	✳
β_{15}	Winterrain lag4	0.127	0.056	0.018	0.127	0.237	✳
β_{16}	Patch*Winterrain	0.120	0.049	0.025	0.120	0.216	✳
β_{17}	Patch*Winterrain lag1	0.047	0.041	-0.034	0.047	0.128	
β_{18}	Patch*Winterrain lag2	0.115	0.044	0.030	0.115	0.201	✳
β_{19}	Patch*Wtnterrain lag3	0.088	0.039	0.011	0.088	0.165	✳
β_{20}	Patch*Winterrain lag4	0.020	0.053	-0.084	0.020	0.123	
β_{21}	Searched	0.131	0.071	-0.008	0.131	0.268	
β_{22}	logit Pr(fox)	-0.014	0.108	-0.221	-0.016	0.203	
β_{23}	logit Pr(fox) lag1	-0.109	0.120	-0.353	-0.106	0.119	
β_{24}	logit Pr(fox) lag2	0.002	0.101	-0.199	0.002	0.201	
β_{25}	logit Pr(fox) lag3	-0.009	0.114	-0.221	-0.013	0.226	
β_{26}	logit Pr(fox) lag4	0.213	0.120	-0.023	0.214	0.447	
β_{fox}	Fox control on foxes	-1.529	0.161	-1.842	-1.530	-1.212	✳

Table 5. Posterior summaries for the effect of the number of years since burning computed for differing levels of the percentage area burnt.

Percent burnt	Mean	SD	0.025	0.5	0.975
10	-0.128	0.197	-0.532	-0.123	0.246
50	0.126	0.131	-0.134	0.127	0.378
90	0.380	0.125	0.135	0.379	0.626

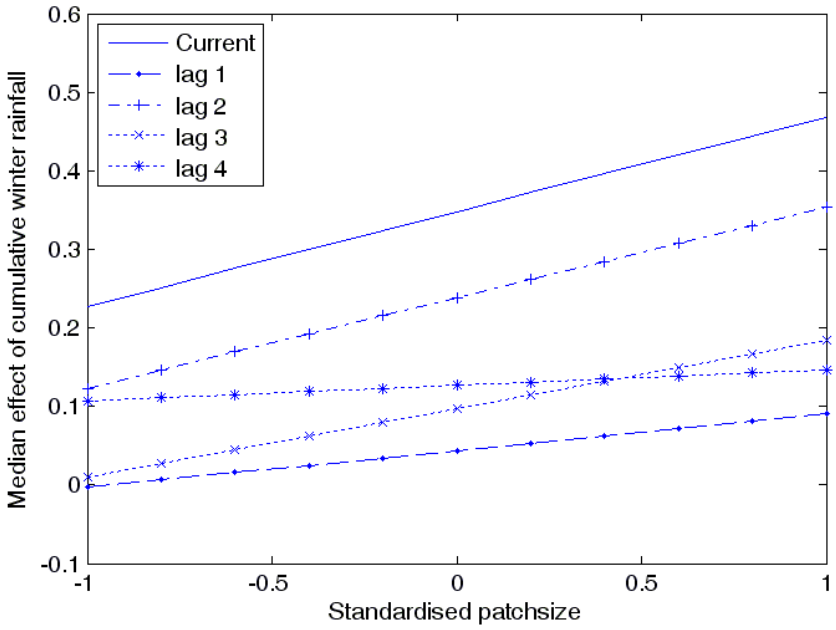

Figure 3. Median effect of standardised cumulative winter rainfall on Malleefowl counts in the current year and at lags of one, two, three, and four years for different levels of standardised patchsize.

Discussion

In this study, Malleefowl monitoring information was collated from all the southern mainland states involving a total of 64 sites over an average of 9.2 years (range= 2-20 years of data), resulting in 590 counts of Malleefowl breeding numbers at these sites. These data were collected by wildlife agencies, community groups and volunteers and provide the most sensitive and comprehensive measure of Malleefowl population trends available. We have used these data to determine trends in Malleefowl populations and to retrospectively examine what environmental factors might be responsible for these changes.

Our analysis found evidence of a significant decline of 2-3% per year in Malleefowl breeding numbers in monitoring sites across Australia (NOT IN NEW RESULTS). This downward trend was most evident in SA (142 counts of breeding numbers at 23 sites) and WA (36 counts at 6 sites) where the declines were significant. In VIC (365 counts at 29 sites) a downward trend was evident but this was not significantly different from zero. In NSW (47 counts at 6 sites) we found a significant positive trend in Malleefowl, although it should be noted that we only obtained monitoring data from two large reserves in the SW corner of NSW (Tarawi and Mallee Cliffs). Elsewhere in central and western NSW several studies have documented declining breeding numbers, especially in very small (<500 ha) isolated remnants (Brickhill 1985, 1987b, Priddel 1989, 1990, Priddel and Wheeler 1995, 2003) and it would appear that the Malleefowl trends in Tarawi and Mallee Cliffs are an exception in NSW and not representative of the remainder of that state.

