Manaaki Whenua
Landcare Research

Pre- and post-control possum home range and habitat use on Māhia Peninsula

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Pre- and post-control possum home range and habitat use on Māhia Peninsula

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Manaaki Whenua – Landcare Research

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Summary

Project and client

Manaaki Whenua – Landcare Research measured pre- and post-control possum movement patterns for Hawke's Bay Regional Council between 2018 and 2021 to inform possum eradication strategies as part of the Whakatipu Māhia – Predator Free Māhia (WMPFM) programme.

Objective

To describe the spatial ecology of adult possums subjected to attempted eradication on Māhia Peninsula by:

- estimating home range sizes, movement distances, and habitat use before and after initiation of intensive control
- identifying movement corridors that might act as pathways for reinvasion or long-distance dispersal.

Methods

- Twenty-seven adult possums were radio-collared or GPS-collared on the northern part of the Māhia Peninsula in May 2019, and their movements were monitored for up to six months before the roll-out of intensive possum control under the WMPFM programme.
- Possums were targeted for collaring in two habitats: continuous forest and scattered possum habitat on farmland.
- Ten additional adult possums were GPS-collared in similar areas and habitats in January 2021, during and after intensive possum control was rolled out. Their movements were monitored over the following 10 months and their recapture was attempted in November 2021.

Results

- Intensive possum control reduced possum abundance by about 97% and 60% in continuous forest and on farmland, respectively.
- Two of three farmland possums collared immediately prior to initiation of intensive control survived to the end of the study, 7–8 months after control started. Another four farmland possums collared 9–10 months after intensive control was initiated survived at least five months, with three confirmed as surviving 10 months to the end of the study.
- Three possums were collared in continuous forest after intensive control started. One died six weeks after collaring and the fate of the other two is unknown. Therefore, pre/post comparison of forest possum home range, and post-control comparison of forest and farmland possum home range was not possible.
- No possums (collared or uncollared) were captured in a wireless leg-hold trap network that traversed the study area during the 10-month post-control monitoring

period in 2021, yet all ten 2021-monitored possums were initially captured in ground-set leg-hold traps, and five were recaptured by the same method at the end of the study.

- Before intensive control, mean possum home range was larger on farmland (28 ha) than in continuous forest (10 ha), and larger for males (28 ha) than for females (8 ha).
- Mean home range size for three post-control males on farmland was 85 ha compared with 48 ha for five pre-control farmland males. However, due to the small sample sizes and marked variation between individuals, we were unable to determine confidently if this represented a real increase in home-range size following control.
- Farmland possums predominantly utilised woody vegetation patches, which were typically located along water courses.
- Post-control sigma (σ, a measure of home range radius that can inform optimal spacing of monitoring and control devices) of collared possums was 259 m for three farmland males and 73 m for the sole female. That female did, however, make occasional forays of up to 1 km from its home range centre.

Conclusions

- Possum eradication efforts within the study area have been more effective in continuous forest than in farmland.
- Farmland possums, particularly those that survived the initial roll-out of intensive control, were relatively invulnerable to the continued presence of the toxic bait station and wireless trap networks. All confirmed intensive control survivors were trappable with ground-set leg-hold traps.
- Home range size of farmland possums throughout the study was large, and most individuals would be exposed to devices spaced 200–350 m apart in possum habitat. For post-control farmland males, devices spaced 500 m apart would be sufficient to detect most individuals. Although we lack post-control movement data for forest possums, very low post-control abundance suggests similar device spacing should also detect most individuals there.
- Should further reductions in possum abundance induce long-distance movement of survivors, they are likely to do so along corridors of woody habitat, predominantly along water courses, even if that habitat is patchy, with non-habitat gaps of up to 250 m.

Recommendations

- The mop-up of possums under the WMPFM programme should continue to be expanded across the northern half of Māhia Peninsula and include alternative control methods in addition to the intensive poison bait station network.
- Consideration should be given to more extensive use of lured, ground-set leg-hold traps, targeted to sites with recent possum detections, for possum mop-up operations.
- Long-term monitoring devices (trail cameras, wireless leg-hold trap networks, chewcards or waxtags), and mop-up effort, should be targeted at key possum

habitats, predominantly native woody vegetation patches along waterways, if practical.

- Long-term monitoring devices located 500 m apart in possum habitat will place monitoring devices within each residual possum breeding cluster on farmland during mop-up operations. Intensive possum control should be undertaken over about 100 ha of habitat centred on each possum detection site.

1 Introduction

Manaaki Whenua – Landcare Research measured pre- and post-control possum movement patterns for Hawke's Bay Regional Council between 2018 and 2021 to inform possum eradication strategies as part of the Whakatipu Māhia – Predator Free Māhia (WMPFM) programme.

2 Background

In 2000 Hawke's Bay Regional Council (HBRC) began its Possum Control Area programme. Over the first 18 years possum suppression was implemented across 700,000 ha of the region. The HBRC is now transitioning from suppression to eradication of possums as part of a Predator Free Hawke's Bay programme.

The Possum Control Area programme was initiated on Māhia Peninsula in 2005/06, with a targeted residual trap-catch rate of 3%. Sentry poison bait stations were established at a density of one per six hectares (2,528 stations) and baited annually. Monitoring conducted in 2015/16 yielded a residual possum trap-catch rate of 0.8% (0.8 possums per 100 trap nights; Anon 2018) in pasture-dominated habitats and 5.0–7.2% residual trap-catch in extensively forested areas (Grandy Lakes pine plantation, Māhia Scenic Reserve, Te Kahika pine plantation), indicating low to very low residual possum densities throughout the peninsula at that time.

