Landscape-scale learning: the effect of fox and cat predation on Malleefowl persistence

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Purpose

The National Recovery Plan for Malleefowl (*Leipoa ocellata*) lists as specific objectives: (1) reducing predation, and (2) monitoring Malleefowl and developing an Adaptive Management framework for the species. A key goal of the ARC Linkage Grant "Adaptive Management of semi-arid and arid ecosystems" is to develop methods for implementing a landscape scale Adaptive Management project. In the first instance, these methods will investigate the effects of predation on Malleefowl population dynamics. Although predation (primarily by foxes; secondarily by cats) is widely accepted as a threatening process, it is not clear how effective predator control is at improving Malleefowl population viability.

The National Malleefowl Recovery Team is planning an Adaptive Management experiment across the species' range to quantify the impacts of fox abundance, and the benefit of predator control to Malleefowl population dynamics. This requires a coordinated set of treatment and control sites across southern Australia, with predator control actions and ongoing monitoring of Malleefowl breeding activity, and supplementary camera trapping to estimate the abundance of predators and other species.

Workshops were held in Perth and Mildura that gathered together managers of Malleefowl habitat to discuss the feasibility of such a landscape-scale project. The Linkage team at the University of Melbourne has developed statistical models that can support Malleefowl and predator monitoring, and explored their power to detect any predation and predator control effects that may exist. The workshops were aimed at discussing these methods with the managers, integrating their feedback into the project plans, and assessing the level of engagement across potential experimental sites.

In this document we summarise the discussions occurring at those meetings and report on further progress, particularly with respect to the analytical methods recommended for testing the effect of predation on Malleefowl. Our key goal is to provide evidence that the intensity of the planned sampling – the number of sites across Australia; the number of mounds monitored on each site; and the number of camera traps deployed to each site – is high enough to contribute to the National Recovery Plan goals.

Background

Overview of the adaptive management project

Malleefowl conservation is a current candidate for Adaptive Management (Benshemesh & Bode 2011). The National Malleefowl Recovery Plan highlights the many potential threats to Malleefowl persistence, and Adaptive Management offers a method for prioritising activities to combat these threats. Under an Adaptive Management program, prioritisation can occur even in the presence of uncertainty regarding the intensity of threat and the effectiveness of the candidate conservation actions (Runge 2011).

Historical Malleefowl monitoring data and community knowledge provide a foundation of evidence to form initial models and predictions (Figure 1). The Adaptive Management project being run through the ARC Linkage project "Adaptive Management of semi-arid and arid ecosystems" aims to address Malleefowl management at multiple scales. At the broadest level, we use ***expert workshops*** and ***network ecosystem models*** to coarsely capture this conservation challenge at the ecosystem level. We have previously enlisted experts to construct models linking threats, drivers and potential actions (Figure 2) and we are developing prioritisation tools to identify the crucial uncertainties that affect our capacity to conserve Malleefowl effectively.

High-priority and high-uncertainty issues, such as the efficacy of predator baiting to improve Malleefowl persistence, can be researched as ***single-threat scientific experiments***. In addition to Malleefowl mound activity, ***supplementary data*** may be collected to support such experiments. As we evaluate the potential for baiting to reduce predation on Malleefowl, fox and cat population densities form a crucial link between baiting and Malleefowl survival. Monitoring predator activity will allow us to distinguish the effect of baiting on predators from the effect of predators on Malleefowl.

All evidence built and lessons learned from these detailed experiments can inform future iterations of the network ecosystem model and allow new priorities to emerge over time. While these models can develop scientific evidence and provide guidance for management, successful Malleefowl conservation will continue to depend on the co-ordinated efforts and enthusiasm of policy-makers, environmental managers and community groups across the Malleefowl's range.

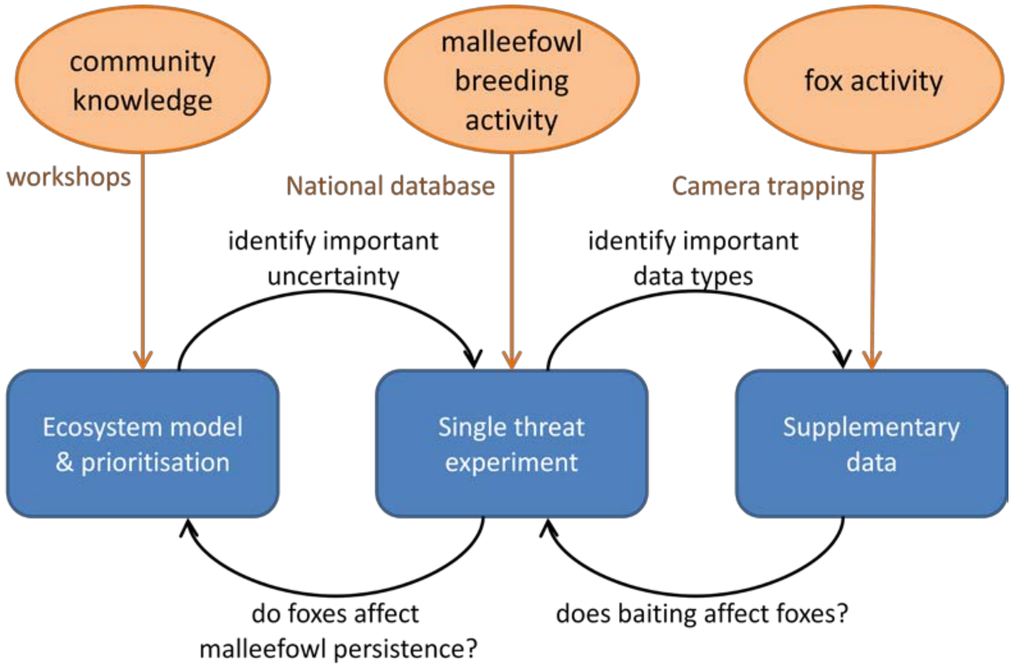

Figure 1. The Adaptive Management project structure. Research is divided into three components (blue boxes), each relying on knowledge and data (orange ovals). Progressing from left to right, projects become more narrow and detailed in scope. Narrow, detailed projects provide learning that can be used to update and influence projects with broader scope.

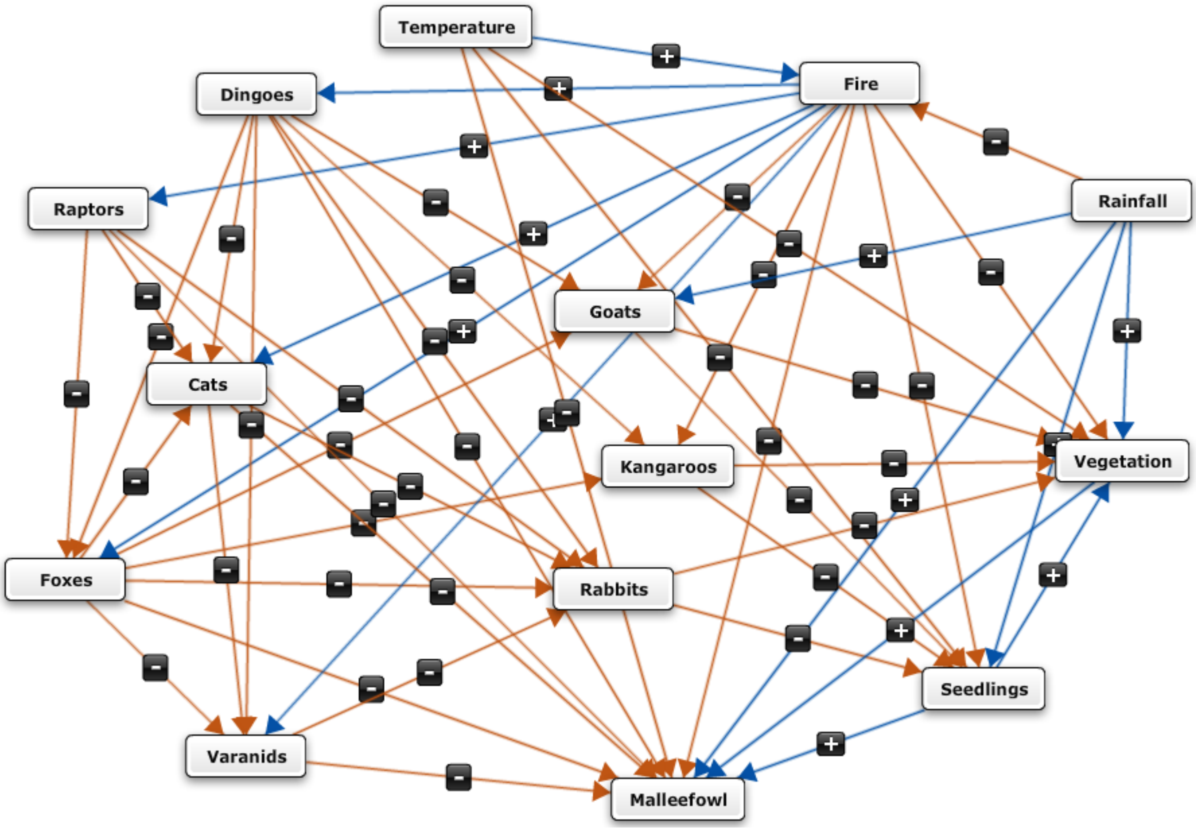

Figure 2: One of the three conceptual cause-and-effect models of the mallee ecosystem devised in the first workshop. Each labelled node refers to a key ecosystem component. Arrows indicate the direct cause-and-effect connections between the nodes, with the signs and colours (red is negative; blue is positive) indicating whether those connections had a positive or negative effect on the population at the arrow-end of the connecting line. Many negative effects have symmetrical positive effects in the opposite direction (e.g., predation is negative for the prey and positive for the predator), although these are not shown here.

