Manaaki Whenua
Landcare Research

Whakatipu Mahia possum eradication modelling (part II): modelling the use of barriers to dispersal

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Whakatipu Mahia possum eradication modelling (part II): modelling the use of barriers to dispersal

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Summary

Project and Client

- In December 2018, the Hawke's Bay Regional Council (HBRC) released an operational plan, launched as Whakatipu Mahia, for eradicating possums on Mahia Peninsula by the end of 2021. The objectives of the plan are to eradicate possums over the entire 14,616-ha peninsula and to maintain this eradication. The area has been divided into 10 control blocks which will be tackled individually as a rolling front, starting at the bottom of the peninsula and working northwards.
- In January 2019, the regional council approached Manaaki Whenua to model the eradication plan and investigate the effectiveness of different control effort. The results from the simulations (Lustig & Gormley 2019) suggested that possum eradication could be achieved in the first 5,500-ha milestone area under the proposed spatio-temporal control regimes but was unlikely to be achieved in the ~9,000-ha milestone area. It was suggested that maximising the use of barriers to dispersal between control blocks 2C and 2B, and between blocks 2E/2D and 2C, could prolong treatment persistence but these features have yet to be accounted for in subsequent modelling. In addition, the simulations assumed: 1) a 'closed population' and therefore did not include immigration from untreated areas outside the eradication area, which, if present, would compromise the effectiveness of any eradication programme; 2) all possum individuals had the same level of trappability, but we know this is not true as there are sub-sets of the population that are much harder to capture, thereby making the goal of eradication more difficult.

Objectives

- Assess whether using buffers of bait stations around high-density possum control blocks and across the neck of the Mahia Peninsula (to limit immigration from untreated areas outside the eradication area into the eradication area) could increase the likelihood of achieving possum eradication in the second ~9,000-ha area.
- Assess whether immigration from untreated areas outside the eradication area can compromise the eradication programme
- Assess how variable possum trappability affects predicted eradication outcomes

Methods

- We combined an agent-based mathematical modelling framework with spatial information on pest habitat distribution, population dynamics and levels of control to investigate the effectiveness of different temporal distributions of control effort.
- We tested whether a buffer of bait stations or kill traps at one station/trap per hectare in blocks 2C and 2B (high-density possum blocks) and across the neck of the Mahia Peninsula (block 2F) will eradicate possums in the second ~9,000-ha area; including immigration from untreated areas outside the eradication area. We included variable trappability in the model to estimate how it affects predicted eradication outcomes.

Results

- Using buffers of bait stations around high-density possum control blocks and across the neck of the Mahia Peninsula (to limit immigration from untreated areas outside the eradication area to the eradication area) could increase the likelihood of achieving possum eradication in both the first 5,000 ha area and the second ~9,000-ha area.
- Immigration from untreated areas outside the eradication area had a very low impact on the modelled eradication outcome and did not compromise the eradication programme
- Small but consistent variations in levels of trappability between possums had a very low impact on eradication outcome. However, when the population exhibited larger variations in levels of trappability the simulations suggested that eradication is unlikely to be achieved under the proposed trapping effort. Where modelled eradication was not successful, the number of remaining animals was low (i.e. less than ten in each control block).

Conclusions and Recommendations

- Control-to-zero density of possums from the entire Mahia Peninsula is feasible if buffers of bait stations around high-density possum control blocks and across the neck of the Mahia Peninsula are used to limit immigration from untreated areas.
- In the absence of an immigration barrier at the neck of the peninsula, reinvasion is likely to occur in the three years following suppression. Possum density at the edge of the eradication area had a very low impact on the modelled eradication outcome and is unlikely to compromise the eradication programme.
- The trappability parameters g0 and σ appear to be particularly important to determine the level of trapping effort (trapping duration and strategy) needed to achieved eradication. Small inter-individual variation in the detection/capture probability can quickly hinder the efficacy of the management scenarios tested. Passive control methods that rely upon possum investigation and contact with the control device may fail to sample individuals that are less active or too wary to approach the control device (low g_0). Active control methods (such as the targeted control proposed in Stage 2) may be particularly useful to target the last survivors with a low trappability.

1 Introduction

The Hawke's Bay Regional Council (HBRC) has been carrying out their Possum Control Area programme since 2000, with suppression of brushtail possums (*Trichosurus vulpecula*) implemented across 700,000 ha of the region. In 2011, a regional predator control programme was initiated in forest (Poutiri Ao ō Tāne), followed in 2015 by a programme based largely in farmland (Cape-to-City). The establishment of Predator Free 2050 has turned the focus towards attempting regional possum eradication.

In December 2018 HBRC released an operational plan for possum eradication on Mahia Peninsula, called Whakatipu Mahia (Hawke's Bay Regional Council 2019). The objectives of the plan are (i) to eradicate possums over the entire 14,616 ha, and (ii) to maintain them at zero density. Whakatipu Mahia is an important step towards the goal of releasing native species from the predation and competition pressure of possums.

The eradication area takes advantage of the geography of Mahia Peninsula, with the surrounding ocean largely creating an effective barrier to pest reinvasion from uncontrolled areas. The eradication area has been divided into 10 blocks of approximately 1,500 ha (Fig. 1). Each control block will be tackled individually as a rolling front, starting in a 1,500-ha zone at the bottom of the peninsula and working northwards, with the aim of eradicating all possums from the entire peninsula by the end of 2021.

