



Controlling invasive predators enhances the long-term survival of endangered New Zealand long-tailed bats (*Chalinolobus tuberculatus*): Implications for conservation of bats on oceanic islands



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ABSTRACT

Invasive mammalian predators pose one of the greatest threats to biodiversity globally, particularly on oceanic islands. However, little is known about the impacts of these invasive predators on bats (Chiroptera), one of the most speciose mammal groups, and one of the most widespread groups of mammals threatened on oceanic islands (> 200 spp.). Nearly 50% of the world's threatened bats are island endemics and because they are often the only native mammals on islands, they fulfil important ecological roles such as pollination and seed dispersal. Long-tailed bats (*Chalinolobus tuberculatus*) are critically endangered because of predation by exotic mammals, particularly ship rats (*Rattus rattus*), introduced by humans to the island archipelago of New Zealand. We monitored the survival of bats in three colonies in temperate rainforest in Fiordland over 22 years. Since 2009, we controlled predators during irruption phases and compared survival of bats in previously untreated areas with survival in forest blocks treated using rodenticides deployed in bait stations. Survival was estimated using multi-state mark-recapture models in Program Mark 7.0 with > 15,000 bats tagged. Survival was primarily dependent on year and age of bats, although seedfall intensity of the dominant canopy tree and predator management was also influential. Survival in long-tailed bats was as high as, or higher, than figures for bats generally in years with low predator numbers or predator control. Survival was markedly higher in treatment years when predators were managed (0.82 compared to 0.55). Population modelling indicated managed colonies will increase ($\lambda > 1.05$) whereas unmanaged colonies will decline ($\lambda = 0.89 - 0.98$) under scenarios that reflect increased frequency of beech mast and predator irruptions. Thus, effective predator control is essential for recovering long-tailed bat populations. Warming temperatures indicate that predator irruptions are becoming more frequent, which would require more predator control in the future than at present if declines in bat populations are to be reversed. These results are relevant to the conservation of threatened bats on oceanic islands, given the abundance of exotic mammalian predators, particularly ship rats, on them.

1. Introduction

Globally, invasive predator species pose one of the greatest threats to biodiversity (Clavero and Garcia-Berthou, 2005; Donlan and Wilcox, 2008; Leung et al., 2002). In terrestrial systems, introduced predators include mammals, reptiles and invertebrates, all of which have had profound impacts on endemic faunas, particularly on oceanic islands (Atkinson, 1989; Hilton and Cuthbert, 2010). The evidence for extinctions and significant declines in mammals, birds, and reptiles attributable to introduced mammalian predators is unequivocal (e.g., Burbidge and Manly, 2002; Clavero et al., 2009; Jones et al., 2008; Towns et al., 2006). However, little is known about the impacts of these invasive

predators on bats (Chiroptera), one of the most speciose mammal groups in the world (Fenton and Simmons, 2015). The effects of habitat destruction, degradation and fragmentation and human impacts have tended to be studied more than mammalian predators in bats (Altringham, 2011).

A high proportion of bats are classed as threatened (Hutson et al., 2001). The primary documented causes of decline are generally related to habitat loss and degradation, harvesting and disturbance (Racey and Entwistle, 2003; Voigt and Kingston, 2016). In other cases, the cause of decline is uncertain, given a range of competing threats (e.g., Christmas Island pipistrelle *Pipistrellus murrayi*; Lunney et al., 2011). There are several documented examples of introduced mammalian predators

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preying upon bats, including feral cats (*Felis catus*), stoats (*Mustela erminea*), and rats (*Rattus* spp.) (e.g., Altringham, 2011; Dowling et al., 1994; Hill and Smith, 1984; O'Donnell, 2000a; Scrimgeour et al., 2012) and one example of their impacting on indigenous bat populations (Pryde et al., 2005a). Nevertheless, because few studies have investigated the role of predation, invasive mammals (particularly ship rats *Rattus rattus* because they are so widespread), may pose a significant threat to bats globally, especially on islands. Bats are widely distributed on oceanic islands, on which invasive predators are a common threat (> 200 threatened bat species; Hutson et al., 2001; Mickleburgh et al., 1992). Examination of the IUCN threatened bat list indicates numerous threatened bat species are present in > 50 island archipelagos where ship rats have been introduced (Hutson et al., 2001; Mickleburgh et al., 1992). These same archipelagos have well-documented impacts of rats on both sea and land birds, invertebrates, reptiles and ecosystem functioning (Harper and Bunbury, 2015; Jones et al., 2016; Shiels, 2011). As bats are cryptic and difficult to study, the potential impacts of introduced predators have not been investigated in many species (Hutson et al., 2001). Nevertheless, nearly 50% of the world's threatened bats are island endemics and because they are often the only native mammals on island, fulfil important ecological roles such as pollination and seed dispersal (Jones et al., 2010).

The impacts of introduced predators on indigenous species, including bats, in the island archipelago of New Zealand have been devastating (Innes et al., 2010; Towns and Daugherty, 1994). Invasion by ship rats is blamed for the final extinction of the greater short-tailed bat (*Mystacina robusta*) and predation by rats, stoats, cats and brushtail possums (*Trichosurus vulpecula*) have contributed to significant declines in the two extant species of bat (O'Donnell et al., 2010). Populations of the endangered New Zealand long-tailed bat (*Chalinolobus tuberculatus*) are declining at rates of up to 9% per annum in areas with high predator numbers (Pryde et al., 2006). Over recent decades, New Zealand conservation managers have developed a wide range of tools for controlling introduced predators and monitoring programmes are now demonstrating substantial recovery in a wide range of taxa (Towns and Broome, 2003). These tools include predator trapping, the use of bait stations loaded with rodenticides, and the aerial application of toxins that kill rodents (Edmonds et al., 2017; O'Donnell and Hoare, 2012; O'Donnell et al., 2011; Towns and Broome, 2003; Elliott and Kemp, 2016). Similar techniques are being applied globally to control or eradicate rats on oceanic islands (Harper and Bunbury, 2015).

