

## Using home-range data to optimise the control of invasive animals

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**Abstract:** Invasive species have been identified by the Convention on Biological Diversity as a significant threat to biodiversity. Conservation managers often lack tools for addressing uncertainty about the control intensity required to achieve cost-effective management of invasive species. We describe a modelling approach for informing the spacing of control-device lines given the availability of home-range data. To demonstrate its utility, we used data on stoats (*Mustela erminea*), an introduced mammalian predator responsible for the decline of endemic birds in New Zealand. We calculated home-range widths using three methods: kernels, circles and the narrowest distance across the raw point data. Using the widths from each method, we then permuted iteratively the relative location and orientation of home ranges between control-device lines, and calculated the probability of encounter with varying distances between lines. Widths across raw points gave lower estimates of the probability of encounter of device lines than kernels, while circles gave estimates that were intermediate between the two. For stoats, the simulation on point-data widths indicates that to ensure control-device lines will intersect 100% of female stoat home ranges they need to be  $\leq 400$  m apart, while the simulation on kernels and circles allowed  $\leq 700$  m. When needing to address uncertainty about the intensity of control to apply, managers should give priority to the collection of home-range data so that control-line spacing can be determined using the simulation described. If sufficient home-range data are available then simulating kernels provides better predictions, otherwise simulating the width across point data provides a conservative option when such data are insufficient.

**Keywords:** adaptive management; eradication; invasive species; monitoring; optimal device placement.

### Introduction

Invasive species are a main driver of global biodiversity loss (Courchamp et al. 2003; Hoffman et al. 2010; Pascal et al. 2010), and have been recognised as the biggest threat to biodiversity in the Pacific (Secretariat of the Convention on Biological Diversity 2010). Invasive species have particularly severe impacts on biodiversity in island ecosystems where there is high endemism (Blackburn et al. 2004). Examples include the decline of New Zealand's native fauna following invasions by rats, mustelids and feral cats (Wilson 2004); the decline of Australia's fauna following the invasion of foxes, and cane toads (Smith & Quin 1996; Phillips et al. 2007); the impact of American mink on water vole communities in the United Kingdom (Macdonald & Harrington 2003); and the impact of Indian mongoose in Hawaii, Jamaica and Puerto Rico (Hays & Conant 2007). Economic impacts can also be substantial. Introduced vertebrates in Australia have been estimated to cause economic losses of \$620.8 million per annum (Gong et al. 2009).

The management and control of invasive species for biodiversity protection lends itself to adaptive resource management (Walters 1986). Several studies have considered how to adaptively manage invasive species with examples including models for optimising search strategies for invasive species detection (Baxter & Possingham 2011), models of time to eradication success given the level of control effort (Fukasawa et al. 2013), and stable isotope analysis to guide adaptive management of American mink by informing managers of behavioural responses of mink to control (Bodey et al. 2010). Despite this there are few interspecies tools available

to guide wildlife managers in the implementation of invasive species control or eradication. Managers require methods for using biological data to inform quick decisions about when, where and how to control invasive species.

There are several important ecological concepts relevant to the management of invasive species (Park 2004). One concept with particular relevance to the spatial management of invasive vertebrates is home range. The concept of home range is well established (Kie et al. 2010), and has been defined as the area traversed by an animal in the course of its daily movements (Burt 1943; Jennrich & Turner 1969). If managers can ensure a control device (e.g. a trap or poison bait station) falls inside a given proportion of individual home ranges within a population, then they increase the probability of those individuals interacting with the control device. The probability of an individual interacting with a control device that falls outside of its home range at a given time is zero. One problem with designing control operations to intersect animal home ranges is that home ranges are typically irregular in shape (Millsbaugh & Marzluff 2001). Even if the mean home range size of the target species is known, managers will not know the shape or orientation across the landscape of the home ranges of individuals they wish to control. Therefore, designing control on the basis of mean home range assumes home ranges are circular. If elongated home ranges are common and aligned with some topographical feature, lines of control devices that are incorrectly spaced and incorrectly orientated may miss some of these home ranges.

