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Risk aversion and uncertainty create a conundrum for planning recovery of a critically endangered species

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Abstract

Making transparent and rational decisions to manage threatened species in situations of high uncertainty is difficult. Managers must balance the optimism of successful intervention with the risk that intervention could make matters worse. We assessed nest protection options for regent honeyeaters (*Anthochaera phrygia*) in Australia. Formal expert elicitation highlighted two methods of nest protection expected to improve nest success. However, the risks and benefits of different actions were uncertain; for example, protecting nests from predators might also increase the risk of nest desertion by adults. To avoid risks, the recovery team opted to collect more information before implementation. The two methods of nest protection were compared using a field experiment. However, the same risk aversion limited the experiment to a single variable (nest predation) and dictated the use of artificial nests. The results of the experiment suggested neither action was likely to significantly reduce predation risks (<3% mean differences in survival between treatment and control). When presented with these results, managers made only minor revisions to their estimates; in part, this reflected low confidence by managers that artificial nests could reflect real predation risks. However, estimates were also revised more negatively for the initially less-favored option, despite absence of such evidence, possibly highlighting confirmation bias. In this uncertain situation, the status quo was initially maintained although it was perceived as suboptimal; implementation of the preferred option (tree collars) is now planned for the 2019 breeding season. We faced what might be a common conundrum for conservation of critically endangered species. High uncertainty affects management decisions; however, perilous species status also leads to strong risk aversion, which limits both the willingness to act on limited information and the ability to learn effectively. Structured methods can increase transparency, facilitate evaluation, and assist decision making, but objective limitations and subjective attitudes cannot be circumvented entirely.

Stefano Canessa and Gemma Taylor contributed equally to this work.

KEYWORDS
cognitive bias, decision tree, expert elicitation, nest success, predator control, reintroduction, value of information

1 | INTRODUCTION

Critically endangered species commonly require ongoing intensive management to support recovery of their populations in the wild. Such ongoing management can include predator control (Major, Ashcroft, & Davis, 2015), provision of breeding/nesting sites (Libois et al., 2012), supplementary feeding (Ewen, Walker, Canessa, & Groombridge, 2014), and nest protection (Homberger, Duplain, Jenny, & Jenni, 2017). Ideally, these management actions would be chosen based on a priori hypotheses and empirical evidence of the factors limiting population growth. However, such empirical evidence is rarely available for most threatened species, and in any event, knowing what needs to be addressed does not equate to knowing how to best address it. Uncertainty is especially paralyzing for management decisions when it leads to risk, whereby choosing the wrong action could make things worse. For example, removing introduced predators may help recover target species, but also trigger damaging trophic cascades (Bergstrom et al., 2009); ambitious translocation programs might successfully restore populations, but they can introduce new risk factors such as diseases (Sainsbury & Vaughan-Higgins, 2012).

In the face of such uncertainty, and dealing with endangered species with small margin for errors, conservation practitioners are often risk averse (Tulloch et al., 2015). Risk aversion is a subjective attitude whereby someone facing two options with similar average outcomes prefers the one with lower risk, that is, the option with the smallest chance of an especially negative outcome (Pratt, 1964). In conservation decisions, risk aversion might be compounded by the common practice of engaging experts to choose and implement what they believe is the best management solution, based on intuition (Armstrong & Ewen, 2002). While this approach can achieve positive on-ground outcomes, management based on intuition means our response to uncertain and risky outcomes is poorly defined, lacks transparency, and is not structured to allow monitoring of uncertainties to improve our choices over time. Management based on intuition has been criticized as resulting in dogmatic approaches to conservation (Martínez-Abraín & Oro, 2013).

Science can assist in these cases by providing more information to reduce uncertainty and helping managers in making decisions with imperfect knowledge. Increasingly, conservation scientists apply structured elicitation of expert knowledge (Martin et al., 2012), experimental studies of prospective actions (Armstrong, Castro, & Griffiths, 2007), strategic monitoring of management outcomes (Nichols & Williams, 2006), and decision-support methods (McCarthy, 2014). However, threatened species remain difficult subjects because of their precarious nature.

Methods of nest protection are a typical example of conservation decisions that entail uncertainty and risk. Successful protection of eggs and nestlings from predators using some form of exclusion barrier has been achieved in shorebirds (Isaksson, Wallander, & Larsson, 2007), giant ibis *Thaumatibis gigantea* (Keo, Collar, & Sutherland, 2009) and passerines (Major et al., 2015). However, unexpected negative outcomes have also been reported, such as increased predation on nesting adults (Isaksson et al., 2007) and nest abandonment (Cohen et al., 2016). The potential for either positive or negative outcomes from nest protection can therefore make it difficult to choose the best management alternative.

In this study, we applied analytical and decision-support methods to assess nest management alternatives in a reintroduced population of the critically endangered regent honeyeater (*Anthochaera phrygia*) in south-eastern Australia. We used formal expert elicitation, a decision tree, and a field experiment to clarify uncertainty about poor breeding success and evaluate practical solutions. Despite technically succeeding, our plan encountered difficulties that highlight how uncertainty and subjective risk attitudes create a challenging conundrum for conservation scientists and managers.

2 | METHODS

2.1 | Background and problem setting

The regent honeyeater is a passerine species endemic to south-eastern Australia classified as Critically Endangered in the IUCN Red List (IUCN 2018). Once common and widely distributed, the wild population is now estimated at a maximum 400 birds (Kvistad, Ingwersen, Pavlova, Bull, & Sunnucks, 2015). We studied the remnant population found in the Chiltern Mt-Pilot National Park, northern Victoria, which has been the focus of a captive-breeding and reinforcement program including four releases of birds since 2010 (Liu, Gillespie, Atchison, & Andrew, 2014).

