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Conservation conundrums and the challenges of managing unexplained declines of multiple species

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ABSTRACT

The conventional approach to conserving threatened biota is to identify drivers of decline, instigate actions to mitigate threatening processes, and monitor interventions to test their effectiveness and ensure target species recover. In Australia, predation by introduced predators is a threatening process for many native mammals. Here we report the results of a 15 year monitoring study in an iconic Australian reserve, Booderee National Park, where exotic Red Fox (*Vulpes vulpes*) populations have been controlled through an intensive poison baiting program since 2003. Unexpectedly, we documented the collapse of native mammal fauna during this period, including fully arboreal species that should be largely unaffected by fox predation – such as the nationally Vulnerable Greater Glider (*Petauroides volans*) and Common Ringtail Possum (*Pseudocheirus peregrinus*).

We used path analysis to explore potential causes of these unexpected declines. We found no compelling evidence to support hypotheses that competition with increasing native species, native predator release, or increases in native herbivores underpinned mammal declines. Beyond the path analysis, data from other studies completed both inside Booderee National Park and outside (where intensive fox baiting does not occur yet depleted fauna species remain), allowed us to rule out several drivers of change. The temporal declines we documented for arboreal marsupials were not anticipated nor explained by any clear mechanism.

We propose the use of experimentally-guided reintroductions and translocations to: (1) restore empty niches such as the currently vacant apex mammal predator niche, (2) reconstruct the now depleted arboreal marsupial guild, and (3) further test key hypotheses associated with mammal decline. We also suggest that given the potential for perverse outcomes following large-scale management interventions (even those where there is high confidence of success), wildlife managers should consider maintaining reference areas (where there is no management intervention). Finally, as the declines we documented were unexpected and rapid, there is a clear need to develop more sensitive early warning signals to alert conservation managers to impending problems, allowing them to alter management regimes before major declines occur.

1. Introduction

Conservation biology aims to address biodiversity loss through identifying key threats driving species declines (Lindenmayer and Burgman, 2005; Johnson et al., 2017), applying threat mitigation actions, and establishing monitoring programs to determine if management practices are effective (Tilman et al., 2017). The underlying premise of this approach is that removing the drivers of decline should result in the recovery of the target species (Caughley and Gunn, 1996; Lindenmayer and Hunter, 2010). However, sometimes the removal of what is thought to be a key threat does not lead to recovery, or worse, is associated with further declines of target and non-target native species (e.g. Zavaleta et al., 2001; Lampert et al., 2014). This may occur because interactive threats are occurring (e.g. Doherty et al., 2015). Indeed, there are a number of cases where well-intentioned conservation interventions aimed at mitigating threats have led to unexpected and perverse outcomes (e.g. Taylor, 1979; Bergstrom et al., 2009). Often, increases in the threat itself occurs after management due to

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overcompensation (an increase in abundance in response to harvest; e.g. (Lazenby et al., 2015) and instability (population cycling) (Zipkin et al., 2009). For example, actions to control some invasive species have led to increases in the threat (Pardini et al., 2009; Zipkin et al., 2009). In other examples, successful removal of a threat facilitated the establishment of a second threat (McGregor et al., 2014) such as a secondary weed invasion. Understanding the reasons for unforeseen outcomes is critical not only for evaluating management (Walsh et al., 2012), but also to accurately inform future management plans and allocate scarce conservation funds to achieve positive conservation benefits.

Australia has a long record of targeted management designed to recover the nation's numerous threatened species (Garnett et al., 2018). In the case of mammals, a group characterized by a loss of approximately 10% of native terrestrial species over the last 200 years (Woinarski et al., 2015), the control of invasive carnivores such as the Red Fox (*Vulpes vulpes*) and the Feral Cat (*Felis catus*) has been an important form of management. Feral predator control is widely considered to be a key component of best practice management in many Australian protected areas (Braysher, 2017). For example, there are plans to substantially reduce populations of exotic predators using intensive poison bating and other control methods across 12 million ha of Australia (Australian Government, 2015). While Red Fox control has demonstrated conservation value (e.g. Kinnear et al., 1988), some recent studies have documented perverse outcomes associated with their removal (Marlow et al., 2015), potentially attributed to meso-predator release of feral cats (Wayne et al., 2017).

Here we report the results of a 15 year mammal monitoring study in an iconic reserve, Booderee National Park, in south-eastern Australia. Monitoring commenced at the same time as an intensification of a poison baiting program aimed at reducing Red Fox abundance to conserve native mammal populations. Baiting reduced Red Fox abundance, but rather than leading to native mammal population recovery, we observed unexpected severe declines and local extinctions in terrestrial and arboreal mammals. We used our monitoring datasets to test empirical support for different hypotheses that might explain the observed temporal trajectories. We discuss general lessons emerging from this study including determining ways to manage biodiversity when drivers of decline remain unclear.