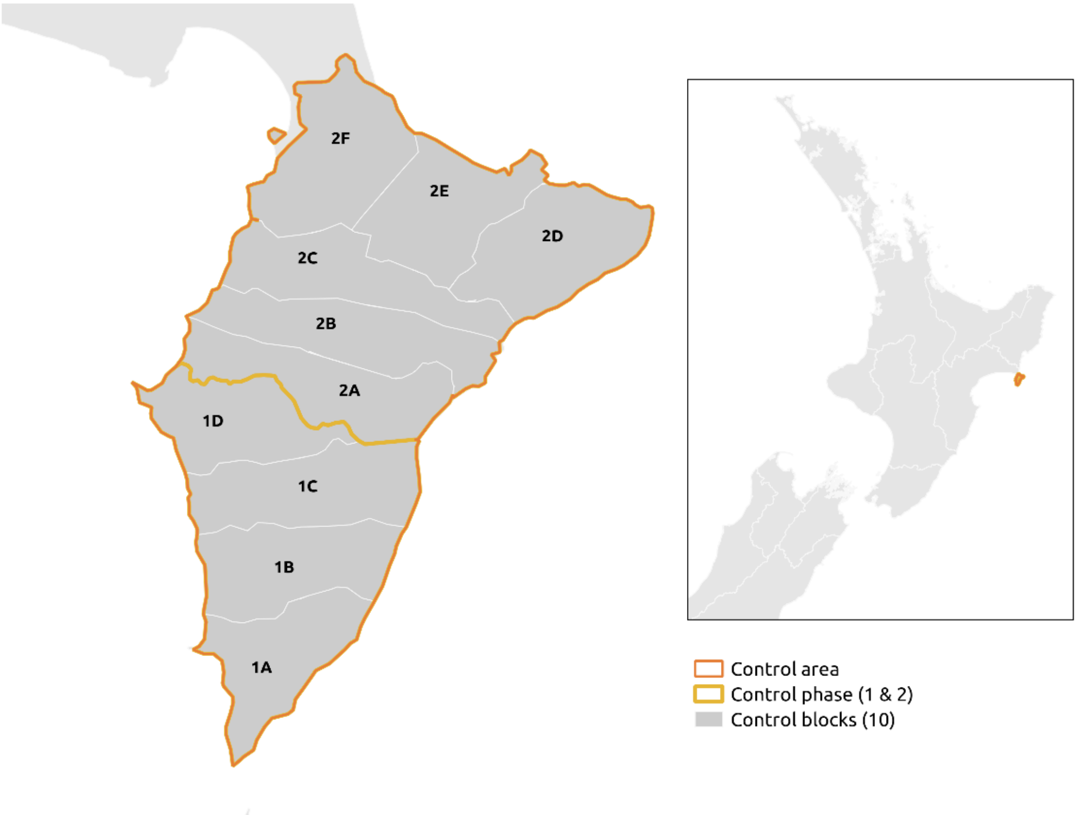

Figure 1. Whakatipu Mahia control phase rollout in the Mahia Peninsula eradication area in Hawke's Bay, New Zealand. The eradication area is delimited by the orange boundaries, the two control phases by the yellow boundary and the control blocks by the white boundaries.

In January 2019, the regional council approached Manaaki Whenua to model the eradication plan and investigate the effectiveness of different levels of control effort. The results from the simulations (Lustig & Gormley 2019) suggested that possum eradication could be achieved in the first 5,500-ha milestone area under the proposed spatio-temporal control regimes but was unlikely to be achieved in the second ~9,000-ha milestone area. It was suggested that maximising the use of barriers to dispersal between control blocks 2C and 2B, and between blocks 2E/2D and 2C could increase the likelihood of achieving possum eradication but these features are yet to be accounted for in subsequent modelling. In addition, the model assumed 1) a 'closed population' and therefore did not include immigration from untreated areas outside the eradication area, which, if present, would compromise the effectiveness of any eradication programme; 2) all possum individuals had the same level of trappability, but we know this is not true as there are sub-sets of the population that are much harder to capture (Warburton & Hickling 1992; Ross et al. 2000), thereby making the goal of eradication more difficult (Vattiato et al. in review*)*.

2 Objectives

We used an agent-based, spatially explicit simulation model (Lustig et al. 2019) for predicting the distribution and abundance of possums across Mahia Peninsula, and for gauging the effects different spatial and temporal distributions of control effort. The model describes the behaviour of adult and juvenile possums located explicitly in a map of their habitat. Key events in an individual's lifetime are birth, death, and dispersal, and these are simulated as stochastic processes (i.e. there is uncertainty in the timing of each event). Adults and juveniles are exposed to a risk of trapping mortality if traps are placed in the occupied grid-cell.

The results of the simulations are then used to:

- assess whether using buffers of bait stations or kill traps around high-density possum blocks (to limit reinvasion from uncontrolled blocks to controlled blocks) and across the neck of the Mahia Peninsula (to limit immigration from untreated areas outside the eradication area to the eradication area) could eradicate possums in the second ~9,000-ha area
- assess whether immigration from untreated areas outside the eradication area can compromise the eradication programme
- assess how variable possum trappability affects predicted eradication outcomes

3 Methods

3.1 Operational rollout in Mahia Peninsula

Control stage

In each block, possum control involves a network of about 1,500 bait stations set approximately 50–100 m apart (one station per hectare or less) (Stage 1 – eradication). Bait stations are active for a minimum of 4 weeks and a likely maximum of 8 weeks. Within each control block, possum presence/absence is assessed daily, based on bait take from stations, as well as additional information including possum sign and interactions with motion-sensitive trail cameras. Additional bait stations and/or leg-hold traps will be placed in areas with possum sign (Stage 2 – targeted control in high-risk areas). At the end of Stages 1 and 2, a network of kill traps (1,500 Victor No. 1 leghold traps) will be deployed at a density of one every 25 ha (Stage 3 – surveillance).

To be consistent with the previous modelling exercise (Lustig & Gormley 2019), we focused on modelling Stage 1 and Stage 3. Stage 2 cannot be integrated in the model without further information from the actual control and surveillance operations in the field. Therefore, model predictions of the effectiveness of control intervention on the possum population are likely to be conservative. We set the density of bait stations to one station per hectare for 8 weeks (Stage 1), followed by 8 to 32 weeks of trapping at a density of one trap per 25 ha (Stage 3) (Table 1, Fig. 1). We investigated the effect of different control durations by comparing control devices in place in each control block for 28 effective control nights (i.e. 4 weeks) with 56 effective control nights (i.e. 8 weeks).

Buffer to reinvasion and immigration barrier

Initially, we simulated the proposed control regime that uses a bait-station network buffer at one station per hectare deployed across blocks 2A and 2B to limit dispersal of possums from uncontrolled to controlled blocks, while eradication is underway in the first 5,500 ha milestone area (Phase 1). The buffer was simulated to be active from June/July 2019. Similarly, while eradication is underway in the second ~9,000-ha milestone area (Phase 2), a bait-station network buffer was deployed across block 2F (neck of the peninsula). The buffer was simulated to be active from October 2019/July 2020.

The results from these simulations suggested that eradication in the second ~9,000-ha milestone area (Phase 2) is unlikely to be achieved under the proposed control regime (Lustig & Gormley 2019). It was suggested that maximizing the use of barriers to dispersal between control blocks 2C and 2B, and between blocks 2E/2D and 2E/2C, could prolong treatment persistence. The current modelling exercise tests whether using a buffer of bait stations or kill traps at one station/trap per hectare in blocks 2A, 2B and 2C will eradicate possums in the second ~9,000 ha area.

Table 1. Timeline used to simulate the operational rollout in the Mahia Peninsula

Phase	Block	Ha	Stage 1 Bait station network (1 / ha)	Stage 3 Kill-trap network (1/ 25 ha)	Buffer (1 / ha)
Phase 1	1A	1317.0	March / April 2019	May / December 2020	
	1B	1419.4	May / June 2019	July / December 2020	
	1C	1543.1	July / August 2019	September / December 2020	Block 2A / 2B
	1D	1251.8	September / October 2019	November/ December 2020	Block 2A / 2B
Phase 2	2A	1446.0	November/ December 2019	January / December 2020	Block 2F / 2B
	2B	1463.2	January / February 2020	March / December 2020	Block 2F / 2B
	2C	1407.8	March / April 2020	May / December 2020	Block 2F / 2C
	2D	1579.0	May / June 2020	June /December 2020	Block 2F / 2C
	2E	1450.2	July / August 2020	August / December 2020	Block 2F / 2C
	2F	1673.6	September / October 2020	November / December 2020	Block 2F