Searching monitoring sites had a small positive effect on Malleefowl counts. This effect was not statistically significant, but has in any case been separated out from other effects such as the trends in each state and environmental variables.

Malleefowl Trends in relation to environmental variables

1. Landscape variables

We used two site variables to investigate the affect that landscape configuration may have on Malleefowl populations: the size of the block of habitat in which the monitoring sites was located (Patchsize), and the proportion of cleared land within five kilometres of the centre of the monitoring sites (5kClr). In regard to Patchsize, we found little evidence of an effect on Malleefowl populations; the variability of responses by Malleefowl was high and although there was a slight positive relationship between Patchsize and Malleefowl numbers, this was not significant. Thus, contrary to our expectations, there was no evidence in our analysis that small isolated patches were more prone to Malleefowl declines than larger patches. We expected small habitat patches to show more declines because extinction probabilities are higher in small populations due to stochastic processes and the lack of immigration (Bennett 1999) and because such declines have been shown for other species (e.g. Mac Nally and Horrocks 2002, Watson et al. 2005). However, our analysis suggests that trends in Malleefowl populations are not especially sensitive to patch size, and further implies that conservation of Malleefowl in smaller reserves is not necessarily handicapped in the short to medium term. In the long term, small and isolated populations are subject to genetic deterioration (Nei et al. 1975, Shaffer 1981) and it seems likely that populations in these small reserves would inevitably decline without careful management to ensure that Malleefowl are not genetically isolated.

Another reason for the lack of affect of patch size is that Malleefowl may obtain some benefit from cleared land, especially crop lands that usually surround small habitat patches. Malleefowl are frequently observed feeding on herbs and fallen grain on cleared land at the edge of reserves, and this additional food source may be especially important during droughts and times of food shortage and mitigate the negative effects of small patch size and fragmentation. It is also worth noting that sites near cleared land may also naturally support higher numbers of Malleefowl: clearing was concentrated toward more fertile soils in higher rainfall areas suitable for agriculture, and this is also where Malleefowl densities tend to be highest. In our analysis, the amount of cleared land within five kilometres of monitoring grids had a positive effect on Malleefowl trends, although this effect was not significant.

That Malleefowl have persisted over the medium term in small patch sizes and in fragmented landscapes is an encouraging result and suggests that, with appropriate management to avoid population and genetic bottlenecks, such sites will continue to be of importance to Malleefowl conservation.

2. Fire

As expected, our analysis showed that Malleefowl numbers were deleteriously affected by past fires. We found a significant negative relationship between past fire and Malleefowl populations, but as most records we were able to obtain on past fire at monitoring sites were only reliable since the 1970s, this finding essentially states that sites that were known to be burnt since 1970 had lower Malleefowl breeding counts than those without fire. While we did not find significant effects of either the proportion of a site that was burnt, or the amount of time since a burn, we did find a significant interaction between these variables which suggested that where most of a site was burnt, Malleefowl populations increased steadily in ensuing decades. However, this affect was less evident and equivocal for sites that were only partly burnt, probably because the birds were initially less disrupted by these partial burns.

These findings broadly agree with previous studies on the short and longer term responses of Malleefowl to fire, that Malleefowl breeding densities are lower in areas burnt within the last few decades than in old-growth mallee has been established in several studies (Woinarski 1989b, Benshemesh 1990, Clarke 2005), and the mitigating effects of patchy or incomplete fires has also been documented (Benshemesh 1990). Of interest in the current study is that Malleefowl began breeding within six-eight years of two monitoring sites being burnt, and this was reflected in the model in which increases in Malleefowl breeding occurred within the first few years after fire. Previously it was thought that 15 years was required before the birds resume breeding in burnt areas (Cowley et al. 1969).

Fire is clearly a threat to Malleefowl, often occurring on a scale in mallee that may devastate even the largest Malleefowl populations and lead to reduced breeding numbers for several decades. However, despite the strong effects of fire shown in this study, fire does not provide a satisfactory explanation for the declines evident in Malleefowl populations. Very few sites in this study were burnt during the course of monitoring (5 sites, only 2 of which were more than 10% burnt), and the predominant pattern observed should have been increasing numbers of Malleefowl rather than the declines that were evident.

3. Rain

Winter rain has a pronounced effect of Malleefowl breeding numbers and this was evident in our analysis. We found significant positive effects of winter rain on Malleefowl and significant lag effects two, three and four years later (the one year lag effect was weakly positive but not significant). There were also significant interaction effects between winter rain and patch size, suggesting that large patches were more responsive to rainfall than smaller patches.