The WMPFM programme was launched in July 2018, assisted by a $1.6 million grant from Predator Free 2050 Ltd. It aims to eradicate possums over the entire 14,616 ha of Māhia Peninsula, including 5,303 ha of possum habitat (exotic and native forest, scrub and fernland; Anon 2018). The geography of the peninsula, with its 95% ocean boundary, means that the effort required to prevent reinvasion will be minimal and focused on a narrow neck of land at the north of the peninsula. The WMPFM is the first step towards a possum-free Hawke's Bay, with lessons learnt to be applied to the other, more difficult to defend areas across the Hawke's Bay region.

The possum eradication effort started by increasing the bait station density to one per hectare (establishing 12,088 new stations), with stations initially pre-fed with non-toxic bait, then baited with brodifacoum or diphacinone, and feratox, and checked and refilled as required every 30–60 days (Anon 2018). Work was rolled out in a series of blocks, starting at the southern tip of the peninsula and progressively working northward. Also, a wireless-monitored raised leg-hold trap network (Zero Invasive Pests, Wellington) was established along the length of the peninsula, following Māhia East Coast Road and other public roads, during this initial eradication effort. Each wireless leg-hold trap is paired with a podiTRAP predator kill trap (Metalform, Dannevirke). That network will be expanded to cover the entire peninsula as mop-up operations are rolled out. Faecal-pellet sniffer dogs are also part of the possum mop-up effort, starting in late 2021. The periods before and after initiation of the intensified possum control effort are hereafter referred to as the pre-control and post-control periods, respectively.

Eradication programmes, including trap and bait station deployment and subsequent proof-of-absence modelling (Anderson et al. 2013), need ecological data from possum populations occupying similar habitats to those being targeted because possum behaviour varies between different habitats. Some data on home ranges and movement behaviour of possums from low-density populations have been collected from other habitats in New Zealand, such as the dryland systems of Central Otago (Rouco et al. 2016) and Marlborough (Yockney et al. 2013), and in forested habitats in the central North Island (Sweetapple et al. 2016). These systems differ significantly from the coastal forest and pasture dominated Māhia Peninsula. This project aims to provide data on home range size and shape for the habitats on Māhia Peninsula.

The study involved fitting GPS collars to adult possums before and after initiation of high-intensity control on Māhia Peninsula. This was used to collect possum location data for the estimation of home-range parameters, habitat use, dispersal-routes and dispersal distance. A further objective of the study was to quantify how the movement patterns of the possum population changed over the course of the eradication programme. The post-control data from survivors may inform optimal spacing for traps and bait stations during the mop-up phase of eradication, and preferred habitat and landscape features of survivors of the initial intensive control effort.

More generally, the project will provide data on the spatial ecology of possums from coastal North Island forests and farmland. This information is needed to parameterise various possum models, including proof-of-absence models, which have often been parameterised using untested assumptions.

3 Objectives

To describe the spatial ecology of adult possums subjected to attempted eradication on Māhia Peninsula by:

- estimating home range sizes, movement distances and habitat use before and after initiation of intensive control
- identifying movement corridors that might act as pathways for reinvasion or long-distance dispersal.

4 Methods

4.1 Collar deployment and retrieval

Live possum trapping using ground-set leg-hold traps (No. 1 Victor) was undertaken in two blocks on the central and northern parts of the peninsula (Figure 1) in May 2019, prior to the roll-out of the new bait station network in those areas. Three habitats were targeted: extensive exotic forest (*Pinus radiata*), extensive native forest (Māhia Peninsula Scenic Reserve; 390 ha), and pasture-dominated landscapes with patchy possum habitat (forest, scrub and fernland patches). All four possums that were subsequently captured in extensive native forest were close (less than100 m) to extensive exotic forest, so habitat classification was simplified to extensive forest and farmland.