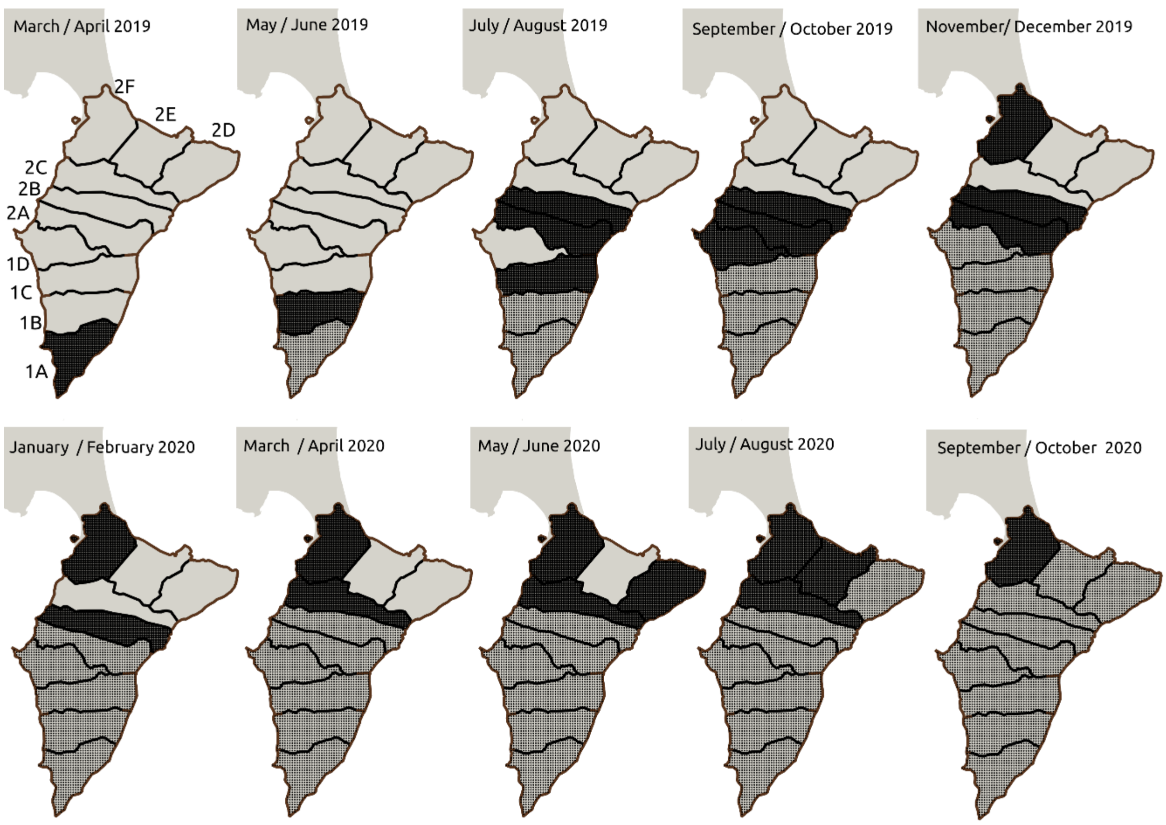

Figure 2 Whakatipu Mahia possum control phase rollout in the Mahia Peninsula eradication area in Te Matau a Māui/Hawke's Bay, New Zealand. The eradication area and control blocks are delimited by the black boundaries. The dark grey shading indicates the location of the bait station network at 1 station per hectare (Stage 1 – eradication and buffer to dispersal), the light grey shading indicates the location of the Kill-trap network at 1 trap per 25 hectares (Stage 3 – surveillance).

Spread model

The model describes the behaviour of individual mammals located explicitly in a map of their habitat. Key events in an individual's lifetime comprise birth, death, and dispersal, and these are simulated as stochastic events, i.e. there is uncertainty in the timing of each event. A module provides the probability of an animal being caught at a particular location with a given local trap density. Such modelling provides detailed forecasts of mammal abundance at regular time intervals into the future. Results are colour-coded so that areas of high and low expected mammal density are easily distinguished. The model allows exploration of how the distribution and abundance of mammals can be affected by control interventions. More details can be found in Lustig et al. (2019).

3.2 Assessing the effectiveness of immigration barriers around high-density possum blocks and across the neck of the Mahia Peninsula

We investigated the expected outcomes of the operational roll-out described in Section 3.1 above. Simulations were run with two starting densities of possums: 0.1 and 0.5 possums per hectare. These starting densities encompass the current estimated population density of possums (0.2 per hectare, derived from an average 0.8% RTC). Individuals were randomly located within the peninsula. All simulations in the report were run with immigration following the methods described in section 3.3. We used mean values of life history and dispersal parameters (Table A1, Appendix).

The two key animal parameters for the control sub-model are g_0 (the nightly probability of capture of an individual by a control device placed at the centre of the animal's home range) and σ (the spatial decay parameter for a bivariate normal home range kernel, to model the decline in detection probability with distance between the home range centre and the control device). We carried out simulations at two levels of g_0 and σ to reflect low probability of capture and large home range (g_0 = 0.08 and σ = 140 m), and high probability of capture and small home range (g_0 = 0.13 and σ = 90 m). These same values were used to parameterize a preliminary possum eradication model for the Mahia peninsula (Howard & Gormley 2019; Lustig & Gormley 2019) and correspond to the potential range of values from several field studies (Glen & Byrom 2014). There were no data available to assess the extent to which the g_0 and σ parameters could vary with different control devices, so both variables were assumed to be the same for bait stations and kill traps. We investigated the effect of different control durations by comparing control devices in place in each control block for 28 effective control nights (i.e. 4 weeks), with 56 effective control nights (i.e. 8 weeks). We carried out 100 simulations for each set of parameters to account for model stochasticity.

3.3 Effect of immigrant population density on the suppression of the possum population on the Peninsula

Previous simulations assumed a 'closed population' and therefore did not include immigration from untreated areas outside the eradication area, which, if present, would compromise the effectiveness of any eradication programme. To account for immigration pressure, we delineated a buffer area of 12 km (maximum juvenile dispersal distance reported in field studies) around the neck of the peninsula (Lustig et al. 2019), in which the possum population was left undisturbed (Fig. 2). This undisturbed population provided immigrants from outside the eradication area, i.e. the population was open rather than closed throughout the whole simulation. The initial density of possums at the edge of the eradication area was arbitrarily set to 30% of the landscape carrying capacity. We then investigated how different initial possum densities at the edge of the eradication area (10% to 70%, by increments of 10% of the landscape carrying capacity) affect suppression of the possum population in the Mahia Peninsula.