The primary affects agree reasonably well with what is known about Malleefowl ecology. Malleefowl do not breed after especially dry winters (Booth and Seymour 1983) and there were several such seasons during the monitoring record. The lag effect of winter rain on breeding numbers is particularly interesting, and may be due to lag in the production of food, such as seed production, or to lags in the recruitment of Malleefowl into the breeding population, or both.

Lag effects in winter rain are likely in regard to food because winter is the main period of growth for shrubs (except eucalypts, Holland 1968) as well as annuals, and some common acacia species appear to require two winters to produce seed. For example, *Acacia brachybotrya* and *A. calamifolia* both produce flowers in winter-spring that do not produce seed until summer 15 months later (personal observation). However, if the lag effects of winter rain on Malleefowl numbers were related to food production, the lack of a significant response after one year would seem unexpected. In contrast, lag effects of winter rain of two to four years, but not after one year, is what would be expected if the effect were due to recruitment of young birds into the breeding population. Captive Malleefowl usually start breeding in their third or fourth year (Bellchambers 1916), and although recent observations suggest males in the wild may breed within a year (Waag 2006), this may be uncommon as one year old birds are still noticeably small (Jessica van der Waag, pers. comm.). Thus, while both these hypotheses would appear to be plausible, the lack of a lag effect after one year and the significant lag effects after two to three years fits the recruitment explanation better. Further investigation into this poorly understood aspect of Malleefowl ecology would be valuable.

Lower than expected winter rainfall has characterised most monitoring sites over the past decade or so and may offer a partial explanation for the declines in Malleefowl described in this study. More than 80% of the sites in this study experienced lower winter rain over the past 10 years, and 95% over the past five years, compared with long term averages between 1961-90 (a period which is accepted as a recent meteorological standard). Given the lag effects for winter rain on Malleefowl of up to four years shown in this study, the average four-year winter rainfall deficit (Figure 4) is especially pertinent to Malleefowl and graphically shows that while winter rain was higher in the early 1990s than the average for the previous 30 years, since 1996 the four year deficit has increased steadily and in 2004-5 was nearly 20% below that expected.

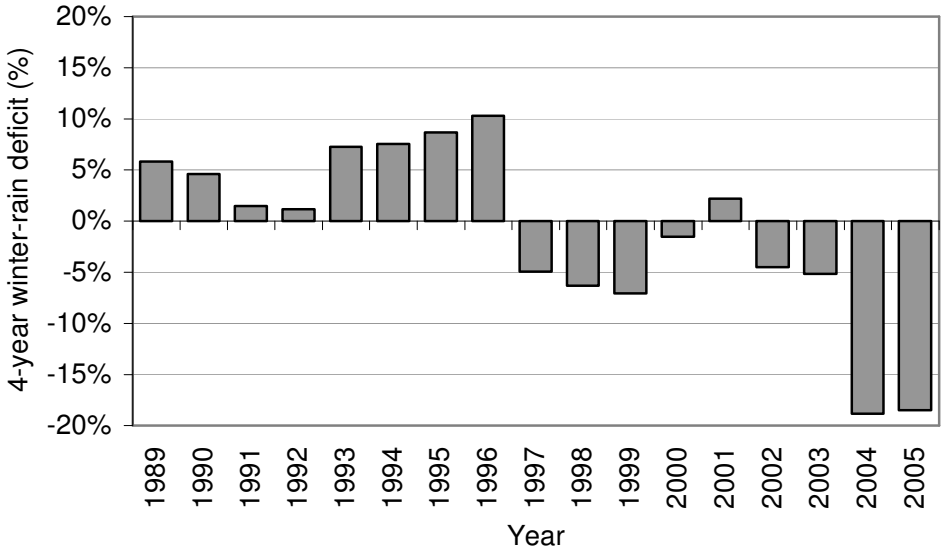

Figure 4. Average four-year winter rainfall deficit for the monitoring sites in this study. For each site and year, the deficit was calculated as the average winter (May-September) rainfall over the past four years, minus the expected rainfall (average winter rain for the period 1961-90), divided by the expected rainfall.

Given the significant relationships between winter rain and Malleefowl numbers, current predictions of climate change for Australia (Pittock & Wratt 2001) provide considerable cause for concern. Winter rain is expected to decline in most semi-arid habitats that support Malleefowl, and the results of this study suggest that each relatively dry winter will have negative ramifications on Malleefowl breeding populations for at least four years. If current climate predictions are correct, and if the changes are not arrested, substantial declines in Malleefowl populations are likely in the future.

