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Title: Be nimble with threat mitigation: Lessons learnt from the reintroduction of an endangered species

Running Head: Lessons learnt from reintroductions

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NR wrote the manuscript; ND, RB, DM, CM, KR, JH, DBL provided edits on the manuscript; NR, ND, RB, DL, CM, DM conceived and designed the research and reintroduction program; ND, DM implemented threat mitigation; KR, JH conducted disease risk assessments.

Abstract

Reintroductions are increasingly being used to restore species and ecosystems. However, chances of successful establishment are often low. Key to improving success is careful consideration of threats, threat mitigation, monitoring and subsequent improvement to management. We demonstrate this planning, implementation and review process using the reintroduction of an endangered mesopredator, the eastern quoll *Dasyurus viverrinus*, in the first attempt to re-establish it in the wild on mainland Australia. In March 2018, 20 captive-bred quolls (10 male, 10 female) were released into Booderee National Park and monitored via telemetry, camera and cage trapping. There were many unknowns and, despite thorough consideration of threats, there were surprising outcomes. Within 3 months, 80% of animals had died; half due to predation, an expected threat. Other threats were unexpected yet, due to good monitoring and responsive management, were quickly detected and effective mitigation implemented. These learnings have been incorporated into revised translocation procedures. One year later, four founder quolls remained and had successfully bred. We highlight lessons applicable to other reintroductions. These are, the importance of: 1) conducting a thorough review of threats and implementing appropriate mitigation; 2) targeted monitoring and responsive management; 3) effective communication, education and engagement with the local community and stakeholders; and 4) ensuring learnings are disseminated and incorporated into future translocation plans. Threat assessment is an important step in identifying potential reasons for failure. However, actual threats can be realized only via experimentation and monitoring. Applying this knowledge to future reintroduction attempts can increase their chance of success.

REC-19-141 Lessons learnt from reintroductions

Keywords: reintroduction; threatened species; monitoring; threat mitigation; conservation translocation

Implications for Practice

- Reintroductions often fail; yet, we demonstrate how quick, reactive, malleable, fact-based management techniques, guided by robust real-time monitoring can effectively enhance the likelihood of success, and support founding populations undergoing reintroduction to new habitat.
- Using the eastern quoll *Dasyurus viverrinus* as our case study, we outline a template for planning, implementation and review that includes a pre-release threat assessment and post-release threat evaluation.
- We advise reintroductions programs to conduct a thorough review of threats, implement appropriate mitigation, have targeted monitoring and responsive management, ensure good engagement, disseminate findings and incorporate them into future planning.

Introduction

A reintroduction is defined as the translocation of a species into an area where it once occurred (Armstrong & Seddon 2008). Translocations are required to re-establish species due to local extinction or, in the case of population augmentation, to bolster populations that have suffered population decline (Seddon et al. 2014). Reintroductions promote species conservation by securing broader distributions of a species and facilitating restoration of lost ecosystem functions (Seddon et al. 2014). They are also an opportunity to test causes of past decline, current threats to reestablishment, and effectiveness of management actions in mitigating these threats (Caughley 1994; Lindenmayer et al. 2018). Reintroductions, especially faunal translocations, are resource-intensive compared to other actions such as the conservation of habitat and animals *in situ* (Lindburg 1992); and should not be attempted without explicit considerations of costs and benefits (Kleiman 1989; IUCN / SSC 2013). Faunal translocations include consideration of where animals are sourced, genetic viability, transportation, quarantining of pest and disease, supplementary feeding, and predator control (IUCN / SSC 2013). In addition, there are ethical considerations regarding experimental animal translocations (McCoy & Berry 2008). This is particularly relevant for threatened species, as translocations can have a proportionally greater negative impact (e.g. mortality of individuals can reduce population size) or positive impact (e.g. successful translocation can enhance species conservation) on the future survival of a species than a non-threatened species population (Griffith et al. 1989; IUCN / SSC 2013).

Good planning, review of knowledge, and risk assessments are central to designing an effective reintroduction plan (IUCN / SSC 2013). This, combined with targeted monitoring and evaluation, allows knowledge to be gained as to what factors are important to enabling species to establish

(Sheean et al. 2012; Robinson et al. 2018). Much of the documentation on reintroduction planning remains buried in gray literature (e.g. translocation plans) or is collated but not subject to peer review (e.g. Soorae 2008; Soorae 2010; Soorae 2011; Soorae 2013; Soorae 2016; Soorae 2018). The latter is a useful catalogue but is subject to potential biases in reporting and evaluating, particularly if objectives are not clearly defined and successes and failures are not equally reported (Ewen et al. 2014). Few examples in peer-reviewed journals exist of programs that document the planning process (but see Pedler et al. 2018) or evaluate management effectiveness (Pérez et al. 2012). In many instances, reintroductions have little or no dedicated monitoring, and this inhibits the evaluation of, and reporting on, factors contributing to program success or failure (Fischer & Lindenmayer 2000; Pérez et al. 2012). It is likely that many reintroductions fail, or require multiple attempts for establishment, but a lack of unbiased reporting prevents such scrutiny (Fischer & Lindenmayer 2000; Sheean et al. 2012). Reintroduction success lies not only in the re-establishment of the target species but also in the knowledge gained about factors contributing to program success (or failure), such as the effectiveness of management actions. Good planning, documentation of risks and risk mitigation coupled with monitoring and evaluation are important to determine the effectiveness of management actions and decisions in contributing to program success (Sutherland et al. 2010; Pérez et al. 2012; IUCN / SSC 2013). This enables new knowledge to be shared, and improvements made to future translocations.

