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ORIGINAL RESEARCH

Establishing effective conservation management strategies for a poorly known endangered species: a case study using Australia's Night Parrot (*Pezoporus occidentalis*)

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Abstract

An evidence-based approach to the conservation management of a species requires knowledge of that species' status, distribution, ecology, and threats. Coupled with budgets for specific conservation strategies, this knowledge allows prioritisation of funding toward activities that maximise benefit for the species. However, many threatened species are poorly known, and determining which conservation strategies will achieve this is difficult. Such cases require approaches that allow decision-making under uncertainty. Here we used structured expert elicitation to estimate the likely benefit of potential management strategies for the Critically Endangered and, until recently, poorly known Night Parrot (*Pezoporus occidentalis*). Experts considered cat management the single most effective management strategy for the Night Parrot. However, a combination of protecting and actively managing existing intact Night Parrot habitat through management of grazing, controlling feral cats, and managing fire specifically to maintain Night Parrot habitat was thought to result in the greatest conservation gains. The most cost-effective strategies were thought to be fire management to maintain Night Parrot habitat, and intensive cat management using control methods that exploit local knowledge of cat movements and ecology. Protecting and restoring potentially suitable, but degraded, Night Parrot habitat was considered the least effective and least cost-effective strategy. These expert judgements provide an informed starting point for land managers implementing on-ground programs targeting the Night Parrot, and those developing policy aimed at the species' longer-term conservation. As a set of hypotheses, they should be implemented, assessed, and improved within an adaptive management framework that also considers the likely co-benefits of these strategies for other species and ecosystems. The broader methodology is applicable

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to conservation planning for the management and conservation of other poorly known threatened species.

Keywords Expert · Cost-effectiveness · Biodiversity offset · IDEA protocol · Counterfactual · Poorly known · Data poor

Introduction

Understanding a species' status, distribution, ecology, and threats, provides the knowledge base required to develop conservation strategies necessary for its effective conservation (Pullin and Knight 2001; Lomolino 2004; Sutherland et al. 2004). Provided the opportunities and organisational relationships exist to apply these strategies, knowledge of their costs and benefits allows the targeted allocation of funding toward actions that work while minimising overall expense (Joseph et al. 2009; Carwardine et al. 2012). A conservation strategy here is defined broadly (Carwardine et al. 2019). At the site-scale, it may include decisions to manage specific threats such as invasive species (see e.g. Comer et al. 2018), or improve vegetation structure (see e.g. Bliege Bird et al. 2018). At the landscape-scale and over the longer term, conservation strategies are largely driven by governments and other land managers implementing policies aimed at a species' conservation and recovery. These could include translocation, biodiversity offsetting, vegetation management policy, pest biocontrol, and protected area designation (see e.g. Maron et al. 2016, Pedler et al. 2016, Silcock et al. 2019, Ward et al. 2019, Kearney et al. 2020).

Ideally, the impact and efficiency of these conservation strategies would be assessed using an evidence-based approach and modified within an adaptive management framework (Keith et al. 2011; Westgate et al. 2013; Salafsky et al. 2019). For poorly known species though, this may not be possible; the knowledge to devise appropriate management strategies may not exist, nor the opportunities to measure their benefits. When knowledge of a species is limited but conservation action is imperative, approaches that allow decision-making under uncertainty are necessary (Milner-Gulland and Shea 2017). Formal expert elicitation is increasingly the preferred approach, and sometimes the only approach available in these circumstances (Kuhnert et al. 2010; Martin et al. 2012; Adams-Hosking et al. 2016). This approach does carry risk; expert judgments may be biased, poorly calibrated, or self-serving (Speirs-Bridge et al. 2010; Burgman et al. 2011a). However, these risks can be minimised by applying structured elicitation protocols that have been developed specifically for application to conservation problems (Mukherjee et al. 2015; Hemming et al. 2018a).

In this paper we used expert elicitation to identify experts' expectations about beneficial management strategies for a very poorly known species: Australia's Night Parrot (*Pezoporus occidentalis*). Once found throughout arid central Australia, the Night Parrot underwent a precipitous decline across its range in the late 19th and early 20th centuries (Leseberg et al. 2021a). Only the occasional unconfirmed report suggested it may still exist. For most of the 20th century it was considered a missing species, until finally, an extant population was discovered in 2013. Classified nationally as Endangered (Environment Protection and Biodiversity Conservation Act 1999 (Cth)), with a recent recommendation it be listed as Critically Endangered (Leseberg et al. 2021b), the Night Parrot has been targeted as a high priority species for conservation action (Australian Government 2015).

Despite considerable advances over the past seven years, the knowledge required to accurately assess the Night Parrot's conservation requirements at multiple scales, remains inchoate. The species is known to require patches of long-unburnt *Triodia* (a hummock-forming grass often called 'spinifex') for roosting and breeding, and diverse grassy floodplains and herb-fields for foraging (Murphy et al. 2017b). Probable threats to the species include introduced predators, inappropriate fire regimes, and possibly competition with introduced herbivores such as cattle, sheep, and European Rabbits (*Oryctolagus cuniculus*) (Murphy et al. 2018). Although the relative contributions and interactions between these threats are not known for the Night Parrot, the impact of these threats on similar arid zone species is well-studied (see e.g. McKenzie et al. 2007, Southgate et al. 2007, Edwards et al. 2008, Legge et al. 2017), as are the management strategies that can ameliorate this impact (see e.g. Andersen et al. 2005, Pedler et al. 2016, Doherty et al. 2017, Comer et al. 2018). But, while the effect of these conservation management strategies for the protection of other threatened species has been tested, this is not the case for the Night Parrot.

This level of ecological knowledge is unlikely to improve significantly in the near term, as the Night Parrot is known to occur at only a handful of locations in relatively remote and disjunct parts of western Queensland, and central and northern Western Australia (Leseberg et al. 2021a). The expense associated with accessing these areas, and the difficulty in conducting comprehensive surveys across the large area it may still occupy, will prevent significant improvements in our level of knowledge in the foreseeable future. Given these circumstances, expert elicitation provides a transparent method of estimating the 'best-bet' management strategies for the Night Parrot while primary data on its ecology, behaviour and population responses to management are still being collected. These strategies represent a set of hypotheses that should be implemented, tested, and improved at the site-scale within an adaptive management framework (Runge 2011; Salafsky et al. 2019). They can also inform regional-scale and longer timeframe conservation strategies, under biodiversity offset policies for example, where the necessary outcomes remain challenging and difficult to achieve (Maron et al. 2012). This method can also be generalised to other poorly known species that require targeted conservation action (Maron et al. 2021).

