Threatened Species Recovery Hub

National **Environmental Science** Programme

Malleefowl adaptive management experiment

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Executive summary

Adaptive management (AM) is advocated in the natural resource management literature as a framework for managing ecological systems under uncertainty, yet it is rarely put into practice. Here, we report on a landscape-scale experiment to learn about the effectiveness of predator control on the breeding activity of a threatened Australian bird, the malleefowl (*Leipoa ocellata*). Over the last 5 years, we established 22 control-treatment sites in 8 clusters across continental Australia and managed foxes and cats in and around treatment sites. We monitored malleefowl breeding activity annually through a network of citizen scientists and recorded fox and cat activity with more than 200 continuously operating motion-triggered cameras. We fitted a zero-inflated Poisson regression model to camera trap data and found no support for a statistically significant effect of predator control on fox activity. Surprisingly, very few foxes were detected in Western Australia compared to other states. The effect of baiting on cat activity was uncertain due to few detections. We fitted a Poisson regression model to 5 years of mound count data but found no evidence for an effect of predator control on malleefowl breeding activity. Results from the malleefowl AM experiment so far provide little support for predator control as an effective conservation strategy for malleefowl. However, we recommend the experiment continue until all sites have been operational for at least 5 years. Our study represents a rare example of a landscape-scale predator control experiment within an adaptive management framework.

Introduction

Adaptive management (AM) is advocated in the literature as way to deal with uncertainty in natural resource management (Holling 1978), yet it is rarely put into practice. Barriers contributing to the AM implementation gap are well-documented (Allen and Gunderson 2011): AM often involves multiple stakeholders with conflicting motivations and values, making it difficult to agree on management objectives; high levels of natural variability within natural systems makes it difficult to plan and implement studies that reliably differentiate between management options, and; it is difficult to sustain monitoring for the time needed to resolve uncertainties that impact on management decisions. As a result, most of the literature discusses AM without actually doing it. For example, Westgate et al. (2013) found that of 1336 published studies world-wide discussing AM, less than 5% claimed to have implemented it, and only 13 of these were supported by published monitoring data, a key part of closing the AM loop.

There are, however, notable examples of large-scale, long-term AM programs focusing on weed suppression (Gannon et al. 2013), habitat management (Aldridge et al. 2004, Nicol et al. 2015), fire management (Moore et al. 2011), reintroductions (Armstrong et al. 2007), and predator control (Innes et al. 1999, Parkes et al. 2006, Whitehead et al. 2008). AM programs designed to learn about the effectiveness of predator control on both predators and native species are of particular interest given the impact of introduced predators on agriculture and biodiversity and high levels of uncertainty surrounding the effectiveness of predator control. However, learning about the effectiveness of predator control requires both predator and prey species to be rigorously monitored across spatially replicated control and treatment sites at a landscape scale (Hone 1999; Reddiex and Forsyth 2006; Saunders and McLeod 2007), which is challenging to do. There are few examples of predator control experiments implemented at such scales within an adaptive management framework.

A landscape-scale predator control experiment has been designed within an adaptive management framework to inform conservation and monitoring of an Australian bird, the malleefowl (*Leipoa ocellata*) (Hauser et al. 2019). Malleefowl is a threatened ground-dwelling bird, distributed in low densities across vast areas of semi-arid Australia (Benshemesh et al. 2018). Its geographic range has contracted considerably since the arrival of Europeans due to clearing of the wheat belts for agriculture (Benshemesh 2007). The species continues to be threatened by introduced foxes and cats, further habitat loss, changed fire regimes, and over grazing by introduced and/or native herbivores (Benshemesh 2007, Hauser et al. 2019). Malleefowl are thought to be most susceptible to fox predation immediately following hatching (Priddel and Wheeler 1990). As a result, fox baiting is the most common and probably the most expensive conservation strategy for the species across the full extent of its range.

Although predator control is a widely-used conservation strategy for malleefowl, the response of malleefowl to fox and cat baiting is highly disputed. Malleefowl has been the focus of an extensive citizen science monitoring program over the last 28 years, growing from a handful of sites in the early 1990s to more than 140 sites in 2020. Repeated statistical analyses of this dataset has found that predator control reduces the prevalence of fox scats on malleefowl mounds, but has little subsequent benefit on malleefowl breeding activity (Benshemesh et al. 2007, Walsh et al. 2012). While this dataset provides valuable insight into drivers of malleefowl activity, monitoring was not designed specifically to learn about the benefits of predator control; sites have been established ad-hoc over time in response to the availability of citizen scientists and the prevalence of fox scats were recorded from mounds opportunistically. To improve our understanding about the effectiveness of predator control, spatially replicated control-treatment sites are needed to tease apart the effect of predator control from other drivers of breeding activity.