The development of an effective reintroduction program should follow a sequence of logical steps starting with defining program objectives (IUCN / SSC 2013) (Fig. 1). These steps are sequential but knowledge gained through the process can be fed back into a program at different stages, and the cycle continued. In this paper, we document our approach to planning, designing and implementing a reintroduction program for the eastern quoll (*Dasyurus vivverinus*) to Booderee National Park (BNP) on mainland Australia. We outline our threat assessment and mitigation, decision making, main results and learnings from this program. More detail of our case study can be found in the Supporting Information (Supplement S1, S2) and in the eastern quoll translocation plan (DoEE 2017). We conclude with a discussion of the broader lessons learnt that are applicable to other reintroduction programs.

Case study of the eastern quoll

The eastern quoll, *Dasyurus viverrinus,* is a small carnivorous marsupial once common throughout southeastern Australia but now listed as endangered both nationally and internationally (Burbidge & Woinarski 2016; DoEE 2018). Its distribution formerly extended from northern New South Wales along the coast and hinterland through to South Australia and Tasmania (Peacock & Abbott 2014), and probably extended into inland New South Wales (Abbott 2013; Atlas of Living Australia 2018; Fig. 2). A combination of disease (Peacock & Abbott 2014) and predation by the introduced red fox (*Vulpes vulpes*) (Short & Calaby 2001) are likely causes of extinction of the species on the mainland, with the only wild population remaining in Tasmania. The eastern quoll currently occupies a variety of habitats across Tasmania including grassland, farmland and forest (Fancourt et al. 2015a). On the mainland, the species was recorded in similarly diverse habitats, with some of the last known locations including coastal rocky foreshores and suburban parks (Robinson 1988; Dickman et al. 2001).

The diet of the eastern quoll consists primarily of invertebrates and mammals, and to a lesser extent birds and vegetable matter (Blackhall 1980; Godsell 1983; Fancourt et al. 2018). Eastern quolls are opportunistic feeders, foraging on carrion and consuming seasonally available prey (Fancourt et al.

2018). The species has two distinct color morphs (black or fawn), with white spots on the body but not the tail and is sexually dimorphic with males on average 1,250 g (range 900-2,000 g) and females averaging 850 g (700-1,100 g) (Godsell 1983).

Program objectives and criteria for success

The area targeted for the translocation of the eastern quoll was Booderee National Park (BNP), a 6,400 ha reserve co-managed between traditional owners, the Wreck Bay people, and Parks Australia, and situated on the south east coast of Australia (Fig. 2; BNP Board of Management & Director of National Parks 2002). BNP is considered to be within the former range of the eastern quoll based on historical occurrence in the region (Robinson 1988; Short & Calaby 2001; Peacock & Abbott 2014). The species was known from Wandandian, 10 kms west of BNP, but considered extinct by 1919 (Short & Calaby 2001; Peacock & Abbott 2014). Records between 1920 and 1930 further show the species occurred at Comerong Island, 24 km to the north (Robinson 1988), with more recent records in the Illawarra region 60-90 km to the north at Port Kembla in 1956 and Bulli in 1961 (Robinson 1988). BNP supports a wide variety of vegetation communities (Taws 1997), including those similar to currently occupied habitat in Tasmania (e.g. grassy clearings in a mosaic of forest, Fancourt et al. 2015a) and formerly occupied territories in the Illawarra region (e.g. coastal rocky foreshores, closed and open forest, Robinson 1988).

The reintroduction program at BNP aims to restore the species to an area it was known to occur historically, thereby re-establishing a mainland population, and reducing the risk of extinction in the wild. To achieve this, the program plans to establish a self-sustaining wild population of eastern quoll at BNP from the translocation of approximately 100 captive-bred individuals over 3 years into unfenced, predator managed areas of BNP. The reintroduction of locally extinct species has been endorsed by the traditional owners of BNP, the Wreck Bay people (BNP Board of Management & Director of National Parks 2002).

Our measures of success for the reintroduction program at BNP are in the short term (1 year): stable or increasing abundance and evidence of breeding (pouch young or distended nipples); medium term (2 years): increasing population with evidence of adult animals born in BNP; and long term (>5 years): population stable and dispersing from the initial release area (DoEE 2017). This paper describes the planning and implementation of the first release (i.e. Year 1) of 20 eastern quolls to BNP; with knowledge learnt from this pilot study informing future translocations.