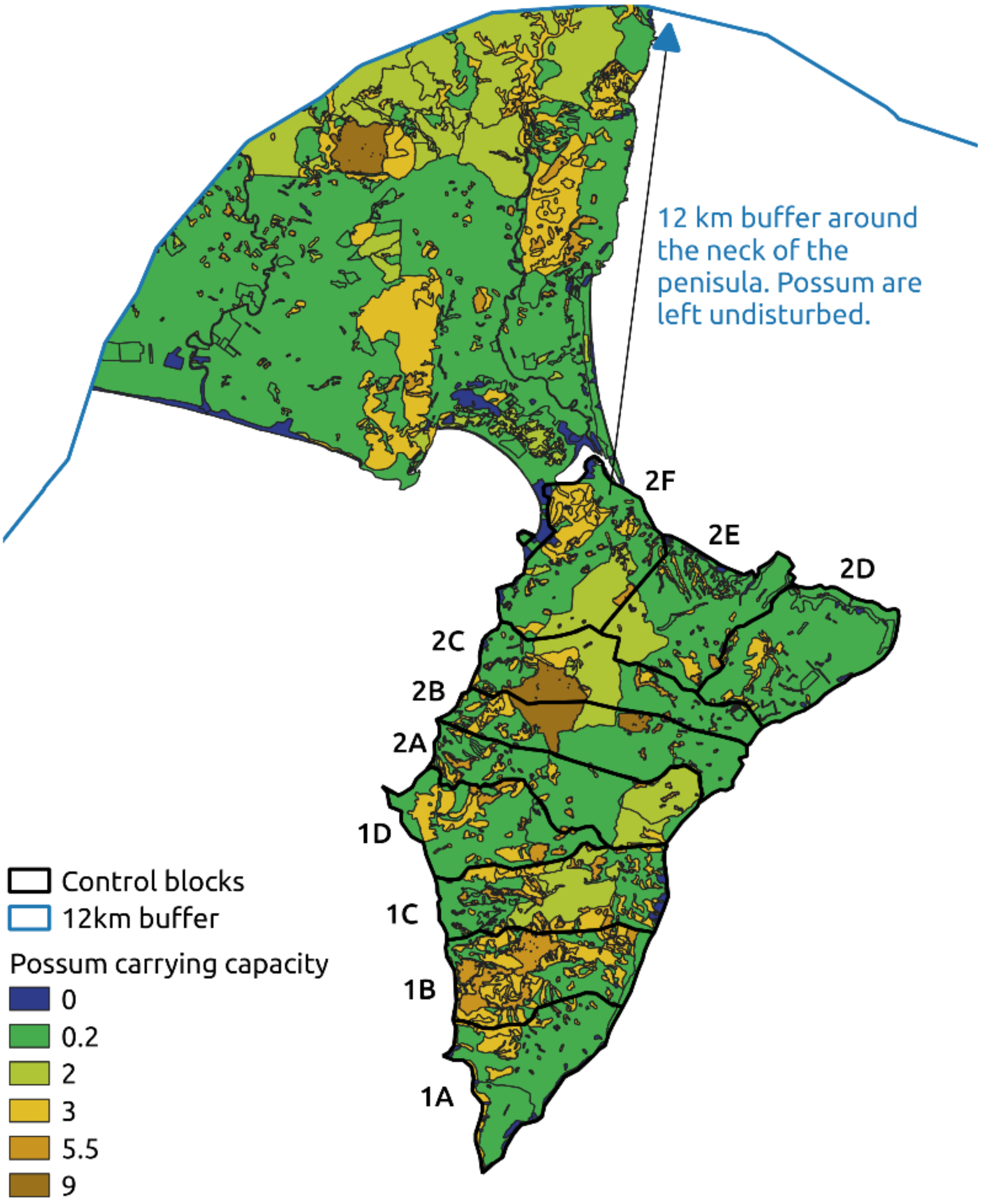

Figure 3 .Possum carrying capacity in the Mahia Peninsula eradication area in Te Matau a Māui/Hawke's Bay, New Zealand. The eradication area and control blocks are delimited by the black boundaries. The gradients of colours represent the local possum-carrying capacity in various land cover classes in Aotearoa New Zealand. We used the LRIS-LCDB-v4.2 database, along with the EcoSat indigenous forest layer, to provide finer differentiation of forest classes (lris.scinfo.org.nz). The blue boundaries represent the buffer around the eradication area in which the possum population is left undisturbed, providing immigrants from outside the eradication.

Simulations were run with a starting density of 0.1 possums / hectare in the eradication area. We carried out simulations at two levels of g_0 and σ to reflect low probability of capture and large home range (g_0 = 0.08 and σ = 140 m), and high probability of capture and small home range (g_0 = 0.13 and σ = 90 m). The duration of control was set to 28 effective control nights per control block. At the end of Phase 2 of control, the model was simulated without control for 3 years to forecast possum population recovery. We carried out 100 simulations for each set of parameters to account for model stochasticity.

3.4 Assessing the effect of variable trappability on predicted eradication outcomes

The model previously assumed that all possums on the peninsula have the same level of trappability (i.e. a 'homogeneous' population). However, there may be sub-sets of the population that are much harder to capture, thereby making the goal of eradication more difficult. This variable trappability (i.e. a 'heterogeneous' population) could result in a significant difference between the simulation predictions and reality (Vattiato et al. in prep).

To incorporate variable trappability in the model, values for *σ* were randomly sampled from Program Evaluation and Review Technique (PERT) distributions (Herrerias et al. 2003). The PERT distribution is a continuous distribution defined by a minimum, most likely and maximum values that the variable can take. We fixed the most likely value, σ = 140 m, to enable a comparison with previous analyses (most likely scenario, personal communication with Hawke's Bay Regional Council). The minimum σ = 90 m and maximum σ = 140 m were determined through a review of the literature on home ranges and capture probabilities (Glen & Byrom 2014; Glen et al. 2017). Values of g_0 were randomly sampled from a beta distribution, a continuous probability distribution defined on the interval [0, 1] and parametrized by two positive parameters that regulate the expected values (mode) and variance of the distribution. We fixed the expected value to g_0 = 0.08 to enable a comparison with previous analyses. We investigated eight values of variance v={0, 0.0001, 0.001, 0.01, 0.02, 0.03 , 0.04 and 0.05}; where 0 indicates a situation in which each possum has an equal probability of being captured by a control device located at the centre of its home range and 0.05 indicates a situation in which each possum might exhibit a different probability of detection and capture (Fig.Figure 8).

Each juvenile possum retained the same g_0 and *σ* values across all trapping sessions, i.e. we assumed these are traits that characterise the behaviour of an animal from birth to death. Both parameters were sampled independently, i.e. we assume no covariance between the probability of detection (g_0) and the decline in detection probability with distance between the home range centre and the control device (*σ*). By drawing the g_0 and *σ* parameters from distributions with sufficiently large variances, we ensured that selected values provide a representative sample of variation across individuals, sexes, and population densities. Both trapping probability of adults and juveniles were assumed to be independent of habitat categories.

Simulations were run with a starting density of 0.1 possums / hectare in the eradication area. The duration of control was set to 28 effective control nights per control block. We carried out 250 simulations for each set of parameters to account for model stochasticity.

4 Results

4.1 Using immigration barriers around high-density possum blocks and across the neck of the Mahia Peninsula increases the likelihood of achieving eradication across the entire Peninsula

The model predicted markedly lower possum abundance across the entire Peninsula as a result of a control strategy using immigration barriers around high-density possum blocks and across the neck of the Mahia Peninsula (Fig.Figure 4).

Under the most likely scenario, i.e. simulations of lower starting possum density (0.1 possums per hectare), lower trappability (g_0 = 0.08) and higher home range size (σ = 140 m), eradication was achieved across the entire peninsula for more than 90% of simulations (Fig.Figure 5). The initial possum density and trappability parameters influenced eradication success, with simulations of higher starting possum density (0.5 possums per hectare), higher trappability (g_0 = 0.13) and smaller home range size (σ = 90 m) having a lower rate of success. Increasing the number of effective trapping nights per block from 28 nights to 56 nights reduced the population further across the entire Peninsula (Fig. A1, Appendix). Where eradication was not successful, the number of remaining animals nevertheless was very low, with on average one individual left in the entire peninsula most likely to be found in block 2B or block 2F (Fig.Figure 4Figure 3).

