Bridging the research-management gap: using knowledge exchange and stakeholder engagement to aid decision-making in invasive rat management

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Abstract The world is facing a biodiversity crisis. Nowhere is that more apparent than on oceanic islands where invasive species are a major threat for island biodiversity. Rats are one of the most detrimental of these and have been the target of numerous eradication programmes; a well-established conservation tool for island systems. For at-risk native species inhabiting large, populated islands, where rat eradication is not an option, control of rat populations has been conducted but this requires continuous management and therefore its long-term viability (and that of the at-risk native species which the project aims to protect) can be uncertain. Large-scale rat management areas or 'mainland islands' have been successfully developed in New Zealand. However, large-scale management is a long-term investment with huge financial implications and committing to such an investment can be met with reluctance. This reluctance, and its subsequent hindrance to decision-making, can be caused by uncertainty relating to species conservation outcomes, and the multiple objectives of stakeholders. We address the issue of uncertainty and the importance of communication between all stakeholder parties in relation to the Mauritius olive white-eye (*Zosterops chloronothos*), a critically endangered passerine endemic to Mauritius and highly threatened by invasive rats. Specifically, we illustrate how the combination of scientific research and communication, knowledge exchange, and stakeholder workshops, can address some of the barriers of decision-making, helping to bridge the research-management gap, and enable the timely expansion of existing rat management for the benefit of this highly threatened bird.

Keywords: mainland islands, Mauritius, rat control, uncertainty, *Zosterops chloronothos*

INTRODUCTION

The world is facing a biodiversity crisis and nowhere is that more apparent than on oceanic islands where invasive species are a major threat (Jones & Merton, 2012; Rodrigues, et al., 2014). Recent research has identified islands as conservation priority areas for evolutionary distinct and globally endangered (EDGE) species, increasing the importance of conservation for island endemics from areas such as Hawaii, New Zealand, the Mascarenes and the West Indies where there are high extinction rates (Diamond, 1989; Jetz, et al., 2014). A major cause of extinction for island birds has been invasive species and rats are the most detrimental; having reached around 90% of all islands they have been identified as a massive threat to ecosystems (Atkinson, 1985; Towns, et al., 2006; Blackburn, et al., 2014).

The eradication of invasive rats from islands is a well-established conservation tool with 474 successful eradications of *Rattus rattus* and *R.norvegicus* (black rat and brown rat) between 1951 and 2014 (Towns & Broome, 2003; DIISE, 2015). However, for species inhabiting large, populated islands, where eradication is not an option, localised rat control has to be conducted. However, this is not a long-term solution for many species of conservation interest as the areas of control can be too small to create viable populations and rat reinvasion rates can be too high. An alternative are large-scale rat management areas or 'mainland islands' which have been successfully developed in New Zealand (Saunders & Norton, 2001; Butler, et al., 2014). However, large-scale management is a long-term investment with huge financial implications and in a world of limited resources and accountability, committing to such an investment can be met with reluctance (Cullen, et al., 2001; Burns, et al., 2012; McCarthy, 2014; Smith, et al., 2015). This reluctance, caused by uncertainty, could hinder decision-making and result in projects maintaining inadequate small-scale management which does not ensure species survival.

Here we address this issue of outcome uncertainty and the importance of communication between scientists, project managers and stakeholders concerning the Mauritius olive white-eye (*Zosterops chloronothos*), a critically endangered passerine endemic to Mauritius and highly threatened by invasive rats (Maggs, et al., 2015; Birdlife International, 2016). The olive white-eye is part of an ancient Indian Ocean white-eye lineage and is in the top 10% of the EDGE bird species list based on their high level of endemism and evolutionary distinctiveness (Warren, et al., 2006; Jetz, et al., 2014). Research has identified rats (black and brown) as a major limiting factor for olive white-eye, preying on nests and causing an estimated annual population decline of 14%; however, rat management can mitigate this threat and ensure population persistence (Maggs, et al., 2015). Based on these findings, small-scale management has been implemented over remnant olive white-eye breeding territories around the Combo region of the Black River Gorges National Park (BRGNP), Mauritius (Fig. 1; Ferrière, et al., 2016). However, small-scale rat management is not adequate enough to enable olive white-eye population viability in the long-term, highlighting the need for large-scale management in the form of a mainland island (Maggs, 2017).

Here we illustrate how a collaborative approach to conservation management can aid decision-making through communication between scientists, managers, and project stakeholders which can facilitate scaling up small-scale rat control to the implementation of a mainland island. For highly threatened species, such as the olive white-eye, this approach ensures the timely implementation of evidence-based decisions and bridges the gap between research and management.