Methods

Threat assessment and mitigation planning

We outlined potential threats to the species' reintroduction as part of a qualitative threat assessment, and included consideration of past, current and future threats (IUCN / SSC 2013). Park managers and ecologists reviewed available knowledge of the species' biology, habitat requirements and susceptibility to threats, along with long-term data on ecological values, and threat management (Lindenmayer et al. 2013a; DoEE 2017) to compile a detailed list of potential threats (Table 1, Supplement S1). The BNP science manager (ND) then qualitatively assigned each threat a rating for possibility of arising and predicted consequences at the population level. We combined these qualitative scores to give an overall threat rating. Further details on threats and how threats were assessed are provided in Supplement S1.

The risk assessment included a Disease Risk Assessment (DRA) to review the reported and anecdotal diseases reported in the species, in closely related species, and in other species at the site of collection and the site of release (Jakob-Hoff R.M. et al. 2014; OIE & IUCN 2014). These data were analyzed to identify and assess potential hazards and formulate a health assessment strategy. The goal of the DRA was to mitigate the risks posed through the unintentional translocation of potentially adverse parasites and pathogens, while retaining valuable host-parasite relationships. The health assessment process included ecto and endoparasite collection and identification, physical and morphometric examinations, haematology, serum biochemistry and specific tests for known potential pathogens.

We identified eleven threats. Of these, four were assessed as high risk: 1) predation by introduced carnivores; 2) mortality caused by parasitism by the paralysis tick (*Ixodes holocyclus*); 3) loss of body condition; and 4) overdispersal, or dispersal beyond the management boundary. For all threats, we outlined mitigation practices to minimize their occurrence and / or impact (Supplement S1). We further outlined decision triggers and protocols for management intervention to ensure decisive action (Lindenmayer et al. 2013b; Cook et al. 2016). For example, if overdispersal occurred, we had decision triggers for the point of intervention, trap permits for neighboring areas to capture and return animals, and options for aerial tracking of animals. Our threat assessment and mitigation was reviewed and approved by The Australian National University Animal Experimentation Ethics Committee (protocol number A2016/30); this process enhanced the application of animal welfare measures to mitigate stressors experienced by the animals.

Source population

Captive-bred animals were sourced from two Tasmanian sanctuaries, Devils@Cradle and Trowunna Wildlife Sanctuary. Captive breeding capacity at two sanctuaries was increased over two years prior to reintroduction to provide a harvestable surplus of captive eastern quolls for translocation. These sanctuaries maintain populations with high genetic diversity through managed stud books, sharing of breeding stock between facilities and regular supplementation with wild animals, often via orphaned young. The minimum generation time to wild (at least one parent) was between 1 and 2, with wild individuals sourced from seven different locations, representing significant genetic population structure (Cardoso et al. 2014). Genetic sampling of all founder individuals and their offspring will be used to monitor genetic diversity over time.

Release design and logistics

Designing and coordinating the release of the eastern quoll involved consideration of factors that could augment or hinder a successful outcome (Batson et al. 2015). We scheduled the release date for March to minimize potential mortality caused by paralysis tick; as identified in our threat assessment (Supplement S1). Our study design included testing of two release methods: immediate and delayed (Supplement S2). Other logistics and planning included pre-release health and welfare checks, transport and release logistics, and supplementary feeding post release (Supplement S2). We ensured that we had an excellent science-management-stakeholder partnership by creating a team comprised of staff from the lead management agency, Parks Australia, researchers from The Australian National University and partner organizations, Rewilding Australia and Taronga Conservation Society. Our reintroduction team held regular meetings to keep everyone up-to-date with progress and resolve issues. Science management partnerships and well-functioning teams are recognized ingredients in successful threatened species monitoring and management, including at BNP (Lindenmayer et al. 2013a; Legge et al. 2018).

Monitoring

We designed an intensive, targeted monitoring program to track the fate of each individual animal that was released. This program ensured that we gathered appropriate data to determine survival, movement and threats to survival but with enough flexibility to respond to emerging issues. We monitored animals via a combination of radio tracking, GPS, cage trapping, cameras stationed at feeding stations and habitat logs, and incidental observations. One week prior to release, we fitted each quoll with a 35 g GPS / VHF collar with mortality signal (Telemetry Solutions, model FLR V LS14250). Fitting the collar one week prior to release allowed us to check the fit of collars, monitor any collar rub and re-adjust collars as necessary to minimize potential negative issues caused by collar injury.

We expected changes in neck circumference due to initial weight losses after release (e.g. Moseby et al. 2011), so we scheduled cage trapping after two weeks to ensure collars were still appropriately sized and monitor weight changes. Following release in March 2018, we tracked animals for approximately 100 days. In the first two months, we tracked animals almost daily. After this period, we continued tracking three to four times per week until 25 June 2018, when we removed collars on all remaining animals. We planned to continue monitoring via other methods (e.g. camera, cage trapping) past this point according to requirements.

Evaluation

We regularly reviewed monitoring data in the first 3 months to facilitate prompt response to new information. The first few days to months following a translocation are typically when most mortality occurs as animals adjust to new surroundings and are exposed to new threats (Moseby et al. 2011; Jolly et al. 2017). The reintroduction team kept in regular communication to convey new information (e.g. mortalities, movements), work through issues and make prompt decisions.