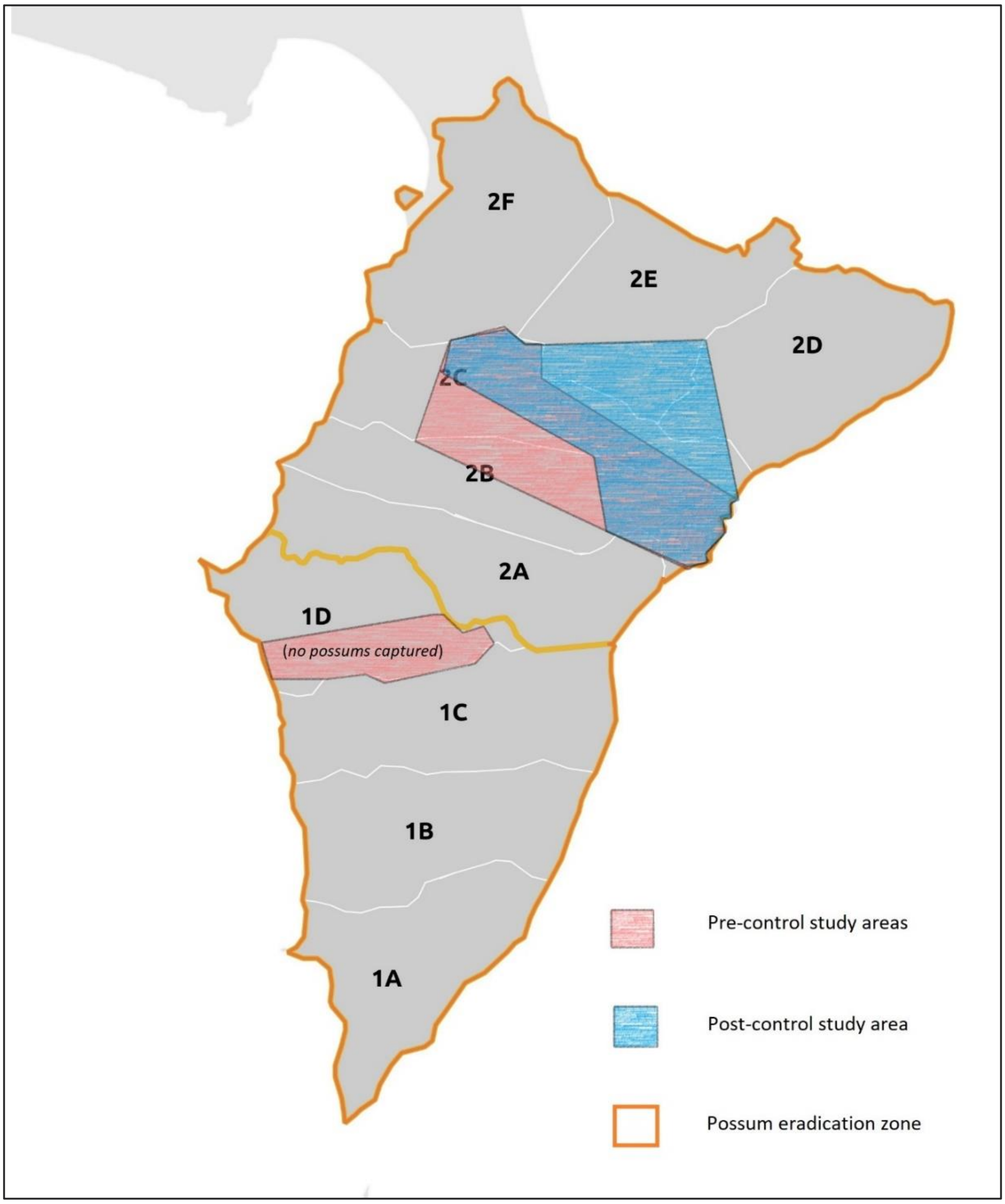

Figure 1. The Māhia Peninsula possum eradication area, showing pre- and post-control (initial knockdown) study areas where attempts to capture and collar possums were made. Note that no possums were captured (or collared) in the southernmost study area. Codes (1A–2F) indicate possum management units in which control was rolled out from south (1A) to north (2F).

Only adult possums (>2.3 kg) were collared to avoid welfare issues of animals outgrowing their collars. Twenty-seven healthy (no visible injuries) possums were fitted with collars and released (Figure 2). Twenty of these were fitted with Lotek Litetrack 60 GPS collars programmed to record the animal's GPS location every 2 hours each night, and with battery capacity to run for 10–12 months. The collars were also RF-communication capable, allowing data to be downloaded remotely by field staff while the collars were still on the animals. The remaining seven possums were fitted with VHF transmitters that did not record GPS locations. The VHF collars had the potential to indicate long-distance dispersal events should they occur during a period of monitoring. All collars were capable of sensing death (no movement for 24 hours) and recording the date and time this occurred. All collared animals were sedated with Zoletil prior to collar fitting and placed to recover in a shaded and sheltered location away from water courses but near their capture location.

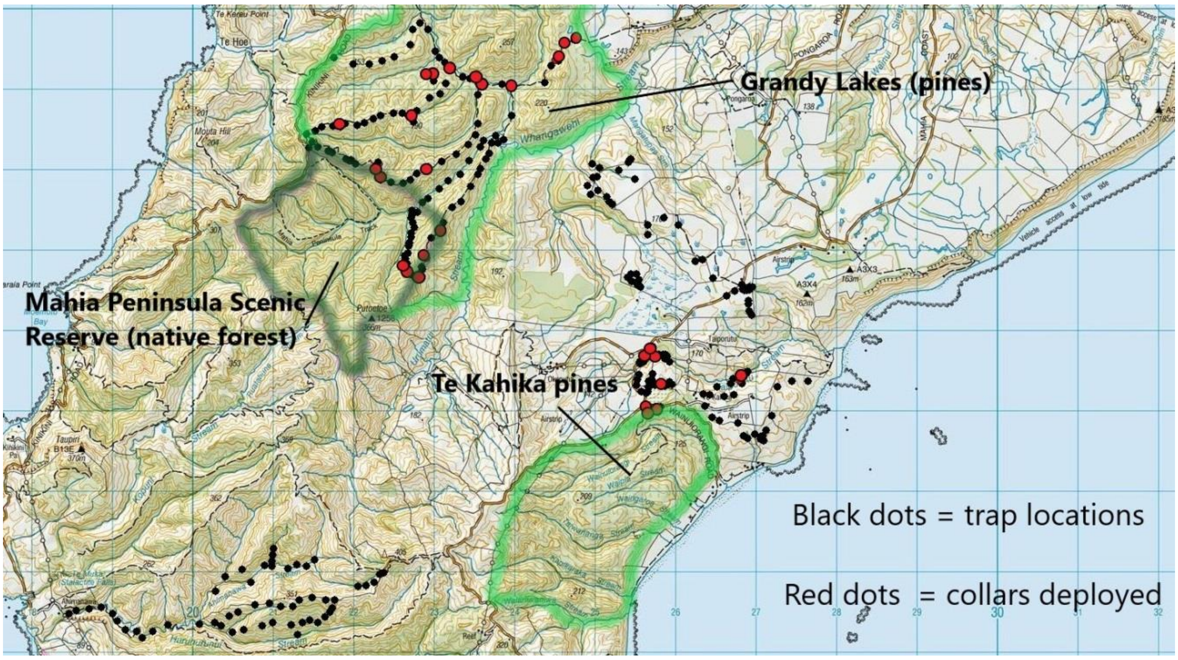

Figure 2. Locations of ground-set leg-hold traps (black dots) and possums collared (red dots) in May 2019 for pre-control possum movement assessment. Map grid lines are 1 km apart.

All deployed collars were searched for in late June and mid-September 2019 using a TR4 receiver and hand-held Yagi aerial. On both occasions the GPS position and signal status (alive/dead) was recorded for all collars heard and GPS data downloaded using a Lotek commander unit. If practical, collars transmitting a 'dead' signal were recovered.