Materials and methods

Preparation for expert elicitation process

To obtain estimates from experts on the potential benefits to a Night Parrot population of various conservation management strategies, we applied a structured expert elicitation approach based on the Delphi-style IDEA protocol ('Investigate', 'Discuss', 'Estimate', 'Aggregate') (Hanea et al. 2017; Hemming et al. 2018a). The approach has been applied before to determine, with reasonable accuracy, the status of the Night Parrot before its rediscovery (Garnett et al. 2011; McBride et al. 2012). Structured expert elicitation overcomes many of the biases associated with the ad hoc collation of opinions or judgments from groups of experts (Burgman et al. 2011b; Martin et al. 2012). To conduct the elicitation we followed a modified nine-step process designed by Hemming et al. (2018a). In parallel we also collated cost data to assess the relative cost effectiveness of the management strategies evaluated through the elicitation (Fig. 1).

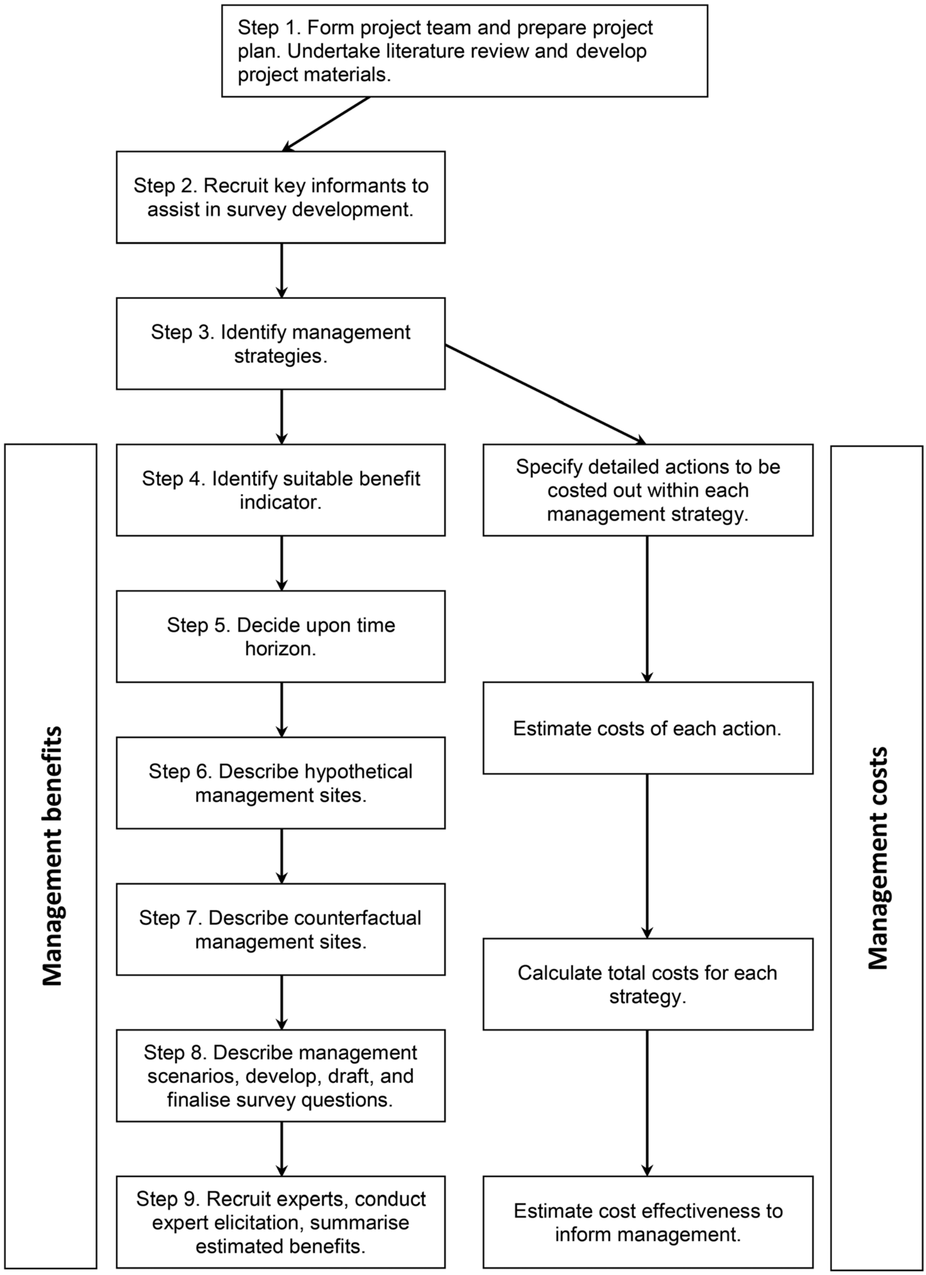

Fig. 1 An outline of the nine-step process used to estimate the benefit of management strategies, and the parallel process used to estimate the cost-effectiveness of those strategies

The first step involved forming a project team (MCE, TN, ZS, JCW, MM) and assigning the roles of problem owner, coordinator, facilitator, and analyst. In contrast to other threatened species, and largely due to the species' relatively recent rediscovery, there was limited literature concerning the ecology and conservation of the Night Parrot that could be consulted and used to develop project materials. To overcome this constraint the project team recruited two researchers with substantial direct, practical experience on Night Parrots (NPL and SAM), to act as key informants during the development of project materials (Step 2) (Burgman et al. 2011a). The project team then reviewed the available literature and consulted with these key informants to identify the threatening processes most likely to affect Night Parrots, and a suite of effective site-based on-ground management strategies that could both abate those threats and be feasibly employed across multiple sites (Step 3) (Table 1).