4. Foxes

While there is no doubt that foxes eat Malleefowl, the degree to which predation by foxes influences Malleefowl numbers has long been controversial and unresolved. This study represents the first attempt to examine this question at the population level across multiple sites, and our findings challenge commonly held views that foxes are a major cause of Malleefowl declines, and that fox control is beneficial and helps reverse declines.

Our analysis found no evidence of a significant effect on Malleefowl populations of foxes or fox control, either in the year that Malleefowl were monitored, or for the following one to four years. Although, the four year lag effect did approach statistical significance, the direction of this effect was positive (i.e. more foxes resulting in more Malleefowl) rather than negative, suggesting that baiting in the longer term might actually be associated with Malleefowl decline rather than recovery (although this was not statistically significant). However, we did find a significant and strong negative effect of fox control (i.e. baiting) on the incidence of fox scats on mounds, suggesting that baiting was associated with a decline in fox numbers. Thus, while baiting did appear to result in a decline in fox numbers, there was no evidence of a benefit to Malleefowl breeding numbers or amelioration of declines.

In light of this finding, it is useful to consider the evidence that has been used to support the argument that foxes pose a serious threat to Malleefowl. Firstly, foxes are known predators of Malleefowl and there is little doubt that foxes account for a considerable proportion of Malleefowl eggs, chicks, juveniles and adults (Frith 1959, 1962a, Booth 1987, Brickhill 1987a, Benshemesh 1992, Priddel and Wheeler 1994, 1996, Benshemesh and Burton 1999, Priddel and Wheeler 2003). Secondly, experimental reduction of fox numbers has been linked to increased survivorship of captive-reared Malleefowl chicks and juveniles that have been released back into the wild (Priddel and Wheeler 1997), further suggesting that removing these introduced predators might benefit wild Malleefowl as well. And finally, an analogy is often drawn between the declines of Malleefowl and the disappearance of many medium-sized mammals (Short 2004), at least some of which have been shown to be sensitive to fox predation and have responded positively to the control of fox numbers.

Our analysis of the monitoring records does not negate any of the findings of previous studies (although some interpretations are challenged), but rather provides conservation perspective and a test of the management hypothesis that emerged from them, that controlling foxes would protect Malleefowl populations from declines. This does not seem to be the case and we were unable to find a statistically significant benefit of fox control to Malleefowl. However, this result should be interpreted in regard to the limitations of this study. Firstly, fox control operations across Australia vary enormously in terms of frequency, timing, intensity, extent and bait type, and by reducing this complexity to a simple score (total baits per year within 100 km^2) we may have oversimplified a complex issue. Secondly, most baiting that occurs in and around Malleefowl monitoring sites is low intensity. We do not know at what level baiting might become of benefit to Malleefowl, if at all, but note that high intensity baiting (>5 baits/km^2/yr) is a relatively uncommon and recent practice at Malleefowl sites and might be under-represented in this study. Thirdly, although a considerable effort was made by a number of people in agencies and in the community, as well as us, to locate accurate fox baiting information from around Malleefowl monitoring sites, this was not a straightforward process and much of the data came from people's recollections rather than official records. In this regard we were lucky that an institutional memory existed and that we were able to track down information that we believe is reliable for most sites. The generally short history of accessible fox control records has also been commented on by Reddiex et al. (2004) who also found that records were difficult to access beyond the past few years, even though such records do presumably exist. In future, it would be advantageous for copies of management records on control of foxes to be kept together with other information relevant to monitoring Malleefowl.

Finally, retrospective descriptive studies such as ours have inherent limitations (Romesburg 1981). For example, we do not know why some sites were chosen for baiting foxes, or particular baiting intensities, but it is possible that these choices may have influenced our results. More reliable knowledge will be gained about the benefits of fox control by conducting well designed management experiments (Reddiex and Forsyth 2004, Reddiex et al. 2004) as has also been recommended in successive national recovery plans for Malleefowl.

Conserving Malleefowl in light of management uncertainties

This study demonstrated the value of monitoring Malleefowl, and of pooling monitoring data. Monitoring is essential in order to describe and understand the

trends of threatened species, and it is fortunate that there are so many Malleefowl monitoring sites scattered throughout the semi-arid zone. That most of these sites are monitored by an army of volunteers each year is especially valuable and relieves agencies of this critical, but time-consuming and potentially expensive task. Indeed, monitoring is often the most expensive part of carefully designed and replicated management experiments (Reddiex and Forsyth 2004).

The network of Malleefowl monitoring sites provides a resource of great value to conservation, but one which we believe is under-utilised. The current study is one part of a larger program that is providing national standards, disseminating protocols, establishing central databases and generally facilitating the monitoring effort on a national scale. All of these components are essential for an effective national monitoring system, but to fulfil its potential the monitoring system should be much more integrated with management and research and used as a template upon which to conduct management experiments with appropriate levels of replication, randomisation and experimental control. Carefully designed management experiments provide more reliable information than descriptive studies (Romesburg 1981, Macnab 1983, Murphy and Noon 1991) and the current Malleefowl monitoring system would seem well-suited for such experiments, particularly as the monitoring information is already being collected.

