Identifying cost-effective recovery actions for a critically endangered species

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Abstract
Threatened species managers are often required to make swift decisions in the face of considerable uncertainty. We tested a structured approach for evaluating conservation options for the critically endangered orange-bellied parrot. The Orange-bellied Parrot Recovery Team provides advice to government agencies to inform the allocation of a limited number of captive-bred birds to different release scenarios. Using a structured expert elicitation approach, we determined that scenarios where more fledglings were released were more cost-effective compared to other options. Following this finding in 2019, the recovery team adjusted plans and allocated additional birds to fledgling release, a response that contributed to an increase in wild birds migrating in 2020 and 2021. The challenges facing orange-bellied parrot conservation, including limitations in animals, time and resources, and high uncertainty, are common for threatened species recovery programs. Here we show that a structured process can help managers grapple with these complex trade-offs to make timely decisions.

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1 Introduction

The world is currently in a biodiversity crisis (IPBES, 2019) with management of threatened species and ecosystems becoming more necessary to prevent biodiversity loss (Bottrill et al., 2011). Often conservation managers of threatened species are faced with significant uncertainty surrounding their conservation decisions (Canessa et al., 2019; Regan et al., 2005). Threatened species generally have very small population sizes which reduces the ability to test novel conservation techniques, making it difficult to determine the most effective management actions (Hernandez, Graham, Master, & Albert, 2006). The small population sizes of threatened species also enhance the fear of failure, and this can further hinder conservation decision making (Meek et al., 2015; Tulloch et al., 2015). Nonetheless, taking action in the face of this uncertainty is often necessary for managers of threatened species, meaning that decisions must be made with limited information, often under tight timeframes and with limited resources (Buxton et al., 2020; Canessa et al., 2019; Fitzgerald et al., 2021).

Conservation managers require tools and frameworks that provide flexible, transparent, and structured support for making decisions. Structured decision making, for example, provides a framework for individuals and groups to think through complex environmental and/or management decisions in a rigorous, inclusive, and defensible way (Gregory et al., 2012). The structure allows groups of decision-makers to explicitly step through the process and bring together knowledge from a range of perspectives to identify the best available options (Cohen et al., 2016; Vercammen & Burgman, 2019; Walsh et al., 2020). Fundamental to most conservation decisions is determining how to allocate limited resources to ensure the greatest conservation gain (Bottrill et al., 2009; Gerber et al., 2018). Approaches such as “Project Prioritisation Protocol” and “Priority Threat Management” have recently been implemented to address the need to compare the cost-effectiveness of potential management actions (Carwardine et al., 2019; Joseph, Maloney, & Possingham, 2009; Martin et al., 2018). These types of approaches are an effective way for making decisions in complex circumstances involving multiple stakeholder groups for both broadscale landscape restoration programs as well as individual threatened species’ recovery programs (Walsh et al. 2020; Camaclang et al. 2021).

To meet this need for structured decision support, the Government of Victoria, Australia, has recently implemented a landscape-scale, spatial conservation action planning tool for assessing the cost-effectiveness of conservation actions (Thomson et al., 2020). This tool, however, mostly considers landscape-scale threat management actions, which alone is not sufficient for maximizing the persistence of some species, and this is particularly true for specialized species with very particular management requirements. To meet this need, the Specific Needs approach was developed. Specific Needs employs a modified, population-specific project prioritization protocol approach within a structured decision-making framework to rank the cost-effectiveness of species-specific and landscape-scale conservation actions within and between species (Bruce et al., 2020; Joseph et al., 2009). Specific Needs also allows for comparison with the library of conservation actions ranked spatially across the state of Victoria. This framework is adaptable, portable and applies decision theory principles to allow for consideration of customized conservation actions by explicitly considering the expected benefits of each identified management scenario, including consideration of costs and uncertainty.