During preparation for expert elicitation, scale, benefit indicators, and timeframe should be well-defined to help experts estimate the benefits of specific management strategies over consistent criteria (Steps 4 and 5) (Hemming et al. 2018a). Night Parrots occur at low densities in isolated areas of intact habitat (Leseberg et al. 2021a) and are relatively sedentary (Murphy et al. 2017b), requiring future management to focus on those specific sites where the bird occurs. It is also important that policy and legislation such as the Australian Environment Protection and Biodiversity Conservation Act and similar state-based legislation, which will influence Night Parrot conservation over the longer term and at regional scales, accounts for the likely impact of site-based management strategies for the species. For these reasons we decided to assess the benefits of management strategies at the 'site' scale. We defined a Night Parrot 'site' as an area capable of supporting a population of Night Parrots, incorporating all of the microhabitats required for roosting and breeding (i.e. long-unburnt patches of *Triodia*) and foraging (i.e. diverse grassy floodplains and herb-fields). Recent research suggests such an area would cover at least several thousand hectares (Murphy et al. 2017b).

Once the spatial scale of a 'site' was determined, a suitable benefit indicator was needed, one that can be measured and monitored at the site level, represents population viability, and is comparable across sites and populations. The number of mature, breeding individuals is a common benefit indicator; however, as Night Parrots are nocturnal and occur at very low densities, it is very difficult to accurately assess the number of individuals in a population (N. Leseberg, S. Murphy, pers obs.). In this case, we chose the number of extant long-term stable roost sites as the benefit indicator, because breeding pairs of Night Parrots are thought to establish long-term stable roosting and nesting sites in patches of suitable *Triodia* that are relatively easy to identify and monitor via predictable calling behaviour (Murphy et al. 2017a; Leseberg et al. 2019). Finally, experts were asked to assess the impact of management on the benefit indicator over a 20-year timeframe. Given that Night Parrots seem fecund (Murphy et al. 2017a, N. Leseberg unpub. data), and that 20 years is a timeframe over which the impacts of the different management actions could be realised (Algar et al. 2013; Silcock and Fensham 2013; Moseby et al. 2016), this was judged to be a suitable timeframe.

To determine the benefits of different management strategies, experts were asked to compare the outcome of implementing each management strategy with the outcome of a counterfactual, or 'do nothing' approach at a specified management site (Steps 6 and 7). This approach helped isolate the specific impact of a management activity, a critical step toward

Table 1 Summary of the possible threats to Night Parrots, the likely management strategy to abate that threat, and specific actions typically required to complete that management strategy. Specific actions were collated following consultation with experts

Likely threat to Night Parrots	Management strategies	Specific actions
Predation by cats	*Generic cat control*: reduce cat numbers through occasional shooting, and/or trapping and humane removal of cats (see e.g. Fisher et al. 2015, Bengsen et al. 2020), supported by seasonal aerial and ground baiting (see e.g. Algar et al. 2013, Comer et al. 2020).	- Plan and coordinate ongoing baiting program, including camera trap surveys to monitor cat activity in preparation for, during, and after control activities. - Aerial baiting program to be run once per year. - Ground baiting program to be run at least once per year. - Opportune shooting and trapping.
Predation by cats	*Intensive cat control*: reduce numbers of cats through employment of expert Indigenous hunters to humanely remove cats (see e.g. Paltridge et al. 2020), and permanent grooming traps (see e.g. Moseby et al. 2020).	- Installation, operation, and maintenance of four Felixer grooming traps to target cats around known long-term stable Night Parrot roost sites. - Employment of six Indigenous hunters and a coordinator/ecologist to conduct monthly cat hunting activities.
Predation by foxes	*Fox control*: reduce numbers of foxes through seasonal aerial and ground baiting, supported by occasional shooting and/or trapping and humane removal of foxes (see e.g. Thomson et al. 2000, Burrows et al. 2003, Bengsen et al. 2020).	- Plan and coordinate ongoing baiting program, including camera trap surveys to monitor fox activity in preparation for, during, and after control activities. - Aerial baiting program to be run once per year. - Ground baiting program to be run at least once per year.
Inappropriate fire regimes	*Fire management*: improve or maintain availability of suitable roosting habitat through a mosaic burning approach tailored for Night Parrots. Using both airborne and ground-based approaches, break up contiguous areas of *Triodia*, protect long-unburnt patches, and encourage a variety of *Triodia* age classes (see e.g. Kelly et al. 2015, Legge et al. 2015).	- Create detailed fire history and update annually to inform management of *Triodia* patches. - Detailed annual monitoring and mapping of long-term stable Night Parrot roost sites. - Establish firebreaks as informed by mapping. - Conduct one day of aerial burning annually. - Conduct three days of ground-based burning by ground crews annually.
Land degradation	*Restoration of degraded land*: improve the overall quality of the available habitat matrix by managing the threatening processes known to impact the arid zone (see e.g. Morton 1990, McKenzie et al. 2007). Strategies include reduction or cessation of grazing by domestic stock, improved burning regimes, and reduced dingo persecution.	- Establish and maintain boundary and internal tracks, standard fencing appropriate for excluding cattle on reserve boundary, and waterpoint infrastructure. - General fire management to reduce large fires, including fire mapping, establishing fire breaks, aerial burning once per year, and ground-based burning once per year.

Table 1 (continued)

Likely threat to Night Parrots	Management strategies	Specific actions
Habitat destruction	*Protect existing habitat*: where suitable habitat exists, designate site as a protected area and manage appropriately, including fencing to exclude stock, general fire and grazing management (not necessarily tailored for Night Parrots), and reduced dingo persecution (see e.g. Watson et al. 2014, Kearney et al. 2020).	- Purchase of land, including negotiations. - Employ rangers to manage reserve. - Remove internal fences, wells and other pastoral infrastructure as required. - Establish ranger station on reserve. - Acquire vehicles to manage reserve. - Ongoing maintenance of access and facilities. -Annual management and planning activities. * *Note* – following activities same as for *'Restoration of degraded land'*. -Establish and maintain boundary and internal tracks, standard fencing appropriate for excluding cattle on reserve boundary, and waterpoint infrastructure. -General fire management to reduce large fires, including fire mapping, establishing fire breaks, aerial burning once per year, and ground-based burning once per year.

understanding the future benefits of management (Maron et al. 2013). To compare the relative benefits of protecting already existing sites and restoring degraded but potential sites, two hypothetical management sites were described; an 'intact' site, and a 'degraded' site. The 'intact' site was a 100 000 ha cattle grazing property containing an appropriate matrix of both *Triodia* roosting habitat and floodplain herb-field feeding habitat, with low grazing pressure and minimal other disturbance, and with a baseline of two long-term stable Night Parrot roost sites. The 'degraded' site was a 100 000 ha cattle grazing property containing the appropriate matrix of both *Triodia* roosting habitat and floodplain herb-field feeding habitat, but which is subject to heavy disturbance via intense grazing and excessive fire, and with no recent records of Night Parrot roosting or breeding, although Night Parrots do occur on an adjacent property. These sites are subsequently referred to as the 'intact' and 'degraded' sites.