It was initially intended that the roll-out of intensive possum control (new bait stations and wireless traps) would encompass the areas with collared possums and would start within six months of collaring, so that individual animals would provide data for both pre- and post-control periods if they survived for a sufficiently long period. However, progress in setting up the additional control devices was slower than anticipated so that none of the collars deployed in May 2019 were still functional when intensive control commenced at their locations. Therefore, a new sample of 10 adult possums were GPS-collared in late January 2021 in zones 2B–2E (Figure 1) to provide post-control movement data.

Subsequent detailed mapping of the bait station roll-out revealed that three possums collared on farmland in January 2021 were at sites where intensive control had not yet commenced (GPS60, GPS74, GPS54; Table 1, Figure 3). Bait station coverage was extended to cover these areas in April/May 2021, resulting in one dying within two weeks (GPS60).

Another (GPS74) dropped its collar in early June. All GPS data collected for those two animals (males GPS60 and GPS74) were, therefore, treated as pre-control data. Trap-catch data obtained in January 2021 from sites not yet covered by the new bait station network were also treated as pre-control data.

Attempts to track these possums and download the GPS data were undertaken in late June and November 2021. During the latter attempt no collars were still functioning so leg-hold traps were set, targeting initial capture locations, to retrieve the collars and euthanise captured possums.

4.2 Data analysis

The GPS data from all possums was visually inspected for outliers, which were identified as those locations that had a high HDOP (dispersion of precision values greater than 5) and that were at a relatively large distance from all temporally sequential locations. Also, we conducted data screening following Bjorneraas et al. (2010) to identify erroneous locations (i.e. outliers) that were beyond the possible range of possum movements or that produced abnormal movement spikes.

We used the adehabitatHR package (Calenge 2006) in R program (R Development Core Team 2019) to estimate home range size. Home range estimates are sensitive to both sample size and estimation methods (Boyle et al. 2009). Therefore, we used two methods, kernel density estimators (KDEs; Worton 1989) and minimum convex polygon, to estimate possum home ranges. Home range estimates for individuals with few locations are unreliable (Girard et al. 2002), so we discarded one individual for which we had fewer than 40 GPS locations.

KDEs were used to create a utilisation distribution (UD) for each monitored possum, and a home range area was then estimated based on the 90% UD. Kernel density methods are flexible and require two major parameter choices to estimate the UD. The first is the overall shape of the animal's distribution (the density kernel), and the second determines how the size of the distribution (bandwidth) is calculated. For this study a bivariate normal density kernel was used to represent the UD (Worton 1989).

Furthermore, KDEs can differ based on the algorithm used to estimate the bandwidth; accordingly, we fitted KDEs using the reference bandwidth, the least square cross-validation bandwidth, and the plug-in band width. However, after careful inspection of differences between bandwidth estimation methods, we retained home ranges estimated using the reference bandwidth, since we considered them to be the most biologically realistic representation of possum home ranges.

Before- and after-control differences in home range size were tested using two-sample *t*-tests. We first compared home range sizes before and after control considering all possums collared; however, this included a different number of possums from farmland and forest in each period, as well as different monitoring timeframes for each possum. To make sure before and after comparisons were not biased by these additional factors, we re-ran the same analyses, but only for the subset of possums inhabiting farmland, and only including data collected during the autumn and early winter (April–July).

To inform future proof-of-absence modelling (Anderson et al. 2013) to confirm possum eradication, a home range parameter (sigma, σ) was calculated. σ multiplied by 2.45 approximately equates to the home range radius. In the proof-of-absence model, σ describes the spatial scale over which detection probability declines as distance from a device increases. We derived σ directly from the GPS-collared possum locations by estimating the maximum likelihood estimate for the standard deviation of a bivariate normal distribution using the function optim in R software. The bivariate normal distribution was centred at each possum home-range centre; the location of the home-range centre for each individual was calculated as the mean of all eastings and all northings obtained for that possum.

Pre-control data collection started in early May 2019 and no post-control data were obtained after July 2021 (see results). Therefore, to ensure that potential seasonal differences in possum behaviour did not influence our results, we used only data from April–July (inclusive) to compare pre- and post-control home range parameters. Data from outside these periods (January–March 2021 and August–November 2021) were examined to determine if they provided further insights into possum movement patterns on Māhia Peninsula.

5 Results

5.1 Pre-control trapping

A total of 333 traps were set for 1,261 trap-nights (932 nights in May 2019 and 329 nights in January 2021), which caught 62 possums (4.9% trap catch), of which 23 possums were fitted with GPS collars and seven with VHF collars. Possum distribution was patchy, with no possums captured in the south-western farmland area (Figure 2). This area was not trapped again during the study, so these data were excluded from all further analysis. Of the other two areas trapped, pre-control trap-catch was 11.1% in extensive forest (mainly *Pinus radiata* plantation at Grandy Lakes; the north-western cluster of traps in Figure 2), and 3.8% in the central eastern farmland cluster (see also Figure 3 for the location of pre-control farmland traps set in January 2021).

The remaining 32 possums were either ear-tagged and released (26) or were injured during capture and euthanised (6).

5.2 Post-control trapping

Post-control collaring was undertaken in late January 2021 using 286 ground-set leg-hold traps (Figure 3), set for 2,054 trap-nights, during which nine possums were caught (0.53% trap-catch). Five possums were captured in extensive forest (all *P. radiata* plantation) from 353 trap-nights (1.4% trap-catch) and the remaining four were caught in farmland-dominated habitats over 1,701 trap-nights (0.2% trap-catch). Seven possums were fitted with GPS collars (three in forest and four in farmland habitats; Figure 3) and two were injured during capture and were euthanised.