Results

Cumulative mortality

In March 2018, we released 20 captive-bred eastern quolls (10 male, 10 female) into the wild in BNP in the first attempt to re-establish eastern quolls on mainland Australia beyond fenced exclosures. Sixteen quolls (seven females and nine males) died in the first 14 weeks following release (Fig. 3, Table S1). Quolls succumbed to a variety of causes of death, primarily predation (female = 4, male = 4) and vehicle collisions (female = 2, male = 2). Predation was attributed mainly to foxes (n = 5); two with evidence of caching of the deceased animal, an additional three likely due to the detection of the red fox in the vicinity and with injuries consistent with fox predation. Two quolls were taken by domestic dogs (*Canis familiaris*); confirmed via reported observation of killing, and detection of dog DNA in saliva on the dead quoll. One quoll was found consumed by a diamond python (*Morelia spilota*). Two quolls succumbed to disease; the first was found in poor body condition with eye lesions and was later euthanised due to confirmation of systemic lymphoma, the other was attributed to a probable *Sarcocystis sp.* infection. One quoll died during surgery to resolve an infection caused by collar injury. The cause of death of one individual remains unknown due to advanced autolysis. Our monitoring revealed that, of 11 threats identified *a priori*, five manifested within the first year post-release (Table 2). Based on this new evidence, we re-evaluated our threat rating and reviewed our risk mitigation (Table S3).

Risk mitigation

The red fox was detected in the original release area by tracks and on cameras; this triggered the targeted deployment of Canid Pest Ejectors (CPE) and employment of a professional shooter. Despite multiple nights searching for foxes in the park, none were seen or shot. However, a fox was later detected on a camera trap triggering a CPE. A quoll was detected on camera at a bait station where a bait had been excavated; the bait was not found and was assumed ingested and the identified quoll remains alive. As per our protocols, this excavation triggered the removal of all buried baits in known quoll locations and replacement with additional CPEs.

Following two road fatalities in 4 days (and four in total), we decided to bring all quolls in a high-risk area (n = 4) into temporary care; this occurred 6 weeks post-release. Two accredited local wildlife carers provided temporary care off-park in small fenced enclosures, approximately 2 x 3 x 2 m. Three quolls remained in the park as their locations were deemed to be at low risk of road trauma. We re-released quolls into a different area of the park 2 weeks later after ensuring that this new location had low risk of road trauma and fox predation. Quolls that had not been taken into captivity were relocated to this new release point 1 to 2 days later. No further road deaths occurred since relocation within the timeframe reported (13 months).

Two pythons were found in quoll inhabited areas and were relocated elsewhere in the park. The first python was detected after consuming a quoll and, after surgery to remove the collar, was relocated.

The second python was found inhabiting a known quoll den location and was similarly removed to another location in the park.

Survivors and breeding

Approximately 4 months post-release, we re-captured the remaining four quolls (three female, one male) and removed collars. Quolls had increased their release weight by 4-14% (Table S2) and all surviving females each carried five viable pouch young between 15 and 30 days of age. At 8 months, we recaptured all four adult quolls and seven juveniles (5 male, 2 female). Prior to trapping, two male juvenile quolls were killed by domestic dog when they entered a dog enclosure; this dog was removed from the park. Following trapping, a female juvenile entered another dog enclosure and was killed. The juvenile quolls were presumably attracted by dog food and were small enough to pass through the barrier fence. Twelve months after initial release, camera monitoring and cage trapping confirmed that the four adult quolls and at least 1 sub-adult quoll born at the park remained within the release area. At 13 months post-release, one of the founder adults (female) was detected outside the park; she was caught and re-released back into the park. Juvenile quolls unaccounted for may still persist in BNP but may have dispersed beyond the area targeted for monitoring.

Discussion

Twelve months post release, 20% of the founder population was confirmed alive. All surviving females had successfully bred, at least nine juveniles had left the pouch and at least one juvenile survived to age 9 months (one year post release of founders). Evidence of breeding indicates that we have partially met our short-term criteria for success in year one of the program. Our intensive monitoring program enabled us to accurately identify almost all causes of adult mortality (15 of 16 deaths) and promptly respond to predicted and unexpected threats. This meant that we minimized adverse outcomes and maximized learning about risks to quoll survival. Five threats identified *a priori* were detected in the first year of monitoring. These were predation by the red fox, predation by a native predator, loss of body condition, ingestion of fox bait (but not causing death) and disease (systemic lymphoma, infection of *Sarcocystis sp*.); another threat (overdispersal) occurred > 12 months post release. It is too early in the reintroduction program to determine the effects of the remaining *a priori* identified threats. Monitoring revealed unexpected threats (e.g. road trauma, dog predation) or threats that were initially underestimated (e.g. injury). With this new knowledge, we have re-assessed the potential occurrence and consequence of threats, threat rating, and mitigation. Mitigation for several threats were considered adequate (e.g. loss of body weight, disease) while other threats required additional mitigation (e.g. red fox control, road trauma). We discuss how to improve threat mitigation and management for future translocations of the eastern quoll to mainland Australia. We also outline broader learnings from our program relevant to the planning of other species reintroductions.