The project team and key informants next developed an expert elicitation survey including a series of questions asking experts to estimate the impact of the selected management strategies on both the 'intact' and 'degraded' sites (Step 8) (Table 2). Given a hypothetical management site and specified management strategy, experts were asked "how many long-term stable Night Parrot roost sites will be present, excluding any additional impacts from mining, agriculture, road or urban development that may occur over the next 20 years?" Additional impacts were excluded to ensure benefits directly from the action were estimated. Responses were requested using the four-step question format (Speirs-Bridge et al. 2010), providing a (i) lowest plausible estimate, (ii) highest plausible estimate, (iii) best guess, and (iv) confidence that the true value is between the lowest and highest plausible estimates (50–100%). Whole-number responses were requested.

Table 2 Experts were asked to estimate the impact of the following management strategies on the Night Parrot population at two hypothetical management sites

Question	Hypothetical site	Management strategy
1	Intact Night Parrot habitat	**Counterfactual 'do nothing'.**
2	Intact Night Parrot habitat	**Protect existing habitat** through designation as a protected area, accompanied by general fire and grazing management (not tailored to suit Night Parrot), erecting new fencing and removing redundant fencing, and minimising dingo persecution. No Night Parrot specific management will be implemented.
3	Intact Night Parrot habitat	**Generic cat control** involving aerial and ground baiting, and occasional shooting and trapping.
4*	Intact Night Parrot habitat	**Intensive cat control** using Indigenous hunters and grooming traps.
5	Intact Night Parrot habitat	**Fox control** involving aerial and ground baiting, and occasional shooting and trapping.
6	Intact Night Parrot habitat	**Fire management** tailored to suit Night Parrot.
7	Intact Night Parrot habitat	**Combined strategies**: generic cat control, fox control, fire management.
8	Intact Night Parrot habitat	**Protect existing habitat and combined strategies**: protect existing habitat, generic cat control, fox control, fire management.
9	Degraded, potential Night Parrot habitat	**Counterfactual 'do nothing'.**
10	Degraded, potential Night Parrot habitat	**Protect and restore degraded land** using same strategies as specified above under 'Protect existing habitat'.
11	Degraded, potential Night Parrot habitat	**Protect and restore degraded land and combined strategies**: generic cat control, fox control, fire management

* Question only included in second round of expert elicitation

Conduct of expert elicitation process

Once the survey format was finalised, potential participants for the expert elicitation were sought based on their work with the Night Parrot or other similar threatened species occupying similar habitats, and relevant knowledge of threatening processes and how these can be managed (Step 9). More than 30 scientists and land managers were invited to participate in the elicitation including representatives from academic institutions, state government, environmental consultants, industry, and Indigenous ranger groups. Ultimately, 12 experts agreed to participate in the expert elicitation process, which included the two key informants. Aside from the two key informants, six experts had previous exposure to on-ground management of known Night Parrot populations through either management roles, membership of the Night Parrot Recovery Team, or both (AHB, STG, AK, RPK, JuR, AWTW). Remaining experts had experience in Night Parrot research and survey, but no direct exposure to the on-ground management of known Night Parrots populations (MB, RAD, JoR). Despite this relatively limited pool of Night Parrot specific expertise, research has shown that including a broader range of experts with varying degrees of expertise results in more accurate estimates than relying solely on highly experienced experts (Burgman et al. 2011a; Hemming et al. 2018b). In addition to experience in the research and management of Night Parrots, the experts held a wide range of research and practical experience in other relevant fields, including but not limited to: botany, threatened species conservation, fire management, invasive species management, development and implementation of conservation policy, and the involvement of industry in conservation and management.

An inception meeting was conducted with the expert participants via teleconference. The purpose of this meeting was to establish a rapport with the experts, and explain the context, rationale, and requirements of the elicitation process (Hemming et al. 2018a). Following this inception meeting, a tailored spreadsheet containing the expert elicitation survey was circulated to experts via email. The spreadsheet included data validation coding to ensure that the 'best' estimates occurred between the low and high estimates, and that confidence intervals were specified correctly. Experts were asked to complete this 'Investigate' phase of the IDEA process by individually answering each question and providing reasons for their estimates. For this step, experts were provided access to a shared online library containing relevant literature that had been compiled during preparation for the elicitation process. To ensure this first round of elicitation was independent, experts were requested not to consult with each other about their answers, reducing common biases associated with expert elicitation (Hemming et al. 2018a).

The results of this first round of elicitation were compiled and the data from each expert cleaned and standardised to 90% confidence intervals, then summarised using an equal weighted group average for each statistic – best estimate, upper estimate, and lower estimate (Armstrong 2001; Hemming et al. 2018a, b). One expert with field experience of Night Parrots across two states provided two separate responses for Western Australian and Queensland sub-populations of the Night Parrot; these were treated separately in the analyses, meaning 13 responses were received in total.

In preparation for the 'Discuss' phase, an anonymised version of the first-round results, including expert comments, was circulated to all experts. A discussion was then conducted via teleconference with all experts. The results of the 'Investigate' phase were reviewed, with particular focus on questions with significant variation among responses. Experts discussed differing views around each management strategy and their potential impact on Night Parrots, and also clarified any uncertainties in the questions or scenarios. During these discussions, the experts decided to include an additional management strategy that involved intensive methods of cat control. As a result of these discussions, the wording of some questions was slightly modified to ensure clarity and consistency of understanding among experts.

A record of the ‘Discuss’ phase was provided to each expert, before all were asked to provide a second, final round of responses as part of the ‘Estimate’ phase. Eleven experts participated in this second round of expert elicitation; only these responses were included in the final aggregation. As part of the final ‘Aggregate’ phase, estimates from the final round were compiled and analysed using the same process from the first round of questioning, this time with 12 responses in total.

