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TrapSim: A decision-support tool for simulating predator trapping

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Contents

Summary

Project and client

- Hawke’s Bay Regional Council (HBRC) contracted Landcare Research to design a decision-support tool to simulate the trapping of predators under various trapping networks. This report describes the development of the tool, TrapSim, presents some examples of its use, and indicates areas for future development

Objectives

- The main objective of this project was to provide an online decision-support tool to simulate the trapping of target predators (stoats, ferrets and feral cats) in the Cape to City footprint.
- The aim of the tool is provide managers with a way of exploring how different trap network designs can affect the relative effectiveness of predator-trapping outcomes.

Methods

- TrapSim is a simulation tool that can be run from any web browser. It was written in the R programming language and deployed using the Shiny R package.
- TrapSim consists of two main modules: a population module that controls for the population growth of the predator populations, and a trapping module that controls for the interaction between animals and traps.
- The user interface consists of a sidebar that provides a way of easily changing parameter values, an interactive map of trap locations and ‘simulated’ animals, and panels that display results in tables and figures.
- We carried out a number of simple simulations of the initially proposed trap layout in Cape to City to show how TrapSim can be used to gain insight into the effect of altering the trapping regime for the purpose of maintenance control.
- We carried out simulations at two levels of trap-checking interval (20 vs 100 nights) and two levels of traps (all traps vs 25% of traps). Simulations were done for single species at two levels of density (0.01 and 0.1/ha), and for multiple species at 0.01/ha

Results

- At low species densities (0.01/ha) the percent kill of predators was high (c. 90%) for both the full and reduced network when the checking interval was 20 days. Increasing the checking interval to 100 days made little difference to percent kill for the full trap network, but resulted in a much lower percent kill for the reduced trap network.
- At higher densities (0.1/ha) the effect of reducing the trap network and/or increasing the checking interval resulted in a substantially lower percent kill of predators. The overall percent kill of predators was substantially lower when the trap-checking

interval was increased from 20 days to 100 days. This effect was more pronounced when only 25% of the trap network was used.

- Species responded differently to changes in the trapping regime. Stoats were less affected than ferrets by a reduction in the trap network or an increase in the checking interval, presumably because the home ranges of individual stoats encompass more traps per individual.
- Simulating the trapping of multiple predator species resulted in lower percent kills compared with single-species simulations. This is due to increased competition for traps and highlights the importance of multi-species models for modelling the efficacy of a trapping network.
- TrapSim is freely available at: https://landcare.shinyapps.io/TrapSim_C2C/

Conclusions

- TrapSim is a useful tool that managers can use to explore the effects of various trapping regimes on the potential trap capture rates of different species, thereby providing a guide for management decisions.
- It is important to note that the results of this (and any simulation) are conditional on the parameter values specified by the user.
- Default values are provided for all parameters. However, these should be treated as indicative and as starting points only.

Recommendations

- TrapSim can be used to examine the relative effect of various trap networks and trapping regimes. It is not a predictive tool and cannot be used to make accurate predictions about trap catch.

1 Introduction

Hawke's Bay Regional Council (HBRC) contracted Landcare Research to design a decision-support tool to simulate the trapping of predators under various trapping networks. This report describes the development of the tool, TrapSim, presents some examples of its use, and discusses its future development.

2 Background

Permanent networks of kill traps have the potential to provide long-term, cost-effective control of vertebrate pests over large scales. These kill-trap networks are often initially established with a large number of devices in order to substantially reduce the pest population to low levels. It is likely, however, that after the population has been reduced, the initial number of traps in the landscape is higher than that required for long-term maintenance of a low-density pest population. This means removing a proportion of devices will reduce the cost of checking and maintaining the network without reducing its effectiveness.

The optimal number of devices in the landscape for maintenance control depends on a number of factors in addition to the population size of the target species. For example, the size of the home range of the individuals has a significant bearing on the density/spacing of traps required. Rats, for example, range over areas of c. 3 ha, whereas mustelids range over areas of c. 300 ha. If trap lines are spaced too far apart (>400 m), then populations of rats could easily live between trap lines and never be exposed to capture, whereas ferrets and stoats are likely to encounter multiple traps. The density of traps therefore depends on the target species.