Our objective was to develop a simulation method for estimating the proportion of home ranges in an animal population that will be intersected by control-device lines

of varying separation distance. The simulation accounted for the size, shape and orientation of the home ranges in a target population. Outputs from the simulation will enable conservation managers to make informed decisions on control-device line spacing. We demonstrate the utility of this simulation using data on stoats (*Mustela erminea*), an introduced mammalian predator implicated in the decline of New Zealand's endemic fauna (McLennan et al. 1996; King & Murphy 2005). Stoat home ranges are sexually dimorphic (Murphy & Dowding 1994, 1995; Alterio 1998) and Buskirk and Lindstedt (1989) showed that variation in trap spacing can result in sex-biased capture success in mustelids.

## Methods

### Stoat radio-tracking data and sensitivity analysis

Stoat radio location data were made available from previous research on stoats that took place in the following locations: the Borland Burn (45°40' S, 167°20' E) and Ettrick Burn (45°25' S, 167°66' E) in Fiordland National Park (Smith & Jamieson 2005; Smith et al. 2007); and Okarito Kiwi Sanctuary (43°24' S, 170°20' E) in South Westland (Miller et al. 2001). The Borland Burn site is subalpine grassland (snow tussock, *Chionochloa* spp.) at approximately 1000–1100 m above sea level. The Ettrick Burn is a low-elevation (c. 400 m) valley dominated by beech (*Fuscospora* spp.) forest and Okarito is a low-elevation (<100 m) podocarp–broadleaved forest. All stoats were live-trapped and radio-tracked during the austral summer–autumn (December–April). Details on the live-trapping and radio tracking methods used are provided in Miller et al. (2001), Smith & Jamieson (2005) and Smith et al. (2007).

We conducted a sensitivity analysis on the radio-tracking data to ensure that any subsequent estimates of home-range parameters were based upon an adequate sample size. This was done for each individual by randomly selecting an increasing proportion of its available location data and calculating the home-range kernel width (see below). Those animals whose results did not asymptote with increasing data were removed from all subsequent analyses. This sensitivity analysis, home range estimation and simulation described below were all undertaken in R (R Development Core Team 2009).

### Home range

We used the location data selected from the sensitivity analysis to provide three different measurements of home range. The reason for using three different home range measures was to look at how they affected decisions on trap line spacing and to provide managers with a range of options, some more conservative than others. The three estimates were kernels, circles and points.

Kernel analysis uses an estimated probability density function and a smoothing parameter (band width) to map contours of a home range (Worton 1989; Seaman & Powell 1996). We used the *adehabitat* package in R to estimate the 95% kernel contour and area (Calenge 2006).

Circular-home-range estimates were created by converting the previously estimated kernels into circles of equivalent area. The corresponding circle diameter then represented the home-range width. This method has been used previously to determine control-device line spacing (Thomas 1994).

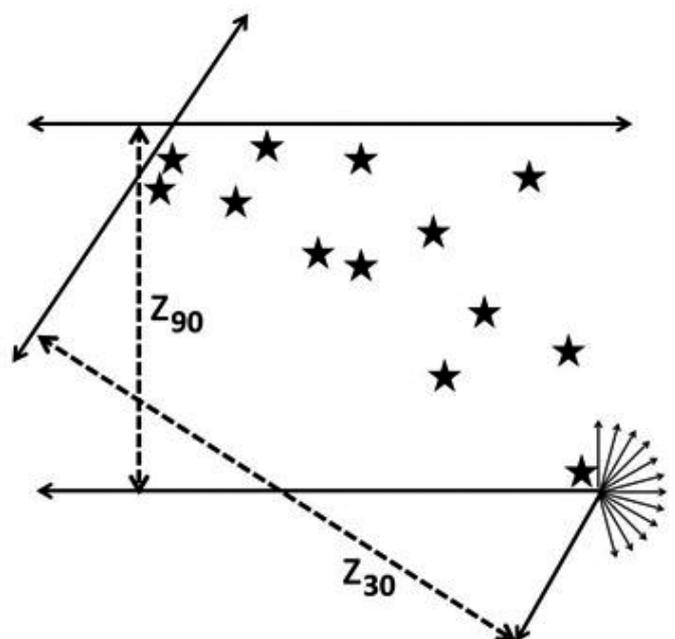
The outer locations (points) for each animal were used to define the limits of its home range. This is a more conservative

method that might be used when there are insufficient data available for kernel estimation.