Adaptive management (AM) has been recommended in the National Recovery Plan for Malleefowl to provide a framework for the monitoring effort at a national level and to better integrate monitoring, management and research (Benshemesh 2005b). AM is a pragmatic and collaborative process of 'learning by doing' that confronts uncertainties in management and seeks to gain reliable knowledge through experimental management (Walters 1986, Walters and Holling 1990). Key components of the AM approach include experimental design, field management treatments and monitoring, structured in such a way that the success of management alternatives can be evaluated.

The approach would seem well-suited to Malleefowl conservation for a number of reasons. Firstly, as demonstrated in this study there is considerable uncertainty about the effectiveness of management actions in reversing Malleefowl declines and in the role of environmental factors. This uncertainty is likely to increase dramatically if climate change predictions are correct. AM embraces such uncertainty and provides a means of identifying best management practice in a coherent and statistically meaningful way. Secondly, Malleefowl still occur over much of their uncleared range, providing opportunities for replicating management treatments and controls (non-treatment sites). The current network of monitoring sites represents a tiny proportion of this range and varying management treatments at these sites is unlikely to compromise the conservation of the species. Thirdly, there is already a strong community involvement in Malleefowl conservation at a national scale and a general enthusiasm for collaboration with agencies and land managers. Further collaboration between community volunteers, land managers, scientists, and other stakeholders will be required across political boundaries to develop and implement an AM plan for Malleefowl management.

However, volunteers cannot implement management treatments, and the active collaboration, involvement and commitment of agencies and land managers will be essential to manipulate the management of monitoring sites according to national plans.

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Appendix 1 Malleefowl breeding counts

Table 7. Numbers of Malleefowl breeding at monitoring sites (State & Site number) used in the analysis: a) SA sites; b) Vic sites; c) NSW and WA sites. In some cases numbers have been adjusted due to uncertainty in records (increments of 0.5; see text for details). Blank cells indicate no data, sites that were omitted from the analysis. Breeding seasons are indicated by the spring year (ie. 1996 indicates 1996/7 breeding season). Shaded cells show when a site was thoroughly searched for mounds. Brackets indicate sites that were split for this analysis.

a) Malleefowl breeding counts at SA sites

SA	1963	1964	1969	1984	1986	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
s01												10	6			7		8	6	7	3	5
s03										13	16	8	5	1	3	2	2	2	0	3	2	0
s05										2	0	1	0		0	0	1	1			0	0
s06							6	8	12		8	7	4	0	1	0	1	1		0	1	0
s07						12	12	10.5	13.5			16	17	18	10.5	7	7	2	0	0	1	4
s08						9		9				7	7.5	5	7		1	3	0	0	1	1
s09												0	0			1		2			0	0
s10							10	10	10	7		8				5		4				6
s11									7				7		5.5	7			6			8
s13											4					1		4				4
s15										0	1	0	0		1	0	0	0			0	0
s16																				3		3
s17															2				1	1		4
s18															1					0		0
s23																					1	0
s30																					0	1
s44																		5			3	3
s45																		0				1
s46																		0				1
s54																					1	0
s57																					1	0
s64																				7	6	6
s65													3	2	4	4	4	4	3	3		1

b) Malleefowl breeding counts at VIC sites

	1963	1964	1969	1984	1986	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
v01a												1	1	1	1	0	0	2	0	0	0	2
V01b												2	0	0	0	0	0	1	1	0	0	0
v02	10	11			9	9	8	7	6	9	1	12	10	8	3	2	1	2	2	3	5	4
v03					9	9	8	10	10	8	7	7	9	7	12	8	10	11	2	11	10	9
v04a						9		12	11	8	2	11	6	9	11	9	12	6	0	9	9	10
v04b						6		2	3	3	1	3	4	3	3	3	5	5	0	5	4	5
v05													5	1	3	3		0	0	2	1	3
v07a					2		0	0	1		1	1	0	0	0	1	2	1	0	1	1	1
v07b					1		1	0	0		0	0	0	1	0	0	0	0	0	0	0	0
v08													4	2	0	2	1	3	0	1	1	2
v09													1	2	1	1	1	1	0	2	0	1
v11													0	0	3	2	2	2	0	1	0	2
v12								4	3			0	3	2	2	1	2	4	0	1	0	4
v13											1	3	2	0	1	0	0	1	0	2	2	2
v14								13			11	9	7	5	6	8	6	12	0	12	10	11
v15.1a			8			11	14	15	12	11	9	8	7	7	7	4	5	3	0	11	10	11
v15.1b			4			3	0	0	0	0		1	3	0	1	1	1	1	0	4	4	6
v15.2			1							5	4	3	3	5	4	5	3	1	1	7	4	5
v15.3a																		1	0	2	1	3
v15.3b																		6	0	10	8	8
v16												5	1	1	0	0	0	0	0	0	0	1
v17										5	2	3	0	0				0	0	0	0	0
v18										3	0	1	3	2	1	1	0	1	0	0	0	3
v19										1	0	2	4	0	0	0	0	0	0	0	0	0
v20						7		6	6		6	7	6	7	5	2	4	5	2	3	3	2
v21									6	5	1	7	5	4	3	3	3	2	0	4	3	2
v22									3		3	2	2	1	1	1		1	0	0	0	0
v23				12							8	8	5	11	14	13	11	17	0	4	3	3
v27																			0	5	4	4