Here, we apply the Specific Needs approach to facilitate comparison of management options for the critically endangered orange-bellied parrot (Neophema chrysogaster) in a structured decision making framework. The migratory orange-bellied parrot is one of the species most at risk of extinction in Australia (Geyle et al., 2018). Each year, individuals migrate from wintering sites on the mainland of south-eastern Australia to their breeding grounds in remote south-west Tasmania. Over the past 25 years the population has dramatically declined and in recent years, approximately only 20 birds have returned each season to the last known breeding location in Tasmania (Troy & Hehn, 2019). Since 2013, intensive management of the wild population has been undertaken to reduce the risk of imminent extinction (Troy & Hehn, 2019). The captive insurance population which is now genetically identical to the wild population (Morrison, Johnson, Grueber, & Hogg, 2020; Smales, Brown, Menkhorst, Holdsworth, & Holz, 2000), was established in 1986 and is used to supplement the wild population (Troy & Hehn, 2019). Despite ongoing direct management, low return rates of juveniles to the breeding location have continued, and the cause and location of this mortality remains uncertain (Stojanovic et al., 2020). As
there is currently limited ability for management to directly influence the threats impacting the birds during their annual migration, conservation efforts have focused on the Tasmanian breeding grounds and the wintering sites on the mainland (Troy & Hehn 2019; Stojanovic et al. 2020).

The Orange-bellied Parrot Recovery Team is the advisory group for the management of the species and includes members from government, zoos, academia and interested nongovernment parties. The current objectives for the recovery team are to: (a) maintain, or increase if possible, the size of the wild population (i.e., prevent extinction anywhere in the wild) and (b) maintain the captive population at a viable level as an insurance population and source for captive-to-wild translocations (Department of Environment, Land, Water and Planning, 2016). Each year, the recovery team recommends how 50–100 captive-bred birds are distributed between four different release scenarios. The number of birds the captive breeding program can provide for release is constrained by a number of factors, including holding facilities for the captive population, financial resources, requirements to maintain healthy genetics and demographics in the breeding population, and disease concerns. The limited number of birds for release has led to complex trade-offs around the allocation of resources (i.e., availability of captive birds for release, as well as financial) required for different release scenarios. The need for rapid decisions about competing strategies is challenging and not uncommon for release programs, such as the critically endangered kakapo (Strigops habroptilus; Elliott, Merton, & Jansen, 2001), the now extinct Christmas Island pipistrelle (Martin et al., 2012), and other captive breeding programs (see Harley, Mawson, Olds, MacFadden, & Hogg, 2018 for other Australian release programs). Here we used the Specific Needs approach to quantify the expected benefit, cost, and uncertainty of alternate management scenarios, with the aim of providing the Orange-bellied Parrot Recovery Team with a structured process to guide the allocation of available resources.

2 | METHODS

Assessing the relative cost-effectiveness of different management scenarios for conservation values with Specific Needs follows a typical structured decision-making framework (Gregory et al., 2012).

2.1 | Define objectives and biodiversity assets

The Specific Needs approach was used to identify management scenarios that would best assist the Orange-bellied Parrot Recovery Team to meet their objectives (see Section 1). The objectives were considered over a 50-year time frame into the future, in-line with the Victorian Government’s biodiversity decision-support framework (Bruce et al., 2020; Thomson et al., 2020).

There are some inherent trade-offs in the decisions the recovery team makes around priority conservation management, most notably in the way in which captive birds were allocated for release scenarios. First, ensuring the captive population remains both demographically and genetically sustainable, places an upper limit on the number of birds available for release each year. Second, the recovery team has yet to determine which of the alternative release methods provides maximum benefit to the wild population. Trialing different management scenarios within each single breeding year requires trade-offs in sample sizes among different release methods.