### Simulation

For each stoat we calculated one home-range width by measuring the maximum distance ( $z$ ) between two parallel lines that encompassed all of the kernel, circle or point data for an animal (Fig. 1). This process was then repeated, rotating the parallel lines by 15° increments to give 12 home-range widths per animal ( $z_0, z_{15}, z_{30} \dots z_{165}$ ). The distance ( $z$ ) represents the minimum distance required to ensure that at least one of the lines will intersect the animal's home range. Conversely, any further increase in distance between the parallel lines creates some chance of not intersecting an animal's home range.

The 12 home-range widths ( $z_0, z_{15}, z_{30}$  etc.) calculated for each stoat were then used in a randomisation test to calculate the probability ( $P_i$ ) that a randomly positioned stoat's home range would be intersected by parallel control lines given their separation distance. The simulation randomly selects  $z$  values from the entire empirical distribution of  $z$  values of all individuals. Each  $z$  value is one realisation of an animal's home-range width given varying orientation towards control device lines. We then accounted for the uncertainty in the location of the home range centre by adding to the drawn  $z$  value a random number from a uniform distribution ranging from zero to half the separation distance of the control-device lines. This places the centre of an animal's home-range at a random location between the control-device lines. We assumed an intersection if the home-range width plus the random number was greater than the device-line separation. This calculation was performed 50 000 times for each control-device line separation distance. We assessed the probability of encounter



**Figure 1.** Diagram representing the minimum distance ( $z_{30}$  and  $z_{90}$ , dashed lines) between two sets of parallel lines that encompass a set of location estimates (stars) from stoat radio-tracking data. The solid lines illustrate two of 12 orientations of parallel control-device lines that were simulated. The small arrows (bottom right-hand corner) show all 12 orientations.

for separation distances from 100 to 5000 m at intervals of 100 m. The probability ( $P_i$ ) was calculated as the number of encounters divided by 50 000. Due to sexual dimorphism in stoat home range we simulated female and male stoat home ranges separately.

## Results

### Home ranges

Data from 41 stoats were available from the three studies. The sensitivity analysis indicated that 32 out of 41 stoats had sufficient location data to reliably estimate their home range. All subsequent results are based on these 32 animals only.

### Home-range width and device spacing

When kernels were simulated, the probability of a stoat encountering a control-device line ( $P_i$ ) fell below one for female stoats when device lines were 700 m apart and for male stoats when they were 900 m apart. As spacing increased,  $P_i$  fell more sharply for females than males, with 83% of females having control-device lines bisect their home range when the lines were 1500 m apart compared with 98% of males.

When circles were simulated,  $P_i$  fell below one for female stoats when control-device lines were spaced 700 m apart and for male stoats when they were 1100 m apart. With increased spacing  $P_i$  fell more sharply for females than males with only 84% of females having control-device lines bisect their home range when lines were 1300 m apart compared with 98% of males.