Motivation for the initial focus on predator management

Recent studies of Malleefowl population dynamics across their range reveal a species that is experiencing substantial declines (Benshemesh et al., 2007). Malleefowl are categorized as threatened across their entire range by state and federal governments, and are listed as Vulnerable on the IUCN Red List (BirdLife International, 2008; Department of the Environment, 2010). Despite a large global abundance (c. 100,000) and an extensive distribution across a range of habitats and environments (1,420,000 km2; BirdLife International, 2010), the species faces a suite of potentially threatening processes. These include the degradation of habitat; mortality from introduced mammalian predators; competition with introduced grazers; and changes in the frequency, spatial distribution and intensity of managment and wildfire.

However, it is not clear which of these threatening process bears primary responsibility for the ongoing decline of the species (Benshemesh et al., 2007). The primary debate is about the relative influence of predation and grazing. Foxes (*Vulpes vulpes*) have long been considered the principal threat to the population's viability (Mellor, 1911; Wheeler & Priddel, 2009), as the bird falls within the 'critical weight range' (Chisholm & Taylor, 2010) of species driven to extinction by fox predation, and mortality by foxes (particularly on juvenile malleefowl) is widely known to occur. Additionally, high-intensity management experiments have shown that intense predator baiting reduces the direct impact of foxes on malleefowl mortality in the younger life-stages (Priddel & Wheeler 1989, 1996, 2003, 2005; Wheeler & Priddel 2009), although the aggregate impacts on long-term population viability are unclear. To complicate feral predator management, feral cats (*Felis catus*) also cause mortality, particularly of chicks (Wheeler & Priddel, 2009), and the abundance and dynamics of the two species are thought to be inter-related, with suppression of foxes increasing the abundance and activity of cats. As an alternative to this top-down explanation, some researchers argue that grazing by sheep and rabbits has greater impact on malleefowl populations than feral predators. Sheep density is a significant predictor of malleefowl absence in the Western Australian wheatbelt (Parsons, 2008), and comparative studies suggest that grazing can reduce malleefowl density by a factor of 10 (Frith, 1962).

Despite the historical primacy of the predation hypothesis, recent analyses of long-term trend data have revealed equivocal evidence about the efficacy of fox baiting on malleefowl population trends (Benshemesh et al., 2007; Walsh et al. 2012). This is of concern given that fox baiting is being recommended and applied – at considerable expense – to help conserve malleefowl populations (Benshemesh et al., 2007; BirdLife International, 2010). However, contrasting analyses and publications have supported the importance of fox predation (Bode & Brennan 2011; Garnett 2012), arguing that *effective* fox baiting can improve Malleefowl population viability.

Predation is therefore the most widely-accepted explanation for Malleefowl population declines. It is supported by the most evidence, and mitigating predation is the most common and (probably) the most expensive management action applied within the species' range. However, predator control also lacks conclusive empirical evidence of its effectiveness. The Malleefowl Adaptive Management project aims to tackle a series of key questions about management effects. However, in the initial set up phase of the project we will focus primarily on the management of invasive predator populations, primarily foxes and potentially cats, until everyone – managers, scientists and the National Recovery Team – are more comfortable with the process.

Once the structure of the Adaptive Management experiment is set up and the management and monitoring data collection begins, we can begin to consider other threats to malleefowl persistence. The data that are already being gathered, and the set-up of the multi-site experiment, can be directed towards answering other questions of interest to Malleefowl conservation. For example, the importance of grazing pressure, fire history, or agriculture in the surrounding landscape could be assessed using these sites and the planned flow of data.

Preliminary experimental design

One of the classic experimental designs is based on having pairs of sites with similar characteristics, with a treatment applied to one of the sites in each pair while the other one is left untreated as 'control'. Such design provides good statistical power to detect the effect of the treatment. In our case, sites within a pair should be similar in terms of climate and vegetation, and the treatment consists of intense predator management. The experimental approach with treatment and control sites helps us distinguish between changes in Malleefowl population size that result from predator management (presumably through a reduction in predator density) and changes in Malleefowl population size that arise from other ecological processes.

Our statistical model will be based around the number of mounds that are active at each site in a given year. We note that the **number of active mounds** has a long-term average (or deterministic trend), with superimposed temporal and spatial fluctuations. Because we are primarily interested in assessing whether predator management can create a long-term improvement in Malleefowl populations, our methods have to take careful account of these fluctuations, and thus take into account that:

1. some sites consistently show more nesting activity than others, perhaps because they are more suitable for Malleefowl in some manner. We therefore need to pair sites that are 'consistently high', or 'consistently low' together, to isolate the effect of fox baiting from the effects of breeding activity due to local habitat quality.
2. some years will be 'bad' for Malleefowl breeding across the entire range; others will be 'good' or 'average'. This fact will influence how we view the impact of predator management, e.g. we are less likely to attribute a breeding activity increase to predator management, if it occurs in both managed and unmanaged sites.

Criteria for inclusion

We are looking for **pairs of sites** where Malleefowl occur and can be compared under **intense predator management** and in the **absence of predator management** (Figure 3). In most cases management will be enforced via baiting, although predator fencing is used at some suitable locations. In the absence of pre-existing protocols, we recommend that **predator baiting be recorded** in a manner consistent with the NSW Threat Abatement Plan (details are supplied below).

We require that there be a Malleefowl population at the centre of each site, with **mound activity monitored** annually. There is no minimum number of mounds required to qualify. In fact, investigating a variety of mound densities may reveal more about the nature of Malleefowl survival.

We require that sites have **appropriate sizes and spacing** to ensure that the management actions at each site do not affect their pair. To ensure that baiting is effectively reducing predator density for the central Malleefowl population, we recommend that an area of *at least* 10,000ha be baited. To ensure that predator baiting does not affect the predator density at the unbaited site pair, we recommend a distance of at least 8 km (and often more, depending on tracks and likely predator and Malleefowl movement) between sites. Size and spacing criteria may be adapted in future if data indicate that management actions are affecting site pairs.

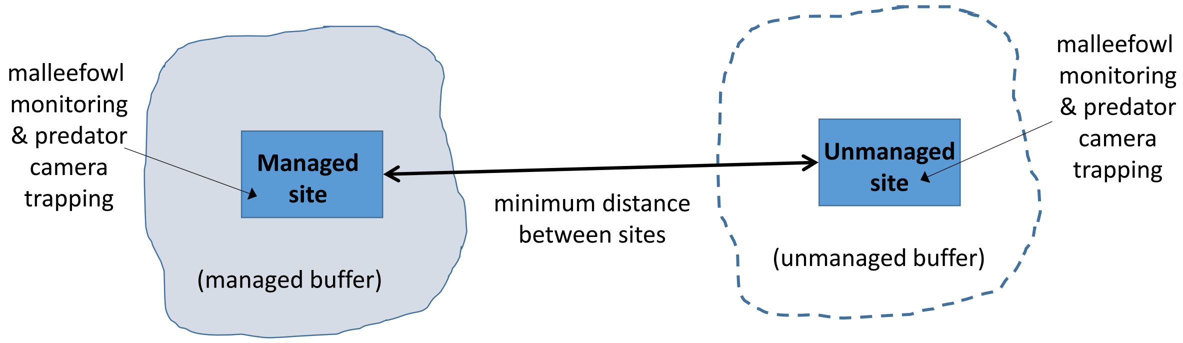

Figure 3. Conceptual diagram of an experimental site pair.

As a secondary consideration, we seek to **monitor predators** at many site pairs via motion-triggered cameras. (However, predator monitoring of this kind is *not* mandatory.) Power analyses performed by University of Melbourne Masters student Rosanna van Hespen suggest that there is a good chance of detecting differences between predator-managed and predator-unmanaged sites with 8-10 cameras installed at each site, collecting data throughout the year. We recommend placing cameras at random locations away from tracks (more detail on her findings is included below).

We will depend on site managers to **upload data promptly** to the National Malleefowl Database for whole-landscape analyses.

Potential sites for inclusion

A broad range of sites have been identified as potentially suitable for inclusion in this landscape-scale experiment (Figure 4; Appendix D). Sites occur across the Malleefowl's range and in a variety of management contexts.

Although the experiment was conceived as using *site pairs*, many sites occur in *clusters* of more than two sites. It is imperative that each cluster include both a predator-managed and a predator-unmanaged site in order to compare Malleefowl persistence across management approaches. Additional sites of each type can potentially assist in boosting the data set and improving our statistical estimates of variation, thereby allowing clearer distinction of the main effect of interest – the effect of predator management on Malleefowl.