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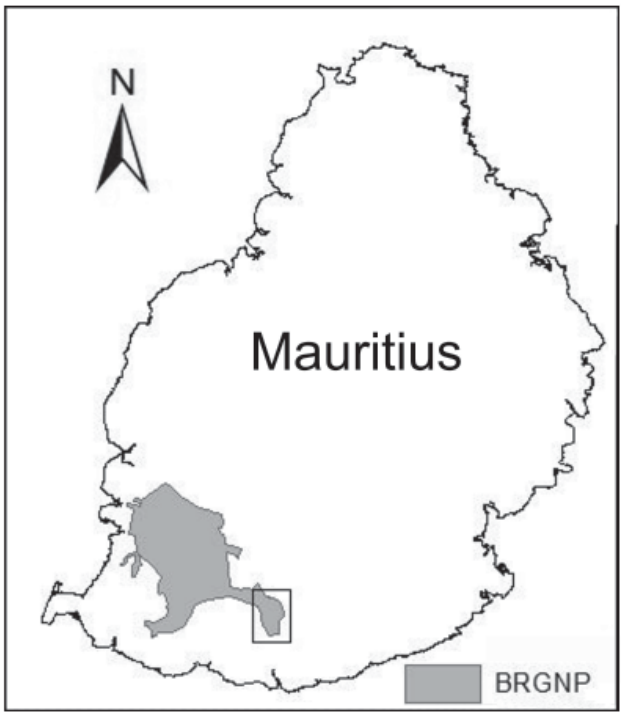

Fig. 1 Mauritius, illustrating the location of the Combo region (black rectangle) within the Black River Gorges National Park (BRGNP).

METHODS

To combat uncertainty, two tools were used; knowledge exchange and stakeholder workshops, in combination with scientific research, to break down some of the barriers to decision-making.

Knowledge exchange

When scaling-up invasive species management there are many logistical and financial considerations. For conservation programmes which have never established such large-scale management, accounting for these considerations and identifying limitations is difficult. Methods and costings of mainland islands have been published (Clapperton & Day, 2001; Gillies, 2002; Gillies, et al., 2006; Scofield, et al., 2011; Burns, et al., 2012; Norbury, et al., 2014; Carter, et al., 2016), but detailed information regularly remains in undocumented individual staff experiences or when data is gathered it remains in inaccessible forms and grey literature. This compounds information inaccessibility resulting in personnel within programmes making decisions based on limited experience rather than evidence (Sutherland, et al., 2004; Pullin & Knight, 2005; Kapos, et al., 2008). Gaining first-hand experience can enable a nuanced understanding of both short and long-term management, which for robust and realistic costing is vital.

To identify the considerations which should be made and gain first-hand information a knowledge exchange was conducted with rat control/eradication experts and conservation managers in the field across New Zealand during April–May 2015. These individuals were identified either through the Hihi Recovery Group, which works closely with numerous mainland island managers, or identifying people through published literature. Using a 'boundary organisation' approach (Cook, et al., 2013; Cvitanovic, et al., 2015) scientific researchers facilitated knowledge exchange between experts across New Zealand and project managers in Mauritius. Grey literature and expert knowledge were gathered, identifying potential management techniques and the demands and practicalities involved which aided scientific research.

The sites visited across New Zealand varied in management type and size but all targeted invasive rat species (black and brown). Meetings with the experts and managers were standardised by discussing the same topics, these included:

- Management history. Have other management techniques been previously used, if so, what was the scale of the management and why did it change?
- Identifying mainland island area. What process was used to identify locations, what were the constraints and benefits considered, how were topography and river courses tackled and what was the conservation objective of the mainland island?
- Management technique. What rat management technique is currently used, over what area, and how long has it been in place, is there a buffer zone, how many staff and volunteers work on the site, have additional techniques been trialled and if so what were the outcomes?
- Maintenance. How often are the traps/stations/fence checked or re-baited, how long does this take and how many staff members does this require, what maintenance demands are there, how often does equipment need replacing and how do weather conditions impact the management and work load?
- Management efficiency. Is rat abundance or presence monitored in the management site, if so, what is the rate of rat incursions or rat abundance and is there a response protocol and if so how quickly is this implemented?

Stakeholder workshops

Improving knowledge exchange between decision–makers and scientists is fundamental to support sustainable evidence-based management. However, despite evidence being available, in some cases decisions can still remain hindered due to multiple objectives from a mix of stakeholders with differing priorities, values or conflicting interests (Conroy, et al., 2002). Science can help overcome these obstacles by providing tools to inform decisions and aid stakeholders to make informed trade-offs if required.