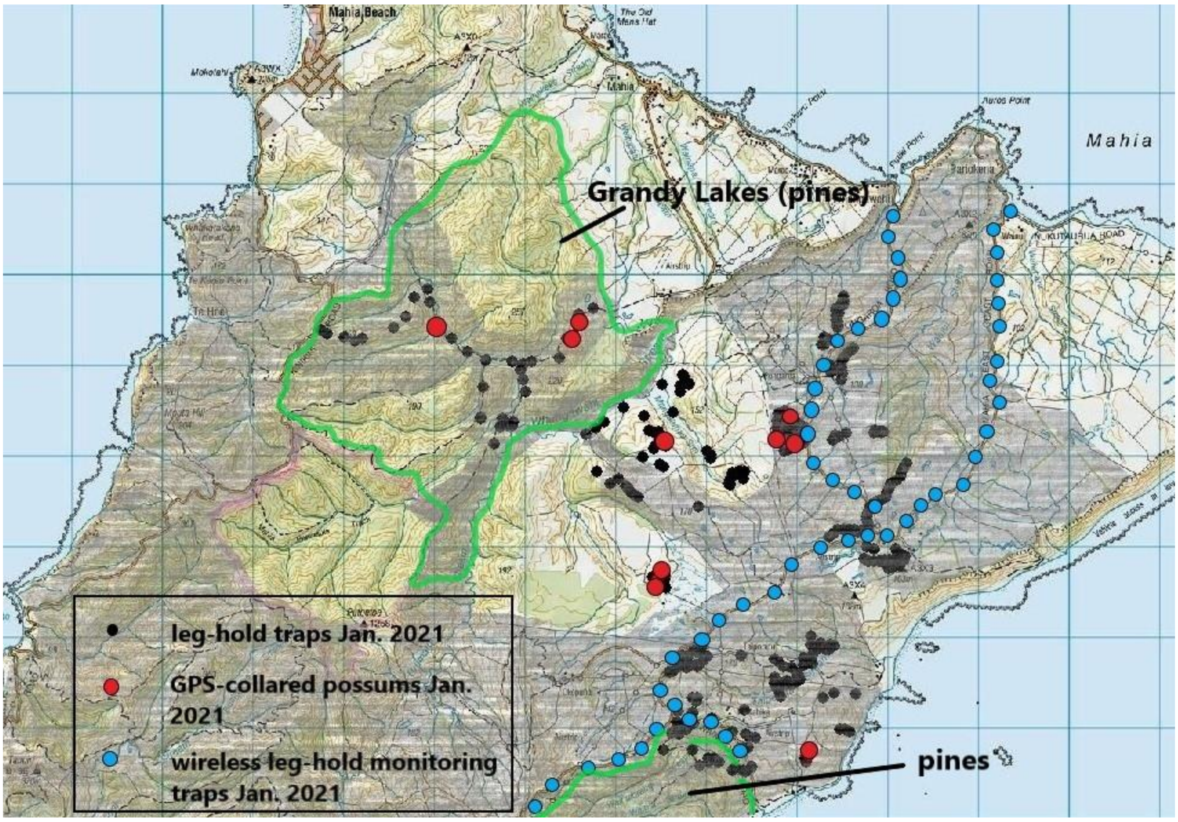

Figure 3. Locations of ground set leg-hold traps and possums GPS-collared in January 2021 for post-control possum movement assessment. The grey-shaded regions are those where the full bait station network was established by 1 January 2021. Wireless raised leg-hold traps paired with podiTRAPs, installed by HBRC prior to January 2021, are also shown (blue dots). Map grid lines are 1 km apart.

Leg-hold traps set for 970 trap nights in November 2021 to recover collars resulted in the capture of eight possums (Figure 4): two in forest (0.36% trap-catch) and six in farmland (1.58% trap-catch).

The three trapping sessions (May 2019, January 2021 and November 2021) in forested habitats (mostly at Grandy Lakes) indicate that possum abundance there was reduced by 97% following the roll-out of intensive possum control, with most of that reduction occurring early in the control effort (Figure 5). For farmland habitats, possum catch rates declined by just 60% between pre-control and the second post-control trapping sessions, but that result is likely to be conservative given the targeted nature of the final trapping session (i.e. aimed at sites where possums were initially captured).