Here, we summarise the ongoing results of a landscape-scale predator control experiment designed to specifically learn about the effectiveness of predator control on both predator activity and malleefowl mound activity. We established 22 replicated control-treatment sites in 8 clusters across continental Australia and managed foxes and cats in and around treatment sites while keeping nearby control sites unmanaged. We monitored malleefowl breeding activity through a network of citizen scientists and deployed more than 200 continuously operating motion triggered cameras across sites to monitor fox and cat activity. We close the AM loop here by analysing mound and camera data to estimate the effect of predator control on predator activity and malleefowl breeding activity. Our analysis synthesises one of the largest single-species monitoring datasets in Australia, with one of the largest ever attempts at AM in the world, to resolve uncertainty about malleefowl monitoring and conservation.

Methodology

Study species

Malleefowl is an iconic ground-dwelling bird with an extensive distribution across a range of habitats and environments in southern Australia (1,420,000 km^2; BirdLife International, 2010). It is categorised as threatened by state and federal governments and listed as Vulnerable on the IUCN Red List (BirdLife International, 2008; Department of the Environment, 2010). It builds large conspicuous mounds (60 – 90 cm high and 3.7 m wide) to incubate its eggs, which is easily monitored as a proxy of the breeding population. The species faces a suite of potentially threatening processes, including degradation of habitat; mortality from introduced mammalian predators, such as foxes (*Vulpes vulpes*) and cats (*Felis catus*); competition with introduced grazers (Frith 1959), and; changes in fire regimes.

Establishing AM sites

Locating mounds

Malleefowl is the focus of a long-term monitoring program sustained almost entirely by citizen scientists that has grown opportunistically from a handful of sites in the early 1990s to over 140 sites in 2020. We established AM sites to run alongside these existing sites to accelerate learning about the effectiveness of predator control. We identified candidate regions for AM sites across the species range based on historic records of mounds, expert opinion, evidence of occupancy from the long-term monitoring program, feasibility for monitoring, existing predator control programs, and willingness of land managers to participate. Candidate regions were surveyed for mounds using one of three methods depending on available resources: ground searchers, aerial photography or LiDAR.

Ground searches typically involved observers (typically 4 – 10) systematically searching a region for mounds in a line formation, spaced to always sight the two adjacent observers (usually 15-25 m apart). Aerial photography images were captured by mounting a high resolution, large-format camera to a fixed wing aircraft, resulting in images with a ground sampling distance of 4 cm. Images were post-processed and manually inspected for potential mounds (Thompson et al. 2015). LiDAR surveys were conducted with a fixed wing aircraft by pulsing a laser beam towards the ground to produce a high-resolution digital elevation model of the landscape. Digital elevation models were then processed to automatically identify possible malleefowl mounds (Saffer 2014). All potential mounds identified with aerial photography or LiDAR were ground-truthed by observers.

Defining AM site boundaries

We defined AM site boundaries after locating mounds within candidate regions. We positioned sites to maximise the number mounds (without being biased towards those that were active at the time), while ensuring they were accessible for monitoring. We initially aimed for AM sites to be 2 x 2 km in size; however, high variation in the density of active mounds meant sites ranged from 105 - 4000 ha. Sites were arranged in clusters with common environmental properties to minimise differences in habitat, climate and management, with at least one control site and one treatment site per cluster. Sites were no closer than 8 km apart to ensure independence in terms of fox and cat capture rates. In total, we established 22 AM sites across the species range in 8 clusters (8 sites in Western Australia, 8 in South Australia and 5 in Victoria). Sites were managed by over a dozen organisations.