c) Malleefowl breeding counts at NSW and WA sites

	1963	1964	1969	1984	1986	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
n01						6	1	16	8	4	1	13	14	1	10	2	6	4	9	29	17	28
n02a														0	0	0	0		0	2	0	2
n02b															0	0	0		0	0	0	0
n02c																1	2		0	2	0	1
n02d																	0		0	0	2	1
n02e																			0	3	2	2
w11										5		4		5	5.5	8	8	3	4	2		
w12											7	7	7	6	6	6		5	5			
w13												4	3		2	2	3.5	1	2	1	1	2
w14												2			2		0					
w01												11			10				1		1	
w02															3							3

Appendix 2 Fox baiting

Table 8. Fox bait effort. Numbers represent the estimated number of baits laid each year within a 100km2 area with the monitoring site at its centre: a) SA sites; b) Vic sites; c) NSW and WA sites. Shaded cells show years before it was believed baiting began at sites, or before records were available and blank cells indicate no reliable data. Brackets indicate sites that were split for this analysis and received similar baiting regimes.

a) Fox bait effort at SA sites.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
s01	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
s03	0	0	0	0	0	0	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
s05	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s06	0	0	0	0	0	0	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6
s07	0	0	0	0	0	0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
s08	0	0	0	0	0	0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
s09	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s10	0	0	0	0	0	0	0	0	0	0	0.3	0.3	0.0	0.0	0.2	0.0	0.0
s11	0	0	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	47.0	47.0	47.0
s13	0	0	0	0	0	0	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
s15	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s16	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s17	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s18	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	15.0	15.0
s23	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
s30	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
s44	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
s45	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
s46	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
s54	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5
s57	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5
s64	0	0	0	0	0	0	0	0	0	0	0	3.0	3.0	3.0	3.0	3.0	3.0
s65	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

b) Fox bait effort at VIC sites.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
v01a	0	0	0	0	0	0.0	0.0	0.0	0.5	0.5	1.0	1.5	1.5	1.5	1.5	1.5	1.5
V01b	0	0	0	0	0	0.0	0.0	0.0	0.5	0.5	1.0	1.5	1.5	1.5	1.5	1.5	1.5
v02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.8	1.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5
v03	0.0	0.0	5.4	5.4	5.4	5.4	3.6	2.3	2.3	2.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
v04a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4
v04b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4
v05	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	8.5	8.5	8.5
v07a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v07b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v08	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v09	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v11	0	0	0	0	0	0	0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v12	0	0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v13	0	0	0	0	0	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v14	0	0	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
v15.1a	0	0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
v15.1b	0	0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
v15.2	0	0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
v15.3a	0	0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
v15.3b	0	0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
v16	0	0	0	0	0	0	0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v17	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v18	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v19	0	0	0	0	0	0	0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
v20	0	0	0	0	0	0.0	0.0	0.0	0.5	0.5	1.0	1.5	1.5	1.5	1.5	1.5	1.5
v21	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	12.7	12.7	12.7
v22																	
v23	0	0	0	0	0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
v27	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0

c) Fox bait effort at NSW and WA sites

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
n01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	1.2	1.2	1.2	1.2
n02a	0	0	0	0	0	0	0.0	3.6	4.5	3.6	2.7	4.5	3.6	3.6	3.6	3.6	3.6
n02b	0	0	0	0	0	0	0.0	3.6	4.5	3.6	2.7	4.5	3.6	3.6	3.6	3.6	3.6
n02c	0	0	0	0	0	0	0.0	3.6	4.5	3.6	2.7	4.5	3.6	3.6	3.6	3.6	3.6
n02d	0	0	0	0	0	0	0.0	3.6	4.5	3.6	2.7	4.5	3.6	3.6	3.6	3.6	3.6
n02e	0	0	0	0	0	0	0.0	3.6	4.5	3.6	2.7	4.5	3.6	3.6	3.6	3.6	3.6
w11	0	0	0	0	0	2.6	2.6	6.8	8.2	23	23	23	23	23	23	23	23
w12																	
w13	0	0	0	0	0	0	0	2.2	4.5	4.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5
w14																	
w01	0	0	0	0	0	0	2.0	1.7	1.4	1.5	1.5	1.5	1.4	1.3	1.6	1.4	1.3
w02	0	0	0	0	0	0	2.0	1.7	1.4	1.5	1.5	1.5	1.4	1.3	1.6	1.4	1.3