Another factor that can affect the number of traps required for an effective network is the time interval for checking and resetting traps. Checking traps too often when populations are low can waste resources, as there are only very few traps to clear and reset. In contrast, checking traps too infrequently can result in many traps being triggered and therefore no longer able to catch surviving animals until the next checking time. So how can managers decide on a trapping network that will meet their aims?

Cape to City[1] is a predator control and ecological restoration programme covering 26,000 ha in the Hawke's Bay region, adjacent to the Cape Sanctuary wildlife restoration project on the Cape Kidnappers peninsula (Figure 1). A network of predator traps is currently being implemented across the landscape in stages. The aim of this trapping network is to maintain target predators (ferrets, stoats and feral cats) at low densities within the Cape to City footprint.

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[1] http://capetocity.co.nz/

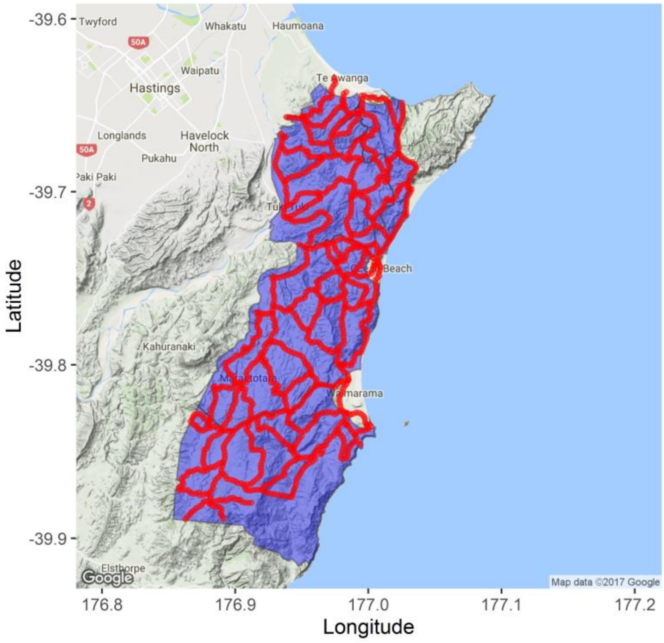


Figure 1 Location of the Cape to City area (blue-shaded) and the proposed trap network (red circles). Plot generated using ggmap (Kahle & Wickham 2013).

3 Objectives

The main objective of this project was to provide an online decision-support tool to simulate the trapping of target predators (stoats, ferrets and feral cats) in the Cape to City footprint. The aim of the tool is provide managers with a way of exploring how different trap network designs can affect the relative effectiveness of predator trapping outcomes. This report describes the development of the tool, gives some examples of simulations, and provides recommendations for its use.

4 Methods

TrapSim is an individual-based model that simulates the nightly captures of animals in a given network of traps using an individual-based simulation model (Warburton & Gormley 2015). The tool simulates nightly capture and *in situ* reproduction of three target predator species (ferrets, stoats and rats) concurrently. Capture of non-target species is not simulated directly, but is approximated by allowing the user to specify a nightly probability of traps becoming inactive until the next checking interval.

TrapSim was written in the R programming language (R Core Team 2017) and implemented using the R packages Shiny (Chang et al. 2016) and Leaflet (Cheng & Xie 2016). It is freely available on the internet at https://landcare.shinyapps.io/TrapSim_C2C/

TrapSim consists of two main modules: a population module that controls the population growth of the predator populations, and a trapping module that controls the interaction between animals and traps.

4.1 Population module

The initial population size of each species is drawn from a Poisson distribution with a mean density specified by the user. The resulting simulated animals are randomly located across the Cape to City footprint using a random point pattern function in the Spatstat package (Baddeley & Turner 2005).