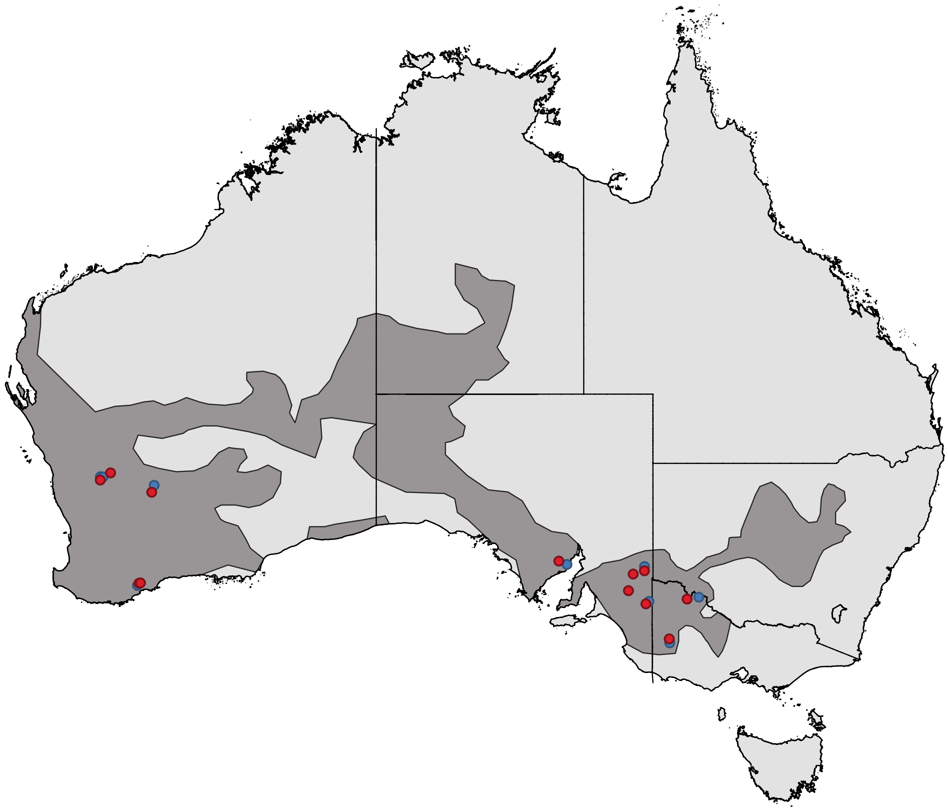

Figure 1: *Location of Malleefowl predator control AM sites across Australia. Red dots indicate baited sites while blue dots represent control sites. The dark shading represents the known geographic range of malleefowl.*

Camera deployment

We deployed 200 motion-triggered cameras across AM sites to monitor fox and cat activity (8-10 cameras per site). A power analysis suggested 8 cameras would likely detect a reduction in fox density from 4 to 2 foxes/km^2 in a single pair of treatment and control sites in 12 months (van Hespen et al. 2019). We placed cameras off-tracks in a regular grid to reduce correlation in capture rates between cameras, to maximise spatial coverage across sites and to maximise comparability between sites (i.e. not all sites have road/track networks). While canid activity is known to be higher on roads (Raiter et al. 2018), we purposely positioned cameras off tracks and away from active mounds to avoid theft, to minimise the spatial variation in capture rates, and to obtain a 'background' rate of predator activity in areas where malleefowl forage and most likely encounter predators. Cameras were deployed at different times between 2015 and 2019 as different organisations joined the AM experiment.

We placed cameras 0.6 m above ground, pointing in a southerly direction to avoid sun glare. Cameras were powered by solar-powered-units and remained continuously active. We did not bait cameras to attract predators because this can lead to different behavioural responses of individuals, potentially increasing temporal and spatial variation in capture rates between cameras and non-random detection of fauna. All cameras were set to a sleep period of 5 min to minimise the number of repeated photo events and to ensure there was enough memory for cameras to remain operational for up to 12 months. We deployed the same camera model within a cluster to ensure consistency in capture rates between control and treatment sites, as different camera models can result in different rates of detection (Rosanna et al. 2019).

Predator control

Land management agencies managed predators in and around treatment AM sites while control sites were left unmanaged. Predator control in Victoria, South Australia and southern Western Australia generally focused on fox control, while sites in northern Western Australian baited for predominantly for feral cats. In most cases, baiting occurred across an area no less than 10,000 ha to minimise the chance of foxes and cats emigrating from areas outside the treatment zone to within the monitored AM site. Predator baiting programs had already been implemented for at least 5 years at most treatment sites.

Data collection and processing

Mound activity

The number of active mounds at AM sites from 2016 – 2020 was recorded by volunteers, citizen scientists and land managers. Monitoring was generally conducted in pairs or small groups between September and November each year during the early egg-laying season when malleefowl were busy tending to their mounds. Known mounds were located using a GPS and classified as being active or not based on evidence of use that year. The status of mounds was recorded using the program Cybertracker, accessed with cell phones, before being uploaded to the National Malleefowl Monitoring database. All uploaded data were screened by experts from the National Malleefowl Recovery Team for classification errors prior to analysis.