2.2 | Identify management scenarios

The recovery team were asked to consider four different release methods for which an allocation from the bird budget was required (total of ~50 birds in 2018/19). These release methods were:

1. Spring release (adults)—released to the wild breeding site in Tasmania in spring (October–November).
2. Nest supplementation—supplementing young produced in wild nests with either eggs or nestlings from captivity in summer (January or February).
3. Fledgling release—supplementing the wild population at the wild breeding site with fledglings from captivity in late summer/early autumn (February or March).
4. Mainland release—releasing birds (adults and/or juveniles) from captivity to an area of orange-bellied parrot range on the Australian mainland before arrivals of migrating parrots in late autumn (April or May).

Ten management scenarios were developed that considered a range of bird allocations to these four different release methods (Table 1). Further details regarding these release methods and additional supplementary actions that are carried out alongside releases aimed at further improving outcomes (such as fire regimes, disease screening, and head-starting) are detailed in Table S1.

Experts were asked to consider what would happen if these scenarios were repeated over a 50-year period. This was not an attempt to realistically capture what the orange-bellied parrot recovery program may look like in 50 years, but to allow comparisons of the likely long-term
benefits between scenarios that reflect trade-offs and decisions currently being made by the recovery team.

Two levels of captive population size and investment into the release program were also considered. For each scenario, the impact of releasing either the current number of 50 birds per year or 100 birds per year (which represents an increased investment in the current captive breeding program) was compared.

2.3 Estimate the benefit of each management scenario

Expert elicitation of the Orange-bellied Parrot Recovery Team members was used to estimate the benefit of each scenario. On May 9, 2019, an expert elicitation workshop consisting of 19 members of the recovery team was conducted, with a follow-up videoconference and remote completion of the survey for those who were unable to attend in person \((n = 5)\). Experts represented a range of areas of orange-bellied parrot research, management, and recovery, including Tasmanian, mainland, and captive population management.

The expert elicitation process followed the 3-step IDEA protocol (Hemming, Burgman, Hanea, McBride, & Wintle, 2018). To estimate changes in persistence probability, individual experts were first asked to estimate the probability of orange-bellied parrots persisting in the (a) nonbreeding range on the mainland, (b) breeding range in Tasmania, and (c) anywhere in the wild as a whole for 50 years if no management is undertaken (the “do nothing” scenario, including or excluding captive breeding). Experts were asked to give their “best guess” estimate for persistence probability, and the upper and lower bounds of that persistence probability (i.e., what was their highest and lowest estimate for probability of persistence), per the 3-step IDEA protocol (Hemming et al., 2018). This method captures the most likely persistence probability value according to each expert and the level of certainty each expert has in their estimate.

Next, experts were asked to estimate the probability of orange-bellied parrots persisting in each of the three locations (mainland, Tasmanian, and anywhere in the wild) in 50 years under each management scenario. Again, experts were asked to give their best estimate for persistence probability and the credible upper and lower bounds.

To incorporate individual expert uncertainty, a triangular distribution was fitted to each expert’s upper, lower and best guess estimates of probability of persistence for each management scenario. Ten-thousand random samples were drawn from this distribution and a mean estimate was calculated for each. The resulting dataset of values was then used to calculate each expert’s estimate of benefit of the management scenarios.

The benefit of the management scenario \((\text{Ben}_A)\) was calculated as the difference between the expert’s “best guess” of probability of persistence under a “do nothing” scenario \((p_{\text{DN}})\), compared to the expert’s “best guess” of probability of persistence if the scenario was implemented \((p_A)\).

\[
\text{Ben}_A = p_A - p_{\text{DN}}.
\]

Because of the migratory behavior of the orange-bellied parrot, along with the interconnectedness of the wild and

| Primary release method | Management scenarios with the percentage of bird budget allocated to releases |
|------------------------|--------------------------------------------------------------------------------|
|                        | MS 1 | MS 2 | MS 3 | MS 4 | MS 5 | MS 6 | MS 7 | MS 8 | MS 9 | MS 10  |
| Spring release (adults) | 25%  | 70%  | 50%  | 25%  | 25%  | 25%  | 25%  | 25%  | 70%  |        |
| Nest supplementation    | 25%  | 30%  | 20%  | –    | –    | –    | –    | 25%  | 25%  | 30%    |
| Fledgling release       | 25%  | –    | –    | 75%  | 50%  | 100% | 60%  | 25%  | 25%  | –      |
| Mainland release        | 25%  | –    | 30%  | –    | 25%  | –    | 40%  | 25%  | 25%  | –      |