In situ reproduction was simulated during the breeding season (as specified by the user) to represent an annual reproductive pulse. The number of new offspring each reproductive period is drawn from a Poisson distribution with mean λ, given by:

$$\lambda = rMax \times N\left(1 - \left(\frac{N}{K}\right)\right)$$

where *rMax* is the maximum rate of increase and *K* is the carrying capacity of the Cape to City footprint. The number of offspring is temporally distributed evenly over the reproductive period so as not to induce a ‘spike’ in the population. Each offspring is spatially distributed at a dispersal distance (*m*) from its parents, which is drawn from a log-normal distribution with mean and standard deviation (SD) for that species. The coordinates for the centre of the home range of the new offspring is given by:

$$x = \sin(\theta) * m + X$$

$$y = \cos(\theta) * m + Y$$

where *X* and *Y* are the coordinates of the parent, and θ is a random uniform angle in radians.

4.2 Trapping module

A matrix is constructed of the distance d_{ij} between each animal *i* and trap *j* before the beginning of each trapping event. This distance matrix is then converted to a probability of nightly capture for each animal−trap pair:

$$p_{ij} = g_0 \exp\left(\frac{-d_{ij}^2}{2\sigma^2}\right)$$

where g_0 is the probability that a trap at the centre of an individual’s home range would capture that individual on a single night and σ is the SD of the home range kernel assuming a bivariate normal home range (Efford 2004). The 95% home range area of an individual equals $6\pi\sigma^2$. Values for g_0 and σ are species-specific and are set by the user.

Each night the simulation loops through each animal that is still alive in the population in a random order to prevent any unintended bias. For each animal, the cumulative probability of being captured (*p.tot*) is calculated across all traps still in operation (i.e. sprung traps cannot capture individuals until they are cleared):

$$p.tot_i = 1 - \prod_{j=1}^{n_{traps}} \left(1 - \left(p_{ij} \times I_j\right)\right)$$

where I_j is a trap indicator, which equals 1 when a trap is still in operation and 0 otherwise. A random binomial is then drawn with this cumulative probability to determine whether the individual is captured. If successful, the trap that captured the individual is drawn from a multinomial distribution with probabilities equal to the capture probabilities (p_{ij}).

The effect of non-target animals was originally simulated in the same way. However, due to computational issues associated with a large number of non-target animals, we simplified the method and included instead a probability of nightly trap failure f that was able to be specified by the user. Each night all the remaining traps are set to $I_j = 0$ with probability f.

4.3 User interface

The user interface of TrapSim consists of a sidebar panel of parameters that can be changed by the user, and a display section that includes a zoomable map of the Cape to City area. There are also options for displaying various map layers, traps and simulated animal locations (Figure 2).

TrapSim initialises with default values for all parameters. However, these can all be changed by the user for each simulation run. Most parameters contain ‘tool tips’ (i.e. a pop-up box appears when the user hovers their mouse over the input box to provide information on the parameter).

The first section allows the user to select the trap network. The default value is to *Keep all traps*, but this can be modified to keep 75%, 50% or just 25% of the proposed trap network.

The user then sets the length of the simulation (default = 100 nights) and the interval between trap checking (default = 30 nights). Finally in this section the nightly by-catch rate can be modified (default = 0.01).

The second section allows the user to specify the start day (default = day 20) and length of the reproductive period (default = 30 days). This is assumed to be the same for all target predators (i.e. the breeding season is the same for all species).

The user can then specify which of the three target predator species (stoat, ferrets and feral cats) are being simulated. There are six parameters for each species. *Density* and *K* are the initial density and the carrying capacity, respectively, in terms of animals per hectare. The default value for the initial density = 0.01 animals per hectare for all species.