Camera data

All camera traps were downloaded and serviced during mound monitoring. Using the software FastStone, we manually sorted raw camera photos into the following categories based on the species identified in the image: bird, cat, dog, echidna, emu, fox, malleefowl, rabbit, reptile, mammal, kangaroo. We collapsed species captured within 30 minutes of one another into a single 'independent' capture event using the package *CamTrapR* (Niedballa et al. 2016) in the software R (R Development Core Team 2014). A 30-minute cut-off was chosen after reviewing similar studies and initial inspection of the data. We extracted the number of independent fox and cat detections for each camera-month at AM sites.

Site characteristics

We extracted 5 km gridded rainfall estimates from the Australia Water Availability Project (AWAP) for each site from 2012 – 2020. Using these data, we calculated the cumulative winter rainfall from May – August as malleefowl breeding activity has been shown to be highly sensitive to rainfall during this period (Benshemesh et al. 2007, Walsh et al. 2012, Benshemesh et al. 2020).

Malleefowl. Image: Butupa CC2.0, Wikimedia Commons

Data analysis

Predator capture rates

Inspection of the raw camera trap data suggested predator capture rates contained more zeros than what would be expected from a Poisson distribution. To test this, we calculated Bayesian p-values for four alternative distributions: Poisson, negative binomial, zero-inflated Poisson and zero-inflated negative binomial. P-values of 0.5 indicate a good model fit whereas values close to 0 or 1 indicate increasing discrepancy between model predictions and observation data (Gelman et al. 1996). We found a zero-inflated Poisson distribution provided the best fit to predator capture data. We modelled monthly fox and cat capture rates separately as:

$$P_{c,m} \sim ZIP\ (\eta_{c,m}) \tag{1}$$

where $P_{c,m}$ is the number of photos taken by camera c in month m and $\eta_{c,m}$ is the mean photographic trapping rate for camera c in month m for foxes/cats respectively. We assumed the capture rate varied between clusters while the effect of predator control varied across states, given by:

$$ln\ (\eta_{c,m}) = a_{1\text{-}8}\ Cluster + b_{1\text{-}3}\ baited * state + (1 \mid Site \mid Camera) \tag{2}$$

where $a_{1\text{-}8}$ is the average monthly photographic trapping rate per cluster and $b_{1\text{-}3}$ is the effect of the predator control on capture rates by state. We modelled a random effect of each camera nested within sites. We fitted the above model using maximum likelihood methods with the 'glmmTMB' package in R.

Mound activity

We modelled the number of active mounds using a Poisson regression model. The observed number of active mounds y_{ij} in site i on yearly visit j was modelled as independent Poisson random variables given by:

$$y_{i,j} \sim Poiss(\lambda_{ij} * Area_i) \tag{3}$$

where λ_{ij} represents the expected count of active mounds and $Area_i$ the area of site i in hectares. The effect of covariates on mound activity was expressed by modelling the natural log of the expected mound count as a linear function of effects:

$$ln\ (\lambda_{ij}) = \alpha + \sum_{h=0}^{4} \beta_{1+h} R_{i,j-h} + \beta_6\ B_i + (1 \mid Site) \tag{4}$$

where α is the average log-mound count (intercept), $\beta_{1\text{-}5}$ are the effects of 0 – 4 year lags in cumulative winter rainfall R, and β_6 is the effect of predator control B. We included a site random effect and fitted models using the 'lme4' package in R.

Results

Raw fox and cat capture rates

Motion-triggered cameras were deployed at AM sites for a total of 4588 trap-months. After initial inspection of the images, 4 cameras were removed from the analysis because they were either not operational or because incorrect dates and times were set and the correct time could not be retrieved. We recorded 1345 independent fox captures (698 in Victoria, 542 in SA, 68 in south WA, 37 in northern WA) and 118 independent cat capture (2 in Victoria, 30 in SA, 13 in south WA, 73 in northern WA). The mean monthly independent capture rate for foxes was highest in Victoria (1.23), followed by SA (0.38), southern WA (0.38) and northern WA (0.02). Capture rates of cats were relatively consistent across states; 0.01 in Victoria, 0.05 in South Australia, 0.04 in southern WA and 0.07 in northern WA.