An approach termed 'interdependency' recognises that all participants in knowledge exchange can contribute, emphasising the need for a two-way exchange between scientists and decision-makers (Contandriopoulos, et al., 2010; Cvitanovic, et al., 2015). This can increase understanding and stakeholder communication through access to the best scientific information, enabling science-based decision-making (Meek, et al., 2015). This process supports collaboration and bridges the research-implementation gap (Knight, et al., 2008), but requires the roles of participants to be outlined from the start to ensure clarity throughout the workshop process; identifying expert advisors, decision-makers or workshop facilitators to mediate between stakeholders.

To ensure collaboration between scientific researchers and decision-makers and avoid conflicting interests, a stakeholder workshop was held in the case of the olive white-eye. During this workshop there were three main objectives to be considered by decision-makers when tackling development from small-scale localised management to a large-scale mainland island: should a mainland island be established, what size it should be to enable population viability and management cost-

effectiveness. The workshop was facilitated by scientific researchers, from the Zoological Society of London (ZSL) and University College London (UCL), who provided expert advice on these three objectives; this was accompanied by field staff providing first-hand information on the status of the species and the current management in place from the Mauritian Wildlife Foundation (MWF) (Ferrière, et al., 2016).

Scientific research on the olive white-eye has successfully developed decision-making tools identifying the mainland island area required to ensure population persistence and management cost-effectiveness (Maggs, 2017). These decision-making tools outline scenarios and assist in identifying informed, evidence-based management for the remnant olive white-eye population, ensuring population persistence and clear financial and logistical requirements over 50 years (see Maggs, 2017 for details). Using these tools, discussions were held between the expert advisors (scientific researchers and field staff) and the key decision-makers (project managers, organisation directors, project funders and government officials) where the scientific evidence was discussed, expert opinion shared and questions raised through open dialogue and in a transparent environment.

RESULTS

Knowledge exchange

In total, over four weeks, 30 individuals participated in the knowledge exchange including managers and volunteers from eight mainland island sites and experts from additional conservation companies, central government (Department of Conservation) and specialist groups across New Zealand (Fig. 2). The rat management techniques identified across these sites and discussed included trapping, ground-based poisoning, self-resetting traps and predator-proof fencing. The information gathered through the knowledge exchange was vital for the detailed long-term budgeting of a mainland island in Mauritius

Fig. 2 The distribution of the mainland islands visited during a knowledge exchange in April and May 2015 and the organisations who participated: Hihi Recovery Group, Biodiversity Restoration Specialists, (1) Shakespear Open Sanctuary (Auckland Council), (2) Tawharanui Open Sanctuary (Auckland Council), (3) Sanctuary Mountain Maungatautari, (4) Boundary Stream Mainland Island (Department of Conservation), (5) Rotokare Scenic Reserve Trust, (6) Bushy Park Sanctuary, (7) Zealandia, (8) Rotoiti Nature Recovery Project (Department of Conservation).

under each of the four management techniques, providing detail into the equipment and materials required and labour demands. This first-hand information was combined with existing literature and fed directly into scientific research conducting cost-effectiveness analysis for the four rat management techniques, accounting for the costs over 50 years. By accurately budgeting each management technique over 50 years the long-term cost-effectiveness of the four rat management techniques against olive white-eye population quasi-extinction risk were robustly illustrated; which acts as the effectiveness score of the rat management techniques (Table 1; see Maggs, 2017 for full details).

Stakeholder workshop

Eighteen delegates from six organisations participated in the stakeholder workshop; these included project management (MWF), organisation directors (MWF and Durrell Wildlife Conservation Trust), scientific researchers (ZSL and UCL), project funders (Chester Zoo) and government officials (National Parks and Conservation Service).

The olive white-eye is a priority species for conservation in Mauritius and it was decided, based on the scientific findings presented, that a mainland island should be established, aiming for the minimum area identified by Maggs (2017) of 275 ha; required at a low population density to ensure a 99% chance of population persistence over 50 years. Using the cost-effectiveness analysis conducted by Maggs (2017), and presented at the workshop, the rat management technique decided upon was Goodnature®A24 self-resetting traps based on their cost-effectiveness, specifically, their low labour requirements and competitive financial costs (Maggs, 2017). Although a relatively new technique, their long-term costs, maintenance and replacements, were accounted for based on manufacturer recommendations; the same long-term costs were accounted for all of the techniques discussed.

Trapping was considered too labour intensive even though it was highly cost-effective when considering equipment costs alone. Poison was ruled out based on the potential environmental impacts and the overall high cost of poison and associated labour. Predator-proof fencing was not considered as an option based on the huge initial setup cost and the long-term financial commitment, also the habitat loss associated with installing a predator-proof fence (at least 8m of forest would need to be cleared both sides of the fence to prevent mammals jumping over (Day, 2004); with highly threatened flora species within the BRGNP this cannot be justified at this time). Fencing is the most cost-effective technique when creating a mainland island over vast areas and could maintain zero rat densities, which the other techniques cannot achieve, but complete rat removal is not required for olive white-eye viability, merely reduced rat densities. The techniques combined were not discussed but could be in an additional option to consider in the future.