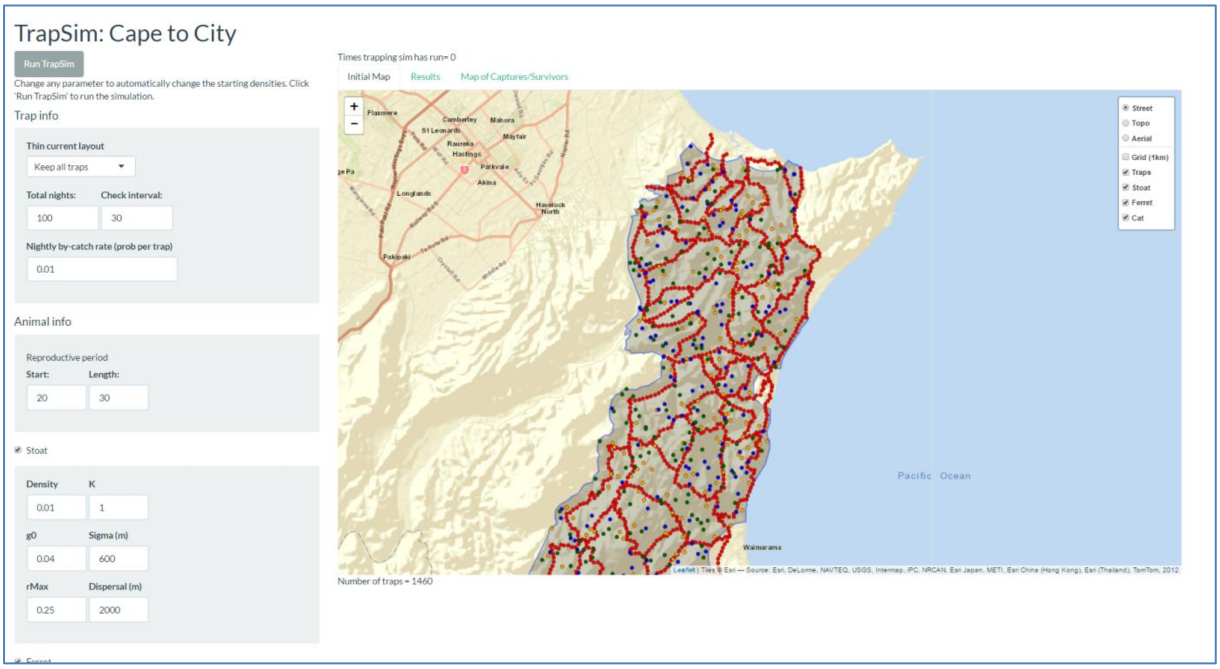
The parameters g_0 and σ govern the trapability of individuals: g_0 is the nightly probability of capture for an animal with a trap at the centre of its home range, while σ describes the size of the home range of an individual. The final two parameters are related to reproduction. The parameter *rMax* is the intrinsic maximum rate of increase and is the maximum number of offspring per individual per year. Dispersal is the mean dispersal distance for offspring from their mothers. The default values for the animal parameters (Table 1) reflect those used by Glen et al. (2017).

Table 1 Default parameter values for each target predator species

Parameter	Stoat	Ferret	Cat
g_0	0.04	0.08	0.04
σ (m)	600	460	350
rMax	0.25	1.1	1
Dispersal (m)	2,000	1,500	2,000
Carrying capacity (per ha)	1	1	1
Initial density (per ha)	0.01	0.01	0.01

Once the parameters have been specified, the user clicks the *RunTrapSim* button and the simulation will run for the specified number of iterations. A single simulation will typically take about 10 seconds under the default parameters. However, this can be substantially longer for longer simulations, especially when the starting density is much higher.

TrapSim provides a range of results for each species, including the daily population size and the number of captures per night, as well as mean and SD of the percentage of total animals killed, and the final population size as a percentage of the initial population size (Figure 3). There is also a map showing the locations of animals (dead and alive) at each time step (for the final simulation only).



TrapSim: Cape to City

Run TrapSim

Change any parameter to automatically change the starting densities. Click 'Run TrapSim' to run the simulation.

Trap info

Thin current layout: Keep all traps

Total nights: 100

Check interval: 30

Nightly by-catch rate (prob per trap): 0.01

Animal info

Reproductive period

Start: 20

Length: 30

☑ Stoat

Density: 0.01

K: 1

g0: 0.04

Sigma (m): 600

rMax: 0.25

Dispersal (m): 2000

☑ Ferret

Times trapping sim has run= 0

Number of traps = 1460

Figure 2 Screen shot of TrapSim showing a selection of the parameters on the left and the map of the trap layout and initial animal distribution on the right.

TrapSim: Cape to City

Run TrapSim

How may repeats: 5

Change any parameter to automatically change the starting densities. Click 'Run TrapSim' to run the simulation.