The regent honeyeater recovery team sought to maximize the viability of the reinforced population at Chiltern Mt-Pilot National Park. Postrelease survival, at least in the short term, has been high (Taylor et al., unpublished data), but breeding success has been poor, with high levels of nest predation by avian and mammalian species including threatened native predators such as squirrel gliders (*Petaurus norfolcensis*) (Taylor et al., 2018). Causes of poor nest success mirror result in the remnant wild population in New South Wales (Crates et al., 2018). Therefore, for this study we defined a fundamental objective of maximizing nest success in the population.

In late 2016, we presented a summary of all available, published and unpublished data on captive-bred and released regent honeyeater nest success to a team of seven species experts, including coauthors RC and DI, and additional past and current members of the recovery team or close collaborators from the Australian National University, NSW government (Office of Environment and Heritage) and The University of New England. We asked the experts to consider information on the causes of nest failure and to suggest possible management actions to overcome them, reflecting known or perceived threats such as the attraction of predators to nests and/or nest abandonment by breeding adults that might be caused by interventions. The option to remove predators was dismissed because most are native, including some threatened species (such as squirrel gliders). Three potential actions were selected: the fitting of tree collars to reduce predator access to nests, the addition of a nest cage to further protect nests in collared trees, and supplementary feeding to boost the capacity of breeding adults to successfully raise young.

2.2 | Articulating initial uncertainty

We represented our decision problem using a decision tree (Behn & Vaupel, 1982; Figure 1). The decision tree started with a decision node with one branch for each action suggested by managers (protect nests with a collar and cage, protect nests with only a collar, supplementary feed breeding pairs) and one under which no nest management is carried out. Each decision branch was followed by the same series of chance nodes describing potential negative events with the associated probabilities: probability that parents desert the nest, that the nest will be depredated, that nestlings would starve, and that nestlings would die for other reasons. Nests that survived all of these chance events would by definition be successful. For simplicity, here we do not include a combined strategy of feeding and nest protection, since later analyses predicted a marginal additive benefit of providing food supplements to breeding birds (see below).

We had limited empirical data about nest success, and no information available about effectiveness of the suggested actions. Therefore, we parameterized the decision tree by formalizing current expert judgement. We used a modified Delphi method over two rounds to elicit from our seven experts the probabilities for each chance

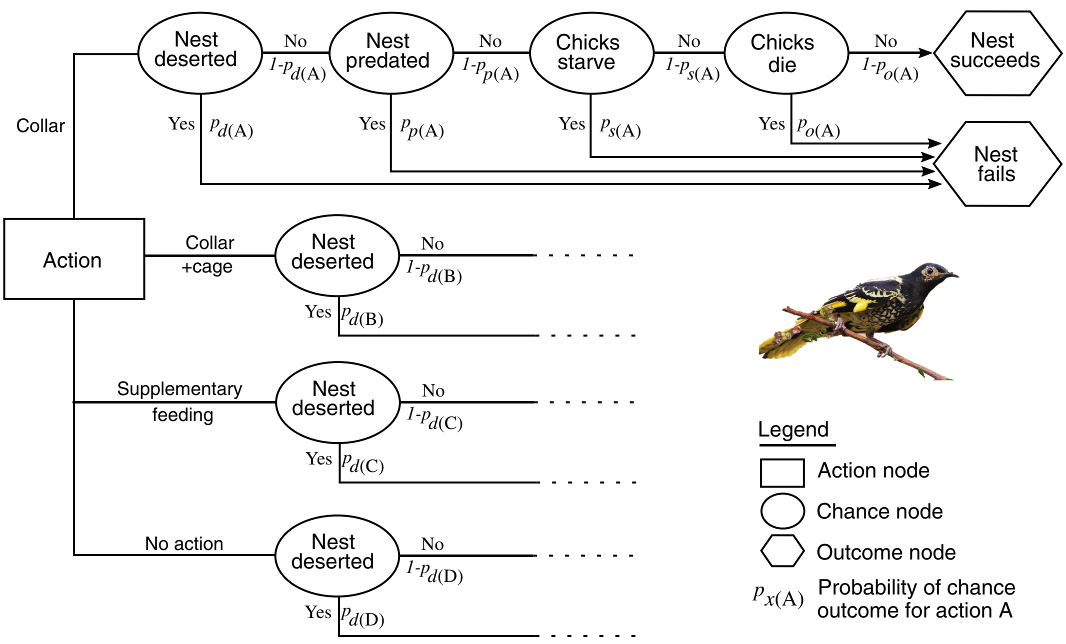

FIGURE 1 Decision tree showing the choices for implementing post-release management with the aim of improving breeding success. For clarity, only the first branch is shown in full; the other three mirror the first. Photo credit: D. Ingwersen

TABLE 1 Mean expert opinion values (best [minimum–maximum]) for each chance node in the decision tree for each of the four alternative actions, before and after the experiment (changes highlighted in bold)