How to mitigate threats?

The two primary causes of death of founder animals were predation, in particular by the red fox, and road fatalities. Predation by the red fox requires broadening the fox control program beyond the park. Reducing road fatalities requires a combination of enforcement, education and engagement.

Improved red fox control

Predation by the red fox was an expected threat based on historical accounts of foxes contributing to declines (Peacock & Abbott 2014), and their predation of other *Dasyurus* species reintroduced in Australia (Morris et al. 2003). Control of foxes is considered vital to the successful re-establishment of species vulnerable to fox predation (Short et al. 1992; Glen et al. 2009; Saunders et al. 2010). There is concern that fox control can lead to mesopredator release of cats (Glen et al. 2009) but this is considered a lesser threat to eastern quolls. Cats and eastern quolls have co-existed in Tasmania with no evidence of decline (Fancourt et al. 2015b) for 200 years (Abbott 2002) and cats are rarely seen at BNP, even after many years of sustained fox control (DoEE 2017; Lindenmayer et al. 2018).

BNP has effective fox control (Lindenmayer et al. 2018; DoEE 2019) but incursion by foxes from neighboring areas cannot be prevented. By limiting foxes in the surrounding region, fewer foxes will reach BNP. NSW National Parks and Wildlife Service Estate (NSW NPWS) and Shoalhaven City Council manage lands adjacent to BNP and have a history of seasonal fox baiting. Additionally, a coordinated fox baiting program (Eastern Shield Wildlife Recovery Program) commenced on private land in the Jervis Bay hinterland seven months prior to the quoll release (R. Brewster, personal communication). The frequency and coverage of baiting outside the park, however, is much lower than within the park. Since the release of the eastern quoll and the impact of red fox predation on released individuals, NSW NPWS have moved from a seasonal to a monthly baiting regime within the adjacent Jervis Bay National Park to support the program (M. Norton, NSW NPWS personal communication); this intensification of baiting was in response to good communication of threats to managers of neighboring land. In addition, fox monitoring efforts within BNP have been enhanced since the quoll release with a network of 50 Reconyx HC600 HyperFire™ fauna cameras now deployed alongside management tracks throughout the park quarterly rather than biannually (DoEE 2019). The detection data from this monitoring program guides the prompt deployment of CPEs to target fox incursions.

Other options for reducing the impact of foxes within BNP can be investigated. These include spreading the risk of predation by having multiple release locations across BNP. This strategy may lessen the impact of a fox killing all quolls within one area. Another strategy could include being mindful of mutually attractive locations for quolls and foxes (e.g. roads and tracks, feeding stations) and targeting such areas for even more intensive monitoring and management. With this in mind and following predation by the red fox during this pilot release, we modified our feeding strategy to minimize potential negative fox-quoll interactions at feeding stations. We did this by providing smaller amounts of food frequently to avoid excess food attracting foxes and closely monitoring the feeding stations using camera traps to ensure rapid detection of non-target species. Supplementary feeding can alleviate loss of body condition and assist with acclimatization (Boutin 1990; Moseby et al. 2015); it is therefore an important component of our threat mitigation. In the long term, animals with good body condition can potentially offset high predation in the remaining population through higher breeding success (Boutin 1990).

Our planned strategy for the ongoing reintroduction program includes translocating a higher number of quolls in subsequent years (total of 100 quolls in 3 years, DoEE 2017) to facilitate a population increase and lower the individual predation risk (Sinclair et al. 1998; Fancourt 2016). Over subsequent generations, the predator response of quolls may be improved either through pre-release anti-predator training (Griffin et al. 2000) or *in situ* under low predation pressure (Moseby et al. 2015). Quolls isolated from known predators can rapidly lose anti-predator behavior (Jolly et al.

2018), and are predator naïve when exposed to scents of unfamiliar predators (Jones et al. 2004). Our quolls have been captive-bred from animals sourced at a minimum of 1-2 generations since the wild. This maximizes the retention of wild traits but they remain unfamiliar to novel threats such as foxes and diamond pythons (not found in Tasmania), as well as cars.

Minimize road fatalities

Despite knowledge that collisions with cars kill eastern quolls in Tasmania (Jones 2000) and reintroduced *Dasyurus* species elsewhere in Australia (Morris et al. 2003), we did not foresee this risk at BNP. This is because our release site was situated behind locked gates, and there are relatively few public roads within the park and these have speed-restrictions (60 km / hr or less). Our immediate response to fatalities caused by cars was to relocate animals to another area of the park assessed as lower risk (less traffic and lower speed limit, 40 km / hr). Following this decision, no further road deaths have occurred. Over the long term, and with an expected growing population, quolls may eventually disperse to areas of higher risk (e.g. outside the park, roads with increased traffic and higher speeds); as occurred with a female founder quoll ~13 months post-release. Our long-term solution is to encourage slower traffic speeds and awareness of the risk of vehicle collisions with endangered animals through a combination of enforcement, education and engagement.