Trap info

Thin current layout: Keep 25%

Total nights: 100

Check interval: 20

Nightly by-catch rate (prob per trap): 0.05

Animal info

Reproductive period

Start: 30

Length: 20

☑ Stoat

Times trapping sim has run= 1

Percentage of total animals trapped

```
       Mean   SD
Stoat  86.13 1.99
Ferret 81.86 3.08
Cat    57.20 3.02
```

Final population as a percentage of initial population

```
       Mean   SD
Stoat  14.63 1.99
Ferret 23.39 4.68
Cat    62.40 5.00
```

```
          X       Y Species   g0        g0u Sigma Dead Day1  Day2 Class
391 1940212 5593211  Ferret 0.08 0.06226497   460    1    1     6     2
467 1942531 5591243  Ferret 0.08 0.08534461   460    1    1     1     2
334 1938795 5588823  Ferret 0.08 0.04811134   460    1    1    18     2
637 1939527 5582296     Cat 0.04 0.05266668   350    1    1    52     2
491 1943816 5596741     Cat 0.04 0.05130314   350    0    1 10000     2
43  1940188 5600850   Stoat 0.04 0.04940616   600    1    1    43     2
```

Figure 3 Screen shot of TrapSim showing the type of results that are displayed.

4.4 Illustrative simulations

To illustrate the use of TrapSim we performed a number of simulations with various combinations of parameters. For the first set of simulations we modelled a single species (stoats only and ferrets only) in order to explore how the different species parameters affect the outcomes. We varied the trap-checking interval (20 vs 100 nights), the initial density (0.01/ha vs 0.1/ha), and the number of traps (all traps vs 25% of traps), resulting in eight sets of simulations for each species. All other parameters were set at default values (Table 1). Simulations were run for 100 nights. Each set of simulations was run 50 times to give an approximate indication of stochastic variability.

For the second set of simulations we included all three target species simultaneously so as to more accurately reflect the real situation of multiple predators. As for the first set of simulations, we varied the trap-checking interval (20 vs 100 nights) and the number of traps (all traps vs 25% of traps). The simulations were only performed with initial densities of 0.01/ha for each of the three target species.

5 Results

For single-species models, stoats had a higher percentage of the population trapped compared with ferrets across all simulations (Table 2). Although g_0 for stoats was half that of ferrets, the larger σ value for stoats meant that each individual stoat had a greater number of traps to potentially encounter due to their larger home range (678 ha for stoats, vs 400 ha for ferrets.)

The effect of the checking interval was negligible for both species when all traps were used and the population was at low densities, due in part to a high number of initial captures (Figure 4). However, at a reduced trap network and/or at high densities, lengthening the time between trap checks substantially reduced the percent kill.

Reducing the trap network had a larger effect for ferrets, especially when the checking interval was long (i.e. 100 days). This effect is due to ferrets having a smaller home range: the reduction in the trap network still resulted in stoats having multiple traps within each home range.

The higher initial predator density (0.1/ha vs 0.01/ha) had a large effect on trapping outcomes, especially with a reduced trap network. In some cases the population at the end of the simulation was greater than the initial population size (Figure 5). This increase in population size is due to traps becoming full and therefore unable to capture more animals, as well as *in situ* reproduction from surviving animals. The effect was exacerbated when the checking interval was longer (i.e. 100 days).

Table 2 Percent kill of stoats and ferrets from simulations run with a single species at a time. Values indicate the mean (SD) across the 50 repeat simulations

Start density	Check interval (nights)	Traps	Stoats % kill (SD)	Ferrets % kill (SD)
0.01/ha	20	All	95.3 (2.1)	89.2 (3.9)
		25%	92.3 (1.1)	87.8 (3.0)
	100	All	93.4 (1.9)	85.8 (2.7)
		25%	74.8 (3.0)	63.3 (2.4)
0.1/ha	20	All	93.3 (0.3)	88.8 (0.2)
		25%	60.5 (0.5)	43.6 (0.3)
	100	All	52.2 (0.5)	39.2 (0.6)
		25%	12.3 (0.2)	7.9 (0.1)