Effect of predator control on predator and malleefowl activity

Mean monthly fox capture rates in Victoria were: 0.657 at baited sites and 2.15 at unbaited sites; 0.389 at unbaited sites in SA and 0.37 at baited sites; 0.431 at unbaited sites in southern WA and 0.367 at baited sites; 0.026 at baited sites in northern WA and 0.018 at unbaited sites in northern WA. The results of our modelling found no support for a statistically significant effect of fox baiting in South Australia (-0.66; 95%CI -2.39 - 1.05) and Victoria (-0.51; 95%CI -3.04 - 2.06).

In contrast, mean monthly capture rate of cats was 0 at baited sites in Victoria (no cats detected) and 0.02 at unbaited; 0.03 at unbaited sites in SA and 0.06 at baited sites; 0.08 at unbaited sites in southern WA and 0.06 at baited sites in southern WA, and; 0.03 at baited sites in northern WA and 0.04 at unbaited sites in northern WA. Our modelling could not detect a statistically significant effect of predator control on cat activity in Western Australia (0.47 95%CI; -0.45 – 1.39) or South Australia (0.52 95%CI; -0.98 - 2.02). Furthermore, we found no evidence for an effect of predator control on malleefowl breeding activity (-0.44; 95% CI -1.66 – 0.73).

Discussion

Despite the intuitive appeal of AM and a plethora of literature on the topic, there are very few documented examples where it is put into practice (Westgate et al. 2013). AM often fails because monitoring data are not evaluated to inform the next iteration of the AM cycle and because it is difficult to sustain for the time needed to learn. In this study, we successfully established a landscape-scale experiment within an AM framework to learn about the effectiveness of predator control as a conservation strategy for malleefowl. Quantifying the benefit of predator control is a matter of national significance in Australia: for example, foxes cost the sheep and wool industry and estimated $28 million per year (NSW Natural Resource Commission). We believe the spatial coverage of sites, the number of contributing partner organisations, and network of citizen scientists that contributed to monitoring and data processing, makes it one of the largest attempts at AM in the world. It is also a rare example where both predator and prey species are rigorously monitored across spatially replicated control and treatment sites at a landscape scale by dozens of managers in cooperation (Reddiex et al. 2006, Saunders et al. 2010).

Our camera trap data revealed significant spatial variation in fox capture rates, with generally higher monthly capture rates in Victoria and South Australia compared to Western Australia. There are few comparative studies of fox capture rates across different regions of the continent, however, there is a small number of studies that suggest fox densities in the arid rangelands of Australia, where many of the AM sites are located, are very low. For example, feral cat and fox densities in Arid Recovery Reserve SA fluctuate according to conditions but averaged 0.8 and 0.6 per km^2 respectively over a 10 year period (Read and Bowen 2001). The relatively few fox detections recorded from our cameras in Western Australia could be explained by a range of factors including the camera model, placement or settings; even though we tried to keep these consistent within clusters, different camera models were used between clusters. Recent studies have shown disparities between camera models, incidences of false negatives and waning camera efficiency during the course of studies, providing very real limitations to their use and comparison of capture events across space and time (van Hespen et al. 2019). However, fox counts were low in Western Australia regardless of the camera model, which suggests that these predators occur at much lower densities in these regions compared to Victorian and South Australia.

When camera data were pooled across control and treatment sites, our analysis revealed support for a very weak but highly uncertain negative effect of predator control on monthly rates of fox activity. This result is consistent with a recent analysis by Benshemesh (2020) of 140 long-term malleefowl sites monitored over 28 years. In that study, fox activity was not monitored using motion-triggered cameras, as was done here, but instead a significant reduction in the prevalence of fox scats on inactive malleefowl mounds was recorded in response to increases in bait density. In the current study, we also found weak evidence to suggest the effectiveness of predator control varies across clusters even within broad geographic regions. For example, fox control reduced fox activity in the Annuello/Wandown cluster in Victoria, but did not have a noticeable impact at the Tooan/Nurcong cluster, which is only a few hundred kilometres away. Similarly, we could not detect an effect of fox control on fox activity in the Oakbore/Dangali cluster, even though baiting appears to be effective in the nearby Blueyaroo/Munyaroo cluster. This regional variation in the effectiveness of fox control could be due to differences in the environmental characteristics at a site or variation in baiting intensity in treatment sites. However, it demonstrates the need for spatial replication in large-scale predator control experiments.