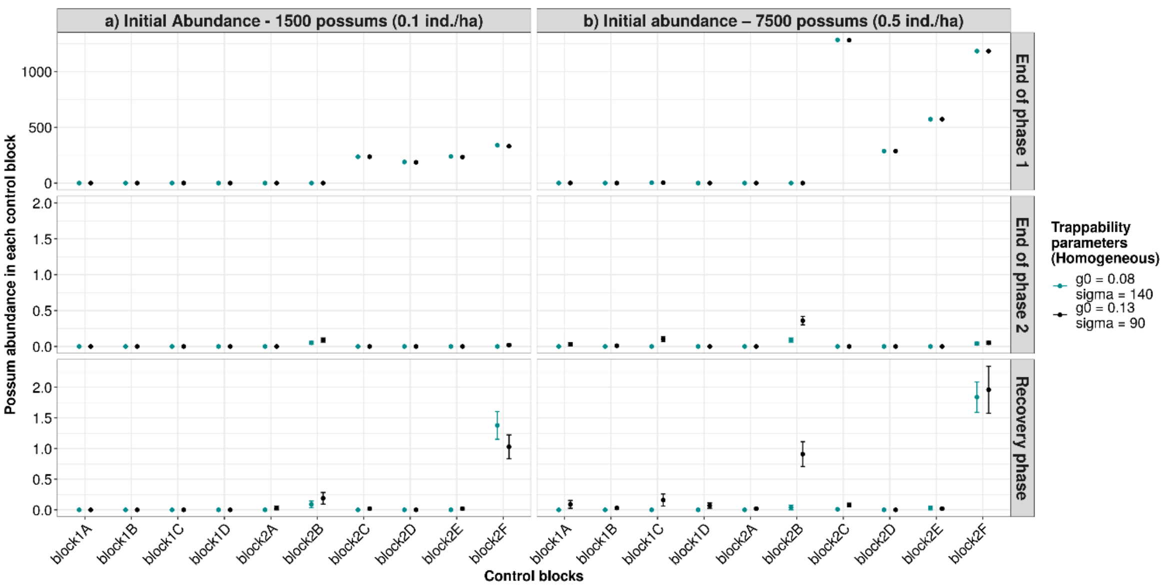

Figure 4. Predicted mean number of possums in control blocks within the eradication area at the end of Phase 1 (first milestone area, 5,500 ha); end of Phase 2 (second milestone area, ~9,000 ha), and 3 years after control stops in the eradication area (recovery phase). The results are shown for 28 effective control nights. The error bars indicate the 90% confidence interval. Different colours (black and cyan) show different levels of g0 and σ parameters. Note that each phase has a different y-axis scale.

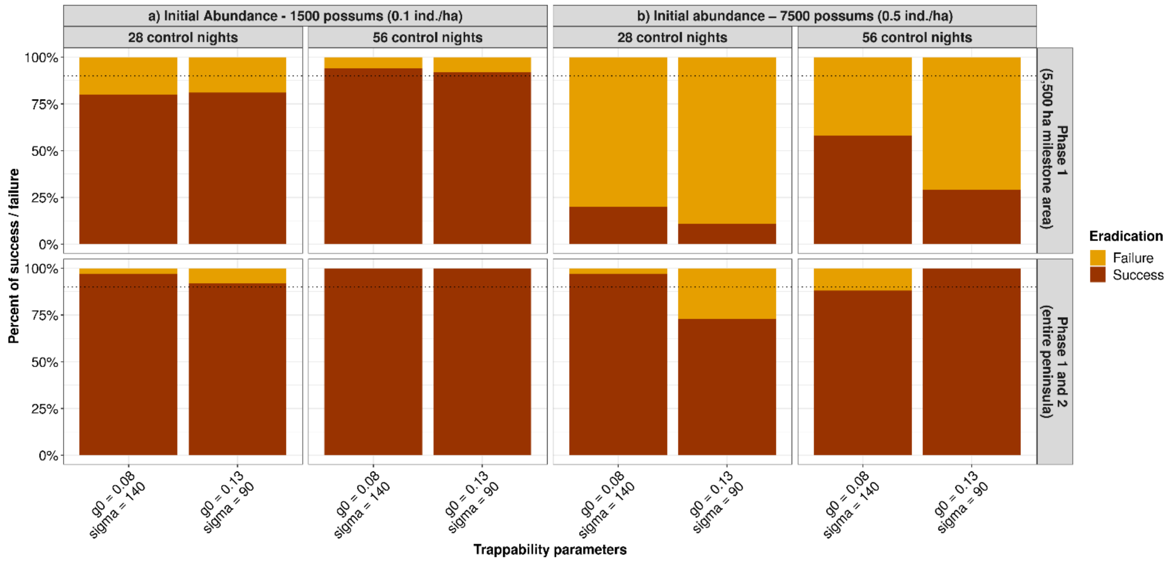

Figure 5. Predicted eradication success. Simulations were run with starting densities of a) 0.1 and b) 0.5 possums per hectare. Results are shown for simulations in which control devices were deployed for 28 or 56 effective control nights. The brown bars indicate the percentage of simulations for which eradication was achieved across the entire peninsula.

4.2 Population density at the edge of the eradication area has a small or no impact on the suppression of possums on the Peninsula

The model showed that possum density at the edge of the eradication area has a very minimal effect on eradication success rate (Fig.Figure 6). Simulations were run with a starting density on the Peninsula at 0.1 possums per hectare. Bait stations were deployed for 28 effective control nights in each control block. For all starting possum densities at the edge of the peninsula, eradication was achieved across the entire peninsula by the end of Phase 2 for more than 90% of simulations (Fig. 6). Population recovery followed a consistent pattern with population abundance mostly increasing at the eradication area margins (control block 2F) (Fig.Figure 7).

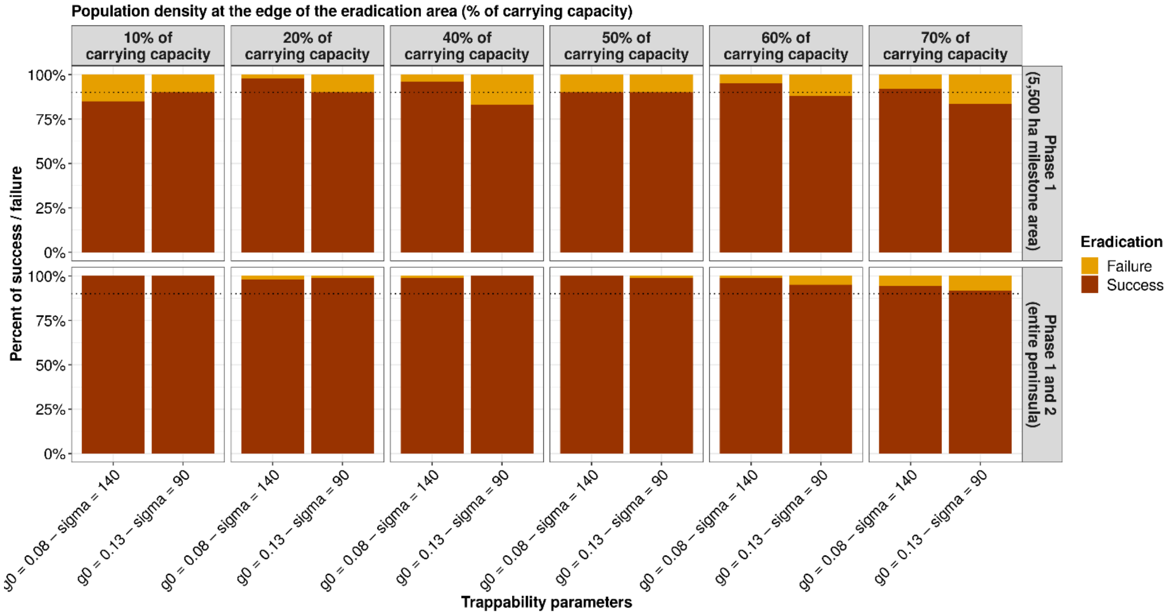

Figure 6. Predicted eradication success for different possum densities at the edge of the eradication area. Simulations were run with starting densities of 0.1 possums per hectare. Results are shown for simulations in which control devices were deployed for 28 effective control nights. The brown bars indicate the percentage of simulations for which eradication was achieved across the entire peninsula.