An evaluation of our planning and management

We followed a logical sequence of steps to plan, design and implement a robust reintroduction program. By following this process, we were able to identify likely threats and prepare appropriate management responses. We enlisted a multi-disciplinary team and designed and implemented an intensive monitoring program that allowed us to detect and respond quickly to new information. Data from the monitoring program facilitated modulation of the program in real-time to identify and respond to actual threats, and will be used to inform future translocations of the eastern quoll. Monitoring will continue to be important but, having detected the main threats, subsequent releases will not require the same level of intensive monitoring. Higher numbers of individuals being released in years two and three mean that capacity and cost of monitoring need to be balanced against minimum requirements for monitoring (Robinson et al. 2018). For future releases, we plan to use a combination of tracking, cage and camera trapping alongside knowledge learnt from this pilot release to maximize our monitoring effectiveness.

Lessons for other reintroduction programs

Reintroductions can be an important tool for restoring biodiversity. However, they can be considered unethical if they are implemented without rigorous prior threat assessment and post-release monitoring and evaluation (Kleiman 1989; McCoy & Berry 2008). Pre-release threat assessment is important to determine the likelihood of reintroduction success, highlight main threats, and outline mitigation strategies. Disease risk assessments and a multi-disciplinary health approach, incorporating physical health, nutrition, genetics, behavior and welfare are also necessary to support a considered science-based translocation plan.

We identified 11 threats to the reintroduction of the eastern quoll at BNP. Monitoring revealed three unexpected new threats (road trauma, collar injury, predation by domestic dogs). Predation by dogs was not considered *a priori*, despite canid predation on other reintroduced *Dasyurus* species (Pollock 1999; Cremona et al. 2017). This was because the incidence of wild dogs in the park is very low (DoEE 2017) and we underestimated the attraction of eastern quolls to urban areas within the park where domestic dogs reside. Our response to *a priori* identified threats and new threats was swift and effective, owing to rapid detection and investigation of mortalities, well-defined reintroduction protocols, and good team communication and decision making. Knowledge from our pilot reintroduction program will be used to make improvements to future planned eastern quoll translocations. Key learnings that we take from this initial release were that predation by foxes and dogs, and collisions with vehicles on roads, are major threats. Beyond the level of control of these threats on park estate, their management can be enhanced through a) good partnerships with neighboring land owners and managers to control for introduced predators on private land within and adjacent to BNP; and b) education and engagement with the local community and park visitors to communicate the value of the reintroduction program and how they can contribute to ensuring its longevity and viability.

Our study contributes to a greater understanding of threats and their mitigation for the establishment of the eastern quoll in the wild on mainland Australia. Reintroductions are being increasingly implemented as a tool to avert species extinction yet with little guidance as to how other programs have succeeded or failed. Our study provides an important model for other programs in the early stages of planning or implementation, and will have particular relevance to those focused on mammal reintroductions into unfenced, predator managed environments. Ongoing evaluation is expected to lead to future modifications and improvements that may have relevance at other stages of reintroduction planning and implementation.

A caveat in our study is that we used a qualitative threat assessment approach based on the best available knowledge but without formal quantification. The latter approaches are considered best practice but many managers do not use such methods (Armstrong & Reynolds 2012). Nonetheless, we have shown that threat assessments, when completed using best available knowledge of the species and the ecosystem, and combined with targeted monitoring, regular evaluation and responsive management, are a valuable step in improving species' translocations.

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Table 1. Threat Assessment of reintroducing eastern quoll to BNP. Threats were assigned a rating based on the combined possibility of occurrence and predicted consequence. See Supplement S1 for more detail on threat assessment, evidence and mitigation.

Potential threat	***Possibility of occurrence***	***Predicted consequences***	***Threat rating***
1. Predation by residual foxes	Possible	Major	High
2. Loss of body weight	Likely	Major	High
3. Mortality caused by paralysis tick	Possible	Major	High
4. Overdispersal (outside the park)	Likely	Moderate	High
5. Ingestion of fox baits	Possible	Minor	Moderate
6. Wildfire	Unlikely	Major	Moderate
7. Predation by feral cats	Unlikely	Major	Moderate
8. Predation of endangered species by eastern quolls	Rare	Major	Moderate
9. Loss of genetic diversity	Likely	Minor	Moderate
10. Predation by native predators	Unlikely	Minor	Low
11. Disease	Unlikely	Minor	Low

Table 2. Re-evaluation of threats to reintroducing eastern quolls to Booderee National Park based on pilot release. See Table S3 for more detail on threat assessment, evidence and mitigation.