Estimating the statistical power of the experimental design

To ensure that the experiment is well designed and useful, we use a statistical approach known as 'power analysis', which can provide support to understand (1) how large an effect of predator management a given experimental design is able to detect, and (2) how the ability to detect those changes increases over time (i.e. monitoring the sites for more years). We base this power analysis on a selection of **41 sites** from those mentioned in the previous section. They belong to **18 clusters**, across the Malleefowl's range. We have avoided using all sites for the power analysis since some of these are very preliminary and we wanted to be conservative.

The power analysis is an intensive approach based on computer simulations. A large amount of datasets of Malleefowl mound activity are simulated according to the best knowledge of the system and the characteristics of the chosen sites. The datasets are simulated with increasing effects of predator management on Mallefowl mound activity, and these are then analysed with a model that attempts to estimate the effect of predator management. For a given design (number of sites, number of years, effect of management), the percentage of attempts in which the model detects an existing effect is called 'statistical power'.

Power analysis is forcibly a simplified version of reality. The model used does not include covariates and assumes that (i) predator management is an on/off decision (i.e., implemented in a consistent manner: similar intensity, timing and duration), and that (ii) the impacts of predator management will be the same for any site, i.e. will cause Malleefowl breeding activity to increase by the same amount (of course, we are open to the possibility that this percentage is zero, or negative). Furthermore, we have not incorporated time lags (e.g. we might expect to see an increase in Malleefowl breeding activity only a few years after predator density is successfully reduced) nor

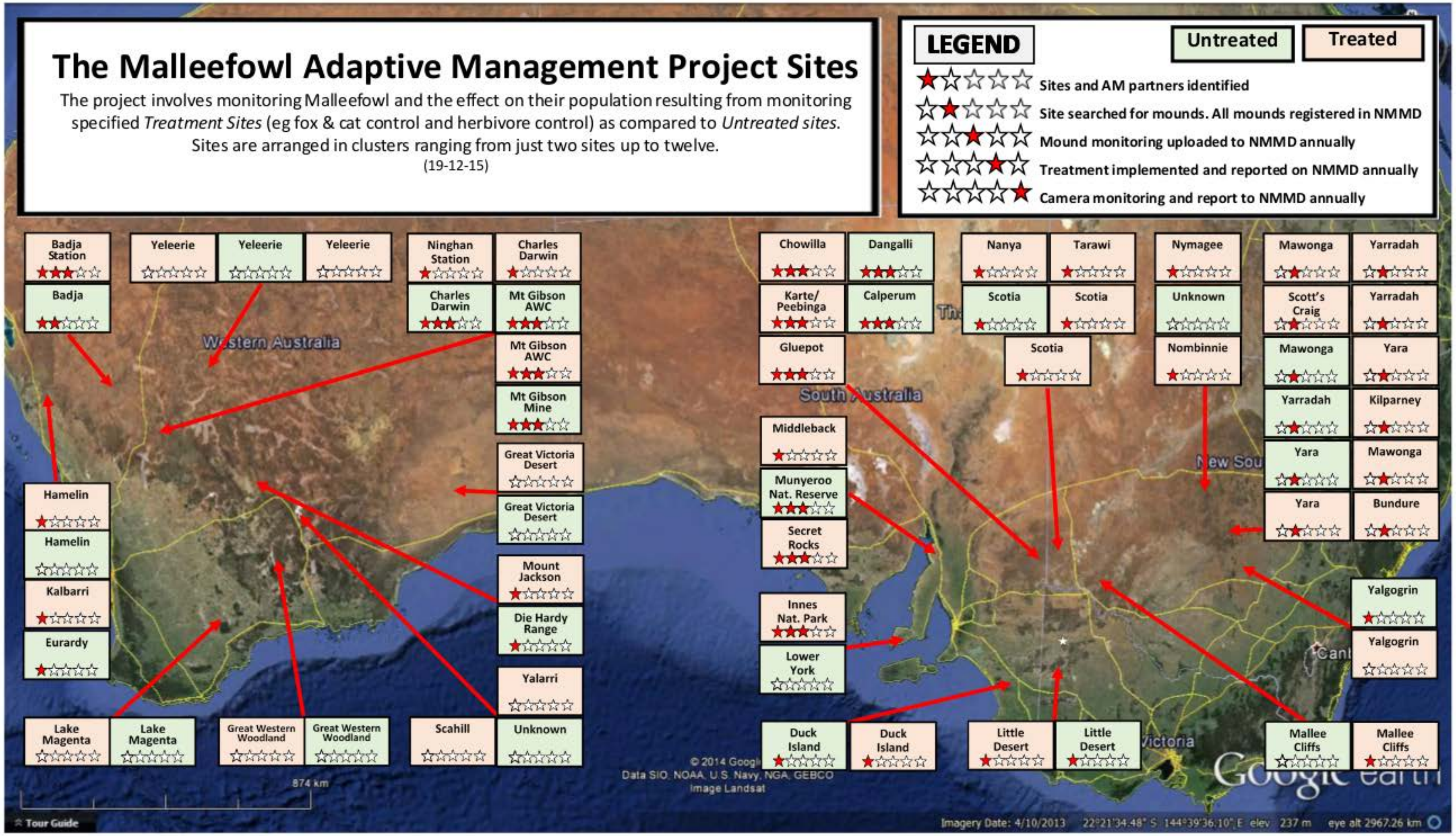

Figure 4. Potential sites for inclusion in the predator control experiment. Star system indicates which requirements have already been met at the site.

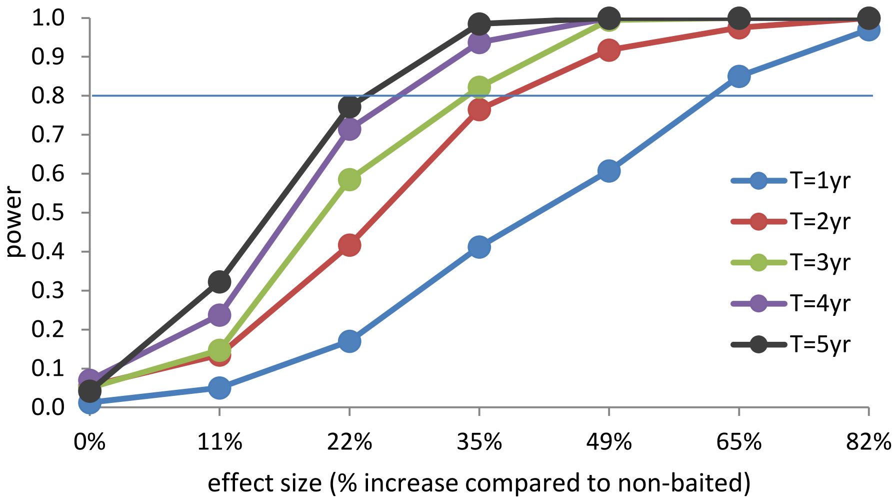

Figure 5. Statistical power to detect differences in Malleefowl mound activity as a response to predator management.

have used site size or buffer size as covariates (we assumed all sites were equal). We want to clarify that this is done for the power analysis only; during the analysis of the actual data collected during the experiment, we will consider expansions of the model to accommodate these potentially important nuances.

The details of the power analysis construction (including a description of the statistical model used) can be found in Appendix B. We report in this section only the results (Figure 5).

The horizontal line marks the 80% power level, a typical target value for designing experiments. In the model, the effect size is defined in units of log(number of mounds), we report it here in a simplified manner as "% increase compared to the average number of active mounds" (which is 2.6) – see details of the modelling in Appendix B for a full description of this.

The results of the power analysis show that, with the chosen setup (41 sites in 18 clusters), after only one year one can only expect to confidently detect the effect of baiting if it is large (~65% increase in active mounds at baited sites). As the experiment sites are monitored for more years, the statistical power to detect an effect of baiting increases. For example, after 4 years of running the experiment, we can expect to be able to detect an effect of 25% increase in mound activity at baited sites with a probability of around 80%.

Advancing the experimental design

A large-scale and diffuse experiment such as this one requires a strong over-arching plan and clear on-ground protocols to ensure that the project is feasible, that data collected are comparable, and that the core research and conservation questions can be addressed by the data. This involves careful selection of variables to be monitored and preliminary statistical analyses. We acknowledge that protocols may be adjusted as the experiment progresses to improve efficiency and consistency. However, we seek to avoid haphazard or 'trial and error' changes. Rather, potential adjustments will be subject to a formal adaptive management process to assess their potential benefits and costs in light of what has already been learned. Any changes in protocol that are expected to improve the quality of experimental inference will be raised at co-ordination meetings before they are adopted.

At the 2015 co-ordination workshops, participants offered their expertise regarding appropriate variable selection and monitoring design. Issues are summarised below as they relate to the Malleefowl population, predator control, predator monitoring and other variables.

Malleefowl

Malleefowl are cryptic creatures but, by comparison, their breeding mounds are highly visible. For this reason the mounds have been the focus of standardised Malleefowl data collection over the past decade.