**Supplementary actions**

| Appropriate fire regimes | Y | Y | Y | Y | Y | Y | Y | N | Y | N |
| Psittacine beak and feather virus (PBFV) screening | Y | Y | Y | Y | Y | Y | Y | N | Y |
| Head-started juveniles   | N | N | N | N | N | Y | Y | N | N | Y |

*Note: Includes the percentage of the bird budget allocated to each release method and whether the supplementary actions (fire regimes, disease screening, head-starting) were included.*
captive populations, the benefit at multiple landscape scales (mainland, Tasmania, anywhere in the wild, and the captive population) was assessed. That is, for each scenario, experts were asked to assess the probability of persistence of orange-bellied parrots at these three wild locations (and the captive population in cases where the scenario could have affected it).

These measures of population persistence probability were converted into the benefit, $\text{Ben}_A$, the overall change in persistence probability for the species achieved by a management scenario $A$, and is the value used to calculate the cost-effectiveness of the management scenario.

### 2.4 Estimate the relative costs of each management scenario

After the workshop, members of the recovery team were asked to cost different management scenarios. Following recommendations in Iacona et al. (2018), a cost datasheet was developed to collect general information around methods, scale, and assumptions, as well as asking experts to cost individual actions which made up a management scenario (e.g., mainland release, appropriate fire regimes) based on labor, consumables, overheads, and capital assets (see Supporting Information).

Actions were costed annually and then manipulated (depending on the action) to obtain costs over 50 years ($\text{Cost}_A$). For instance, for actions that were required annually, like disease screening, annual costs were multiplied by 50, whereas one-off costs, like building a captive breeding enclosure, were not multiplied. It is difficult to realistically cost actions over a 50-year timeframe, but the aim was to be standardized in the collection method across different actions. Thus, although significant assumptions were made in gathering the costs, they should make for a valid comparison of cost-effectiveness across scenarios.

### 2.5 Calculate the cost-efficiency of each management action

The cost-effectiveness of each scenario, that is the return on investment (ROI) received from undertaking the Action ($A$) over the 50-year time frame was calculated as:

$$\text{ROI}_A = \frac{\text{Ben}_A}{\text{Cost}_A},$$

where $\text{Ben}_A$ is the change in persistence probability achieved by undertaking the management scenario over 50 years and $\text{Cost}_A$ is the cost of successfully implementing the management scenario for 50 years.

ROI$_A$ was estimated for each scenario at each location (Tasmania, the mainland and anywhere in the wild) and was compared across scenarios to determine the most cost-effective actions.

Linear mixed-effects models with a normal distribution were performed using R (R Core Team, 2019) with the lme4 software package (Bates, Mächler, Bolker, & Walker, 2015) on estimates of benefit and cost-effectiveness of management scenarios. Fixed effects for both models were management scenario and bird number. Expert was included as a random effect. $p$-values were obtained by likelihood ratio tests.

### 3 RESULTS

#### 3.1 Summary of experts

Twenty-four responses were received to the expert elicitation of the benefit of management scenarios from members of the recovery team. Each expert indicated their population or populations of focus (Tasmania, mainland, or captive) and their years involved in orange-bellied parrot and threatened bird research or management (Table 2).

#### 3.2 Benefit of management scenarios

There was considerable variation among experts in their responses for each scenario (Figure 1a); however, two actions were consistently associated with the most beneficial scenarios. Scenarios that included an increase in allocation of birds to the fledgling release were, on average, more beneficial than scenarios that approximated the existing management scenario (management scenario 1; $\chi^2(6) = 15.14$, $p < .01$; Table S3), while scenarios where the total annual bird budget was 100 birds were consistently more beneficial than scenarios with a budget of 50 birds ($\chi^2(1) = 53.70$, $p < .001$; Table S3). Individual experts also had considerable uncertainty around their “best guess” estimate, indicated by their upper and lower estimates of probability of persistence (Figure S1).