Despite some evidence for a reduction in fox activity due to fox control, we found no evidence for an effect of predator control (fox or cat control) on malleefowl breeding activity. Rather, malleefowl mound activity was strongly associated with cumulative winter rainfall (May -August) which is again consistent with studies by Benshemesh (2020) and Benshemesh (2007), both of which found that reductions in fox activity (in their case, the prevalence of inactive mounds containing fox scats) had no immediate or lagged benefit to malleefowl. There are at least four possible explanations for this result. First, it is possible that foxes predate on malleefowl but treatment did not reduce fox activity enough to reduce predation. Second, foxes may not pose any significant pressure on malleefowl, meaning that breeding activity is unaffected by even large reductions in fox activity rates. If this is the case, this throws into question the ongoing widespread use of fox baiting for malleefowl conservation. Third, a reduction in fox activity may have had an effect on malleefowl breeding activity, but natural variation in mound counts may have made this effect difficult to detect. Finally, it is possible that reductions in fox activity has reduced malleefowl predation, but these benefits are yet to be seen in mound activity data due to temporal lags. However, we believe this is unlikely to be the case given that many AM treatment sites were baited well before AM sites were established.

We assumed predator control at treatment sites covered a sufficiently large enough area to reduce the chance of individuals immigrating into treatment sites. In practice, differences in the effectiveness of predator control between clusters may have been due to differences in how predator baiting was implemented by managers. It is therefore possible that our treatments were insufficient to reduce predator densities, or that any reduction in predator density may not be detected in the form of an activity index by our cameras. While we provided recommendations on the preferred baiting regime (at least 5 baits per km^2 over at least 100 km^2), we were unable to control exactly how predators were managed at AM sites. We attempted to collect information on the timing, frequency, spatial extent and density of predator control so that this information could be included in our modelling, however, our preliminary results were inconclusive because: 1) it was difficult to obtain baiting information from managers, and; 2) there were too few AM treatment sites to draw inference about baiting intensity on predator and malleefowl activity. However, Benshemesh et al (2020) modelled the effect of bait density on an index of fox activity at 140 long-term monitoring sites (the prevalence of inactive mounds containing fox scats) and found that a one standard deviation increase in the density of baits per square kilometre (10.06) decreased the logit probability of inactive mounds having fox scats by 38.3% in the year of baiting and 22.8% the following year.

Assumptions and future research priorities

We made many assumptions, most of which were unavoidable due to logistical constraints. Firstly, our model assumed that there is no change in the probability of detecting predators between sites or sampling periods, and that the only cause of differences in detection is due to reduced fox densities caused by predator control. Foxes may detect camera traps, which could cause them to avoid cameras over time. There is therefore a small possibility that fox and cat behaviour towards camera traps could change due to, for example, increased wariness or reduced curiosity, affecting detectability between years. However, this should not be a problem if fox and cat behaviour is consistent in control and treatment sites. Secondly, we assumed that new mounds are infrequently built by breeding adults and that our knowledge of the location of mounds remains accurate over time. In practice, malleefowl often return to the same mound to breed, but may also move between mounds or build completely new mounds. The mound monitoring program involves all known mounds at a site, but it is possible that newly built active mounds may go undetected at a site, giving the impression that mound activity is changing when in fact it is not. Once again, this should not be a problem if malleefowl behaviour is consistent in control and treatment sites. Nonetheless, to reduce the effect of new mound building we plan to re-survey AM sites every 5 years so that the chance of the chance of active mounds being undetected with AM sites in low.

Although the results of our study suggest predator baiting provides little benefit to malleefowl breeding activity, we believe the experiment should continue so that: 1) certainty around the effectiveness of predator control can be further resolved and 2) any temporal lags in the benefits to malleefowl can be detected. Continuing the AM experiment will require continued ongoing coordination between the National Malleefowl Recovery Team and key partner organisations. Crucial to the project is an efficient flow of mound, camera and baiting data from on-ground managers to the Recovery Team in preparation for statistical analysis to close the adaptive management loop. While mound and camera data are relatively up-to-date, obtaining accurate predator baiting information at treatment sites remains the greatest challenge. Improvements in record keeping of such data would allow for information to be included in modelling so that thresholds in baiting intensity or effort can be explored.

Conclusion

We have successfully established one the largest predator control experiments in Australia and one of the biggest ever attempts at adaptive management. Analysis of the AM data so far provides no statistical evidence that predator control benefits malleefowl breeding activity. We recommend the experiment continue so that each site has operated for at least 5 years to further resolve uncertainty and to detect any possible lagged effects of predator control on malleefowl breeding activity. The AM experiment could then be adjusted again to learn about the effect of actions other than predator control, such as fire management or herbivore control.

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Data sets

Datasets can be accessed upon request through the National Malleefowl Recovery Team

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Further information:

http://www.nespthreatenedspecies.edu.au

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