	Collar	Collar + cage	Feeding	Status quo
Expert opinion on outcome of management				
Desertion	0.24 (0.14–0.35)	0.61 (0.44–0.81)	0.24 (0.14–0.35)	0.24 (0.14–0.35)
Predation	0.49 (0.31–0.75)	0.13 (0.07–0.38)	0.64 (0.48–0.84)	0.64 (0.48–0.84)
Starvation	0.28 (0.16–0.41)	0.28 (0.16–0.41)	0.17 (0.06–0.27)	0.28 (0.16–0.41)
Chicks die	0.18 (0.09–0.32)	0.18 (0.09–0.32)	0.18 (0.09–0.32)	0.18 (0.09–0.32)
Updated opinions on outcome of management after nest experiment				
Desertion	0.24 (0.14–0.35)	0.61 (0.44–0.81)	0.24 (0.14–0.35)	0.24 (0.14–0.35)
Predation	**0.51 (0.36–0.72)**	**0.38 (0.24–0.58)**	0.64 (0.46–0.84)	0.64 (0.46–0.84)
Starvation	0.28 (0.16–0.41)	0.28 (0.16–0.41)	0.17 (0.06–0.27)	0.28 (0.16–0.41)
Chicks die	0.18 (0.09–0.32)	0.18 (0.09–0.32)	0.18 (0.09–0.32)	0.18 (0.09–0.32)

node of the decision tree (following methods detailed in Davies et al., 2018). Before eliciting opinions, we provided the feedback received during development of the possible management actions to the experts to ensure they had the same set of background information. For each chance node, we elicited three values from each expert: the most likely value and the lowest and highest values such that the expert would be 100% confident that the true value would be found between those bounds. Estimates were then averaged to obtain a unique set of three values for each chance node to reflect uncertainty (Table 1).

We solved the decision tree using the DecisionTools Suite 7 (Palisade) add-in for MS Excel. For each chance node, we used the mean lowest, highest, and most likely probability values to define a beta-PERT distribution (Vose, 1996). We then drew a random value from each of these distributions and calculated the discrete outcome for each branch of the tree (nest success) as

$$p_{NS(A)} = \left(1-p_{d(A)}\right)\left(1-p_{p(A)}\right)\left(1-p_{s(A)}\right)\left(1-p_{o(A)}\right),$$

where $p_{NS(A)}$, the probability of nest success of action A, is the product of four probabilities: $(1 - p_{d(A)})$ is the probability that the nest will not be deserted, $(1 - p_{p(A)})$ is the probability that the nest will not be predated, $(1 - p_{s(A)})$ is the probability that nestlings will not starve, and $(1 - p_{o(A)})$ is the probability that nestlings will not die for other reasons. We repeated this calculation 10,000 times, using the Monte Carlo simulation function within DecisionTools, to generate a distribution of nest success outcomes for each action taking full account of uncertainty.

For each iteration, we recorded which action had the highest outcome, and calculated the expected value of perfect information (Runge, Converse, & Lyons, 2011) as the difference between the highest outcome in that iteration and the outcome of using the action with the highest elicited mean nest success. In other words, in a given iteration the value of information was the difference between the outcome of the action that we would choose if we knew which action was best, and the outcome of the action that we would choose under uncertainty. We also used a more general sensitivity analysis to assess how nest survival with no management changed across a 0–1 range for each of the chance node probabilities.

2.3 | Experimental validation of expert opinion

Our initial exploration of the decision tree (see Section 3), and the general opinion of the recovery team, suggested that additional information would be needed about nest protection strategies before a choice would be made. However, the recovery team also considered that an experimental intervention involving live birds would pose high risks of nest desertion that were deemed unacceptable unless a potential reduction in predation could be demonstrated beforehand. Therefore, we used artificial nests with eggs to experimentally quantify any changes in predation rates that would occur by using a cage or collar. We ran two experiments, one with collars and one with cages, within Chiltern-Mt Pilot National Park. The recovery team suggested collars and cages should be assessed separately in the field experiments to quantify their ability to stop, respectively, climbing predators and both climbing and flying predators. This evidence could then be used by experts to update beliefs on the effectiveness of the management strategies under consideration (either collar-only or cage-and-collar) and to allow assessment of a future possible new strategy (cages only; not considered further here).

The experiments used the same methods but were conducted sequentially (early and late autumn 2017, during the species' secondary breeding season) due to logistic constraints. In each experiment, we used artificial nests ($N = 40$ in cage experiment; $N = 48$ in collar experiment) consisting of wicker canary nests lined with coconut fiber on the inside and sphagnum moss on the outside. Each nest contained three eggs; two commercially available fresh quail eggs (of a suitable size to approximate regent honeyeater eggs) and one hand molded plasticine egg of a similar size and color. We based our nest and egg design on methods used to investigate predation rates in yellow-faced honeyeater (*Lichenostomus chrysops*) in south-eastern Australia (Boulton & Clarke, 2003). We assigned half of the nests in each experiment as treatment nests and paired them with the other half (control nests). Nests were attached to trees in locations similar to those typically used by regent honeyeaters, at variable heights below 3.5 m (Figure 2a). Paired nests were placed at a similar height and within a similar setting (i.e., fork of a branch, within epicormic growth or on a horizontal branch), approximately 50–100 m from each other. The trial lasted 14 days in total to replicate the regent honeyeater incubation period. During this time nests were checked daily, both passively (using camera traps) and actively, for signs of predation, which was defined as any event that caused one of the quail eggs to become unviable. Individual nests were removed from the study once nest predation was detected.

We estimated daily nest survival using MARK (Cooch & White, 1999), as a constant or as a function of treatment (management using cage or collar vs. not using cage or collar) and/or nest height. Models were ranked by Akaike information criterion (corrected for small sample sizes; AICc), the model with the lowest AICc receiving the greatest support. Models within two AICc points were considered to receive similar support. Where more than one model was <2 AICc, we used model averaging to determine survival for control and treatment nests. There is currently no goodness-of-fit test for nest survival models in MARK, but model assumptions were met (Dinsmore & Dinsmore, 2007). We then converted daily nest survival to the probability that a nest would survive the 14-day incubation period for the species.