Appendix 3 Excluded sites

Data were received from a number of sites that was not included in the analysis. Figure 5 provides an overview of the reasons for excluding data, and Table 9 provides a more detailed list of sites and seasons that were excluded.

Of the 88 site-years that were not included in the analysis (590 site-years were included), the most frequent reason (37% of total) was that too few mounds were visited to enable an estimate of breeding numbers at the site ("Low visitation" in Figure 5). A further 24% were excluded because there was only one breeding count for the site ("Lone"), 17% because no breeding had ever been recorded at the sites, and 9% because although data were recorded at most mounds, the data were incomplete or ambiguous ("Unreliable"). The remaining 11% were excluded for a variety of reasons.

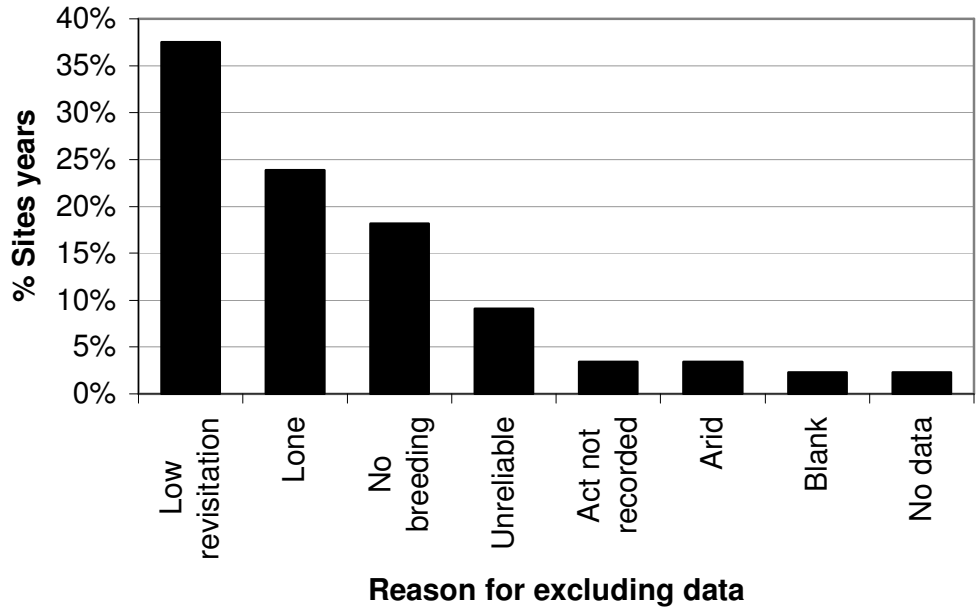

Figure 5. Summary of reasons for omitting monitoring data that were submitted but not analysed in this report. The Y axis shows the proportion of omitted site-years in each category on the X axis.

Table 9. Sites and years for which data was submitted but not used in the analysis for this project. Reasons for excluding these site-years are provided in the Notes and Reason columns. **"0" indicates that no breeding has ever been recorded at the site in question; see text for details.**

State	Grid	Part	Season	Reason	Note
S	01		1997	Low revisitation	Only 25 of 41 nests monitored, 5 with act history
S	01		2000	Unreliable	Many supposedly active nests without eggshell the following years, and unusually high number of active nests
S	04		1996	Lone	No other acceptable monitoring visits
S	04		2005	Low visitation	Only 14% of nests revisited
S	06		1993	Unreliable	Suspicious: 30% of stated active nests had neither prints nor were scraped
S	08		1992	Low visitation	Only 13% of nests visted
S	08		1999	Low visitation	30 nests either not found or activity not stated
S	09		1997	Blank	Activity not recorded
S	09		1998	Blank	Activity not recorded
S	10		1989	Low visitation	Only 5 nests visted
S	10		1996	Low visitation	
S	10		1997	Low visitation	
S	10		2000	Unreliable	Appears to be a copy of 1999 data (collected Jan/Feb 2000)
S	10		2004	Low visitation	
S	13		1992	Low visitation	
S	13		1998	Low visitation	
S	13		2000	Low visitation	
S	16		1998	Unreliable	Unreliable data: 2 nests marked as active but data is contrary and confusing
S	19		1999	Lone	No other acceptable monitoring visits
S	19		2004	Low visitation	only 35% nests monitored
S	19		2005	Low visitation	only 63% nests monitored (prev active nest not revisited)
S	20		1999	Lone	No other acceptable monitoring visits
S	21		1999	Lone	No other acceptable monitoring visits
S	21		2004	Low visitation	only 26% nests monitored (prev active nest not revisited)
S	21		2005	Low visitation	only 28% nests monitored (prev active nest not revisited)
S	22		2004	0	no activity ever recorded at this site
S	22		2005	0	no activity ever recorded at this site
S	24		2004	0	no activity ever recorded at this site
S	24		2005	0	no activity ever recorded at this site
S	25		2004	0	no activity ever recorded at this site
S	25		2005	0	no activity ever recorded at this site
S	27		2005	Lone	No other acceptable monitoring visits
S	29		2004	0	no activity ever recorded at this site
S	29		2005	0	no activity ever recorded at this site
S	35		2004	Low visitation	Only 2 nests recorded
S	35		2005	Lone	10 nests recorded, but no other acceptable monitoring visits