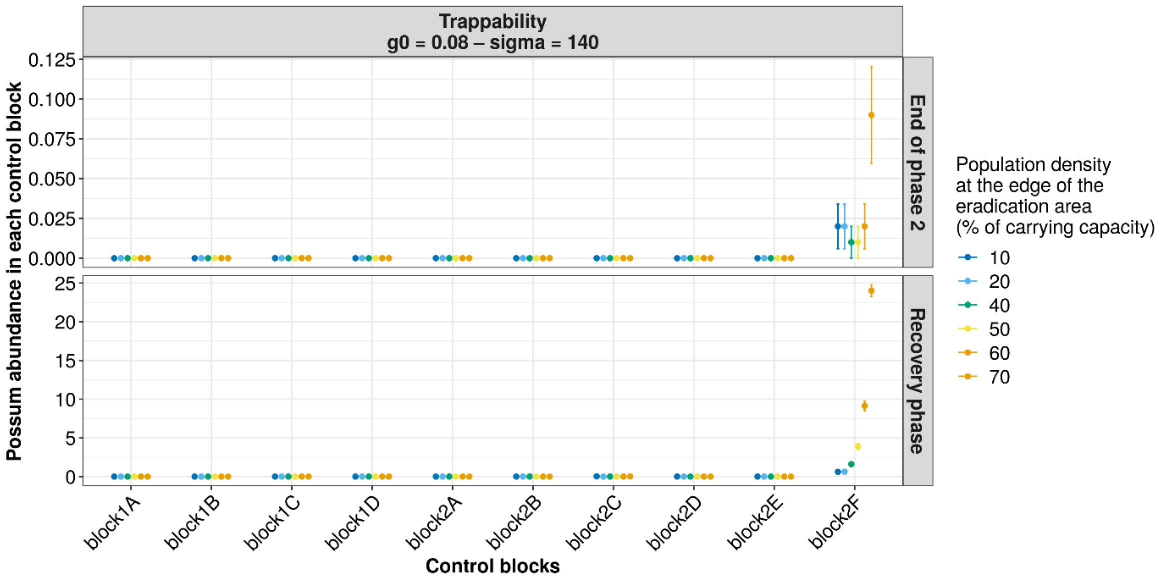

Figure 7. Simulated possum population recovery. Predicted mean number of possums in each control block at the end of Phase 2 of control, and 3 years after control stops in the eradication area (recovery phase). Different colours show different levels of possum density at the edge of the eradication area. Note that each phase has a different y-axis scale. The results are shown for 28 effective control nights. The error bars indicate the 90% confidence interval.

4.3 Assessing the effect of variable trappability on predicted eradication outcomes

The model showed that a relatively small but consistent variation in the level of trappability between possums (variance ≤ 0.0001) (Fig.Figure 8) within the population on the peninsula is unlikely to affect eradication success rate (Fig.Figure 9). However, if the population exhibits much larger variation in the level of trappability (variance > 0.001), the simulations suggested that eradication is unlikely to be achieved under the proposed trapping effort. Where modelled eradication was not successful, the number of remaining animals was low (i.e. less than ten in each block) (Fig. 10) and was characterised by a low trappability (result not shown).

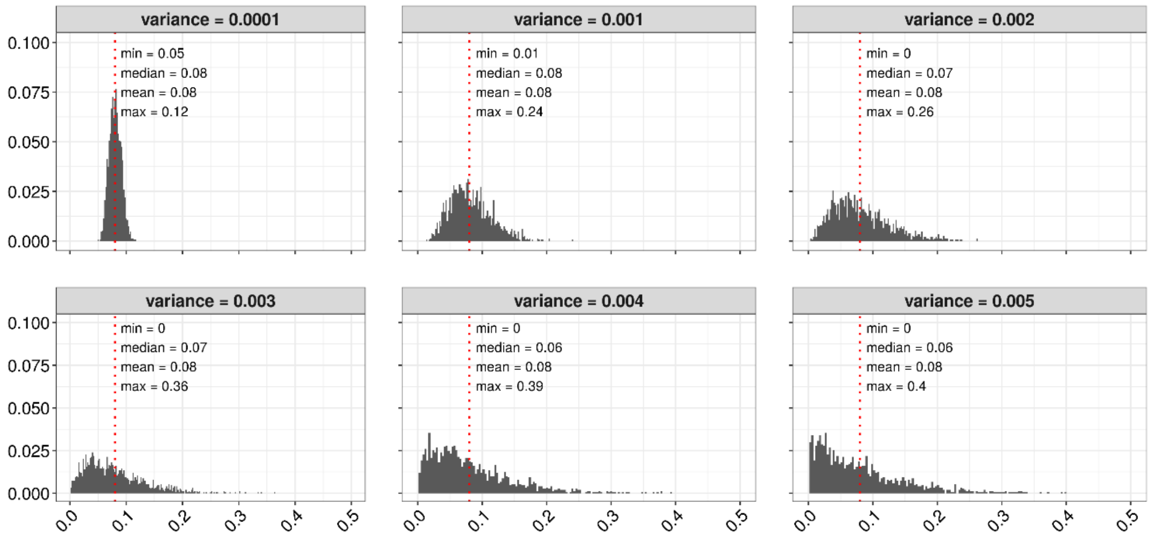

Figure 8. Initial distribution (frequency) of the probability of capture g0 ('trappability') for different level of variability. g0 was sampled from a beta distribution for which we fixed the mean to 0.08 and investigated the effect of changing the variance of the distribution. The dotted red line indicates the mean of the distribution (fixed to g0 = 0.08). The variance of the distribution varies between 0.0001 (i.e. all animals have a similar level of trappability) to 0.05 (i.e. there is large variation in trappability between animals).