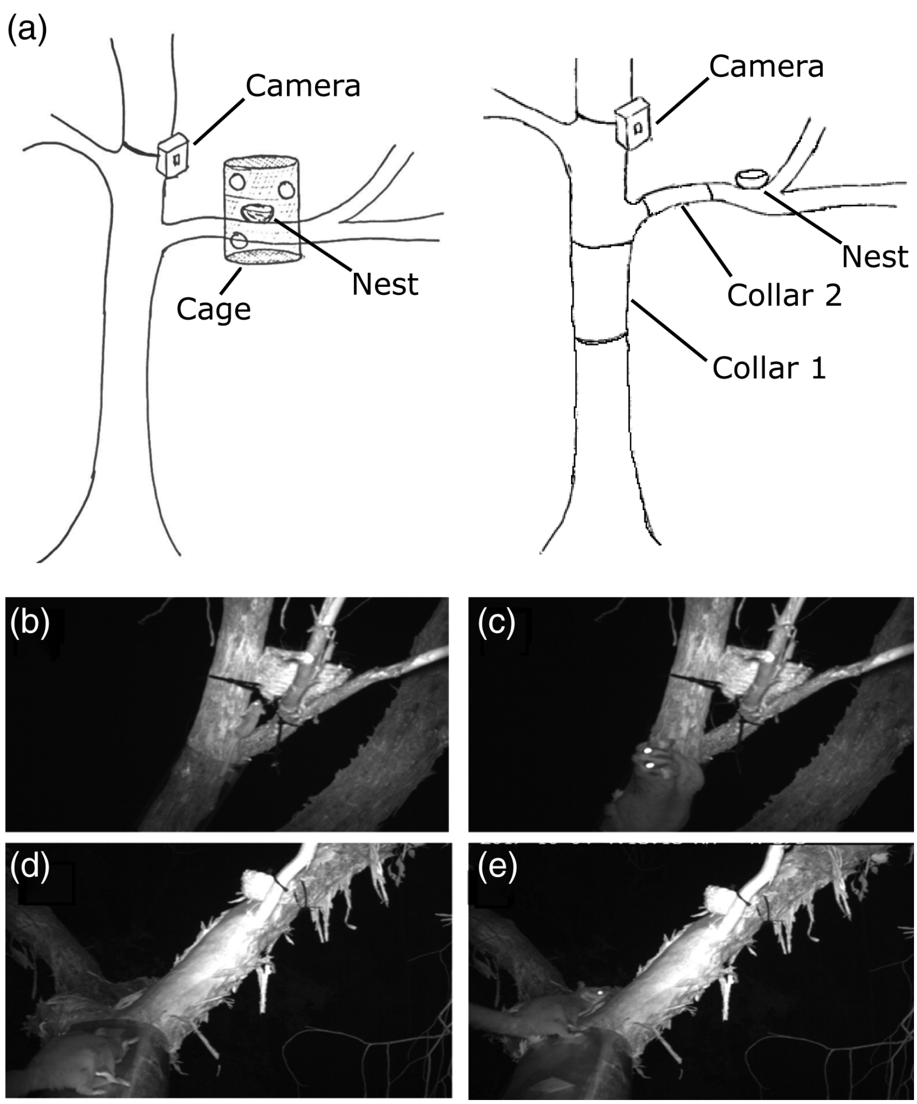

FIGURE 2 (a) Diagrams showing set up of the cages (left) and collars (right) on the artificial nests. For clarity, natural foliage giving concealment not shown and distance from camera varies; (b) shows one treatment tree with the nest and a feather tail glider (*Acrobates pygmaeus*) with the collar just below the animal; (c) same nest with a squirrel glider (*Petaurus norfolcensis*) holding onto the collar; (d) squirrel glider balancing on a collar and (e) reaching the nest branch past the collar

2.4 | Updating initial uncertainty

At the conclusion of field trials, experts were shown the outcomes of the artificial nest experiments. Artificial nests are obviously a surrogate, and the experiment only considered incubation whereas management was conceived to improve nest success until fledging. Therefore, it was agreed from the beginning that estimates of probabilities obtained from the experiment could not be used directly in the decision tree. Instead, when model estimates from the experiment became available, we gave experts the opportunity to update their previous opinions on the probability of predation for actual regent honeyeater nests. After obtaining revised estimates from experts, we updated the decision tree and repeated all analyses to identify the action with the highest support.

3 | RESULTS

3.1 | Articulating initial uncertainty

Experts were generally in agreement about most probabilities in the decision tree (the between-experts standard deviation was between 0.07 and 0.22 for all probabilities). The only marked disagreement was that five of the seven experts agreed that installing a cage would considerably increase the risk of nest desertion, while the other two considered background rates to be already so high that there was little opportunity to further increase the risk of nest desertion. The range of uncertainty (maximum–minimum) of mean estimates was between 0.2 and 0.45 for all probabilities, raising no obvious question about overconfident or uninformed experts.

Simulating the decision tree showed substantial overlap between the distributions of outcomes for alternative actions (Figure 3a). Using branch collars would provide the best option under the initial uncertainty, providing a mean nest success rate of 0.22 (range 0.10–0.37) compared with a mean success rate of 0.16 (range 0.07–0.28) for no management. Uncertainty in predation rate had the biggest influence on the expected outcome: nest success ranged from 10.4 to 20.6% across the range of inputs for predation, whereas all other inputs led to less marked variations in outcome (13.9–17.2%; Figure 4). By contrast, the expected value of perfect information was low (EVPI = 0.02, range 0–0.18), reflecting the experts' opinion that collars were the best option across the whole uncertainty range.