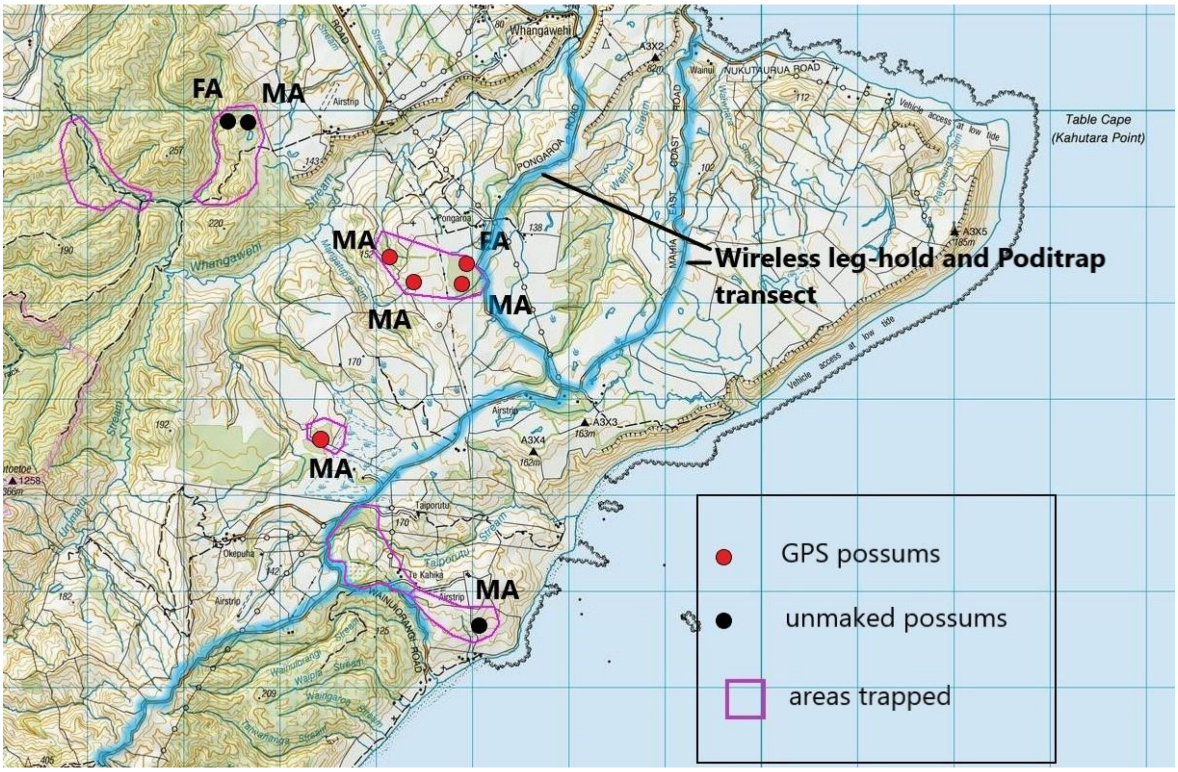

Figure 4. Areas trapped and possums captured during collar-retrieval trapping at Māhia Peninsula in November 2021. Sex (M/F) and age class (A = adult) is indicated for all possums. Unmarked possums are those without collars or eartags. Map grid lines are 1 km apart.

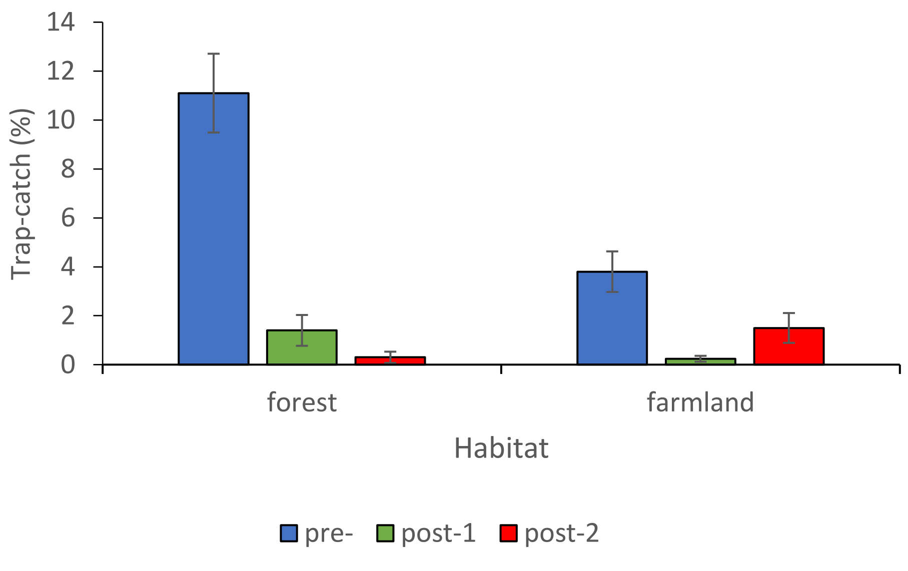

Figure 5. Possum trap-catch results (captures per 100 trap-nights) from Māhia Peninsula conducted in May 2019 before (pre-) the start of possum control, during possum collaring in January 2021 (post-1), and during collar retrieval in November 2021 (post-2). Data are from only those areas trapped in November 2021, when trapping was targeted at sites where possums were collared in January 2021. Error bars are binomial standard errors.

5.3 Post-control possum survival

Two possums collared in Grandy Lakes pine forest in January 2021 were not subsequently relocated. That left eight possums with which to measure survival during the initial eradication effort. Of these, six (75%) were still alive at the end of June 2021, having potentially been in areas covered by active bait stations for 2–15 months. Of the remaining two possums, one farmland possum died 2 weeks after the establishment of nearby bait stations, and one forest possum died or lost its collar in mid-March, 5 months after nearby bait stations were established.

By November 2021 at least five collared possums, all on farmland, were alive. These five represented 71% of possums with known outcomes and at least 83% of possums alive in June 2021 (Table 1). Three of these, all collared on Pongaroa Station (where intensive control was initiated in March 2020), had potentially survived 20 months of intensive possum control. The other two survived the initiation of intensive control within their home ranges, and the following 6–7 months. A sixth possum collared in January 2021, 9 months after intensive control was initiated in its home range, was alive in June but was not relocated in November 2021.

Four of the five collared possums recaptured in November 2021 had lost their collars; they were identified by ear-tags. The sole recovered collar (GPS54) was extensively damaged, non-functioning since July 2021, and had a strap that was 95% worn through.

One unmarked possum was caught in June 2021, near the junction of Pongaroa and East Māhia Coast Roads, in a podiTRAP.[1] No other possum captures were recorded from the wireless raised leg-hold and podiTRAP trap networks shown in Figures 3 and 4 (approximately 60 of each trap type) during the first 11 months of 2021.

All 10 individual possums captured in areas already under intensive possum control were adults. Nineteen of 64 possums (30%) caught in areas without intensive control during the study were juveniles. Statistical analysis of those proportions indicates that we can be 94.4% confident that the difference (30% vs 0%) was real, and was not due to chance (Fisher Exact Test; $P = 0.056$), While 95% confidence is the usual cut-off point for accepting a finding as representing a genuine difference between sampled populations, our result is so close to that value that it is very likely that intensive control reduced juvenile abundance more than adult abundance. This suggests that juvenile possums were more susceptible to the poison bait station network than adults.