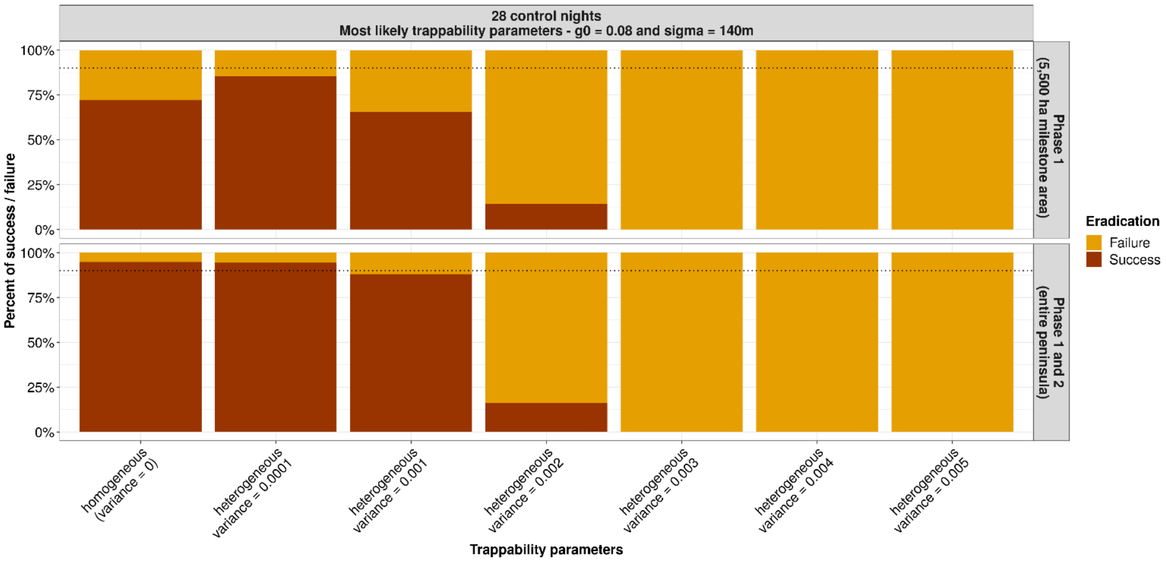

Figure 9. Predicted eradication success for level of variability in the probability of capture g0. The brown colours indicate the percentage of simulations for which eradication was achieved across the entire peninsula. Simulations were run with starting densities of 0.1 possums per hectare. Results are shown for simulations in which control devices were deployed for 28 effective control nights.

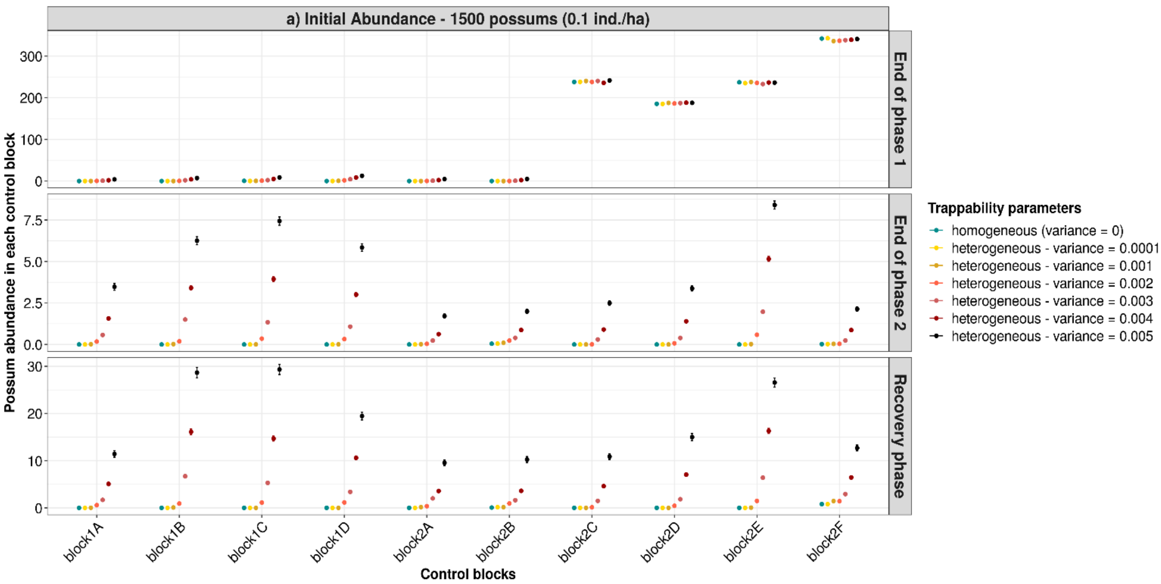

Figure 10. Predicted mean number of possums in control blocks within the eradication area at the end of Phase 1 (first milestone area, 5,500 ha); end of Phase 2 (second milestone area, ~9,000 ha), and 3 years after control stops in the eradication area (recovery phase). Different colours indicate different level of variability in the probability of capture g0, from a homogeneous population (variance=0) to a heterogeneous population (0.0001 ≤ variance ≤ 0.005). Note that each phase has a different y-axis scale.

5 Discussion

We combined an agent-based mathematical modelling framework with spatial information on pest habitat distribution, population dynamics and levels of control (Lustig et al. 2019; Lustig & Gormley 2019) to investigate the effectiveness of different temporal distributions of control effort. The modelling forecasted the relative abundance of possums at regular time intervals.

The results from the simulations suggest that possum eradication could be achieved across the entire peninsula if buffers of bait stations around high-density possum control blocks and across the neck of the Mahia Peninsula are used to limit immigration from untreated areas.

The control regime that led to successful suppression of possums in more than 90% of the simulations involved a network of bait stations set at a density of one per hectare for a minimum of 4 weeks, followed by trapping at a density of one trap per 25 hectares (surveillance) until the end of the control roll-out. A control buffer, involving a bait-station network at one station per hectare, deployed across blocks 2A and 2B (July–October 2019), could minimise the reinvasion risk from untreated areas of the peninsula while eradication is underway in the first 5,500-ha milestone area. Similarly, using a control buffer, involving a bait-station network at one station per hectare, deployed across blocks 2F (January–December 2020) and 2C (May–December 2020), could minimise the reinvasion risk from untreated areas while eradication is underway in the second ~9,000-ha milestone area.

The model showed that possum density at the edge of the eradication area has a very low effect on the suppression of possums in the eradication area and did not compromise the effectiveness of the eradication programme. This is not surprising, as the eradication area takes advantage of the geography of the Mahia Peninsula, with a lagoon and settlement at the neck of the peninsula creating an effective natural barrier to pest reinvasion from uncontrolled areas. In the absence of an immigration barrier (i.e. five parallel lines of leghold traps placed 100 m apart), reinvasion was likely to occur in the 3 years following suppression. Immigrant possums were only found in control block 2F during the recovery phase, suggesting that reinvasion could be spatially limited around the neck of the peninsula.

Possum density at the edge of the eradication area and dispersal are the two factors that are likely to have the most impact on the level of reinvasion. However, dispersal is challenging to model because of the difficulty of gathering data needed to inform model parameters, particularly for juveniles. For example, we did not take account of possible stochastic effects on dispersal that might result from events such as variations in food availability. Consequently, it is likely that the model does not generate the possible range of immigrant possum densities observed empirically. Nevertheless, the model is still useful in predicting possible spatial patterns of reinvasion.

The trappability parameters g_0 and σ are particularly important to determine the level of trapping effort (trapping duration and strategy) needed to achieved eradication. Priority should be given to validating these parameters since they form the basis for all subsequent analyses. In particular, the results of the model confirmed that it can be disproportionally difficult to suppress a population of possums that exhibit a high level of variability in the probability of detection/capture between individuals. Where modelled eradication was not successful (i.e. for more than 10% of simulations), the number of remaining animals was low (i.e. less than ten in each control block). It is worth noting that Stage 2 of control (the targeted control phase) was not included in the model. The likelihood of possum eradication is expected to increase from the use of additional bait stations and/or leghold traps in Stage 2 and could be particularly effective for targeting the last survivors with a low trappability.