Workshop participants discussed the life history stages of the Malleefowl and their relative importance for population persistence. While some argued that recruitment is the crucial stage, very few of the many eggs laid and hatched survive to become breeding adults. Therefore an increase in breeding adults (and active mound density) should be indicative of improving persistence. We should be mindful of time lags, and that Malleefowl behaviour (e.g. mound maintenance) may be affected by predator presence, even if the predator occurs at a low density. Thorough mound searches (e.g. LiDAR, photogrammetry, ground searches) are needed to identify all mounds at each site and confidently monitor fluctuations in breeding activity. Malleefowl will sometimes establish new mounds. Mound searches need to be repeated every 10 years to ensure this natural process is not seen as a demise of the local population.

Motion-triggered cameras (encouraged primarily to monitor predator density, see below) can provide supplementary data on Malleefowl density at each site. Efficient photo sorting protocols have been developed that enable the separate filing of all identified animals, and so these data will be available at all sites containing cameras for no extra cost. However, we note that the recommended number and arrangement of cameras is tuned to confidently detect changes in predator activity, not Malleefowl or other species activity/abundance.

Predator management

The primary goal of the project is to assess whether predator management has a positive effect on Malleefowl population dynamics. The secondary goal is to assess whether this positive effect is the result of measurable reductions in predator population density in treated areas. Predator management varies between different locations, as does the absolute density of predators. We would like our conclusions to reflect these differences, particularly in the likely scenario that predator management does not have a consistent benefit across the Malleefowl's range. For example, the results of the project might show that high intensity predator management significantly benefits Malleefowl populations in the Victorian Murray Mallee, but not in the Western Australian Coolgardie.

The perfect statistical set-up would apply baiting of particular intensities to the different sites in the experiment. However, one of the benefits of both an Adaptive Management approach, and of the statistical methods that we are applying, is that we can be opportunistic about the data we use to parameterise our model. This is fortunate, we may not be able to alter baiting regimes in our treatment (baited) sites. First, if baiting is currently occurring at low intensity, we may not have the resources to implement additional baiting. Second, we may have the ability to reduce more intensive baiting projects, which are usually informed by the local context of the site, the obligations of the baiting managers (e.g., management requirements for mining sites), or objectives that are more broad than simply Malleefowl management. Finally, predator abundance in some sites may be managed by one of Australia's predator-exclusion fences (of which a large proportion exist in habitat suitable for Malleefowl), such as the Australian Wildlife Conservancy's potential site at Scotia. These represent the highest intensity predator management possible; they cannot be compared to the effects of poison baiting, and yet provide a very powerful statistical contrast among the treatment and control locations, and also between different project sites.

Incorporating the intensity of baiting into the statistical analysis is best achieved by a one-dimensional description of the amount of baiting occurring in the treated site. However, this is a difficult proposition because the character of predator baiting varies across Australia. Among other factors, a baiting regime is defined by the type of bait (e.g., the toxin, the meat used, the method of storage), the delivery method (e.g., aerial, hand baiting, bait stations), the spatial extent of the application, the frequency of treatment during baited periods (e.g., once a week), the timing of those baited periods (e.g., late winter, year-round), and the intensity of baiting (generally the number of baits per hectare). Moreover, the effectiveness of a given baiting regime will vary extensively in both time and space, in a manner that is currently unpredictable (Table 1).

Table 1: Evidence for the highly variable performance of fox baiting in both space and time. Reproduced from: Threat abatement plan for predation by European red fox. Department of the Environment, Water, Heritage and the Arts (2008).

Bait density (km^{-2})	**Initial fox population density (km^{-2})**	**Baiting regime**	**Estimated population reduction (%)**	**Location**
6	Unknown	Aerial 1 day	86	WA Wheat Belt
12	7.2	Ground: 10 days free-fed, then 10 days toxic	70	NSW Tablelands (farmland)
1.7 -- 3.1	0.05 – 0.2	Ground: 9-13 days free-fed, then 10-14 days toxic	91	NSW Tablelands (forests)
4.4	1.3 -- 1.9	Ground: 16 days free-fed, then 2 days toxic	50	NSW Tablelands (farmland)
0.14	Unknown	Ground: 13 days free-fed, then 10 days toxic	97	NSW coast
5	0.5 -- 1.0	Aerial 1 day	79	WA wheat belt and rangelands
10	0.5 -- 1.0	Aerial 1 day	82	WA wheat belt and rangelands
5	0.5	Aerial 1 day	95	WA wheat belt and rangelands

We approach the question of baiting intensity in three steps. First, on issues of appropriate levels of baiting, we defer primarily to the recommendations contained in the *NSW Fox Threat Abatement Plan 2010*. This document outlines levels of fox control that balance concerns of effectiveness, cost, non-target risk and humaneness. The recommendations are useful because baiting strategies are outlined for a range of delivery methods, across a range of Malleefowl habitat types. However, where different guidelines exist, we acknowledge that these will be appropriate. Second, we primarily defined the intensity of baiting in terms of the median number of baits distributed per hectare, per year, within the vicinity of the treated site. We use two definitions of “vicinity”: first, over 100 km^2 surrounding the site, as used by Walsh et al. (2012). This area more than encompasses the dispersal range of malleefowl (Booth 1987; Priddel & Wheeler 1994; Coombes et al. 2007). It also will include most of the area from which new foxes will disperse (Coman et al. 1991; Marlow 1992; Meek & Saunders 2000), although not in the most arid environments, where foxes often disperse 40-50 km (Saunders et al. 1995). We would like to augment this data with the median number of additional baits distributed per hectare, per year, in an 8km buffer around the treatment site (this is based on the OEH guidelines, which considers the average home range of a fox in the resource-poor landscapes that are generally Malleefowl habitat). Finally, we assume that the amount of baiting implemented in the treatment site may be altered adaptively through time, in response to the estimated reduction in fox activity that follows an initial decision about baiting. Power analyses (see below) suggest that with the camera trapping set-up recommended in our sites, it will be possible to assess whether initial levels of fox baiting are having a substantial effect on abundances within a year or two. At this point, the amount of baiting can be altered if the reduction in predator abundance is less than hoped (e.g., less than 50%). The Adaptive Management statistical framework is designed to be flexible enough to incorporate such changes in management intensity where agreed.

Best practice data retention according to the NSW Threat Abatement Plan

Recording data on control effort

Data detailing the density, frequency and extent of each fox control method employed should be recorded to allow control programmes to be reviewed to maximise their cost-effectiveness. The following minimum standards are recommended:

Ground-baiting

1. Date of activity
2. Coordinates of each bait station (point location), or polygons describing the area aerially baited.
3. Coordinate system (e.g. GDA 94)
4. Action taken during the activity (set-up baiting station; monitor baiting station only; monitor station and replace removed baits; monitor station status and remove afterwards).
5. Observation (set up only, bait undisturbed, bait disturbed, bait taken or M-44 triggered)
6. Bait or bait-head type (e.g. fresh meat, Foxoff)
7. Toxin (1080, PAPP)

Recording any species active at bait stations (including foxes) is not required. First, because free-feeding and daily monitoring to minimise non-target risk are not required, and second because there are better methods for monitoring fox activity.

Foxes and cats

Strictly speaking, an Adaptive Management program will focus on the efficacy of actions (such as predator management) to meet objectives (self-sustaining Malleefowl populations). In the event that existing predator management activities are not found to benefit Malleefowl, we must ask whether (a) predation is not a significant threat to Malleefowl persistence, or (b) the management activities were not effective in reducing predator densities and thus, some other management activities may still offer benefits to Malleefowl. This can be addressed in parallel with the primary management question by monitoring predator densities throughout the experiment.

Given that predators are expected to respond to baiting in a matter of months, data on predator densities will offer important feedback to land managers on the effectiveness of their approach.

Participant experiences and advice

A number of different methods are currently in use for monitoring fox and cat densities. Participants discussed:

- **predator bait uptake:** This was thought not to be a good measure of predator activity.
- **predator track observation:** While this is used at some sites and is a good indicator of predator presence, its reliability for detecting changes in activity is unknown.
- **sand pads:** These have been used at some Malleefowl sites. They have given conflicting information when compared to motion-triggered cameras in some circumstances. It was noted that regular visiting and raking/clearing of pads may be prohibitively labour-intensive.
- **predator scats on mounds:** These are already collected and recorded at sites in the National Malleefowl Monitoring Database. Walsh *et al.* (2012) did not detect a relationship between Malleefowl breeding activity and this predator index.
- **other scat indices for predators:** Such methods have been used at some sites.
- **genetic analysis of predator scats:** This method has been used at some sites.
- **spotlighting on tracks:** This method has been used at some sites.
- **motion-triggered cameras:** This is the approach preferred by the Adaptive Management team, and was thus discussed in greatest detail with participants (see more below).
- **GPS collars with a camera array:** This approach allows predator density estimation via mark-recapture modelling.

Joe Benshemesh has performed a feasibility study using motion-triggered cameras in Victoria, with data analysed by Masters student Rosanna van Hespen (see summary of her findings below). Solar-powered cameras can potentially be left to collect data for a year, with data collection integrated into mound monitoring protocols. Photo sorting can be performed by volunteers given basic training.