Of six adult male possums captured in November 2021, four were close to adult female possums (Figure 4). A fifth male was caught where an adult female was collared in January 2021 and was still located in June 2021. That female was not relocated in November 2021.

[1] https://www.trap.nz/user , Whakatipu Māhia project; accessed 18/2/22.

Table 1. Fate of 10 possums GPS-collared at Māhia Peninsula in January 2021. A range of survival times is given for those possums inhabiting areas where possum control was initiated prior to collaring, reflecting the possibility that they had either immigrated into the area since control was initiated or had been present at those sites throughout the whole of the control period. Possums recaptured (alive) in November 2021 were euthanised. NC = possum not caught in November 2021

Possum ID	Sex	Habitat	Control started	Fate	Collar on possum Nov. 2021?	Survival post control (months)
GPS48	M	pines	Oct. 2020	died/March 2021	-	2-5
GPS56	F	pines	Oct. 2020	?	NC	?
GPS67	F	pines	Oct. 2020	?	NC	?
GPS60	M	farm	May 2021	died June 2021	-	<1
GPS74	M	farm	May 2021	alive Nov. 2021	no	5+
GPS54	M	farm	Apr. 2021	alive Nov. 2021	Yes*	6+
GPS58	F	farm	May 2020	alive July 2021	NC	5-12+
GPS64	F	farm	Mar. 2020	alive Nov. 2021	no	11-20+
GPS68	M	farm	Mar. 2020	alive Nov. 2021	no	11-20+
GPS71	M	farm	Mar. 2020	alive Nov. 2021	no	11-20+

* Collar not functioning since July 2021.

5.4 Possum movement patterns

Useable GPS data sets were obtained from 18 possums for the pre-control period and four possums from the post-control period.

Home range size varied greatly between male and female possums, and between the two habitats investigated (Table 2, Figures 6 & 7). Mean pre-control home range size in farmland habitats (28 ha) was three times that in extensive forest (10 ha) (t = -2.37, df = 6.15, P = 0.05; Table 1). Mean pre-control home range size of males (48 ha) was four times that of females (12 ha) and this difference between sexes reached statistical significance (over 95% confidence) for possums in farmland (t = -3.26, df = 4.28, P = 0.03, but not in forest (t = -1.61, df = 7.88, P = 0.15; Table 2).

Table 2. Autumn/winter possum home range area (estimated using the 90% contour of a Kernel Density Estimator using the reference bandwidth) and σ estimates (estimated using a bivariate-normal distribution), discriminated by sex and habitat type, from before and after the start of intensive possum control on Māhia Peninsula, 2019–2021. Group data are means, with equal weight given to categories within sex, habitat and temporal parameters

Control phase	Collar No.	Habitat	Sex	σ (m) (bivariate-normal)	Home range area (ha) (90% KDE)
Pre-control	GPS91	forest	F	54.5	4.3
	GPS93	forest	F	66.5	7.4
	GPS85	forest	F	82.8	7.7
	GPS94	forest	F	86.4	9.5
	GPS86	forest	F	94.7	11.0
	all	forest	F	77.0	8.0
	GPS88	forest	M	70.1	7.1
	GPS82	forest	M	75.3	9.2
	GPS95	forest	M	79.8	8.9
	GPS80	forest	M	85.9	10.7
	GPS87	forest	M	97.9	13.4
	GPS83	forest	M	132.5	20.1
	all	forest	M	90.3	11.6
	all	forest	M + F	83.7	9.8
	GPS92	farmland	F	60.7	5.5
	GPS79	farmland	F	95.5	10.2
	all	farmland	F	78.1	7.9
	GPS76	farmland	M	105.6	17.5
	GPS60	farmland	M	156.9	32.2
	GPS74	farmland	M	192.6	38.2
	GPS78	farmland	M	257.1	78.7
	GPS84	farmland	M	265.6	74.6
	all	farmland	M	195.6	48.2
	all	farmland	M + F	136.9	28.1
Total pre-control		**all**	**M + F**	**110.3**	**18.9**
Post-control	GPS58	farmland	F	73.3	4.2
	GPS71	farmland	M	144.8	26.7
	GPS68	farmland	M	294.8	106.4
	GPS54	farmland	M	337.0	122.7
	all	farmland	M	258.9	85.3
	all	farmland	M + F	162.8	44.7
Total post-control		**all**	**M + F**	**162.8**	**44.7**