6 Conclusions and Recommendations

- Control-to-zero density of possums from the entire Mahia peninsula is feasible if buffers of bait stations around high-density possum control blocks and across the neck of the Mahia Peninsula are used to limit immigration from untreated areas.
- In the absence of an immigration barrier, reinvasion is likely to occur in the 3 years following suppression. Possum density at the edge of the eradication area had a very low impact on eradication outcome and is unlikely to compromise the eradication programme.
- The trappability parameters g_0 and σ are particularly important to determine the level of trapping effort (trapping duration and strategy) needed to achieved eradication. Small levels of inter-individual variation in the detection/capture probability can substantially hinder the efficacy of the management scenarios tested. Passive control that relies upon possum investigation and contact with the control device may fail to sample individuals that are less active or too wary to approach the control device (low g_0). Active control methods (such as the targeted control proposed in Stage 2) may be particularly useful to target the last survivors with a low trappability.

7 Acknowledgements

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8 References

Glen AS, Byrom AE 2014. Implications of landholder buy-in for the success of regional-scale predator control: review of predator movements. Landcare Research Contract Report LC1956.

Glen AS, Latham MC, Anderson D, Leckie C, Niemiec R, Pech RP, Byrom AE 2017. Landholder participation in regional-scale control of invasive predators: an adaptable landscape model. Biological Invasions 19(1): 329–338. https://doi.org/10.1007/s10530-016-1282-3

Hawke's Bay Regional Council 2019. Hawke's Bay Regional Council 2019 Whakatipu Mahia Operational Plan.

Howard S, Gormley A 2019. Whakatipu Mahia possum eradication modelling. Manaaki Whenua – Landcare Research Contract Report LC3378.

Lustig A, James A, Anderson D, Plank M 2019. Pest control at a regional scale: identifying key criteria using a spatially explicit, agent-based model. Journal of Applied Ecology 56: 1515–1527. https://doi.org/10.1111/1365-2664.13387

Lustig A, Gormley A 2019. Whakatipu Mahia possum eradication modelling. Manaaki Whenua – Landcare Research Contract Report LC3455.

Ross JG, Hickling GJ, Morgan DR, Eason CT 2000. The role of non-toxic prefeed and postfeed in the development and maintenance of 1080 bait shyness in captive brushtail possums. Wildlife Research 27(1): 69–74.

Vattiato G, Davidson S, Binny R, Byrom A, Plank M, James A (in prep.) Invasive pest detectability in New Zealand: a review.

Vattiato G, Plank M, James A, Binny R (under review) Individual heterogeneity affects the outcome of pest eradication.

Warburton B, Hickling GJ 1992. Behavioural responses of possums to traps. Landcare Research Contract Report LC9293/19.

Warburton B, Cowan P, Shepherd J 2009. How many possums are now in New Zealand following control and how many would there be without it? Landcare Research Contract Report LC0910/060.

Appendix 1 – model parametrisation

We used the most recent field-based estimates to calibrate life-history and control parameters. Values are reported in Table A1 and were extracted from Lustig et al. in press. The probability that an adult in the grid cell *(x,y)* was captured within *k* nights of trapping was expressed as:

$$P \quad = 1 - e^{-2\pi g_0 \sigma^2 k \rho_{(x,y)}}$$

where g_0 is the probability of capture by a trap placed at the centre of the animal's home range, σ is the spatial decay parameter for a normal home-range kernel to model decline in encounter probability with distance between the home range centre and trap, and ρ is the density of traps (i.e. traps per unit area) in the grid cell.

Dispersing juveniles had a probability of being trapped in each grid cell they travelled through during the dispersal phase, which was expressed as:

$$P \quad = 1 - e^{-A g_1 \rho_{(x,y)}}$$

where g_1 is the probability of a juvenile being captured by a trap, and A is the area covered by a dispersing juvenile as it passes through one grid cell. More specifically, we assume that juveniles encounter a trap if it is within a distance *W* of its path. Therefore, the area A covered by a juvenile was given by:

$$A = VW\partial t, \text{ with } \partial t = \frac{R t_{max}}{d_{max}}$$

where *R* is the spatial resolution, *V* the mean velocity of a juvenile during dispersal, d_{max} the maximal dispersal distance, and t_{max} the maximal time of dispersal. More details about trapping probability are given in Lustig et al., 2019.

Table A1: Animal and trappability parameter values (Lustig et al. 2019)

Parameter	Abbreviation	Value	
Spatial parameters			
Spatial resolution	R	500 m	
Life history parameters			
Life expectancy	l	12 years	
Reproduction rate	r	0.77 (0.51–1.05) / year	
Maximum dispersal distance	d_{max}	12,000 m	
Control parameters (two columns correspond to two different scenarios)			
Probability of capture of an adult	g_2	0.08	0.13
Spatial decay parameter	σ	140 m	90 m
Probability of capture of a juvenile	g_1	0.08	0.13
Area covered by a dispersing juvenile per grid cell	A	0.037 ha	0.037 ha

We investigated the effect of different control efforts by estimating the success of leaving the control devices in place in each control block for 28 effective control nights (Fig. 4 and Fig. A1), compared with 56 effective control nights (Fig. A1).

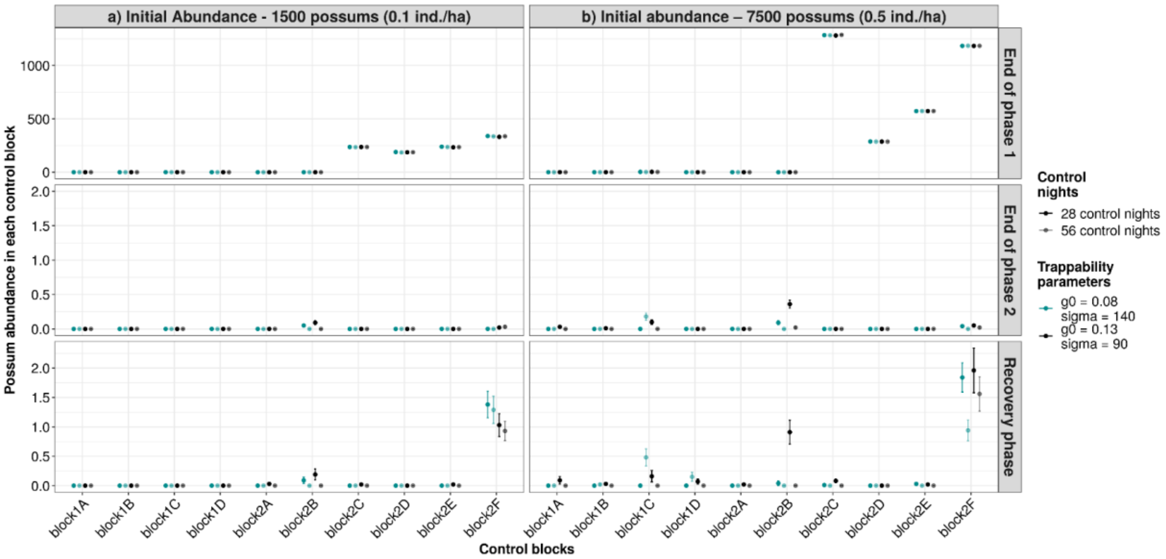

Figure A1. Predicted mean number of possums in the eradication area at the end of Phase 1 (first milestone area, 5,500 ha); end of Phase 2 (second milestone area, ~9,000 ha), and 3 years after control stops in the eradication area (recovery phase). The results are shown for 28 effective control nights. The error bars indicate the 90% confidence interval. Different colours (black and cyan) show different levels of g_0 and σ parameters. Different grading (pale / bold) show different control duration. Note that each phase has a different y-axis scale.