The benefit of each management strategy was evaluated by calculating the difference between the average estimated number of long-term stable roosts gained over the 20-year timeframe as a result of the management strategy, and the average estimated number of long-term stable roosts gained over the 20-year timeframe under the counterfactual ‘do nothing’ scenario (Maron et al. 2021). Averages were taken across all experts, with experts evenly weighted. The estimated minimum and maximum plausible number of roosts gained for each management strategy were also calculated. The minimum benefit was the difference between the average minimum outcome for the management strategy and the average maximum outcome for the counterfactual ‘do nothing’ scenario, representing the overall benefit if the worst outcome from the management actions, and best outcomes from the ‘do nothing’ scenario were true. Similarly, the maximum benefit was the difference between the average maximum outcome for the management strategy and the average minimum outcome for the counterfactual ‘do nothing’ scenario, representing the overall benefit if the best outcome from the management actions, and worst outcomes from the ‘do nothing’ scenario were true. Results are reported below as (estimated number of long-term stable roosts gained as a result of management [minimum - maximum]).

Cost-effectiveness of management strategies

We applied standardised methods (Iacona et al. 2018; Carwardine et al. 2019) to estimate costs per hectare of performing the management strategies. The team for this part of the project (JCW, SS, TN, MM) interviewed experts from government, non-government, and Indigenous conservation organisations with experience delivering these management strategies for the Night Parrot or co-occurring threatened species that required similar actions. In consultation with these experts, a series of specific actions involved in each management strategy were identified, assuming best-practice methods that aligned with the hypothetical site scenario and defined management strategies (Table 1). For example, ‘intensive cat control’ assumed Indigenous hunters were very experienced cat trackers, familiar with the local environment, and with demonstrated ability to perform their role, while grooming traps were placed in optimum locations and worked as expected. Experts were asked to estimate the cost, including a best guess, minimum, and maximum cost, for each specific action, referring to past budgets for real projects if possible. This included start-up costs and ongoing annual operational costs for labour, equipment, consumables and overheads involved in the planning, implementation, and monitoring aspects of each strategy (Maron et al. 2021).

All cost estimates from both the interviews and additional sources were collated, converted to a cost per hectare, and adjusted for the hypothetical management scenarios so they represented the cost of managing a 100 000 ha site over a 20-year timeframe. To allow comparison of the costs of each management strategy over the 20-year timeframe, all future costs were converted to a present value using a discount rate of 5% (Carwardine et al. 2019). To compare the cost-effectiveness between management strategies, the cost of each action required to gain a single long-term stable Night Parrot roost was calculated by dividing the total cost of the management strategy by the number of Night Parrot roosts that experts estimated would be added because of the management strategy. To calculate the maximum cost estimate, the average cost was divided by the minimum number of Night Parrot roosts gained as a result of the management strategy. Similarly, the minimum cost estimate was calculated by dividing the average cost by the maximum number of Night Parrot roosts gained as a result of the management strategy.

Results

Effectiveness of management strategies

The results from the first round of elicitation showed general agreement among experts regarding the trajectory of the population under the counterfactual 'do nothing' scenario, and the relative benefit of the different management strategies. However, there was wide uncertainty around the outcomes of each action. Following discussion of the first-round results and completion of the second round of elicitation, there was no change in the ranking of management strategies according to their relative benefit, but the uncertainty bounds were smaller, as presented below.

For the 'intact' site, experts believed that the counterfactual 'do nothing' scenario would result in a slight decrease in the average number of long-term stable Night Parrot roost sites over the 20-year timeframe, from 2.0 to 1.9, (1.9 [0.2–6.8]). While all the management strategies at the 'intact' site resulted in some improvement relative to the counterfactual 'do nothing' scenario, the uncertainty around the estimated benefits was high; experts thought that declines were still possible, even with the most effective management strategies (Fig. 2).

At the 'intact' site, the greatest benefit was expected from the combination of protecting habitat, generic cat control and fox control, and fire management. This resulted in an estimated increase of 5.5 [-6.1–13.6] additional long-term stable roost sites over 20 years compared with the counterfactual 'do nothing' scenario. Intensive management of cats using grooming traps and involving expert Indigenous hunters was the most beneficial single management strategy, resulting in an estimated 3.4 [-6.2–11.2] additional long-term stable roost sites over 20 years. Cat management using generic techniques such as aerial and ground baiting, and occasional trapping and shooting, resulted in an estimated 2.6 [-6.4–10.4] additional long-term stable roost sites over 20 years. The management strategy providing the least benefit was fox control, resulting in an estimated increase of 0.6 [-6.7–7.0] additional long-term stable roost sites over 20 years. Several experts raised concerns that fox or dog control via baiting could potentially have adverse effects on Dingo (*Canis dingo*) populations, which in turn could increase cat predation of Night Parrots via mesopredator release (Allen et al. 2011). Several experts also pointed out in their comments that fine-scale mapping of Night Parrot habitat would be an important requirement to maximise the impact of any of the management strategies.

For the 'degraded' site, experts believed that the counterfactual 'do nothing' scenario would result, on average, in no long-term stable Night Parrot roost sites being established over the 20-year timeframe (0.0 [0.0–1.6]). Both management strategies assessed for the 'degraded' site resulted in some improvement relative to this counterfactual 'do nothing'