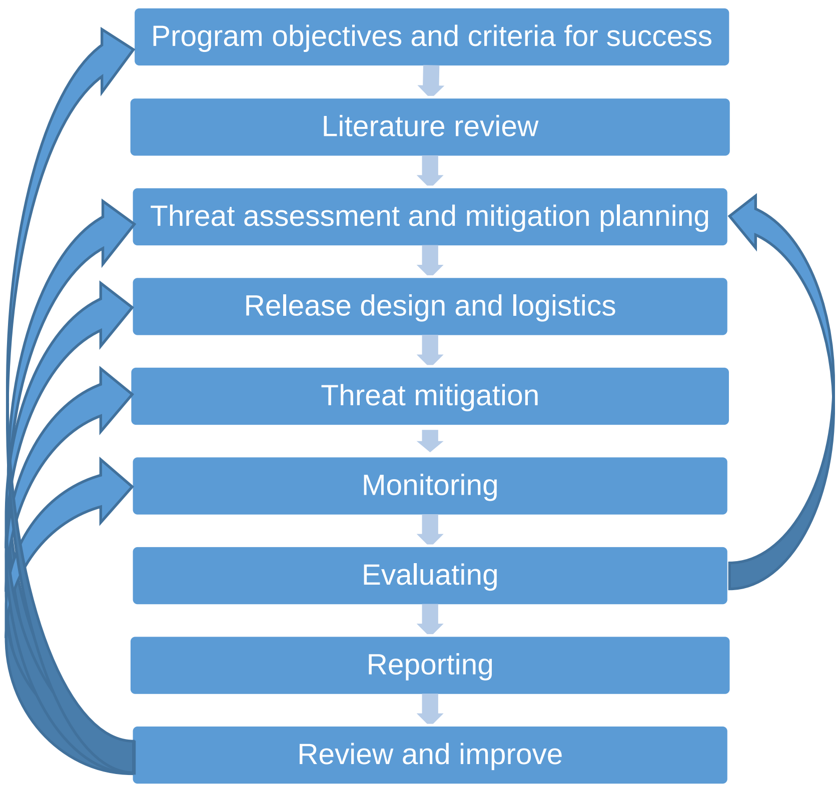
Potential threat	***Original threat rating***	***Threat detected***	***Potential occurrence of threat***	***Consequences (at the population level)***	***Current threat rating***
1. Predation by residual foxes	High	Yes	Almost certain	Major	High
2. Loss of body weight	High	Yes	Likely	Moderate	High
3. Mortality caused by paralysis tick	High	No	Likely	Minor	Moderate
4. Overdispersal	High	Yes	Likely	Moderate	High
5. Ingestion of fox baits	Moderate	Yes	Possible	Minor	Moderate
6. Wildfire	Moderate	No	Unlikely	Moderate	Moderate
7. Predation by feral cats	Moderate	No	Rare	Moderate	Low
8. Predation of endangered species by eastern quolls	Moderate	No	Rare	Moderate	Low
9. Loss of genetic diversity	Moderate	No	Likely	Minor	Moderate
10. Predation by native predators	Low	Yes	Likely	Minor	Moderate
11. Disease	Low	Yes	Possible	Minor	Moderate
12. Road trauma	Not *a priori* identified	Yes	Likely	Major	High
13. Predation by domestic dog	Not *a priori* identified	Yes	Likely	Minor	Moderate
14. Collar injury	Not *a priori*	Yes	Likely	Moderate	High

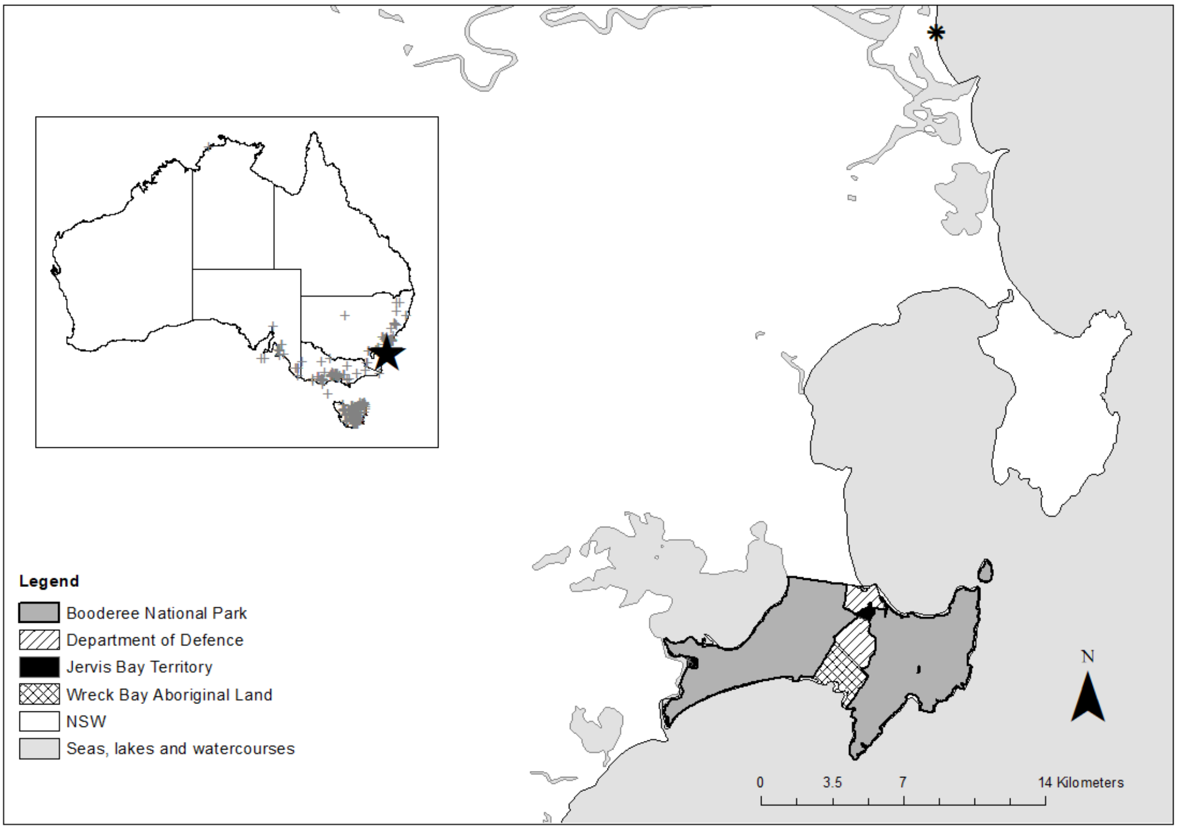
Potential threat	***Original threat rating***	***Threat detected***	***Potential occurrence of threat***	***Consequences (at the population level)***	***Current threat rating***
	identified				