#### 3.3 Cost-effectiveness of management scenarios

The considerable variation associated with the benefit estimates resulted in similarly large variation in estimates of the cost-effectiveness of management actions (Figure 1b). Unlike the benefit results, increasing the bird budget from 50 to 100 birds per year reduced the cost-effectiveness of affected actions, due to the increased cost.
of captive breeding and release ($\chi^2(1) = 99.63, p < .001$; Table S4).

Again, management scenarios which included an increased allocation in the fledgling release (management scenarios 4, 5, 6 and 7) were on average more cost-effective than the scenario most closely approximating the existing management (management scenario 1: $\chi^2(6) = 33.33, p < .001$; Table S4).

Detailed comparisons suggest that the estimated benefits of appropriate fire management in the breeding range are sufficient to outweigh the extra cost of this landscape management action ($\chi^2(1) = 41.05, p < .001$). Although there was a perceived benefit of disease screening, the process is expensive, so undertaking releases with this safeguard is no more cost-effective than without screening ($\chi^2(1) = 0.27, p = .59$).
4 | DISCUSSION

The Specific Needs approach provided a structured process to assist the Orange-bellied Parrot Recovery Team in allocating a limited number of birds to four different release scenarios, a decision that had previously been made through a facilitated discussion. For the past 4 years, the recovery team has allocated roughly equal numbers of birds to each release type—approximately Management Scenario 1: the “mixed release strategy.” The results of the expert elicitation, however, showed that the recovery team currently views fledgling release as an essential component of the release strategy, with the four scenarios that allocated a higher proportion of birds to this action (Management Scenarios 4, 5, 6, and 7) being assessed as more cost-effective than the current management scenario. On the back of this result, the recovery team rapidly adjusted their management strategy in late 2019, increasing the production and allocation of birds to fledgling release for the following season. Following this change in strategy, over 100 wild birds migrated north from the breeding site in autumn 2020—the largest number in over a decade. This estimated benefit of fledgling releases in the results reflects the optimism of recovery team members following promising early outcomes from fledgling release trials, but the team were nevertheless cautious to adjust their approach due to the uncertainty created by the small sample sizes (Orange-bellied Parrot National Recovery Team meeting, May 2019).

The recovery team member's uncertainty in the effectiveness of different management strategies was reflected in the large degree of variation among experts in the results, as well as within their individual estimates (when asked to give upper and lower intervals). However, despite their uncertainty the recovery team is still required to provide recommendations for the allocation of captive birds to different release scenarios. The Specific Needs approach allowed recovery team members to acknowledge their own uncertainty, capture the differences of opinion between members, but also identify and quantify the collective opinion to invest more resources in the fledgling releases. Uncertainty is ubiquitous with threatened species management programs, but these results demonstrate that structured and inclusive approaches can allow for more transparent rapid decision making, which is particularly important when delays in action can cause long-term problems for species (Buxton et al., 2020; Canessa et al., 2019).

Of course, where possible, it is important to resolve areas of uncertainty to improve outcomes for threatened species management. The Specific Needs approach produces two measures of uncertainty, both within individual experts (their upper and lower values of probability of persistence) and between experts (the level of variation around the best estimates of probability of persistence). These measures of uncertainty can be used, in tandem with benefit estimates, to identify where research might be best focused to fill knowledge gaps (i.e., value of information analysis, Canessa et al., 2015). Our findings show a high level of variation in both measures, particularly for actions that include fledgling release, potentially reflecting the uncertainty in sources of mortality during juvenile migration (Stojanovic et al., 2020) as well as the lack of data about the return prospects of release juveniles. A value of information analysis could be used to help guide investment in resolving that uncertainty, like investing in transmitters to determine source of mortality during migration (Bruce et al., 2020; Canessa et al., 2015). In the meantime, however, the current approach provides a process that enables collective decision making to occur while research questions are addressed.