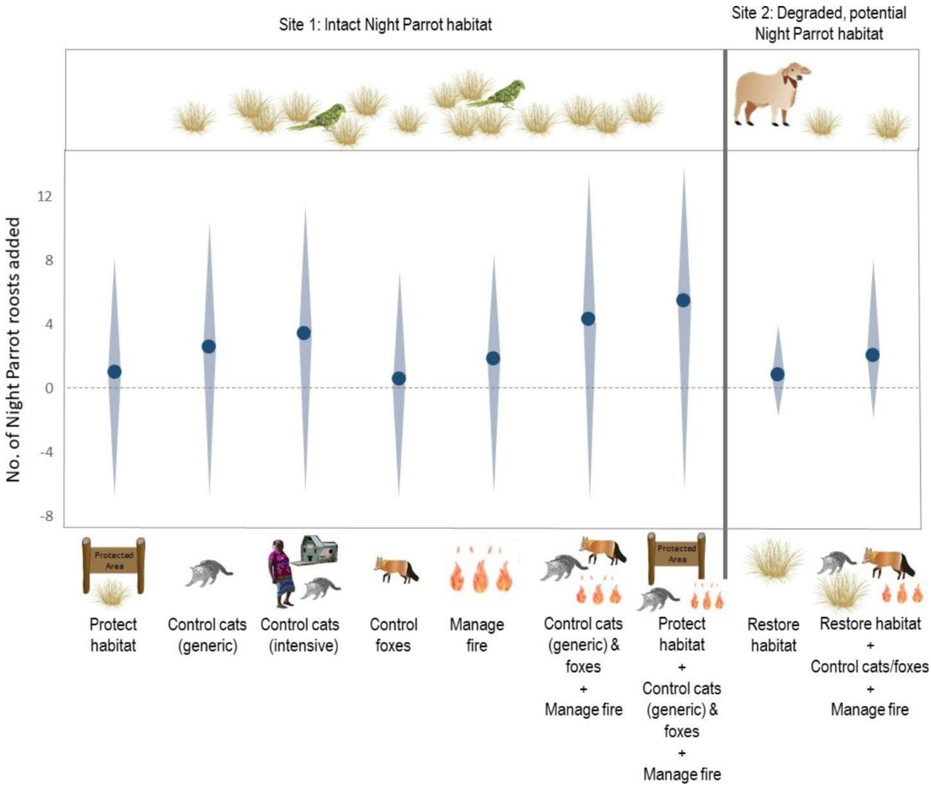

Fig. 2 The average estimated number of long-term stable Night Parrot roost sites gained after applying the specific management strategies, or combinations of strategies, over the 20-year timeframe

scenario, but this was minimal. Even for the management strategy that provided the greatest benefit – the combined strategy of protecting and restoring the degraded land coupled with generic cat control, fox control and fire management – the estimated increase in the number of additional long-term stable roost sites over 20 years was only 2.1 [-1.6–8.2], compared to the counterfactual 'do nothing' scenario. Several experts stated in their comments that the Night Parrot's requirement for long-unburnt *Triodia* (i.e. >30 years since last fire) and uncertainty about the timeframe required to establish such habitat, meant the 20-year timeframe was unlikely to be enough time to establish habitat suitable for Night Parrots.

Cost-effectiveness of management strategies

Based on the cost data collected from experts (Appendix S1), the cheapest interventions were intensive cat control by expert Indigenous hunters and using grooming traps, and fire management. Generic cat control was much more expensive than intensive cat control, largely due to the ongoing costs associated with aerial baiting. A cat control regime focused on shooting and trapping would probably be more comparable in cost to the intensive cat control strategy assessed here. The most expensive were the combined strategies, with the establishment of infrastructure associated with protecting an area, and aerial baiting associated with ongoing cat and fox management being the significant contributors to the overall cost. As with expert estimates for the effectiveness of management strategies, estimates for the costs of those strategies were highly variable, given uncertainty around site condition, location and intensity of management required for these hypothetical sites. For example, the average estimated cost of habitat protection combined with cat control, fox control, and fire management, was $4.5 million annually over 20 years for the 100 000 ha 'intact' site, but estimates ranged from $1.2–7.9 million per year.

After converting costs of management to an annual cost per additional Night Parrot roost, the most cost-effective interventions were intensive cat control by Indigenous hunters and using grooming traps, and fire management (Fig. 3). Fox control and habitat protection were both costly relative to the expected benefit. Restoring 'degraded' sites was much less cost-effective on average than most strategies at 'intact' sites, due to smaller gains in the number of roosting sites. As with the estimates for benefits, uncertainty was high. Because the minimum estimates for even the most beneficial management strategies could still result in fewer roosts compared to the counterfactual 'do nothing' scenario (i.e. a negative benefit value), the upper cost estimate per roost site gained for each management strategy was undefined.

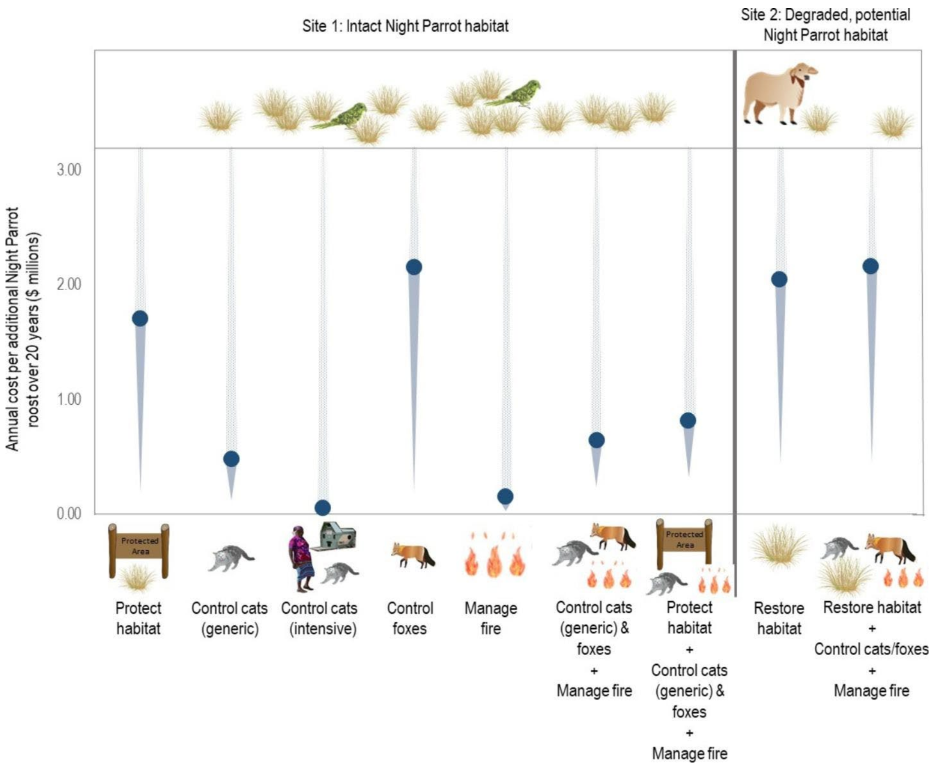

Fig. 3 The estimated annual cost per additional long-term stable Night Parrot roost gained after applying the specified management strategy, or combination of strategies, over the 20-year timeframe, compared to the counterfactual 'do nothing' scenario. Standardising the costs in this way allows the cost-effectiveness of each action to be compared directly. Because the worst-case scenario under each management strategy could result in fewer roosts compared to the baseline scenario, the maximum cost estimate per roost for each management strategy is undefined

Discussion

Field research on the Night Parrot has only been possible since 2013. Because the species is extremely cryptic and genuinely rare, obtaining data and knowledge required to confidently implement conservation management strategies will take years, and probably decades. Confronted with uncertainty around the outcomes of management, an expert elicitation approach has allowed a first approximation of the strategies most likely to benefit the Night Parrot in the short and long term, and their cost-effectiveness. The approach used here could be applied to determine an initial set of conservation strategies for other poorly known threatened species that need immediate conservation attention, and a working hypothesis of their relative benefits.