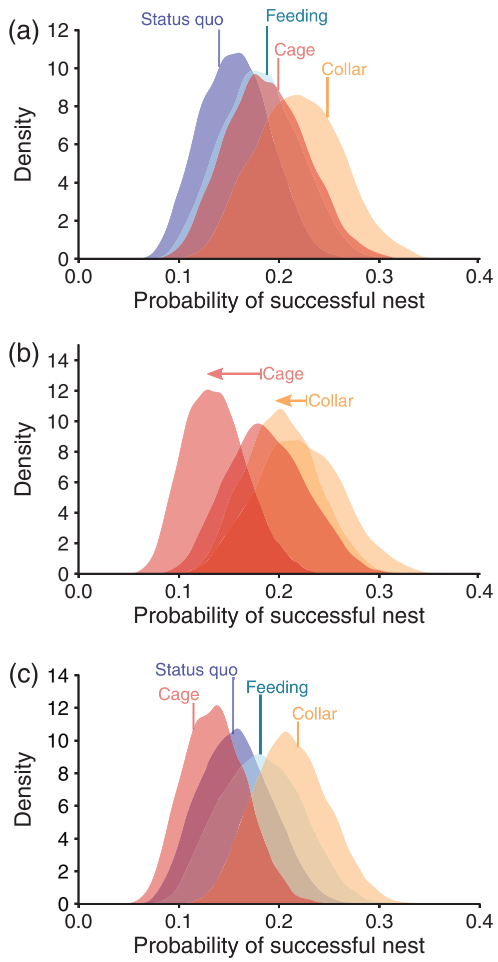

FIGURE 3 Frequency distribution of probability of nest success from 10,000 iterations of the decision tree using the Monte Carlo simulation function built in DecisionTools Suite 7. Panels show (a) the initial elicited expert opinions; (b) the shift in the distribution of outcomes for collars and cages when experts revised their estimates after being informed of the field experiment outcomes (arrows mark mean estimates before-after); (c) the four updated distributions. Note "Cage" label indicates *collar+cage* action as in Table 1

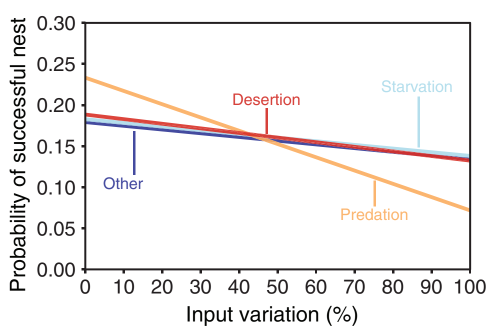

FIGURE 4 Relative influence of uncertainty in each chance node of the decision tree for the *status quo* action (no nest management) on probability of nest success. The full range of uncertainty in each chance node is divided into input percentiles. Steeper slopes indicate greater contribution of uncertainty in input values touncertainty about nest success. Curves correspond to different chance nodes of the decision tree

TABLE 2 Results of model comparison for daily nest survival for cage and collar treatments using artificial nests in Chiltern-Mt Pilot National Park, Victoria, Australia

Model	K^b	AICc[c]	ΔAICc[c]	Weight[d]	Deviance
Cage ($n = 40$)					
DNS (treatment + height)	3	172.44	0	0.38	166.37
DNS (height)	2	172.84	0.4	0.31	168.81
DNS (treatment)	2	173.94	1.5	0.18	169.9
DNS (.)[a]	1	174.48	2.04	0.14	172.47
Collar ($n = 50$)					
DNS (height)	2	156.97	0	0.4	152.87
DNS (.)[a]	1	157.84	0.87	0.26	155.81
DNS (treatment + height)	3	157.96	0.99	0.24	151.74
DNS (treatment)	2	159.71	2.73	0.1	155.6

Note: *K* indicates the number of parameters, weight indicates the normalized AIC weight, and deviance indicates model deviance.
[a](.) indicates a constant term (intercept-only).
[b]Number of parameters.
[c]AICc: corrected Akaike's information criterion.
[d]Normalized AICc weight.

3.2 | Experimental validation of expert opinion

Half of all artificial nests (10 of 20) protected with cages survived the nominal 14-day incubation period (compared to 6 of 20 control nests), and two of 25 nests survived that were protected with collars (compared to 0 of 25 control nests). Camera trap images confirmed a range of nest predators and characteristic indentations in plasticine eggs allowed further, albeit less refined, classification of nest predators. Predators of caged nests were categorized as mammal (17%), mammal or large bird (54%), and unidentified (29%). A similar range of predators were captured on cameras of collared nests; bird (65%), mammal (26%), and unidentified (9%, one camera failed). Images show that marsupials such as squirrel gliders could navigate around the collars and that a grey shrike-thrush (*Colluricincla harmonica*) entered a cage (Figure 2b–e).

In the cage experiment, model comparison showed limited support for positive influence of either treatment, or nest height on survival, with ΔAICc = 2.04 for the null model (Table 2). Model averaged predictions suggested nests would have higher survival rates with a cage than without, but confidence intervals largely overlapped ($DNS_{cage} = 0.94$, 95% CI [0.89, 0.97]; $DNS_{control} = 0.91$, 95% CI [0.85, 0.95]; over the 14-day nesting period, these correspond to mean survival of 0.42 and 0.27 for cage and control respectively). For the nest collar experiment, model comparison also showed very little influence of either treatment or height, with ΔAICc = 0.87 for the null model (model averaged predictions: $DNS_{collar} = 0.61$, 95% CI [0.50, 0.71]; $DNS_{control} = 0.58$, 95% CI [0.45, 0.69]). In this case, model averaged predictions gave very low (<0.01) probabilities of survival across the 14-day incubation period for nests with and without a collar.