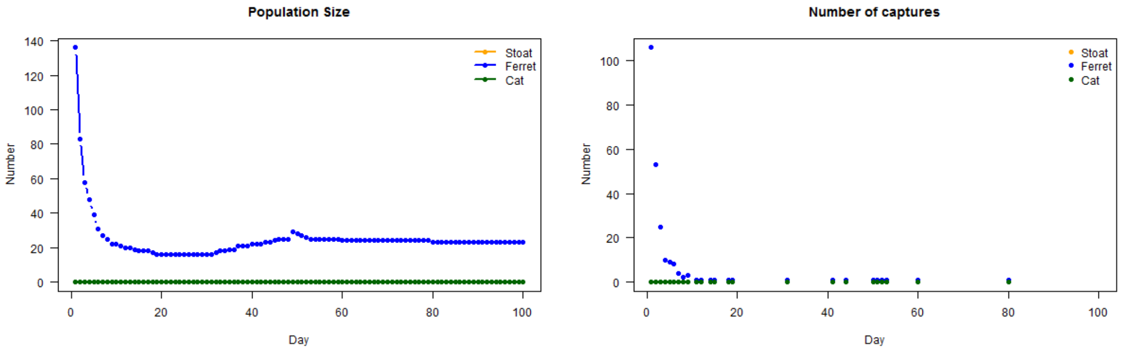


Figure 4 TrapSim plots showing the population size over time (left) and the number of captures per day (right) of ferrets from an initial density of 0.01/ha, where traps were checked every 100 days and all the traps were set.

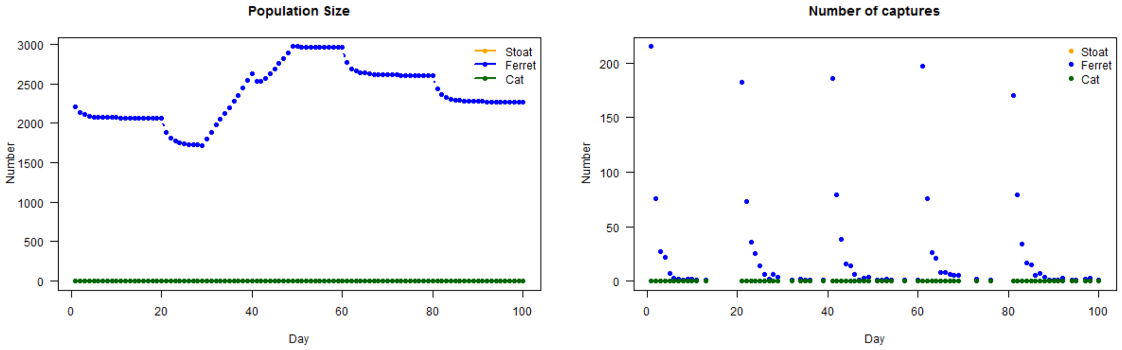


Figure 5 TrapSim plots showing the results of checking traps every 20 days for an initial density of ferrets of 0.1/ha and 25% of the traps set.

When multiple species were simulated simultaneously, the percent kill per species was lower than when the species were simulated separately (Table 3). This is due to increased competition for traps and illustrates the need to simulate multiple species when modelling the efficacy of a trapping network.

Table 3 Percent kill of stoats and ferrets from simulations run with multiple species (stoats, ferrets and cats). Values indicate the mean (SD) across the 50 repeat simulations

Start density	Check interval (nights)	Traps	Stoats % kill (SD)	Ferrets % kill (SD)	Cats % kill (SD)
0.01/ha	20	All	93.4 (1.9)	89.0 (2.4)	86.2 (3.6)
		25%	89.8 (2.9)	82.9 (1.9)	65.3 (2.8)
	100	All	92.3 (2.1)	85.6 (3.1)	76.6 (2.9)
		25%	47.1 (3.9)	34.7 (3.9)	14.2 (1.6)

When the full trap network was simulated, the predator population was lower than the initial population at the end of the 100-day simulation regardless of whether traps were cleared every 20 days (Figure 6a) or after 100 days (Figure 6b). With a reduced trap network, the predator population was often higher at the end of the 100-day simulation when traps were cleared only at the end (Figure 6d) compared with checking every 20 days (Figure 6c).