Immediate priorities for night parrot management

The Night Parrot's decline coincided with the decline and extinction of much of arid Australia's small to mid-sized mammal fauna, with which, as a largely ground-dwelling species, the Night Parrot shares many ecological similarities (Short and Smith 1994; Murphy et al. 2018; Leseberg et al. 2021a). The conceptual model used to explain these declines posits that habitat degradation and competition with increased numbers of introduced and native herbivores, along with changed fire regimes, reduced the amount of ground cover, and therefore habitat, available (Morton 1990; Woinarski et al. 2015). The subsequent spread of introduced carnivores, sustained by high numbers of rabbits, and possibly aided by the persecution of Dingoes, forced the local extinction of many small to mid-sized mammals (Burbidge and McKenzie 1989; Smith and Quin 1996; McKenzie et al. 2007). It is unsurprising that the management strategies judged to be most successful for the Night Parrot are the same as those known to be effective for most, if not all, threatened fauna of arid central Australia: namely, protection of habitat from introduced herbivores, control of feral predators, and appropriate management of fire (Kearney et al. 2019).

Long term conservation of the night parrot

Perhaps the most important finding of this research is that attempting to restore degraded Night Parrot habitat was thought to be the least effective and most expensive conservation option. This finding relates to the Night Parrot's ecology, and requirement for long-unburnt *Triodia* to support long-term stable roost sites. At Pullen Pullen Special Wildlife Reserve (SWR) and at two sites where Night Parrots have been found in central Western Australia, the long-unburnt *Triodia* where long-term stable roost sites were established is at least 50 years old (S. Murphy, A. Burbidge unpub. data). While rainfall and site factors will determine how quickly areas of recently burnt *Triodia* develop the size and structural complexity required to support Night Parrots, experts agreed that at a typical site, this timeframe will be in the order of decades. Research on other *Triodia* dependent arid and semi-arid zone species supports this conclusion (Moseby et al. 2016; Verdon et al. 2019). It is possible that consideration of management impacts over a timeframe longer than 20 years, for example 30 or 50 years, may have provided further clarity on the impact of changed fire management. However, given the uncertainty around the response of *Triodia* to fire management and the probable importance of site-specific factors, it is unlikely this would significantly change the conclusions reached here.

While roosting habitat is critically important for the Night Parrot, mobile granivorous species in particular also require a complex interplay of nesting and feeding resources that changes with variation in weather patterns, and can disappear from landscapes that seem to be superficially intact (Bolton et al. 2018). It follows that the effective restoration of habitat for such species requires more than just restoration of the outwardly apparent structural elements such as tree or ground cover (Belder et al. 2018); it requires both the removal of threats and reconstruction of habitat to a more complete previous state. This can be achieved at the landscape-scale within a permissive management environment (see e.g. Legge et al. 2015). However, there is increasing evidence that under current policy settings and funding regimes it is now very difficult to achieve the ambitious and expensive restoration of destroyed or degraded habitat required to meet national threatened species conservation objectives (Reside et al. 2019; Collard et al. 2020). The responses of the experts consulted here confirm that successful restoration of ecologically relevant areas of degraded Night Parrot habitat will be equally challenging. This does not mean that attempts to rehabilitate marginal habitat will not be beneficial for the Night Parrot in the long term. Rather, it portends a prolonged and precarious path to recovery if restoring degraded habitat becomes the primary approach.

This finding has particular consequences for how conservation policy is implemented for the Night Parrot. Of particular concern is the implementation of biodiversity offset policies. Broadly, biodiversity offsetting is the process whereby a loss of biodiversity due to the impact of some activity, for example the clearing of habitat in preparation for a mining project, is ‘offset’ by generating ecologically equivalent gains elsewhere (Maron et al. 2012). This could take the form of restoring an equivalent area of land somewhere else. The ultimate goal of biodiversity offsetting is to achieve no net loss of biodiversity; however, a known problem with the concept is the often unrealistically long timeframes required for no net loss to be achieved (Bekessy et al. 2010; Gibbons et al. 2018). For Night Parrots, restoration of potential habitat as part of an offset strategy is likely to be extremely expensive, with outcomes highly uncertain, and potentially impossible over any meaningful timeframe. Further, multiple uncoordinated site-based interventions that rely on habitat restoration to offset the destruction of known Night Parrot habitat could inadvertently lead to extensive habitat loss, and population declines that will be very difficult to reverse.

Limitations of expert elicitation

The Night Parrot occurs across a wide area, and in situations with a variety of management approaches possible. To cover the gamut of these possible conservation circumstances, the scenarios and management strategies assessed here were relatively broad. Care should be taken when interpreting these results for application in specific situations. A good example is the management of Night Parrots at Pullen Pullen SWR in western Queensland, currently the only location where specific on-ground conservation for Night Parrot occurs. Pullen Pullen SWR is dominated by rocky substrates, and there is not currently an Indigenous ranger capability with the expertise necessary to track cats in that specific landscape. If implemented literally on Pullen Pullen SWR, the intensive cat control strategy assessed in this research would probably not produce the same results as predicted by the experts here.

Similarly, fire is suppressed on Pullen Pullen SWR because patches of *Triodia* are naturally isolated by bare rocky areas with no fuel (Murphy et al. 2018). For that reason, targeted fire management may not produce the same benefit on Pullen Pullen SWR as it could at sites where Night Parrots have been found in Western Australia, where the *Triodia* is more contiguous and fire represents a greater risk (Jackett et al. 2017). These site-specific differences do not negate the results of this research. Instead, they reinforce the need to either: carefully interpret the results of expert elicitation when applying general conclusions in specific scenarios; or, ensure scenarios and management strategies put to experts in similar expert elicitations are tailored to accurately reflect the specific site characteristics and management strategies available.

Critical to the ability of the expert elicitation process to minimise bias is diversity in the panel of experts (Burgman et al. 2011a). Given the Night Parrot's relatively recent rediscovery and the limited scope for direct exposure to Night Parrot research, there are relatively few Night Parrot experts. For this exercise though, equally as important as expertise in Night Parrots was knowledge of the different threatening processes affecting arid zone species, and experience managing them. This does introduce the possibility of bias, with most experts used in this elicitation to some degree involved with the development and delivery of the specific management options considered here. The diversity of additional experience held within the group, and outlined earlier, does help overcome this (Burgman et al. 2011a; Hemming et al. 2018b).