As well as the rat management technique it was also identified that the mainland island would have to take a 'multi-species/multi-threat' approach, targeting a number of invasive species until the impact of individual species is known in order to avoid the 'surprise factor' of secondary unexpected and undesired results (Alterio, et al., 1999; Saunders & Norton, 2001; Caut, et al., 2009; Carter, et al., 2016). This would involve targeting small Indian mongoose (*Urva auropunctata*), feral cats (*Felis domesticus*) and potentially crab eating macaques (*Macaca fascicularis*) as well as rats. This level of predator control would also benefit other highly threatened endemic species such as the Mauritius cuckoo-shrike (*Coracina typica*), echo parakeet

Table 1 The minimum area required for a mainland island to ensure a 99% chance of population persistence for the Mauritius olive white-eye over 50 years, the total cost of establishing and running a mainland island over 50 years, the establishment costs alone and the average annual costs; comparing trapping, ground based poisoning, self-resetting traps and predator-proof fencing (Maggs, 2017).

	Area (ha)	Total Cost (£ millions)	Establishment Costs (£)	Annual costs (£)
Trapping	275	2.9	186,700	37,908
Poisoning	300	7.9	40,925	157,913
Self-resetting traps	275	3.8	130,315	37,505
Predator-proof fencing	275	5.7	1,766,472	80,196

(*Psittacula eques*) and Mauritius pink pigeon (*Nesoenas mayeri*), which are found within the same regions.

Finally, it was suggested that, if possible, the site of a mainland island should be combined with existing conservation management areas (CMAs), which have been established on mainland Mauritius in the BRGNP to protect native vegetation communities by removing exotic flora (Cheke & Hume, 2008). The control of rats would encourage habitat regeneration and resources could be combined for both invasive fauna and flora control.

DISCUSSION

This case study aimed to illustrate how a collaborative approach to conservation management, through knowledge exchange and stakeholder workshops, can aid communication and decision-making. In this case, it was used to guide the timely expansion of rat management from existing small-scale control (32 ha) to a mainland island (275 ha), relatively quickly and effectively, which is vital for highly threatened and declining species, such as the olive white-eye.

A mainland island has never been established in Mauritius. The rat management techniques used for the olive white-eye have been limited to localised snap-trapping and ground-based poisoning (Maggs, et al., 2015). In the past, feasibility studies have been conducted for various techniques, including predator-proof fencing, but taking the step from localised to landscape scale management was not taken due to resource limitations and long-term financial and logistical uncertainty (Day, 2004).

Here we have tackled the barriers of logistical and financial uncertainty and decision-making through a 'co-production' approach with full cooperation between scientific researchers and decision-makers (Cvitanovic, et al., 2015; van Kerkhoff & Lebel, 2015). Conducting knowledge exchange allowed project managers to gain first-hand information and fill knowledge gaps from leading experts in the field of invasive species management. Incorporating this into a robust analysis of the financial and logistical requirements of a mainland island helped to minimise uncertainty, justify expenditure and identify the long-term financial support required from funders (Maggs, 2017). A stakeholder workshop then allowed scientific research to be fed directly back to all involved, successfully highlighting project priorities and enabling all participants to come to a unified decision on future management goals for the olive white-eye; guiding science-based conservation while maintaining transparency among stakeholders.

Through this collaborative approach, in just three years, long-term management goals have been identified to establish the first mainland island in Mauritius to protect the olive white-eye and ensure long-term population viability. Implementation of a mainland island within the national park has started in the Brise Fer CMA with the introduction of olive white-eye planned for 2021 if rat management can maintain adequately low rat densities over a prolonged period. The area of the mainland island will be increased with growth in capacity, aiming to reach the full mainland island size (275 ha) within 5–10 years. Without these processes, project decisions could have taken years longer to reach the same point if field trials were required (to test all potential rat management techniques), accurate long-term financial requirements were not known, open discussion was not had or scientific research was not fed back to decision-makers; delays which would have detrimental impacts on highly threatened and declining species like the olive white-eye.

The methods discussed here address ways to approach existing challenges, reduce uncertainty and enable evidence-based decision-making. The approaches taken, although case-specific, provide methods for researchers and managers to adopt and apply to different scenarios depending on the decision-making barriers and uncertainty being faced; bridging both the knowledge-action boundary and the research-management divide (Roux, et al., 2006; Cook, et al., 2013), which is rarely achieved in conservation.

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