2. Methods

2.1. Study area

Our work was focused within and around Booderee National Park in south-eastern Australia (Fig. 1) which is a 6600 ha IUCN Category I reserve that supports > 205 terrestrial vertebrate species, including threatened taxa and threatened ecological communities (Lindenmayer et al., 2014). Four species of large terrestrial mammalian predators either recently occurred in the park but are now locally extinct, or extremely rare (Spotted-tailed Quoll *Dasyurus maculatus* last seen in the mid-1980s; M. Fortescue, personal communication; Dingo/dog *Canis* spp. rarely seen in the last 15 years), or are likely to have prehistorically occurred in the region but are now globally extinct (Thylacine *Thylacinus cyanocephalus)*, or regionally extinct (Tasmanian Devil *Sarcophilus harrisii*).

Booderee National Park is ranked as one of Australia's best-managed protected areas (WWF Australia, 2008) and the control of processes threatening biodiversity is a key part of the plan of management for the reserve (Lindenmayer et al., 2013). The park's management program includes an intensive poison baiting program to control populations of the Red Fox. A large wildfire burnt half the park in 2003, however, subsequent analysis has demonstrated that the majority of fauna were either minimally affected by this fire event or have since recovered (Lindenmayer et al., 2016a). Overlaid on these management programs, has been a monitoring program that has run since 2003. The monitoring work has quantified patterns of temporal change in a range of vertebrate groups including mammals, birds, reptiles and frogs, as well as native vegetation (Lindenmayer et al., 2014). The focus of this paper is mammals because major changes in site-level species richness and losses of individual species have not been observed for other monitored vertebrate groups. The individual mammal species examined were the following arboreal marsupials: Greater Glider (*Petauroides volans*), Common Ringtail Possum (*Pseudocheirus peregrinus*), Sugar Glider (*Petaurus breviceps*), Common Brushtail Possum (*Trichosurus vulpecula*), the scanscorial Brown Antechinus (*Antechinus stuartii*), the ground-dwelling Bush Rat (*Rattus fuscipes*), Swamp Rat (*Rattus lutreolus*), Eastern Chestnut Mouse (*Pseudomys gracilicaudatus*), Long-nosed Bandicoot (*Perameles nasuta*) and the macropods: Eastern Grey Kangaroo (*Macropus giganteus*), Black Wallaby (*Wallabia bicolor*) and Red-necked Wallaby (*Notamacropus rufogriseus*).

2.2. Study design

We established 129 permanent monitoring sites across the seven key vegetation types in Booderee National Park (Fig. 1) – warm temperate rainforests, forests, woodlands, heathlands, shrublands, swamps and sedgelands. We employed a stratified, randomized and replicated process to distribute long-term monitoring sites widely throughout the study area. This was to limit the potential for geographic bias in our results. We replicated sites within each vegetation type with a focus on replicating the most common classes. The number of samples was generally proportional to the total area occupied by each vegetation class.

We established a permanent 100 m long transect at each of our 129 sites. We used 100 m transects because of high heterogeneity in vegetation cover at Booderee National Park, where changes in vegetation type often occur over a short distance (Stirnemann et al., 2014). Transect lengths in excess of 100 m would have resulted in many transects spanning two vegetation types. We ensured that each transect was confined to a single vegetation type.

2.3. Fox baiting and control program

A control program for the Red Fox, an exotic carnivore that occupies the apex mammal predator niche in our study system, was first implemented in 1999 with 120 stations (each measuring 10 m × 10 m) baited every six months. Bait stations were located in all vegetation types and dispersed widely throughout Booderee National Park. Data on bait take were gathered each time the bait station was checked and new baits were laid. Control efforts were greatly intensified in 2003 with baits laid monthly to 2014 and then fortnightly to the present day. Allied with the fox baiting program, a network of 2 m × 2 m sand plots was established throughout Booderee National Park and footprints, tracks and scats of all animals detected in these plots were recorded every month. Since 2015, remote cameras have been deployed at 50 locations distributed widely across the eastern and eastern parts Booderee National Park. Cameras were deployed for 14 nights per site each year. If a fox is detected, a professional marksman was deployed.

2.4. Field surveys of terrestrial and scansorial mammals

Each of our 129 monitoring sites consisted of star picket markers set at 0 m, 20 m, 40 m, 60 m, 80 m and 100 m points along a permanent transect. Our trapping protocols at each site involved opening along the transect for three consecutive days/nights, ten Elliott box traps (10 cm × 10 cm × 30 cm; Elliott Scientific Equipment, Upwey, Victoria) at 10 m intervals and four small (20 × 20 × 50 cm) and two large (30 × 30 × 60 cm) wire cage traps. We baited all traps with a mixture of peanut butter and rolled oats. We completed trapping surveys in the summer of all years between late 2003 and 2016, surveying approximately 75 sites each year.

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