Ultimately, expert elicitation should only provide a starting point for management. The scenarios outlined here are relatively general, and do not capture the nuance or detail that will influence management at specific sites. Similarly, the costs data compiled here are only a guide to the relative costs of the specific management actions; their magnitude and perhaps even their relative benefits are likely to differ among sites. The next step should be implementing an adaptive management approach to on-ground management that empirically tests the results of this research. Assessing and refining management based on actual outcomes rather than expert opinion is likely to improve conservation outcomes for the Night Parrot (Salafsky et al. 2001; Scheele et al. 2018).

Several recent discoveries of Night Parrots have been made by Indigenous ranger groups on the Indigenous Estate (see e.g. Mills and Collins 2017, Collins 2021). The locations of these discoveries indicate that a significant proportion of the Night Parrot's total population will occur on land under Indigenous ownership, management and co-management (Leseberg et al. 2021a). While some Indigenous Knowledge of the Night Parrot and its preferred habitat has been lost (Collins 2021), it is becoming increasingly clear that much still exists (Jones 2019, D. Johanson and R. Paltridge pers. comm.). Capturing this specific knowledge, and Indigenous Ecological Knowledge (IEK) more broadly, could provide important insights for management of the Night Parrot.

Attempts to incorporate IEK into this research were limited for several reasons. First, the knowledge that Night Parrots mostly occur on the Indigenous Estate in Western Australia, where IEK remains relatively intact, only emerged part way through this project. In contrast, IEK from Queensland Night Parrot country is highly fractured as a result of the early dispossession of people in those regions (Watson 1998). Second, we acknowledge the methods used in this project for disseminating and collecting data were developed by, and specifically for, researchers familiar with western science; they are largely unsuited to engaging with the Indigenous people who possess detailed knowledge of Night Parrot ecology and landscapes. These senior IEK holders, for whom English may not be their first language, often live in remote communities where communication services are limited. Further, the interviews and group discussions involved people whom senior Indigenous Knowledge holders are unlikely to have ever met, meaning a sense of trust and shared understanding has not been established (Woodward et al. 2020).

Incorporating IEK typically requires unhurried, face-to-face interviews, preferably conducted by people with genuine connections and relationships to people in communities (see e.g. Thomson 1962, Burbidge et al. 1988, Woodward et al. 2020). Also required is the consent of the knowledge holders which is established over time. The scope and timeframe of our project did not permit this, but we acknowledge that the overall objective of setting priorities for Night Parrot management would benefit greatly by adopting a two-way, right-way approach. Finally, we also acknowledge the need for initiatives that promote Indigenous-led management of the Indigenous Estate. If expert elicitation to inform management on Indigenous-managed land is conducted in collaboration with Indigenous-led management rather than in isolation from it, successful integration that sustains the ongoing stewardship of Country, including species like the Night Parrot, is more likely (Woodward et al. 2020).

Implications for other species and wider ecosystem management

This process targeted the Night Parrot and did not consider the costs or benefits of the specified management strategies to other species, or at the landscape scale. Although complex, it is often more cost-effective to manage for multiple threatened species (Lindenmayer et al. 2018). The threats to the Night Parrot are apparently similar to those that have affected many of arid central Australia's small to mid-sized mammals (McKenzie et al. 2007), so while the overall cost of managing those threats for the Night Parrot may seem high, that high cost is mitigated by the likely benefit to a suite of species (Kearney et al. 2019; Ward et al. 2021). Recent discoveries demonstrate that where the Night Parrot has been found, it often co-occurs with other threatened species, such as the Greater Bilby (*Macrotis lagotis*), Kowari (*Dasyuroides byrnei*), and Great Desert Skink (*Egernia kintorei*), species that share threatening processes with the Night Parrot and are likely to benefit from similar management actions (McAlpin 2001; Kearney et al. 2021; Leseberg et al. 2021a). This elicitation was focused solely on understanding the benefits and costs of managing the Night Parrot at the site scale, and did not consider the benefits of the selected management strategies on other species. If the aim of the elicitation process is to understand the costs and benefits of management to other species or at the landscape or regional scale, the scenarios should be tailored to help tease out these interactions. These costs and benefits to other species can then be accounted for when assessing the overall cost-effectiveness of that management (Chadés et al. 2015).

Appendix S1

Best, minimum, and maximum cost estimates for Night Parrot management strategies for a 100 000 ha area over 20-year management timeframe (average annual present value to nearest $AU1000, with discount rate of 5%)

Management strategy	Estimate	Minimum	Maximum
Protect existing habitat	$ 1 713 000	$ 915 000	$ 2 619 000
Generic cat control	$ 1 260 000	$ 54 000	$ 2 466 000
Intensive cat control	$ 183 000	$ 135 000	$ 246 000
Fox control	$ 1 260 000	$ 54 000	$ 2 465 000
Fire management	$ 284 000	$ 199 000	$ 368 000
Combined: generic cat control, fox control, fire management	$ 2 803 000	$ 308 000	$ 5 298 000
Protect existing habitat and combined: generic cat control, fox control, fire management	$ 4 516 000	$ 1 223 000	$ 7 917 000
Protect and restore degraded land	$ 1 713 000	$ 915 000	$ 2 619 000
Protect and restore degraded land and combined: generic cat control, fox control, fire management	$ 4 516 000	$ 1 223 000	$ 7 917 000

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Authors' contribution Martine Maron conceived the idea for this research. Martine Maron, Megan Evans, Tida Nou, Scott Spillias, Zoe Stone, Jessica Walsh, Nicholas Leseberg, and Stephen Murphy developed and undertook the expert elicitation approach which formed the basis of the manuscript. Nicholas Leseberg, Stephen Murphy, Mike Bamford, Allan Burbidge, Kate Crossing, Robert Davis, Stephen Garnett, Rod Kavanagh, Robert Murphy, John Read, Julian Reid, Stephen van Leeuwen, and Alexander Watson participated as experts. Nicholas Leseberg wrote the first draft of the manuscript. All other authors provided comments on the draft and approved the final manuscript.

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Declarations

Competing interests John Read is the CEO of the Thylation group of companies, which developed and supply the Felixer cat management tool.

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