There are a range of options for camera placement. The pilot set was placed off-track and off-mound throughout the Malleefowl site and many fox photos were collected across the year; predator densities may be lower in some other sites. Placing cameras on active mounds would help confirm the presence of foxes, although interactions between predators and Malleefowl chicks and adults do not necessarily occur at mounds. Camera locations could be baited, although this could attract predators to the area and is likely to require animal ethics clearance. Fast shutter speeds are needed to pick up foxes in images. Cameras should also be useful for monitoring cats, as well as kangaroos, goats and other animals at sites.

Camera models, numbers and placement were discussed further by some land managers and researchers in emails after the workshops were held:

- First, it was agreed by all contributors that the *same camera model* must be used at all sites within a cluster, so that camera detection parameters are equal and predator activity rates can be compared statistically. However, *different camera models* can be used at different clusters, with this information incorporated into the statistical analysis.
- Many land managers have considered purchasing Reconyx cameras, which have a faster trigger time and better detection rate than the KeepGuard cameras used in the pilot study. However, Reconyx cameras typically cost 2-3 times as much as KeepGuard cameras.
- The Adaptive Management team emphasise that the purpose of this experiment is *not* to maximise predator detections, but rather to confidently estimate differences in predator activity between predator-managed and unmanaged sites. Practices that would maximise detections include: using Reconyx cameras, setting cameras to high sensitivity, locating cameras near tracks and on mounds, using lures.
- Rather, we are seeking *adequate detections at individual camera locations* and *enough cameras in time and space* to quantify the temporal and spatial variation in predator dynamics, and deduce the underlying rate of predator activity. We are seeking relatively large and common species in habitat where relatively clear areas can be selected for camera placement. If cameras are run all year round then we should obtain an adequate number of photos. (This has been confirmed in the Victorian pilot study, although we acknowledge that predator densities are likely to be much lower in other regions around Australia; tests of lower predator densities by simulation are included below.)
- Under the assumption that we can achieve adequate detection, we prefer to avoid locating cameras near roads or tracks. First, such cameras may be at higher risk of theft. Second, these cameras may be capturing predators that pass through and do not hunt within the area. Third, we cannot be sure that the locations we choose at paired sites have precisely the same elevated detection rate. Therefore we prefer to select locations relatively randomly throughout each site to capture the range of possible high-predator-use and low-predator use scenarios.
- In this manner, variance in activity and detection among camera locations is of equal or greater concern than obtaining high detection rates at individual locations. Given a fixed budget, the choice between Reconyx and KeepGuard cameras is a trade-off between obtaining high detection rates from few cameras and lower detection rates from many cameras. The optimal trade-off will depend on the camera costs, detection rates, and the variable spatial behaviour of the predator (these factors are considered in statistical analyses provided later in the report).

Workshop participants noted the difference between measuring predator density and predator activity. The Adaptive Management team suggest that predator activity is as likely an indicator of predation pressure as density, and activity can be measured more robustly. Some participants nevertheless recommended that high-intensity monitoring to estimate density be pursued at the beginning of the program.

Participants also noted predator behaviours that might affect monitoring data. For example, foxes tend to disperse in spring. Young males are active and seeking territory, and this could be the peak predation time. What is the nature of the predation relationship, regulating or limiting? Predator densities could also initially increase in response to baiting, affecting Malleefowl and other species of conservation value. This could arise due to new individuals migrating into the territory, or could be a response by cats when foxes decline. Either scenario is primarily a concern when baiting begins somewhere new, and not at sites where baiting has been applied for some time.

Many participants shared their experiences of detecting trends in fox populations. Multiple monitoring methods can yield conflicting information. There is a threshold density below which foxes are no longer detected, but they may still be causing harm to the Malleefowl population. Participants recommended that we continue to monitor sites even if baiting ceases, as this will provide additional comparative information.

Analysis of pilot data in Victoria

Under the supervision of José Lahoz-Monfort, Libby Rumpff and Cindy Hauser, Rosanna van Hespen has completed a Masters project exploring the power of the proposed experimental design to detect differences in fox activity or density at one pair of Malleefowl sites. The mathematical model structure is described more thoroughly in Appendix C.

Van Hespen's approach assumes that an equal number of cameras are allocated to each of two sites, one managed for predators and the other not. The number of photos containing the predator (fox or cat) are counted each month and analysed over 12 months. The model incorporates *temporal variation* via a *month random effect* and *spatial variation* via a *camera random effect*. That is, photo numbers are expected to fluctuate from month to month in the pair (e.g. springtime generates higher fox activity and therefore more photos in both sites simultaneously) and from camera to camera (e.g. one camera will consistently capture more foxes than another because it is located in an area that foxes use more frequently). By including this variation, we are equipped to distinguish the effect of predator management from the other 'noise' in the naturally varying ecosystem.

Van Hespen proposes two useful statistical tests for ascertaining whether predator management is having an effect. The first tests for differences in *predator activity* at the managed and unmanaged sites, and the second uses a method by Rowcliffe *et al.* (2008) to test for differences in *predator density* using the same data.

Van Hespen evaluated the performance of these statistical tests by simulating data and analysis, drawing on fox photo counts from a Victorian pilot study. In the pilot study, Joe Benshemesh placed sixteen KeepGuard KG680v (aka ScoutGuard) cameras in Wandown Nature Reserve, where Malleefowl and foxes coexist (foxes are not baited). A 4GB SD card and 6V 12Ah lead-acid dry-cell battery permit collection and storage of photos for a full calendar year, although the pilot data available for this study included complete data for 5 months. Van Hespen additionally estimated the detection distance (μ_r = 7.6m, σ_r = 1.1m) and angle of a camera (μ_θ = 19°, σ_θ = 9°) by performing field tests. The ultimate measure of each statistical test is its *power*; that is, the probability that the test will correctly detect a difference in predator activity or density at each site when there truly is a difference between the sites.

The power of the statistical test depends on many factors, and van Hespen investigated the implications of varying:

1. the number of cameras placed at each site,
2. the proportion of predators removed at a site where they are managed,
3. the initial predator density at an unmanaged site,
4. the amount of camera-to-camera spatial variation,
5. the amount of month-to-month temporal variation,
6. the average predator speed of movement, and
7. the differing detection distance and angle of two camera brands (KeepGuard KG680v ScoutGuard and Reconyx HC500 Hyperfire).

Van Hespen's thesis demonstrates that in most circumstances, increasing the number of cameras at each site will increase our power to detect differences in predator activity or density (Figure 6). Under baseline conditions with 8 cameras placed at each site, there is a 50% chance of detecting a difference when half of the predators are removed from the managed site. When management removes 70% of predators, the power to detect a difference rises to 90% when data are collected from 8 cameras per site for 12 months.

More power plots are included in Appendix C. They show:

- a relatively equal power to detect differences for unmanaged predator densities from 1-4 individuals per km^2,
- decreasing power to detect differences as camera-to-camera spatial variation increases from 0 to double the variation observed in the pilot study,
- relatively little change in the power to detect differences as month-to-month temporal variation shifts from 0 to double the variation observed in the pilot study,
- relatively little change in the power to detect differences as the average predator speed of movement changes, and
- consistently higher power to detect differences when allocating a budget to KG680v cameras (assumed $400/camera) compared to allocating the same budget to HC500 cameras (assumed $800/camera).

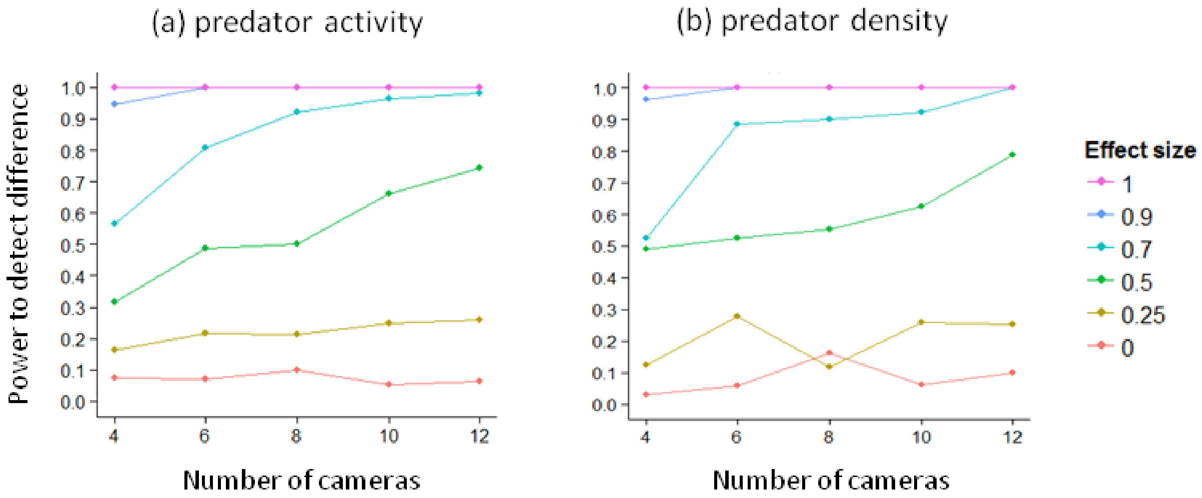

Figure 6. Estimated power to detect a difference in predator (a) activity, or (b) density in a pair of predator managed and unmanaged sites observed over 12 months. Effect size is the proportion of predators removed in the managed site. Note that some fluctuations arise due to the simulation sample size.