Once management actions have been implemented, it is also possible to resolve uncertainty by monitoring and assessing management outcomes (McCarthy & Possingham 2007). For instance, the size of the wild population is closely monitored at the breeding site, where the wholly colour-banded population is concentrated in a small area, and birds frequent supplementary feeding stations which are closely monitored throughout the breeding season to determine spring arrivals, fledging success, and survival to the end of the breeding season prior to autumn departures. Since 2014, only two adults (one male and one female) have eluded capture and banding, meaning measurement of population size at key points in time involves a census approach, rather than an estimate. Following the commencement of the preferred management strategy outlined here, the largest number of orange-bellied parrots in over a decade were present at the breeding site in autumn, prior to northern migration (118 birds in autumn 2020; Troy & Lawrence 2021). This was followed by the largest number of birds returning to the breeding site the following spring, in over a decade (51 birds in spring 2020; Troy & Lawrence 2021). Although we cannot provide evidence the change in management strategy directly influenced this observed increase, this positive trend has reinforced the Recovery Team's confidence in the likely benefits of fledgling releases. In late summer 2021, there was another large release of fledglings which contributed to another record-breaking population count prior to the autumn migration (192 birds in autumn 2021; Troy & Lawrence 2021).

Our findings also highlights the need to consider both benefit and cost-effectiveness of management actions when making conservation decisions (Bottrill et al., 2009; Gerber et al., 2018). For instance, the results suggested there was a benefit to increasing the number of release
birds from approximately 50–100 birds per year, yet, this trend was complicated when the costs of the actions were incorporated. The additional cost of increasing captive capacity was estimated to be justified only for management scenarios where the relative benefit of more release birds was high—prompting the recovery team to consider what further investment or resource reallocation may be needed to sustainably achieve an increased level of captive bird production, while still maintaining the genetic and demographic integrity of the single source population. Estimation of costs of conservation often involves a lot of uncertainty (Salomon, McCarthy, Taylor, & Wintle, 2013). Previous work has provided guidelines for assessing the cost of conservation management actions (Iacona et al., 2018); however, the consideration of cost-effectiveness when making conservation decisions remains infrequent (Pienkowski, Cook, Verma, & Carrasco, 2021). Consideration of cost-effectiveness can not only assist species’ managers in choosing actions for implementation, as demonstrated here, but can also add to a well-developed evidence base to assist in funding allocation (Cook, Pullin, Sutherland, Stewart, & Carrasco, 2017).

Where there are various sources of funding available, estimates of cost-effectiveness can be used to guide the allocation of funding across different aspects of a recovery program. The results of this assessment indicated management scenarios involving mainland release (Management Scenarios 3, 5, and 7) were among the most beneficial, likely owing to the potential benefit this action may have on survival of migrating and wintering birds (Stojanovic et al., 2020). Although the additional cost of this action meant these management scenarios were not the most cost-effective option, mainland release is supported by funding from different jurisdictions to the other releases. By accessing an alternative funding source to other recovery activities, mainland release becomes a more cost-effective option for orange-bellied parrot. This was a strategy the recovery team chose to pursue. It is rare for a threatened species recovery program to have only one funding source, so it is important to consider the diversity and limitations of different funding sources when determining the best mix of actions. Additionally, demonstrating the cost-effectiveness of actions to potential funders has been shown to increase funding allocations to conservation actions (Brazill-Boast et al., 2018; Joseph et al., 2009; Martin et al., 2018).