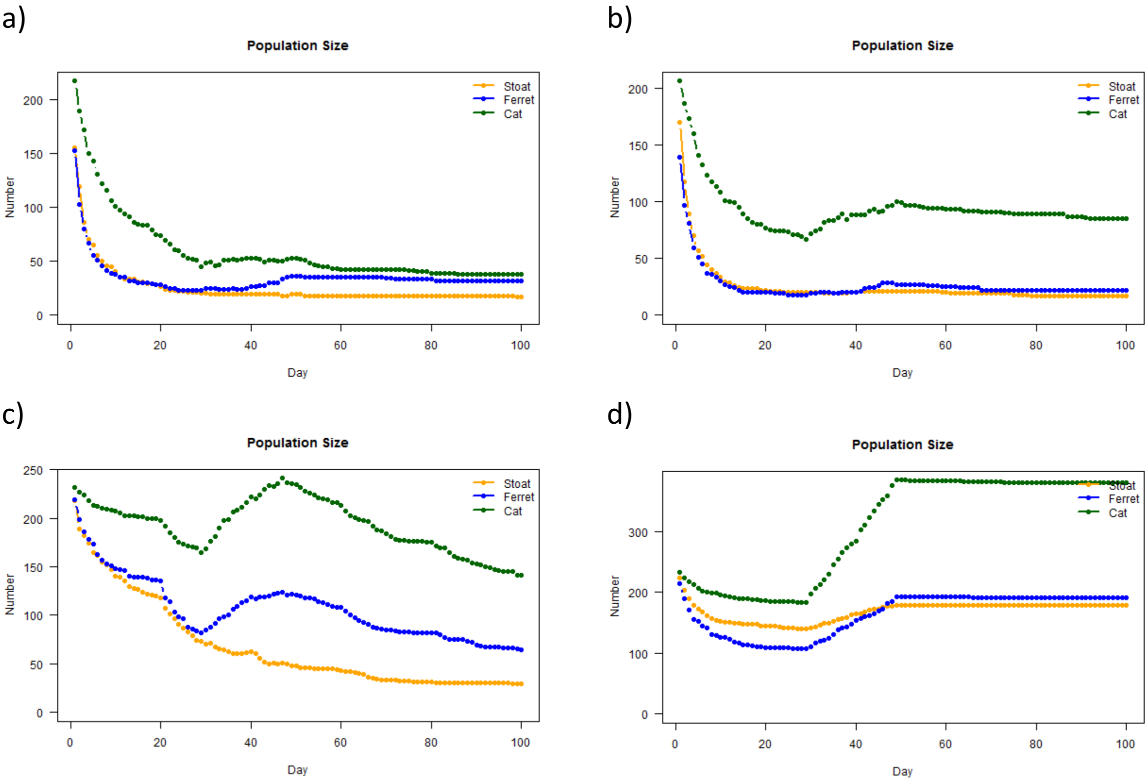


Figure 6 TrapSim plots showing the results of simulating all three target species where traps were checked every 20 days (a & c), every 100 days (b & d), and with a trap network of all traps (a & b) and only 25% of the traps (c & d).

Running the simulation for longer periods reveals more about the dynamics of each population. For example, simulating a 25% trap network for 1,000 days shows only a marginal increase in the predator populations at the end of the simulation when traps are checked every 30 days (Figure 7a) vs every 100 days (Figure 7b).