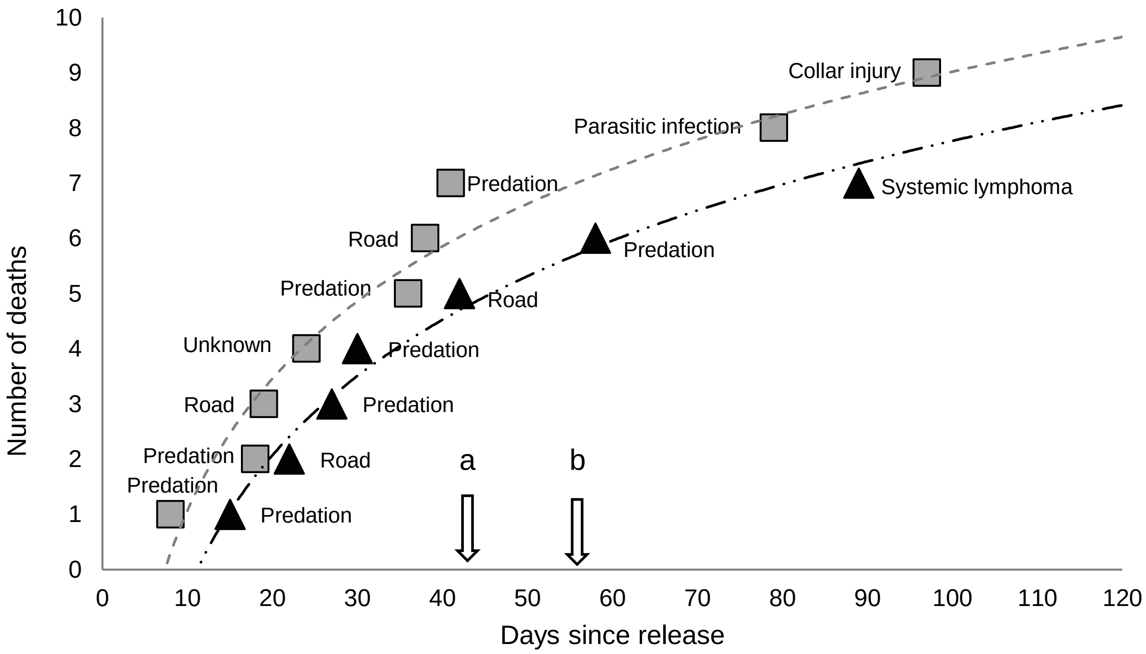
Figure 1. Steps in planning, designing and implementing a successful reintroduction, based on World Conservation Union reintroduction guidelines (IUCN / SSC 2013). There is a logical progression through each step with learning fed back into the process at different stages (arrows). For example, evaluation of data enables information to be fed back into the program and changes made concurrently (e.g. to threat mitigation). Knowledge gained through this process is integrated back into the planning process and the cycle continued.

Figure 2. The location for the eastern quoll translocation at BNP and the nearest record (*) at Comerong Island (Atlas of Living Australia 2018), with surrounding land tenure. Inset map shows location of BNP (star) with species occurrence records (grey crosses); erroneous records from inland and northern Australia have been removed.

Figure 3. Cumulative deaths of male (grey squares) and female (black triangles) quolls. Four quolls were taken into care 43 days post release (a) and were re-released at a new location 14 days later (b).


Program objectives and criteria for success
Literature review
Threat assessment and mitigation planning
Release design and logistics
Threat mitigation
Monitoring
Evaluating
Reporting
Review and improve


Legend
Booderee National Park
Department of Defence
Jervis Bay Territory
Wreck Bay Aboriginal Land
NSW
Seas, lakes and watercourses
N
0
3.5
7
14 Kilometers



10
9
8
7
6
5
4
3
2
1
0
Number of deaths
Collar injury
Parasitic infection
Predation
Systemic lymphoma
Road
Predation
Predation
Road
Unknown
Predation
Road
Predation
Predation
Road
Predation
Predation
Predation
a
b
0
10
20
30
40
50
60
70
80
90
100
110
120
Days since release