Van Hespen additionally investigated a before-after site pairing, where one set of cameras is used to observe 12 months without predator management and a subsequent 12 months of intense predator management at the same site. This approach showed a consistently higher power to detect changes in predator activity and density, because temporal variation was estimated to be substantially lower than spatial variation in the pilot study. In this scenario, the number of cameras allocated to the site had only a weak influence on statistical power.

This statistical modelling approach inevitably has limitations. For example, Rowcliffe *et al.*'s (2008) conversion from predator activity to density makes unrealistic assumptions about predator distribution and movement patterns; our best estimates should be unaffected but confidence intervals are likely to be too narrow. Even so, van Hespen's simulations show a reasonable possibility of detecting differences between predator managed and unmanaged sites using 12 months of camera data. Confidence will grow stronger as multiple years of data are collected. A landscape-scale experiment has the further advantage of leveraging common factors from multiple sites, while acknowledging the individual characteristics of each site cluster.

Other variables

Of course, many other factors will influence Malleefowl persistence at a site beyond predator density. In the first instance, we seek pairs or clusters of sites with similar habitat and weather conditions to strengthen our inference. As a second approach, we can collect data on these influencing factors (e.g. rainfall) for inclusion in our statistical models. Our third long-term strategy may be to include more driving processes (e.g. grazing, fire) into the experimental design itself. This would only be considered after we have seen evidence that this Adaptive Management approach is benefiting Malleefowl conservation and learning through our initial treatment of predators.

A workshop participant shared their experience that fox activity had proven to be more sensitive to rainfall and landscape than to fox management in their area. This observation is why we are pursuing a landscape-scale experiment, where we can observe great variation in landscape context and use the larger sample size to seek out common, if subtle, responses to predator management.

Next steps

Tim Burnard and Joe Benshemesh are playing a crucial role in developing each site that may be included in this experiment (see Figure 4). We seek to understand the environmental and management context of each site and its suitability for joining a cluster. Burnard and Benshemesh can potentially assist in identifying suitable locations; LiDAR, photogrammetry and ground search protocols for finding mounds; training staff and volunteers to monitor Malleefowl mounds; administration of the National Malleefowl Monitoring Database; and camera placement and data management protocols.

The University team are continuing to develop their statistical methods in readiness for data collection. They seek to integrate the Malleefowl mound and predator photo data more comprehensively. They will work with database managers to streamline the data collection system.

The Adaptive Management team seeks to hold the second annual co-ordination meetings in April 2016 in Perth and Mildura to present and receive feedback on research progress and discuss advancement of the various sites listed for inclusion. We welcome all interested land managers and monitoring co-ordinators to these meetings.

Conclusions

This report outlines an ambitious project to discern the benefits of predator control for the persistence and conservation of Malleefowl. The report authors believe that in accordance with the recovery plan, an Adaptive Management approach provides a robust framework for assessing and prioritising the risks faced by Malleefowl.

We seek the co-operation of numerous land managers across Australia to contribute monitoring data, and in turn will analyse and report back findings that address local population trends. Additionally, the accumulated data set across the Malleefowl’s range has potential for a much greater impact by teasing out the common effect of predator management on Malleefowl from the ‘noise’ of local population dynamics.

In order to achieve quality data sets and reliable inference, participants must agree to embark on consistent and thoughtfully designed monitoring. This report outlines the research team’s current conception of what is required, and the spatial and temporal scales over which we can expect to detect the effect of predator management on Malleefowl.

We are heartened by the supportive and constructive feedback that we have received from land managers thus far. At many sites there are challenges for meeting the criteria for inclusion. We have already witnessed the ingenuity of managers in securing the right conditions for participation, and we hope to collaborate with many managers to address barriers to participation. Continuous communication with Tim Burnard, Joe Benshemesh and the University research team will facilitate progress, with annual co-ordination meetings providing an excellent opportunity to consolidate findings and share ideas.

Acknowledgements

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Appendix A: workshop participants

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Appendix B: statistical detail of the power analysis

For the power analysis, the 18 clusters with 41 sites are divided between West area (WA and southern SA) and East area (NE SA, Victoria and NSW). We then use historical mound activity data from the national database to:

- calculate the number of active mounds per site (either observed, at sites that are currently monitored; or estimated based on similar sites and experience, for sites that are not monitored yet)
- calculate the average mound activity for sites in the West (4.0 mounds) and East (2.3 mounds) areas.
- characterise temporal variation in mound activity, from year-to-year. Even at a single site, the proportion of active mounds changes greatly between years.

The purpose of this power analysis is to work out – ahead of time – the probability that an experiment would be able to correctly recognise the benefits of predator control (in statistical terms, this is usually called the 'power to detect an effect'). This statistical power will increase over the years, so we explore scenarios of running the predator control experiment for 1 to 5 years.

Model specification

In each of the 18 clusters, there is at least 1 treated and 1 untreated site; in this case, 'treatment' refers to predator control, either through baiting or exclosure. Mound activity is monitored at each of these sites. For each site s and year t, the number of mounds found active (random variable a) can be described statistically with a Poisson distribution with mean $\lambda(s,t)$ (i.e., year and site specific): $a \sim Pois\big(\lambda(s,t)\big)$. We model the mean number of active mounds λ as a log regression with time and cluster-specific variation as:

$$\log\big(\lambda(s,t)\big) = \beta_{area} + \varepsilon_S(cluster) + \varepsilon_T(t) + \beta_{treat}treated(s)$$

where β_{area} is the average log-probability (intercept) of either area West or East, ε_S is a cluster-specific term (spatial variation), ε_T is a year-specific term (temporal variation) and β_{treat} is the effect of predator control (the indicator covariate $treated(s)$ is 1 for treated sites and 0 otherwise). Note the cluster-specific terms are shared by all control/treatment sites within the cluster.

Power analysis simulations

Once we have assumed a model that describes mound activity in a statistical way, and we have chosen values for the model parameters based on the historical dataset, the way to conduct power analysis based on simulations is to follow these simple steps, for each scenario defined by a number of years T and an effect size β_{treat}:

1) Simulate a data set of mound activity observations (active/inactive) using the model above (assumed as the reference "truth")
2) Analyse the simulated data set using the same model structure
3) Determine whether the estimation of the existing effect of predator control (β_{treat}) is found to be statistically significant at the customary $\alpha = 0.05$ significance level (i.e. whether the 95% Credible Interval does not include the value zero)
4) Repeat steps 1 to 3 a large number of times

5) The estimation of the statistical power G for each scenario is the percentage of simulations in that scenario in which the assumed effect of predator control is detected.

The simulation study is conducted in program R, calling program JAGS from R for analysis within the Bayesian framework of inference.

In our study, we generate data with an average of $\lambda = 2.57$ active mounds per site (close to the historical average), and a number of years ranging from 1 to 5. The following table summarises the range of effect sizes explored (parameter β_{treat} in the model, on the log scale) and their equivalent in terms of increased average number of active mounds:

effect size (β_{treat}), log scale	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
corresponding average λ	2.57[*]	2.83	3.13	3.46	3.83	4.23	4.67	5.17
% increase compared to β_{treat}=0	---	11%	22%	35%	49%	65%	82%	101%

[*] mean over all sites considered

The “% increase compared to no treatment” is only valid for the mean of $\lambda = 2.57$, and is shown here to provide an intuitive idea of the effect size. For each specific cluster, the “% increase” will depend in the actual number of active mounds per site. The parameter β_{treat}, on the other hand, is the true reference and is used directly in the model.

Technical note: the 5% significance level implies that there is a 5% chance of declaring that an effect exists when in fact it does not; a trade-off exists between this error and statistical power, so that lowering that probability of falsely detecting an effect implies a lower power to detect a true effect.

Appendix C: van Hespen's tests of differences in predator activity and density

The model assumes that the number of predator (fox or cat) photos observed each month is drawn from a Poisson distribution:

$$P_{s,c,t} \sim \text{Poisson}(\lambda_{s,c,t}),$$

where $P_{s,c,t}$ is the number of photos observed in month t from camera c given predator treatment s (s = 0 indicates no predator management, s = 1 indicates intensive predator management such as baiting), and $\lambda_{s,c,t}$ is the expected number of photos observed in month t from camera c under predator treatment s.

The expected number of photos taken by camera c in month t is

$$\log(\lambda_{s,c,t}) = \log(\mu_s) + C_{s,c} + T_t$$

where μ_s is the mean number of photos observed in a month under predator treatment s across all cameras and months, $C_{s,c}$ is the random effect of camera c under treatment s and T_t is the random effect of month t. We assume that the random effects have distributions:

$$C_{s,c} \sim N(0, \sigma_c^2)$$

$$T_t \sim N(0, \sigma_t^2),$$

where σ_c^2 is the camera-to-camera variation and σ_t^2 is the month-to-month variation.

