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Niche and movement models identify corridors of introduced feral cats infringing ecologically sensitive areas in New Zealand

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ABSTRACT

The mitigation of the impact caused by introduced mammalian predators is a priority for conservation managers. Reducing predator population numbers is the most realistic strategy in mainland areas or large islands, and could be a feasible alternative to pest eradication. However, the success of control campaigns depends not only on removal of resident individuals, but also on managing reinvasions facilitated by connectivity with surrounding source populations. We combined niche analysis and fine-scale movement analyses of feral cats (*Felis silvestris catus*) to identify least-cost corridors from sources surrounding controlled areas of the ecologically sensitive area of Tasman Valley and Aoraki/Mt. Cook National Park, New Zealand. Intensive control of exotic predators has been executed during the last ten years in this area, where they pose a threat to native species such as endangered ground-nesting birds. Species distribution models revealed that cat distribution in the region was limited by its main prey, the European rabbit, and to mid-elevation (~1600 m) areas. Using GPS-tracking data and step-selection functions, we found that cats moved in an optimized fashion suggesting a maximum energy gain associated with high rabbit presence, while avoiding landscape obstacles such as rugged terrain. Connectivity between the high probability of cat presence in source and destination locations (in the control area) was facilitated by 1–3 corridors between valleys and multiple paths within valleys. Identification of least-cost paths, rooted in ecological and behavioral mechanisms underlying space use, can identify realistic putative corridors for focused implementation of control measures for introduced species in ecologically sensitive areas.

1. Introduction

Biological invasions cause severe ecological and economic damages, and are one of the most pressing challenges currently faced by conservation managers. Introduced mammalian predators (hereafter referred to as introduced predators) are significant drivers of ecosystem change by predation, competition, and habitat alteration (Mack et al., 2000). These impacts are more prominent in insular ecosystems due to vacant niches and to the particular behavior and ecology of naïve native species (Mack et al., 2000; Courchamp et al., 2003).

Although a desirable solution, complete eradication of introduced predators is often impractical in large mainland areas or on large islands. Control campaigns to reduce pest population numbers to less harmful levels might be the most realistic strategy in these environments (Baxter et al., 2008). However, control campaigns require enormous logistic and economic efforts, and their success over time might depend not only on keeping predator numbers low within the controlled area, but also on minimizing the influx of introduced predators from surrounding regions (Rushton et al., 2006). A better understanding of the behavioral and ecological mechanisms driving the space-use and movement of introduced predators can be used to improve control strategies. Because the space-use of animals is a multiscale process (Boyce, 2006), it is necessary to understand the factors determining the spatial distribution of introduced predators within a region of management interest. Additionally, analyses of individual decision-making can reveal the behavioral strategies that make a species successful at exploring and exploiting an invaded environment. Theoretical and methodological advances in the context of niche theory and animal movement analyses can assist to study these behavioral and ecological mechanisms.

The ecological niche theory relies on the principle that individual species thrive under specific environmental conditions. Therefore, the ecological niche links species' fitness to an environmental space shaped by a dimension of complex interdependent variables (see Hirzel and Le Lay (2008) for a complete review). The presence and distribution of a species in a given environmental space are determined by its dispersal abilities, the capability of the environment to provide the volume of requirements that ensure positive population growth without immigration (Grinnelian niche), and the capability of the species to persist considering interactions with other local species (Eltonian niche) (Hirzel and Le Lay, 2008). Spatial distribution modeling (SDM) is the

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operational application of ecological niches to predict the probability of presence of a species over a geographic area given a set of environmental variables (Hirzel and Le Lay, 2008).

From a behavioral perspective, individual animal home-ranges are shaped and adjusted according to mechanisms related to the distribution of critical resources and the energy required to obtain and defend them (Mitchel and Powell, 2007; Recio and Seddon, 2013). Variations in specific landscape features such as slope, vegetation or substrate type (see the "energy landscape" concept, Wilson et al. (2013)) will drive the movement cost for animals. Hence, species that move more efficiently to exploit opportunities for energy gain while minimizing movement costs can be favored by natural selection (Shepard et al., 2013). In the case of introduced species, this optimization of movement behavior can ensure a successful establishment in an invaded environment.

At a large scale, niche analysis assists in identifying species distribution from models depicting the habitat suitability (i.e., HSM models) over a geographic area. At a small scale, movement analyses allow the identification of the individual decisions underlying habitat selection patterns. Previous combinations of resource selection functions (RSF) (Boyce and McDonald, 1999) and movement analyses have identified corridors for endangered species to ensure regional connectivity between populations (Squires et al., 2013). However, a multiscale approach to identify the most likely paths or corridors used by introduced predators to access a managed area has not previously been implemented.