When raw-data points were simulated,  $P_i$  fell below one for female stoats when control-device lines were spaced 400 m apart and for male stoats when they were 500 m apart. As spacing increased,  $P_i$  fell more sharply for females than males with 85% of females having control-device lines bisect their home range when lines were 1000 m apart, compared with

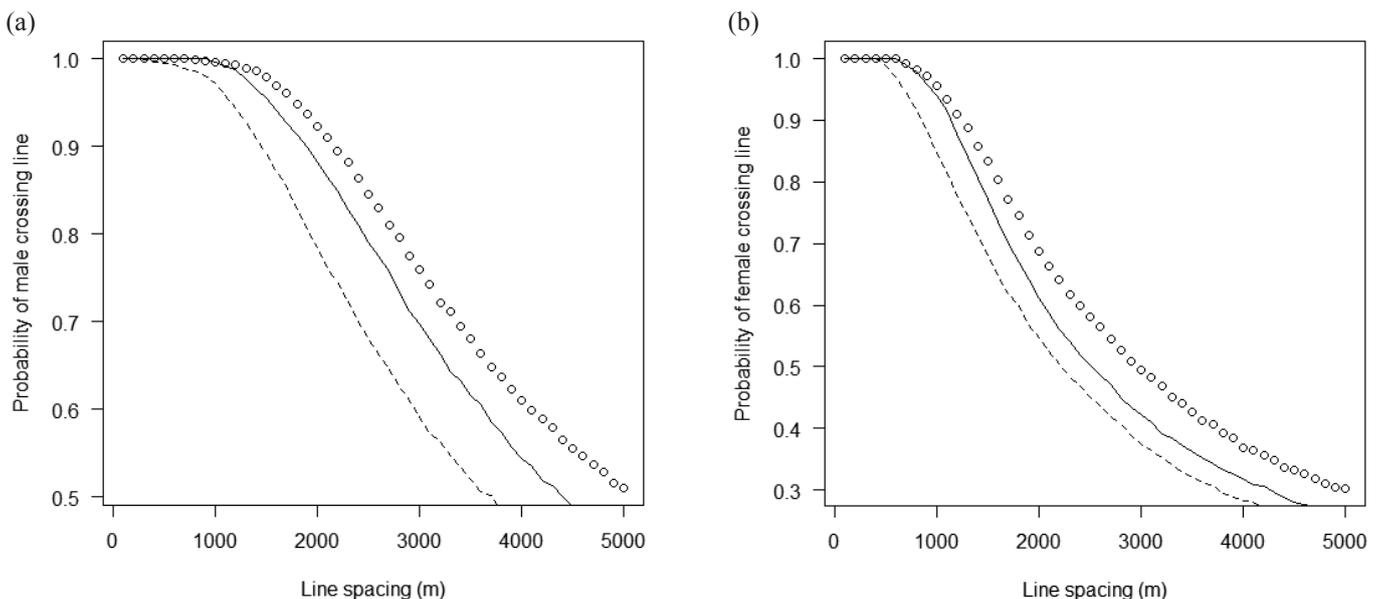
97% of males.

Simulations using kernels allowed for the widest control-device line spacing across the full range of  $P_i$  (0–1), while simulating the distance across raw-data points was more conservative (Fig. 2). Simulating circles produced intermediate results (Fig. 2).

## Discussion

Home range is one of the core concepts of modern spatial ecology (Börger et al. 2008). We have described a simulation that can be applied to estimates of animal home-range use that will assist the planning and implementation of invasive species control. This method can be applied to a wide range of pest species both in New Zealand and abroad that form home ranges and are controlled with either traps or poison baits. The application of this tool does, however, require data on home range to be available for the target species. If home range data are not available, their collection could be made a research priority. An investment in research to collect home-range data may be a small cost compared with implementing management that is either ineffective, or is more costly than is necessary to meet management objectives.

The Department of Conservation is the main government agency in New Zealand tasked with controlling stoats to protect threatened fauna (Department of Conservation 2013). The Department’s standard operating procedure recommends control device lines should be no further apart than 800–1000 m for stoat control (Department of Conservation 2009). Our home range simulations suggest that this allows a reasonably high rate of intersection between stoat home ranges and trap lines. However, a device line spacing of 700 m is required to ensure 100% of female home ranges are intersected, based on our simulation of kernels. If managers were to use 1000-m spacing we estimate that 5% of females would be missed. Female stoats are almost always pregnant, can have



**Figure 2.** Probability  $P_i$  of (a) male and (b) female stoats encountering parallel control-device lines. Circles =  $P_i$  derived from kernel-home-range estimates, solid lines =  $P_i$  derived from circular-home-range estimates (created by converting the previously estimated kernels into circles of equivalent area), dashed lines =  $P_i$  derived from measurements between the outer locations (points) recorded for each individual stoat.

up to 12 kits, and implantation of blastocysts is delayed for 12 months (King & Murphy 2005). Therefore, missing 5% of females would not be satisfactory for an island eradication, nor for some mainland management scenarios where endangered species are present that are highly sensitive to stoat predation.