We use Bayesian methods to estimate the parameters μ_s, σ_c^2 and σ_t^2 from data set $P_{s,c,t}$. To test whether *predator activity* differs between management activities, we test whether our posterior estimate of $\mu_0 - \mu_1 > 0$ with 95% confidence.

We also extend the model using Rowcliffe *et al.*'s (2008) approach to estimate predator density at each site:

$$D_s = \mu_s \frac{\pi}{vr(2+\theta)},$$

where D_s is predator density at the site under predator treatment s, μ_s is the mean number of photos observed per month under predator treatment s, v is average predator speed of movement, r is the detection distance of a camera, and θ is the detection angle of a camera. We allow for some uncertainty in our estimates of v, r and θ such that

$$v \sim N(\mu_v, \sigma_v^2)$$

$$r \sim N(\mu_r, \sigma_r^2)$$

$$\theta \sim N(\mu_\theta, \sigma_\theta^2).$$

This enables us to estimate μ_s, σ_c^2, σ_t^2, μ_v, σ_v^2, μ_r, σ_r^2, μ_θ, and σ_θ^2 from data set $P_{s,c,t}$. To test whether *predator density* differs between management activities, we test whether our posterior estimate of $D_0 - D_1 > 0$ with 95% confidence.

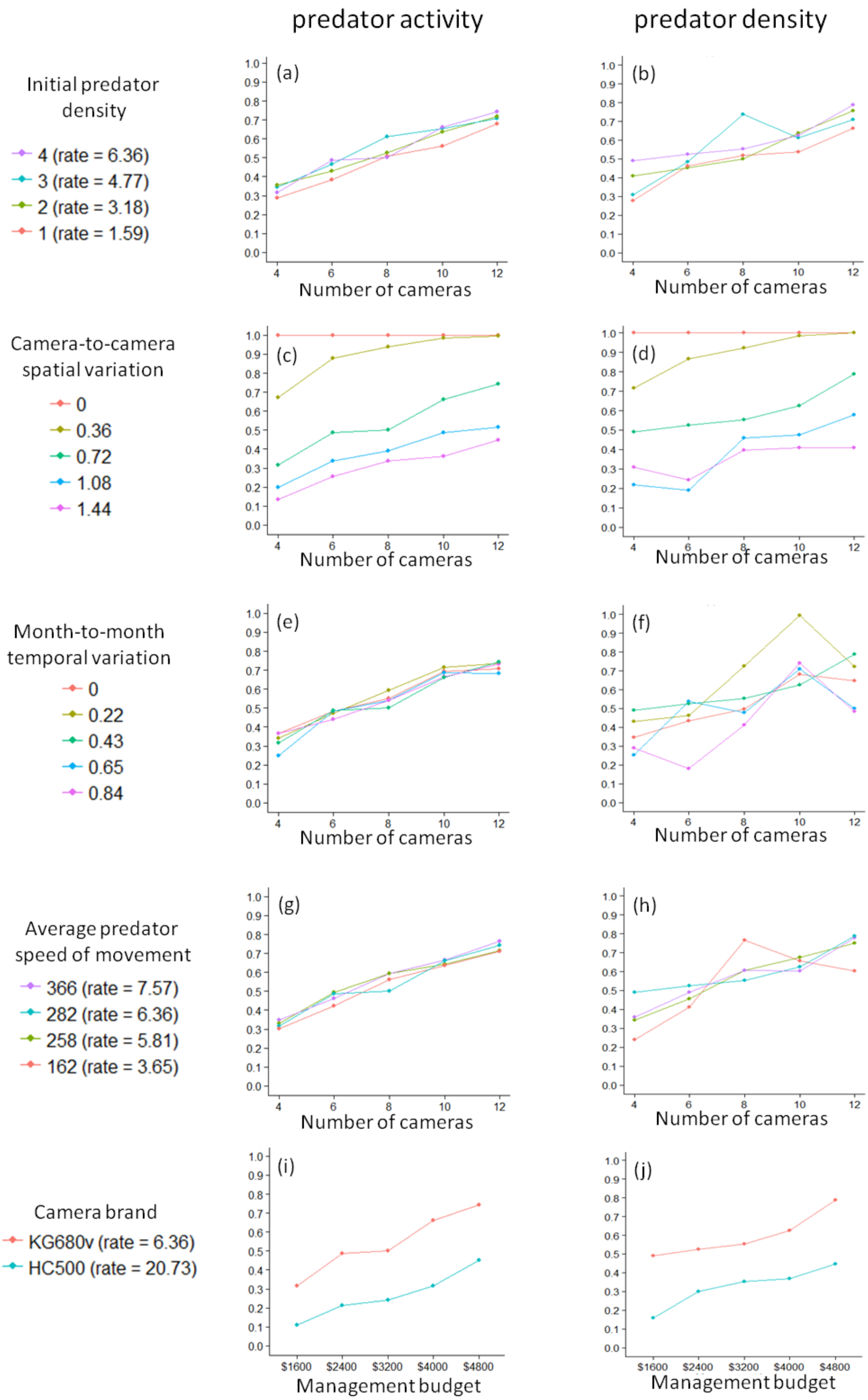

Figure C1. Estimated power to detect a difference in predator activity (a,c,e,g,i) or density (b,d,f,h,j) in a pair of predator managed and unmanaged sites observed over 12 months. Note that some fluctuations arise due to the simulation sample size.

Appendix D: catalogue and status of sites

Table D1. Site names, clusters and mound counts.

Site name	Sites and AM partners identified	Site searched regist'd in NMMD	Mound monitoring uploaded to NMMD annually	Treatment implem'd and reported on NMMD annually	Camera monitoring and report to NMMD annually	state	Cluster #	treatment/ control	Total number of mounds	Known Mounds		
									control	NMM	C	T
Scotia (Stage 3)	Y					NSW	14	C	25	25	0	0
Scotia (Stage 4)	Y					NSW	14	T	25	25	0	25
Scotia (Stage 1 & 2)	Y					NSW	14	T	25		0	25
Tarawi	Y					NSW	14	T	50	107	0	50
Nanya	Y					NSW	14	T	43	43	0	43
Mallee Cliffs 1	Y					NSW	15	T	50	150	0	50
Mallee Cliffs 2						NSW	15	C				
Nombinnie	Y					NSW	16	T			0	0
Unknown						NSW	16	C				
Nymagee	Y					NSW	16	T	7		0	7
Yarradah 1		Y				NSW	17	C				
Yarradah 2		Y				NSW	17	T				
Yarradah 3		Y				NSW	17	T				
Yara 1		Y				NSW	17	C				
Yara 2		Y				NSW	17	T				
Yara 3		Y				NSW	17	T				
Mawonga 1		Y				NSW	17	C				
Mawonga 2		Y				NSW	17	T				
Mawonga 3		Y				NSW	17	T				
Bundure		Y				NSW	17	T				
Scotts Craig		y				NSW	17	T				

Kilparney		Y				NSW	17	T				
Yalgogrin 1	Y					NSW	18	C	0		0	0
Yalgogrin 2						NSW	18	T				
Gluepot	Y	Y	Y			SA	9	T	50		0	50
Danggali	y	Y	Y			SA	9	C	18	18	0	0
Calperum Taylorville	Y	Y	Y			SA	9	T	14	14	0	14
Karte and Peebinga	Y	Y	Y			SA	9	T	50	70	0	50
Chowilla	Y	Y	Y			SA	9	T	19	19	0	19
Innes National Park	Y	Y	Y			SA	10	T	47	47	0	47
Lower York	y					SA	10	C				
Secret Rocks 1	Y	Y	Y			SA	11	T	80	243	0	80
Secret Rocks 2	Y					SA	11	T				
Munyeroo	Y	Y	Y			SA	11	C	50	50	0	0
Duck Island 1	Y					SA	12	T	0		0	0
Duck Island 2	Y					SA	12	C				
Little Desert 1	y					Vic	13	T				
Little Desert 2	Y					Vic	13	C				
Mt Gibson mine	Y	Y	Y			WA	1	C	80	306	0	0
Ninghan Station	Y					WA	1	T	40		0	40
AWC - Mt Gibson 1	Y	Y	Y			WA	1	C	29	29	0	0
AWC - Mt Gibson 2	Y	Y	Y			WA	1	T	53	53	0	53
Charles Darwin 1	Y	Y	Y			WA	1	C	30		0	0
Charles Darwin 2	Y					WA	1	T	30	30	0	30
Hamelin	Y					WA	2	T	30		0	30
Hamelin DPaW						WA	2	C	30		0	0
Eurardy	Y					WA	2	C	9	9	0	0
Kalbarri	Y					WA	2	T	15		0	15
Mt Jackson	Y	Y	Y			WA	3	T	80		0	80

Die Hardy Range	y	y				WA	3	C	50	80	0	0
Badja	y	y	y			WA	4	T	83	83	0	83
Badja/Karara	y	y				WA	4	C	50		0	0
Great Western Woodland						WA	5	T	0		0	0
Great Western Woodland						WA	5	C	0		0	0
Lake Magenta						WA	6	T	0		0	0
Lake Magenta						WA	6	C				
Great Vic Desert						WA	7	T	10		0	10
Great Vic Desert						WA	7	C	10		0	0
Scahill						WA	8	T	0		0	0
Yalarri						WA	8	T	0		0	0
Unknown						WA	8	C				

Table D2. Site names and status of Malleefowl monitoring.