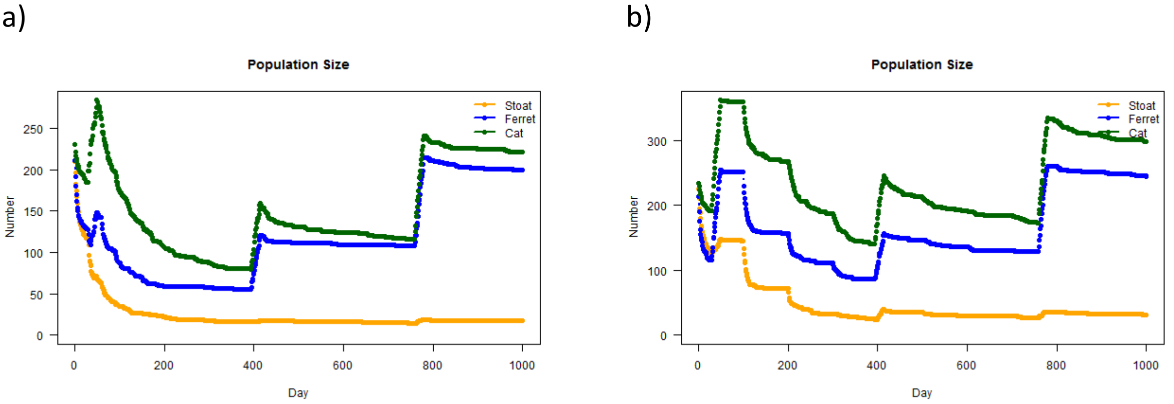


Figure 7 TrapSim plots showing the results of simulations of all three target species where traps were checked every 30 days (a), and every 100 days (b), and with a trap network of 25% of the traps set, run for 1,000 days.

6 Conclusions and recommendations

TrapSim is a useful tool that managers can use to explore the effects of various trapping regimes on the potential trap capture rates, thereby providing a guide for management decisions. For example, the brief simulations performed above show that if a species is at a density of c. 0.1/ha, then reducing the trap network to just 25% of the original traps will not be enough to suppress its population size. Even when all of the proposed traps in the network are used, checking of traps may need to occur more frequently than every 100 days. The simulations also highlight that species will respond differently to a trapping regime due to factors such as home range size, trappability and reproductive rates. For example, reducing the trap network to 25% of the original traps may result in a much lower population of stoats but a higher population of stoats and ferrets.

The simulations in this report were carried out to illustrate the use of the tool, and as such were intentionally restricted to explore only a small set of changes in a few parameters. They do not represent the full range of simulations that could be carried out. Furthermore, we recommend repeating simulations a larger number of times (i.e. ≥100) in order to better capture the stochastic variability.

It is important to note that the results of this (and any simulation) are conditional on the parameter values specified by the user. There are a large number of parameters in TrapSim that affect the outcomes of the trapping simulations (e.g. g_0, σ, carrying capacity, dispersal distances). Default values are provided for these, however, and we acknowledge that the values of some parameters have been better studied than others. Furthermore, some parameter values were estimated from studies in regions that may differ from the habitat in Cape to City. The default parameter values in TrapSim are a starting point and should not be treated as reflecting the real situation.

TrapSim is similar to the model used in Glen et al. (2017), but there are a number of differences. Our model builds on their model by simulating the simultaneous capture of multiple predator species. This is a valuable extension given the competition for traps within and between species. For example, our small set of simulations showed that when multiple species are simulated concurrently (Table 3), the percent kill per species is lower than when the species are simulated separately (Table 2) due to increased competition for traps. This illustrates the need to simulate multiple species when modelling the efficacy of a trapping network. TrapSim includes the effect of capture of non-target species, although this is done indirectly using a simplification to allow for computational efficiency (see methods above).

The model of Glen et al. (2017) simulates dispersal where the choice of home range centre for dispersing juveniles is partially density dependent. We have simplified the dispersal step by allowing individuals to disperse to any region irrespective of the local density. This was done to allow for computational efficiency. However, given the relative low densities simulated during maintenance control we feel this is justified.

There are a number of future developments that could benefit TrapSim. These include (i) simulating immigration from outside the Cape to City boundary, (ii) allowing animal parameters such as carrying capacity or σ to vary with habitat type, and (iii) relaxing the assumption that all species reproduce once a year and during the same season.

TrapSim can be used to examine the relative effects of various trap networks and trapping regimes. It is not, however, a predictive tool and cannot be used to make predictions about trap catch.

7 Acknowledgements

Dean Anderson and Cecilia Latham provided valuable input and advice on the simulation modelling. Campbell Leckie and Rod Dickson provided valuable feedback on an earlier iteration of the simulation model. Natalie de Burgh kindly provided the shapefile of the Cape to City footprint and details of the trap locations. This work was funded by the Hawke's Bay Regional Council and Landcare Research.

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