Our example of stoats in New Zealand is one where managers will almost always want to intersect a high proportion of home ranges, because of the sensitivity of endemic birds to stoat predation (Wilson et al. 1998; Innes et al. 1999; Dilks et al. 2003; Whitehead et al. 2008). However, there may be management scenarios with other invasive species where it is not necessary to strive to intersect 100% of the home ranges of the target animal in the management area. The simulation we have described can be used to determine the probability of parallel lines intersecting whatever proportion of home ranges is warranted for a given management context.

There was little variation in home range size between the three datasets used in the simulation. However, an important consideration when using this simulation to design control will be whether home range size of the target species varies with sex, age class, season or habitat. If so then home-range data should be collected across these categories so that the simulation and consequent device line spacing can account for this variation. Control-device line spacing could then be adjusted between habitats or seasons, or if more practical, a spacing chosen that guarantees a high intersection rate for all habitats, seasons or age classes.

The question remains, what type of home range estimate is best for use in our simulation? We have provided three examples here and there are many other methods of home-range estimation that may be considered (White & Garrott 1990; Millspaugh & Marzluff 2001). On the basis of these three examples, we recommend that if there are sufficient location data per individual then the more robust kernel estimates of home range should be used (Millspaugh & Marzluff 2001). However, if sample sizes are small, kernel estimates can become inflated (Millspaugh & Marzluff 2001), which would result in an inaccurate and elevated probability of home ranges intersecting control-device lines. It would therefore be safer to take the more cautious approach of using points, accepting that the use of points may be overly conservative and result in control that might be more costly than is necessary. The sensitivity analysis described here can be used to assess whether sample size is sufficient to use kernels. If sample sizes are not sufficient, the collection of adequate home-range data should be a priority.

We included circles in our analysis because trap line spacing has sometimes been determined by converting home-range estimates into circles and spacing lines at a distance equivalent to the diameter of the circle (Thomas 1994). This method does not account for elongated or irregularly shaped home ranges. Circular home ranges fell between the conservative option of estimating distances across point data and home-range estimates using kernel analysis. In the absence of information on orientation, the diameter of a circle should approximate the mean width of a kernel (across the 12 estimates of width) especially when orientation of home ranges is random. Given a specific control-device line spacing, the probability of missing individuals in the population will increase with increasing elongation of home-range kernels. Consequently, circles are a reasonable approximation, but more accurate estimates of probabilities of intersection will be obtained using kernels in the simulation procedure.

The probability of intersection ( $P_i$ ) is not the probability

of removal. This requires the additional consideration of the probability an animal will encounter a device along the line, and the probability the animal will interact with the device given an encounter. Nevertheless, invasive species management that is guided by simulations of  $P_i$  will be more effective than operations that are planned using either the manager's intuition or inadequate data. Also, the simulations on  $P_i$  we have described will be a useful starting point for invasive species management programmes that use an adaptive resource management approach (Walters 1986). Such programmes could incorporate information on encounter and interaction probabilities into their planning as it becomes available.

## Conclusion

Worldwide, invasive species are a significant threat to biodiversity. Despite years of research, conservation managers still lack tools for confronting uncertainty about how to design operations to control invasive species. We have described a method for simulating home-range data that will be of utility to conservation managers aiming to control invasive species. We encourage further research in this area, as conservation managers need innovative science-based tools to assist them in protecting biodiversity for future generations.

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