Here, the Specific Needs approach has been used to compare between conservation management options for a single critically endangered species. By standardizing the benefit estimations of management actions using a common metric (change in persistence probability in 50 years), this method can be also used to compare the relative cost-effectiveness of investing in different species and actions, or indeed where an action may benefit multiple species. Standardized methods of comparing between conservation projects are essential tools for government agencies needing to make decisions about the allocation of investment across projects. This approach is now regularly applied by the Victorian State Government to help compare the relative cost-effectiveness of conservation actions across projects, including the outputs of the spatial conservation action planning tool (Bruce et al., 2020; Thomson et al., 2020). Consistent methods and metrics, such as those used here also have value because they can be easily updated with further expert elicitation as new information and knowledge comes to light.

The issues associated with decision-making for orange-bellied parrots are not unique—managers of critically endangered species must regularly make swift decisions despite uncertainty. Often resources, time and population size limit conservation actions, and the risk of failure is high. These factors can reduce the willingness of groups to allocate sufficient resources to what they view as the best management options where complex trade-off decisions are at play. The orange-bellied parrot provides a good example of a complex species management program which includes trade-off between investing in captive and wild management. Structured, transparent, and inclusive processes rooted in cost-effectiveness principles, such as the one implemented here, can help groups grapple with those common issues and help enable timely decisions using the best available information.

ACKNOWLEDGMENTS

We acknowledge the traditional aboriginal owners of country throughout south-eastern Australia pay our respect to them, their culture and their elders, past, present, and future. We thank the 2019 members of the Orange-bellied Parrot Recovery Team who contributed their knowledge and experience to the process and completed the expert elicitation survey, including: Mark Carey, Peter Copley, Andrew Crane, Steve Davidson, Paul Eden, Loren Foster, Toby Gallagher, Marianne Gee, Daniel Gowland, Mark Holdsworth, Michael Johnson, Kim Miller, Nicole Mojonnier, Craig Morley, Saint Rooke, Dejan Stojanovic, Shannon Troy, and Lisa Tuthill. We also thank those who have contributed knowledge, data, time, and expertise to the development of the decision support tools presented here, particularly Jim Thomson, Nick McCristal, and David Parkes.

CONFLICT OF INTEREST

The authors declare no potential conflict of interests.

AUTHOR CONTRIBUTIONS

Rachel A. Pritchard, Ella L. Kelly, and William L. Geary contributed to project design, data collection, data analysis and paper writing. James R. Biggs, Annika N. Everaardt,
Richard Loyn, Michael J. L. Magrath, Peter Menkhorst, and Carolyn J. Hogg contributed data and were involved in data collection, provided advise on experiment design and contributed to the writing of the paper.

DATA AVAILABILITY STATEMENT
De-identified dataset and code for analysis are provided here: https://github.com/elkelly/OBP_paperanalysis

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REFERENCES
Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48.

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., ... Possingham, H. P. (2009). Finite conservation funds mean triage is unavoidable. *Trends in Ecology & Evolution, 24*, 183–184.

Bottrill, M. C., Walsh, J. C., Watson, J. E. M., Joseph, L. N., Ortega-Argueta, A., & Possingham, H. P. (2011). Does recovery planning improve the status of threatened species? *Biological Conservation, 144*, 1595–1601.

Brazill-Boast, J., Williams, I., Rickwood, B., Partridge, T., Bywater, G., Cumbo, B., ... Maloney, R. F. (2018). A large-scale application of project prioritization to threatened species investment by a government agency. *PloS One, 13*, e0201413.

Bruce, M., Walsh, T. V., Rumpff, L., Cannan, L., Geary, B., Thomson, J., ... Loeffler, E. (2020). *Biodiversity 2037: Manual for the identification and prioritisation of biodiversity actions and knowledge gaps*. East Melbourne: Department of Environment, Land, Water and Planning.

Buxton, R. T., Avery-Gomm, S., Lin, H.-Y., Smith, P. A., Cooke, S. J., & Bennett, J. R. (2020). Half of resources in threatened species conservation plans are allocated to research and monitoring. *Nature Communications, 11*, 4668.