New Zealand (NZ) is an illustrative example of the dramatic consequences of the massive introduction of exotic biota (Heinis, 2011), including carnivore species such as ferrets (*Mustela furo*), stoats (*Mustela nivalis*), weasels (*Mustela putorious*), and feral cats (*Felis silvestris catus*), i.e., individual cats that live and breed in the wild entirely independent from humans and human food resources (Berkeley, 1982). In NZ, feral cats are a significant predator of native wildlife (Gillies, 2001), and responsible for the local extinction and decline of endemic birds (Gillies and Fitzgerald, 2005). New Zealand has achieved relative success eradicating or reducing numbers of introduced predator species on small islands (King et al., 2001). However, there are local areas of ecological interest in mainland NZ where control campaigns could benefit from the identification of putative corridors used by predators in neighboring source populations. This would enable control measures to be focused along those corridors to limit reinvasion of the core area.

We applied a multiscale approach to identify putative corridors used by feral cats to move from source surrounding populations, into the ecologically sensitive area of the Tasman Valley and Aoraki/Mount Cook National Park, NZ. We used trapping data and GPS-telemetry data from tracked cats to produce spatial distribution models (SDM) at a regional scale, and then we apply step selection functions (SSF) to understand feral cat movement decisions at a fine-scale. The results were then applied in conjunction with least-cost path analyses to identify putative corridors. We predicted that, according to the generalist character of the feral cat, it occupies a broad niche at the regional scale, with high suitability habitat widely extended and mostly conditioned by the distribution of its main prey, the European rabbit (*Oryctolagus cuniculus*). We also predicted that feral cat movements and corridors from source to destination sensitive areas are determined by the distribution of rabbits, and by landscape features reducing movement obstacles. We anticipate that the conclusions from this study could be applied to management decisions for other species and regions of the world to moderate the impact caused by established or expanding invaders.

2. Material and methods

2.1. Study area

The study area was located in the central South Island of New Zealand (Fig. 1), covering an area of 9134.22 km^{2} with an elevation of

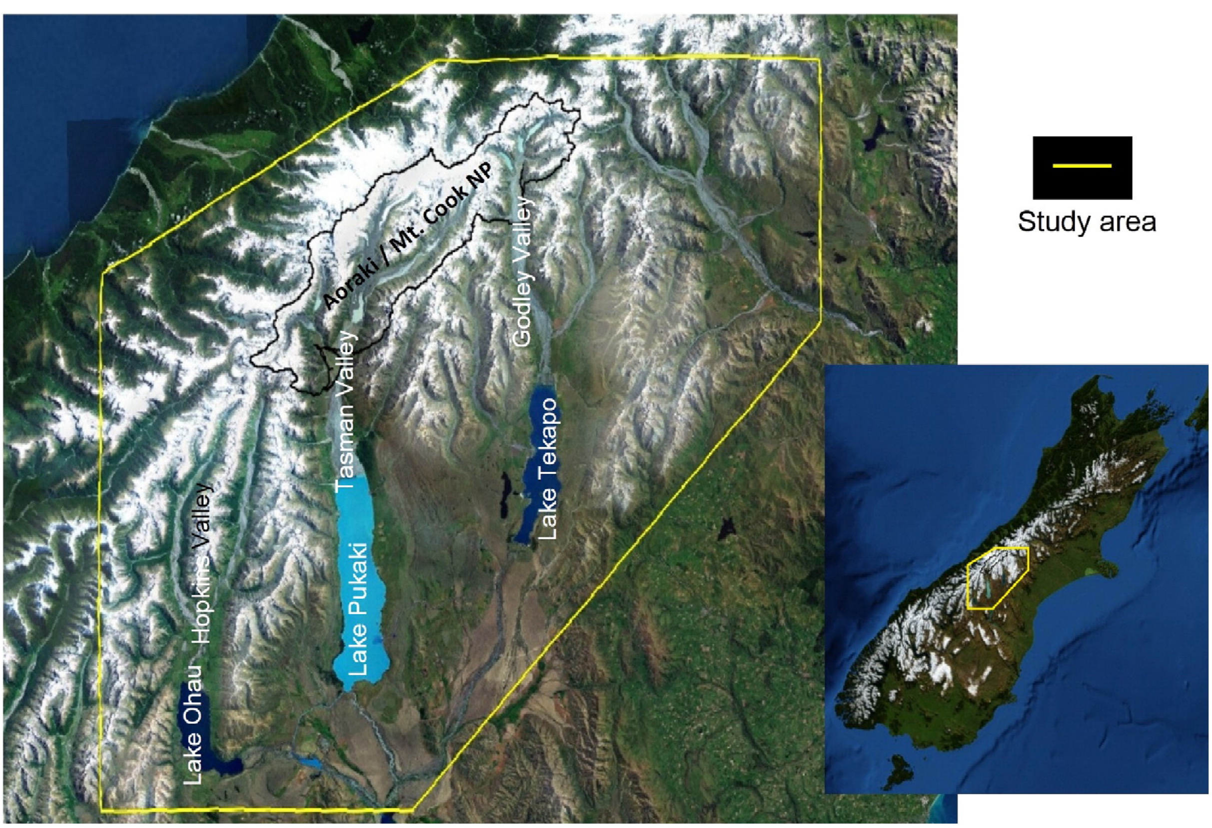

Fig. 1. Study area in the central South Island of New Zealand.