3.3 | Updating initial uncertainty

After the results of the experiment were made available, experts increased their mean estimated risk of predation for nests protected by a collar by an average of 0.04, and for nests protected by a cage by an average of 0.25 (Table 1). Overall, experts still estimated either action would still reduce predation compared to the status quo by 17% for collars and 40% for cages. Simulating the updated decision tree again suggested tree collars as the best management action, albeit with a slightly reduced overall improvement in nest success compared to earlier opinions (20.3% nest success on average; range 10.3–33.5%), whereas opinions shifted such that nest cages became the worst option (13.7% nest success on average; range 5.4–26.1%) (Figure 3b,c).

4 | DISCUSSION

Our study shows the reality of decision making in response to a conservation threat for a critically endangered species. The recovery team had to deal with limited information to predict management outcomes, balancing the expectations of benefits, and risks of management. As is normal, subjective attitudes to risk shaped decisions. However, the complex risk landscape of the recovery program led to a conundrum, where risk was perceived to be too great to act under uncertainty, but also too great to effectively reduce that uncertainty. Adopting a decision-analytic approach with best practices for expert elicitation and decision support helped identify the management interventions with the highest support. However, analysis can only indicate the optimal choice while accounting for uncertainty.

Ultimately, decision-makers have the final authority, chance events can lead to eventually poor outcomes even under a good decision process, and some practical limitations remain difficult to overcome. In this situation, the recovery team decided to maintain the status quo in the subsequent breeding seasons, even though this was not perceived as the best action. Implementation of the preferred action of collars on real regent honeyeater nests is now planned for the 2019 breeding season. In the remainder of this discussion, we reflect on lessons learnt from this study which are likely relevant to most threatened species programs worldwide.

Risk aversion underlies most components of this study. It made the recovery team reluctant to implement management without learning more, but it also limited opportunities to learn effectively by dictating an experiment should focus first on predation and should use artificial nests instead of real ones. After the experiment, the revised scores still suggested that both nest protection options were expected to reduce predation, and the main difference between the two was the expected risk of nest desertion. However, verifying nest desertion experimentally would lincur the same problem: a realistic experiment with live breeding regent honeyeaters is deemed too risky, and a surrogate (with another species or captive-breeding birds, an option discussed within the recovery team) might again be of limited value. Indeed, predation was chosen for the experiment described here precisely because studying desertion was considered too risky, at least until a method of successfully reducing predation could be found, making a further decision to test nest desertion more compelling.

Such patterns of risk aversion are well known in economics and behavioral research, but have been rarely explored in conservation (Tulloch et al., 2015). It is common for conservation managers to perceive learning and experimental approaches as risky, but well-planned adaptive management can account for such risks. Indeed, adaptive management is based on finding a solution to the trade-off between the short-term risks and long-term benefits of learning (Runge, 2011). Such a deadlock might be broken by combining an adaptive approach with better tools to deal with risk aversion, such as utility functions (Kirkwood, 1997) and stochastic dominance (McCarthy, 2014).

It is a basic principle of decision analysis that values and preferences drive decisions, and therefore the subjective components of a decision must be embraced (Keeney & Raiffa, 1993). Our initial analysis suggested the value of learning about individual actions was limited in absolute terms, improving nest survival by <2% on average. However, there is no universally agreed or "correct" threshold to decide when value of information is "high enough"; again, it is a matter of preference (Canessa et al., 2015). In our case, the team still felt learning more about predation rates would be beneficial for the decision, and possibly still hoped for a realized value of information at the highest end of the predicted range, so the experiment was carried out.

The experimental results then suggested that the proposed actions were unlikely to significantly reduce predation, particularly for collars alone, and that initial judgments might have been overly optimistic. Interestingly, however, expert judgments did not shift accordingly when shown these results. Cages became the worst-ranked action (worse than no action), because the revised predation rate did not offset the high expected desertion rate. Conversely, collars were still expected to be effective and remained the highest-ranked action. Part of the discrepancy between experimental results and expert judgments may be due to knowledge that artificial nests tend to have lower survival than real ones, with different predation patterns (Batáry & Báldi, 2005; Zanette, 2002). This was the most important reason for revising expert judgments rather than using experimental estimates directly, and reflects a limitation common to most threatened species programs (Canessa, Guillera-Arroita, et al., 2016). On the other hand, it remained unclear why experts reduced estimates of predation for cages six times more heavily than for collars, given the largely similar experiment results. The discrepancy might be due to implementation details; experts expressed doubts about the realism of nest and collar placements. Results were obviously relative to the treatments tested, and a new experiment could assess a different version of collars and cages.

Another possibility is that differences might be the result of conservatism or confirmation biases (Tversky & Kahneman, 1974), whereby evidence that weighed more strongly against prior beliefs was given less importance. For example, another expert found it difficult to separate estimates of predation probabilities from their own perceptions of the general risk of the cage strategy. Decision-analytic approaches and formal expert elicitation provide some protection against such biases but cannot prevent them entirely. In the next iteration for this species, we might alter the expert group bringing in experts for other species and contexts, or devote additional time to the training and feedback phases, for example including a training module on heuristics (Martin et al., 2012).