Canessa, S., Guiller-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., Taylor, G., Clarke, R. H., Ingwersen, D., Vandersteen, J., & Ewen, J. G. (2019). Risk aversion and uncertainty create a conundrum for planning recovery of a critically endangered species. *Conservation Science and Practice, 2*, e138.

Camalang, A. E., Currie, J., Giles, E., Forbes, G. J., Edge, C. B., Monk, W. A., ... Martin, T. G. (2021). Prioritizing threat management across terrestrial and freshwater realms for species conservation and recovery. *Conservation Science and Practice, 3*, e300. https://doi.org/10.1111/csp2.300

Carwardine, J., Martin, T. G., Finn, J., Reyes, R. P., Nicol, S., Reeson, A., ... Chadès, I. (2019). Priority threat management for biodiversity conservation: A handbook. *Journal of Applied Ecology, 56*, 481–490.

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.

Cook, C. N., Pullin, A. S., Sutherland, W. J., Stewart, G. B., & Carrasco, L. R. (2017). Considering cost alongside the effectiveness of management in evidence-based conservation: A systematic reporting protocol. *Biological Conservation, 209*, 508–516.

Department of Environment, Land, Water and Planning. (2016). *National recovery plan for the orange-bellied parrot Neophema chrysogaster*. Canberra: Australian Government.

Elliott, G. P., Merton, D. V., & Jansen, P. W. (2001). Intensive management of a critically endangered species: The kakapo. *Biological Conservation, 99*, 121–133.

Fitzgerald, D. B., Smith, D. R., Culver, D. C., Feller, D., Fong, D. W., Hajenga, J., ... Young, J. A. (2021). Using expert knowledge to support endangered species act decision-making for data-deficient species. *Conservation Biology. 0(0)*, 1–12. https://doi.org/10.1111/cobi.13694

Gerber, L. R., Runge, M. C., Maloney, R. F., Iacoma, G. D., Drew, C. A., Avery-Gomm, S., ... Zablan, M. A. (2018). Endangered species recovery: A resource allocation problem. *Science, 362*, 4–286.

Geyle, H. M., Woinarsi, J. C. Z., Baker, G. B., Dickman, C. R., Dutson, G., Fisher, D. O., ... Garnett, S. T. (2018). Quantifying extinction risk and forecasting the number of impending Australian bird and mammal extinctions. *Pacific Conservation Biology, 24*, 157.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., & Ohlson, D. (2012). *Structured decision making: A practical guide to environmental management choices*. Hoboken, UK: John Wiley & Sons. Retrieved from http://ebookcentral.proquest.com/lib/unimelb/detail.action?docID=862851

Harley, D., Mawson, P., Olds, L., MacFadden, M., & Hogg, C. (2018). The contribution of captive-breeding in zoos to the conservation of Australia’s threatened fauna. In *Recovering Australian threatened species: A book of Hope* (pp. 281–294). Melbourne, Australia: CSIRO Publishing.

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.

Hernandez, P. A., Graham, C. H., Master, L. L., & Albert, D. L. (2006). The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography, 29*, 773–785.

Iacoma, G. D., Sutherland, W. J., Mappin, B., Adams, V. M., Armsworth, P. R., Coleshaw, T., ... Possingham, H. P. (2018). Standardized reporting of the costs of management interventions for biodiversity conservation: Conservation cost standards. *Conservation Biology, 32*, 979–988.

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services*. Bonn, Germany: IPBES. Retrieved from https://ipbes.net/global-assessment

Joseph, L. N., Maloney, R. F., & Possingham, H. P. (2009). Optimal allocation of resources among threatened species: A project prioritization protocol. *Conservation Biology, 23*, 328–338.

Martin, T. G., Kehoe, L., Mantyka-Pringle, C., Chadès, I., Wilson, S., Bloom, R. G., ... Smith, P. A. (2018). Prioritizing recovery funding to maximize conservation of endangered species. *Conservation Letters, 11*, e12604.