In this paper, we report on the control of ship rats and stoats using bait stations loaded with rodenticides at a landscape scale (> 1000 ha) to improve survival of long-tailed bats. Careful use of rodenticides can lead to effective control of ship rats, brushtail possums and stoats (Elliott and Kemp, 2016). While the rodenticides target rats directly, stoat control in forests results from secondary poisoning where rats are the primary vector of the toxins (Gillies and Pierce, 1999; Murphy et al., 1999). Pryde et al. (2005a) showed that significant reductions in survival of long-tailed bats coincided with ship rat and stoat population irruptions in the Eglinton Valley, a temperate rainforest in southern New Zealand. Predation appeared to occur in maternity roosts. Although long-tailed bats roost high in trees (Sedgeley and O'Donnell, 1999), both predators commonly live and feed in the forest canopy (Elliott et al., 1996a; Smith et al., 2009). In these forests, predator irruptions follow heavy beech (*Nothofagaceae* spp.) mast seeding in 3–6 year cycles (King, 1983; O'Donnell and Phillipson, 1996). A preliminary population viability analysis using survival data from ten breeding seasons indicated that long-tailed bat populations were declining on average 5% per year (Pryde et al., 2005a). Consequently, the New Zealand Department of Conservation commenced predator control at several key sites as part of its Bat Recovery Programme (O'Donnell, 2010).

There have been relatively few studies of the population dynamics and survivorship of bats (Lentini et al., 2015) considering > 1300 species have been identified (Fenton and Simmons, 2015), and few of

these have been long-term studies, largely due to logistic challenges in undertaking mark-recapture studies in bats (O'Shea et al., 2004). Nevertheless, knowledge of the factors that influence survival is crucial to understanding drivers of population dynamics of bats, especially as a high proportion of species is threatened. The aims of this paper are to (1) model factors influencing long-term survival of long-tailed bats; (2) examine whether predator control has resulted in biologically significant increases in survival of long-tailed bats; and (3) make predictions about future responses to management using population modelling. Predictive modelling is particularly important because the frequency and spatial extent of rat population irruptions are predicted to increase with climate change (Christie, 2014). The frequency of beech mast and predator irruptions are increasing over the last c.40 years in New Zealand from an average of once every five years in the 1980s (Elliott, 1996) to every 2 in 5 years over the last ten years (Appendix 1).

2. Methods

2.1. Study area

The study was conducted in the Eglinton Valley, eastern Fiordland in the South Island, New Zealand (44°58'S, 168°01'E) (Fig. 1). The 50-km long valley is glaciated with steep sides and a 0.5–1.5 km wide flat floor. The valley is dominated by temperate beech dominant rainforest (red beech *Fuscopora fusca*, silver beech (*Lophozonia menziessii*), mountain beech *Fuscopora cliffortioides*), which covers gentle glacial terraces and outwash fans on the lower hill-slopes and then rises steeply to the timberline at c. 1200 m above sea level. Mean annual rainfall in the central valley (Knobs Flat) is 2300 mm, but increases markedly in a gradient to > 5000 mm at the head of the valley.

2.2. Mark-recapture sessions

Long-tailed bat-capture-recapture sessions were conducted annually during the breeding season over 22 summers (1993–2015). Free-ranging bats were captured in free standing 4.2-m² harp traps (Faunatech Ausbat, Victoria, Australia) during the austral summer (October–March 1993–1998; December–February 1999–2015). A subsample of bats caught was fitted with 0.7-g transmitters (BD2A, Holohil Systems, Carp, Ontario, Canada) to identify roost sites and catch all bats present in the roost at the time. Three to five bats carried transmitters at any one time. Transmitters were attached between the scapulae using a latex-based contact adhesive (F2®, Ados Chemical Co., Auckland, New Zealand) after the fur had been partly trimmed. Bats were followed daily for as long as transmitters remained attached or functional, a mean of 11.9 ± 6.4 (SD) days (O'Donnell and Sedgeley, 1999).

Roosts were located during the day by radio tracking using handheld receivers and receivers mounted on vehicles. Bats were caught at a subset of accessible roosts as they emerged at dusk using 2.0-m² or 4.2-m² harp traps suspended in front of roost cavities. Roosting cavities were identified either by watching bats flying into or out of the roost tree from the ground at dawn or by climbing the tree (using single rope climbing techniques) and identifying the occupied cavity using a radio receiver at close range.

Each bat was banded on the forearm with an individually numbered 2.9 mm narrow flanged bat band (The Mammal Society and Porzana Ltd., East Sussex, UK). Age, sex, and reproductive status of all bats were recorded. Reproductive (parous) females were defined as animals with large, bare nipples. These females were either pregnant (determined by palpation of the abdomen), lactating, or post-lactating (reproductive females). Nipples remained conspicuous after females gave birth once. Females without visible nipples or with nipples with hair grown over them were classed as non-reproductive (nulliparous). Young of the year (termed juveniles) were identified by their unfused phalangeal

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