Although here we have mostly discussed the difficulties we encountered, we still found the decision-analytic process useful, and felt difficulties might have been magnified had we chosen a less structured approach. In particular, breaking a decision problem down into subcomponents, which can then be approached and solved with the most appropriate tools, is a key advantage of decision analysis (Gregory et al., 2012). We found application of a decision tree especially useful, despite it being an underused tool in conservation (Canessa, Converse, et al., 2016; Rout et al., 2013). Nest success is the result of a sequential chain of events, each influenced by management actions to a different extent. If we had simply elicited the expected nest success, experts would have had to balance different components implicitly, making it difficult to compare and discuss key trade-offs and uncertainties. Breaking the decision into subcomponents also made it easier to incorporate new knowledge, since the nest experiment only focused on a single node in the tree (nest predation). We then implemented formal elicitation methods to estimate parameters, an approach increasingly used in the management of threatened species (e.g., Gerber et al., 2018; McBride et al., 2012; Runge et al., 2011; Runge, Rout, Spring, & Walshe, 2017). The quantitative elicitation was fundamental to avoid linguistic uncertainty that might have been hidden by qualitative descriptions of risk. It also helped to reveal the apparent discrepancies between perceived and quantified risks, and between experimental results and expert judgments. Finally, it facilitated transparent reporting for future iterations and discussions within and outside the recovery team.

Most of the limitations highlighted in our study, such as small sample sizes and risk aversion for threatened species programs, are likely common to many conservation programs for critically endangered species. The conundrum we faced, created by a combination of objective and subjective uncertainties and risks, might be common for such programs. Tools exist to deal with those limitations, some of which we implemented, but they cannot guarantee success. Regardless, decisions must be made at some stage: in the regent honeyeater case, managers recognized that no action would also be a decision, and a suboptimal one according to current knowledge. We recommend managers facing similar problems should carefully consider risk aversion and possible biases before discussing specific actions. Elicitation processes should be iterative and allow for wide ranging discussion (e.g., Hemming, Burgman, Hanea, McBride, & Wintle, 2018). Finally, studies should be designed to provide truly relevant information about the components of the system which have the greatest influence on decisions. Embracing risk aversion as a fundamental subjective component of decisions, but dealing with it using objective methods, may present the best way forward in such cases.

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CONFLICT OF INTEREST

The authors declare there are no conflicts of interest associated with this publication.

AUTHOR CONTRIBUTIONS

All authors conceived the ideas; G.T., R.H.C., J.G.E. ran the expert elicitation; G.T., J.V., R.H.C., D.I. ran the field experiments; S.C., G.T., J.G.E. did the analysis; S.C., G.T., J.G.E. wrote the manuscript; and all authors provided editorial advice.

ETHICS STATEMENT

The research was approved by Monash University (ethics #BSCI/2015/16) and DEWLP (scientific permit #10008288 and ethics 17-003).

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REFERENCES

Armstrong, D. P., Castro, I., & Griffiths, R. (2007). Using adaptive management to determine requirements of re-introduced populations: The case of the New Zealand hihi. *Journal of Applied Ecology*, *44*, 953–962.

Armstrong, D. P., & Ewen, J. G. (2002). Dynamics and viability of a New Zealand robin population reintroduced to regenerating fragmented habitat. *Conservation Biology*, *16*, 1074–1085.

Batáry, P., & Báldi, A. (2005). Factors affecting the survival of real and artificial Great Reed Warbler's nests. *Biologia*, *60*, 215–219.

Behn, R. D., & Vaupel, J. W. (1982). *Quick analysis for busy decision makers*. New York, NY: Basic Books.

Bergstrom, D. M., Lucieer, A., Kiefer, K., Wasley, J., Belbin, L., Pedersen, T. K., & Chown, S. L. (2009). Indirect effects of invasive species removal devastate World Heritage Island. *Journal of Applied Ecology*, *46*, 73–81.

Boulton, R. L., & Clarke, M. F. (2003). Do yellow-faced honeyeater (*Lichenostomus chrysops*) nests experience higher predation at forest edges? *Wildlife Research*, *30*, 119–125.

Canessa, S., Converse, S. J., West, M., Clemann, N., Gillespie, G., McFadden, M., … McCarthy, M. A. (2016). Planning for ex-situ conservation in the face of uncertainty. *Conservation Biology*, *30*, 599–609.

Canessa, S., Guillera-Arroita, G., Lahoz-Monfort, J. J., Southwell, D. M., Armstrong, D. P., Chadès, I., … Converse, S. J. (2015). When do we need more data? A primer on calculating the value of information for applied ecologists. *Methods in Ecology and Evolution*, *6*, 1219–1228.

Canessa, S., Guillera-Arroita, G., Lahoz-Monfort, J. J., Southwell, D. M., Armstrong, D. P., Chadès, I., … Converse, S. J. (2016). Adaptive management for improving species conservation across the captive-wild spectrum. *Biological Conservation*, *199*, 123–131.

Cohen, J. B., Hecht, A., Robinson, K. F., Osnas, E. E., Tyre, A. J., Davis, C., … Melvin, S. M. (2016). To exclose nests or not: Structured decision making for the conservation of a threatened species. *Ecosphere*, *7*, e01499.

Cooch, E., & White, G. (1999). Program MARK: Survival estimation from populations of marked animals. *Bird Study*, *46*, S120–S139.

Crates, R., Rayner, L., Stojanovic, D., Webb, M., Terauds, A., & Heinsohn, R. (2018). Contemporary breeding biology of critically endangered Regent Honeyeaters: Implications for conservation. *Ibis*, *161*, 521–532.

Davies, O. A., Huggins, A. E., Begue, J. A., Groombridge, J. J., Jones, C., Norfolk, D., … Ewen, J. G. (2018). Reintroduction or natural colonization? Using cost-distance analysis to inform decisions about Rodrigues Island Fody and Warbler reintroductions. *Animal Conservation*, *21*, 110–119.

Dinsmore, S. J., & Dinsmore, J. J. (2007). Modeling avian nest survival in program MARK. *Studies in Avian Biology*, *34*, 73.

Ewen, J. G., Walker, L., Canessa, S., & Groombridge, J. J. (2014). Improving supplementary feeding in species conservation. *Conservation Biology*, *29*, 341–349.