State	Grid	Part	Season	Reason	Note
S	36		2004	0	No activity ever recorded at this site
S	36		2005	0	No activity ever recorded at this site
S	47		2001	0	No activity ever recorded at this site
S	47		2005	0	No activity ever recorded at this site
S	48		2001	Lone	7 nests, but no other acceptable monitoring visits
S	48		2005	Low visitation	Only 1 nest monitored
S	49		2001	Lone	18 nests, but no other acceptable monitoring visits
S	49		2005	Low visitation	11 or 18 nests not found
S	52		2004	Lone	27 nests, but no other acceptable monitoring visits
S	52		2005	Low visitation	18 nests of 27 not found
S	56		2004	Unreliable	14 nests, one active but with xsticks the following year: unreliable
S	56		2005	Lone	No other acceptable monitoring visits
S	59		2004	0	No activity ever recorded at this site
S	59		2005	0	No activity ever recorded at this site
S	60		2004	Unreliable	14 nests, one active but with xsticks the following year: unreliable
S	60		2005	Lone	No other acceptable monitoring visits
S	63		2004	0	No activity ever recorded at this site
S	63		2005	0	No activity ever recorded at this site
V	01		1994	Act not recorded	April search, Activity NOT recorded
V	04		1986	Unreliable	April search, only currently active mounds recorded
V	07		1989	Unreliable	June search, no follow-up, profile3 only
V	15	3a	1997	Low visitation	Few nests checked
V	15	3a	1998	Low visitation	Few nests checked
V	15	3a	1999	Low visitation	Few nests checked
V	15	3a	2000	Low visitation	Few nests checked
V	16		1994	Low visitation	Few nests checked
V	26		1990	Low visitation	Few nests checked
V	26		1991	Low visitation	Few nests checked
W	01		2000	Low visitation	Few nests checked (Nugadong)
W	02		2004	Low visitation	Few nests checked (Old Well Maya)
W	11		2004	Low visitation	
W	11		2005		Not visited (Corackerup)
W	12		2000	Low visitation	(Foster Rd)
W	12		2003	Low visitation	
W	12		2004	Low visitation	
W	14		1999	Act not recorded	Too few activity records to provide a reliable breeding count (Hills)
W	14		2002	Act not recorded	Too few activity records to provide a reliable breeding count (Hills)
W	15		1998	Lone	No other acceptable monitoring visits (Tieline)
W	15		2001	Low visitation	too few nests checked (Tieline)
W	16		2000	Arid	Special case: results not directly comparable to area-standardised monitoring (Yeelirrie)
W	16		2004	Arid	Special case: results not directly comparable to area-standardised monitoring (Yeelirrie)
W	16		2006	Arid	Special case: results not directly comparable to area-standardised monitoring (Yeelirrie)

State	Grid	Part	Season	Reason	Note
W	18		2005	Lone	No other acceptable monitoring visits (Eyre)
W	19		2001	Lone	No other acceptable monitoring visits (Hidden Valley (Mullewa))
W	20			No data	No data provided (Kalgoorlie)
W	21			No data	No data provided (Meredin)
W	22		2004	Lone	No other acceptable monitoring visits (Windarling)
W	22		2005	Lone	No other acceptable monitoring visits (Windarling)
W	-1		2004	Lone	No other acceptable monitoring visits (Eatons)
W	-2		2004	Lone	No other acceptable monitoring visits (Carters)
W	-3		2005	Lone	No other acceptable monitoring visits (Reudaveys)
W	-4		2005	Lone	No other acceptable monitoring visits (Mt Gibson)
W	-5		2005	Lone	No other acceptable monitoring visits (While Wells Station)