	Searching sites for new mounds			**Mound monitoring**	
Site name	**LiDAR/ photogrammetry**	**Ground truthing**	**Ground-based search**	**Sites on website**	**Monitoring teams**
Scotia (Stage 3)	Interest in future scans			No	AWC recruits volunteers
Scotia (Stage 4)	Interest in future scans			No	AWC recruits volunteers
Scotia (Stage 1 & 2)	Interest in future scans			No	AWC recruits volunteers
Tarawi	Interest in future scans			Yes	Unknown
Nanya	Interest in future scans			No	Unknown, students?
Mallee Cliffs 1	Interest in future scans			Yes	NSW NP staff (extra effort needed?)

Mallee Cliffs 2					
Nombinnie	Interest in future scans			No	Potential for volunteers
Unknown					
Nymagee	Historical aerial survey	Conducted for aerial		No	Landholder + LLS
Yarradah 1					
Yarradah 2					
Yarradah 3					
Yara 1					
Yara 2					
Yara 3					
Mawonga 1					
Mawonga 2					
Mawonga 3					
Bundure					
Scotts Craig					
Kilparney					
Yalgogrin 1	Interest in future scans	needed		No	Potential for volunteers
Yalgogrin 2					
Gluepot	Past aerial photography, interest in more			Historical	Volunteers
Danggali	Interest in future scans			Patchy	DEWNR, ALT or AWC recruits volunteers
Calperum Taylorville	Interest in future scans			Yes	Volunteers
Karte and Peebinga	Needed			Yes	Volunteers
Chowilla	Interest in future scans			Probably not	Volunteers
Innes National Park	Interest in future scans			Yes	Volunteers
Lower York					
Secret Rocks 1					
Secret Rocks 2					

Munyeroo					
Duck Island 1					
Duck Island 2					
Little Desert 1					
Little Desert 2					
Mt Gibson mine	Photogrammetry completed, LiDAR to come?	completed	completed	yes	Mining staff + consultants
Ninghan Station	LiDAR to come	Upcoming		not yet	Local volunteers + recruit outsiders
AWC - Mt Gibson 1	Photogrammetry to come	Upcoming		No?	MPG - Joy
AWC - Mt Gibson 2	Photogrammetry to come	Upcoming	Completed	Yes?	MPG - Joy
Charles Darwin 1	LiDAR to come	Upcoming	completed	yes	NCMPG + BHA
Charles Darwin 2	LiDAR to come	Upcoming		no	NCMPG + BHA
Hamelin					
Hamelin DPaW					
Eurardy		No	Yes, in parts	Yes	BHA
Kalbarri	Anthony Desmond seeking funding				DPaW recruit volunteers
Mt Jackson	NA	NA	Yes	Yes	Cliffs
Die Hardy Range	Photogrammetry to come	Upcoming	NA	No	DPaW recruit volunteers
Badja	NA	NA	Completed	No	Mining staff
Badja/Karara	NA	NA	Completed	No	Mining staff
Great Western Woodland	NA	NA	Upcoming	No	Nadju people
Great Western Woodland	NA	NA	Upcoming	No	Nadju people
Lake Magenta					
Lake Magenta					
Great Vic Desert	No current plans,			No	Spinifex?

	needed				
Great Vic Desert	No current plans, needed			Yes	Spinifex?
Scahill	Jennifer Jackson seeking funding		NA	No	DPaW recruits volunteers
Yalarri	Jennifer Jackson seeking funding		NA	No	DPaW recruits volunteers
Unknown					

Table D3. Site names and status of predator monitoring.

	Camera trapping of foxes, cats, etc						
Site name	**Equipment**	**Camera placement**	**Camera maintenance**	**Image sorters**	**Maximum area?**	**Treatment**	**Baiting**
Scotia (Stage 3)	Reconyx but not for this purpose		AWC would try to recruit volunteers	AWC would try to recruit volunteers	15000ha	Fox & cat Control	No, for now
Scotia (Stage 4)	Reconyx but not for this purpose		AWC would try to recruit volunteers	AWC would try to recruit volunteers	25000ha	Fox & cat Control	Yes ++
Scotia (Stage 1 & 2)	Reconyx but not for this purpose		AWC would try to recruit volunteers	AWC would try to recruit volunteers	8000ha total	Fox & cat Control	Fenced
Tarawi	No		NSW NP staff	unknown	33000ha	Fox & cat Control	Yes
Nanya	No		Can probably be found	students?	40000ha	Fox & cat Control	Yes
Mallee Cliffs 1	Some Reconyx cameras on mounds for other purpose		NSW NP staff	unknown	57000ha	Fox & cat Control	Yes
Mallee Cliffs 2						Fox & cat Control	
Nombinnie	No		OEH staff	Potential for volunteers	100000ha	Fox & cat Control	YEs
Unknown						Fox & cat Control	

Nymagee	No, some in past and possibly some Reconyx available		LLS	Unknown	12000ha	Fox & cat Control	Yes
Yarradah 1						Fox & cat Control	
Yarradah 2						Fox & cat Control	
Yarradah 3						Herbivore Control	
Yara 1						Fox & cat Control	
Yara 2						Fox & cat Control	
Yara 3						Herbivore Control	
Mawonga 1						Fox & cat Control	
Mawonga 2						Fox & cat Control	
Mawonga 3						Herbivore Control	
Bundure						Fox & cat Control	
Scotts Craig						Fox & cat Control	
Kilparney						Fox & cat Control	
Yalgogrin 1	No		Volunteers	Potential for volunteers	1000ha	Fox & cat Control	No
Yalgogrin 2						Fox & cat Control	
Gluepot	No		Volunteers	unknown	54000ha	Fox & cat Control	Yes
Danggali	No		DEWNR staff	DEWNR and AWC to discuss volunteers		Fox & cat Control	No
Calperum Taylorville	No		Volunteers	unknown	350000ha	Fox & cat Control	Yes
Karte and Peebinga	No		Volunteers	unknown		Fox & cat Control	Unknown
Chowilla	No		DEWNR staff or volunteers	unknown	93000ha	Fox & cat Control	Yes
Innes National Park	150 Scoutguards, not IR	currently used for foxes and wallabies	Staff or volunteers	unknown	85000ha	Fox & cat Control	Yes

Lower York						Fox & cat Control	
Secret Rocks 1				Volunteers	26000ha	Fox & cat Control	Yes
Secret Rocks 2						Herbivore Control	
Munyeroo						Fox & cat Control	
Duck Island 1						Fox & cat Control	
Duck Island 2						Herbivore control	
Little Desert 1						Fox & cat Control	
Little Desert 2						Fox & cat Control	
Mt Gibson mine	Some old Reconyx, needs updating with solar	~6 on mounds, ~2 on tracks, can be shifted	Mining staff	Mining staff		Fox & cat Control	None
Ninghan Station	Some, IPA funding could be sought	Not placed	Local volunteers	Local volunteers with training		Fox & cat Control	Yes
AWC - Mt Gibson 1	No	No				Fox & cat Control	
AWC - Mt Gibson 2	Yes	Yes, own design				Fox & cat Control	
Charles Darwin 1	No		BHA staff	BHA staff		Fox & cat Control	No
Charles Darwin 2	No		BHA staff	BHA staff		Fox & cat Control	Yes
Hamelin			BHA			Fox & cat Control	
Hamelin DPaW						Fox & cat Control	
Eurardy	No		BHA	BHA		Fox & cat Control	No
Kalbarri	No		DPaW recruits volunteers	DPaW recruits volunteers		Fox & cat Control	Yes
Mt Jackson	No		Cliffs?	Cliffs?		Fox & cat Control	Yes
Die Hardy Range	No		DPaW recruits volunteers	DPaW recruits volunteers		Fox & cat Control	No
Badja	6-8 old solar cameras	Yes, currently at active mounds, could be shifted	Mining staff	Mining staff		Fox & cat Control	Yes

Badja/Karara			Mining staff	Mining staff		Fox & cat Control	No
Great Western Woodland	No		Nadju people	Nadju people		Fox & cat Control	Yes
Great Western Woodland	No		Nadju people	Nadju people		Fox & cat Control	No
Lake Magenta						Fox & cat Control	
Lake Magenta						Fox & cat Control	
Great Vic Desert	No		Spinifex or mining staff?	Spinifex or mining staff?		Fox & cat Control	Yes
Great Vic Desert	No		Spinifex or mining staff?	Spinifex or mining staff?		Fox & cat Control	No
Scahill	No		DPaW recruits volunteers	DPaW recruits volunteers		Fox & cat Control	Minimal
Yalarri	No		DPaW recruits volunteers	DPaW recruits volunteers		Fox & cat Control	Minimal
Unknown						Fox & cat Control	