Gerber, B. D., Converse, S. J., Muths, E., Crockett, H. J., Mosher, B. A., & Bailey, L. L. (2018). Identifying species conservation strategies to reduce disease-associated declines. *Conservation Letters*, *11*, e12393.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., & Ohlson, D. (2012). *Structured decision making: A practical guide to environmental management choices*. Hoboken, NJ: John Wiley & Sons.

Hemming, V., Burgman, M. A., Hanea, A. M., McBride, M. F., & Wintle, B. C. (2018). A practical guide to structured expert elicitation using the IDEA protocol. *Methods in Ecology and Evolution*, *9*, 169–180.

Homberger, B., Duplain, J., Jenny, M., & Jenni, L. (2017). Agri-evironmental schemes and active nest protection can increase hatching success of a reintroduced farmland bird species. *Landscape and Urban Planning*, *161*, 44–51.

Isaksson, D., Wallander, J., & Larsson, M. (2007). Managing predation on ground-nesting birds: The effectiveness of nest exclosures. *Biological Conservation*, *136*, 136–142.

Keeney, R. L., & Raiffa, H. (1993). *Decisions with multiple objectives: Preferences and value trade-offs*. New York, NY: Cambridge University Press.

Keo, O., Collar, N. J., & Sutherland, W. J. (2009). Nest protectors provide a cost-effective means of increasing breeding success in giant ibis *Thaumatibis gigantea*. *Bird Conservation International*, *19*, 77–82.

Kirkwood, C. W. (1997). *Strategic decision making*. Belmont, CA: Duxbury Press Belmont.

Kvistad, L., Ingwersen, D., Pavlova, A., Bull, J. K., & Sunnucks, P. (2015). Very low population structure in a highly mobile and wide-ranging endangered bird species. *PLoS One*, *10*, e0143746.

Libois, E., Gimenez, O., Oro, D., Mínguez, E., Pradel, R., & Sanz-Aguilar, A. (2012). Nest boxes: A successful management tool for the conservation of an endangered seabird. *Biological Conservation*, *155*, 39–43.

Liu, S., Gillespie, J., Atchison, N., & Andrew, P. (2014). The recovery programme for the Regent honeyeater *Anthochaera phrygia*: An example of conservation collaboration in Australia. *International Zoo Yearbook*, *48*, 83–91.

Major, R. E., Ashcroft, M. B., & Davis, A. (2015). Nest caging as a conservation tool for threatened songbirds. *Wildlife Research*, *41*, 598–605.

Martin, T. G., Burgman, M. A., Fidler, F., Kuhnert, P. M., Low-Choy, S., McBride, M., & Mengersen, K. (2012). Eliciting expert knowledge in conservation science. *Conservation Biology*, *26*, 29–38.

Martínez-Abraín, A., & Oro, D. (2013). Preventing the development of dogmatic approaches in conservation biology: A review. *Biological Conservation*, *159*, 539–547.

McBride, M. F., Garnett, S. T., Szabo, J. K., Burbidge, A. H., Butchart, S. H., Christidis, L., … Watson, D. M. (2012). Structured elicitation of expert judgments for threatened species assessment: A case study on a continental scale using email. *Methods in Ecology and Evolution*, *3*, 906–920.

McCarthy, M. A. (2014). Contending with uncertainty in conservation management decisions. *Annals of the New York Academy of Sciences*, *1322*, 77–91.

Nichols, J. D., & Williams, B. K. (2006). Monitoring for conservation. *Trends in Ecology & Evolution*, *21*, 668–673.

Pratt, J. (1964). Risk aversion in the small and in the large. *Econometrica: Journal of the Econometric Society*, *30*, 122–136.

Rout, T. M., McDonald-Madden, E., Martin, T. G., Mitchell, N. J., Possingham, H. P., & Armstrong, D. P. (2013). How to decide whether to move species threatened by climate change. *PLoS One*, *8*, e75814.

Runge, M. C. (2011). An introduction to adaptive management for threatened and endangered species. *Journal of Fish and Wildlife Management*, *2*, 220–233.

Runge, M. C., Converse, S. J., & Lyons, J. E. (2011). Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. *Biological Conservation*, *144*, 1214–1223.

Runge, M. C., Rout, T. M., Spring, D. A., & Walshe, T. (2017). Value of information analysis as a decision support tool for biosecurity. In A. P. Robinson, T. Walshe, M. A. Burgman, & M. Nunn (Eds.), *Invasive species: Risk assessment and management* (p. 308). Cambridge, England: Cambridge University Press.

Sainsbury, A. W., & Vaughan-Higgins, R. J. (2012). Analyzing disease risks associated with translocations. *Conservation Biology*, *26*, 442–452.

Taylor, G., Ewen, J. G., Clarke, R. H., Blackburn, T. M., Johnson, G., & Ingwersen, D. (2018). Video monitoring reveals novel threat to critically endangered captive-bred and released regent honeyeaters. *Emu – Austral Ornithology*, *118*, 304–310.

Tulloch, A. I. T., Maloney, R. F., Joseph, L. N., Bennett, J. R., Di Fonzo, M., Probert, W. J., … Possingham, H. P. (2015). Effect of risk aversion on prioritizing conservation projects. *Conservation Biology*, *29*, 513–524.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, *185*, 1124–1131.

Vose, D. (1996). *Quantitative risk analysis: A guide to Monte Carlo simulation modelling*. Chichester, England: John Wiley & Sons Ltd.

Zanette, L. (2002). What do artificial nests tells us about nest predation? *Biological Conservation*, *103*, 323–329.

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