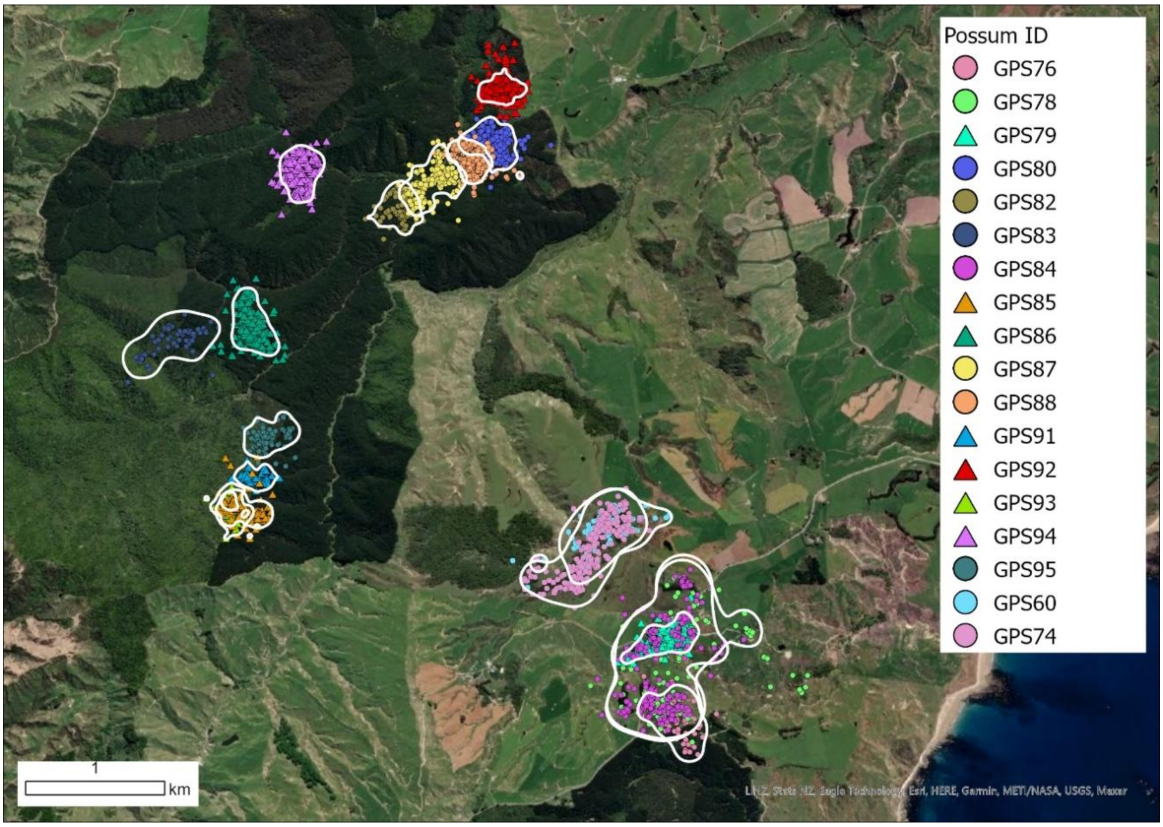

Figure 6. GPS fix positions (dots) and home ranges (white lines) for 18 pre-control possums from April to July, in 2019 and 2021, on Māhia Peninsula. Circles indicate male possums, and triangles indicate females.

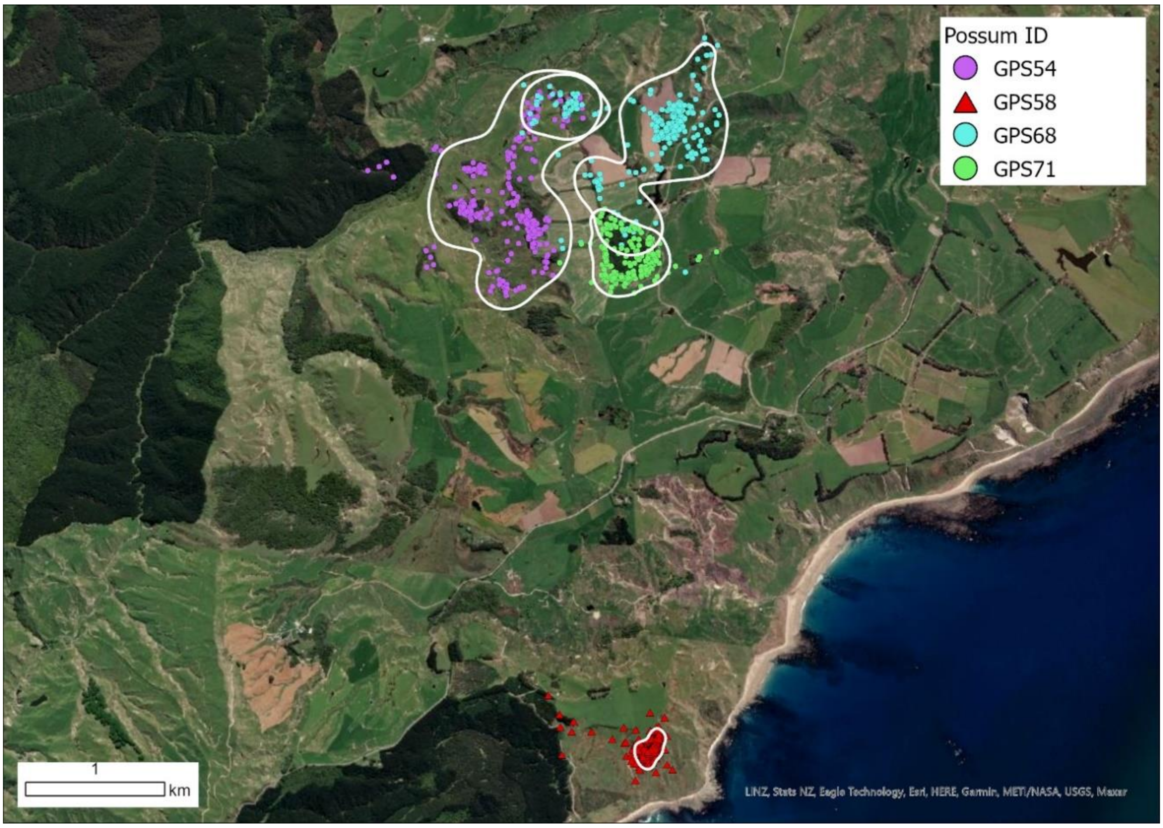

Figure 7. GPS fix positions (dots) and home ranges (white lines) for four post-control possums from April to July 2021 on Māhia Peninsula. Circles indicate male possums, and triangles indicate females.

No useable telemetry data were collected from extensive forest habitats during post-control monitoring, and data from just one female were obtained from farmland habitats during the same period. Although mean home range size for the three post-control males (85 ha) was nearly twice as large as for pre-control farmland males (48 ha; Table 2), the difference was not statistically significant (t = -0.61, df = 2.85, P = 0.59). In contrast to males, the post-control home range of the single female possum we collected data for was small, at 4.3 ha, although that possum did make occasional forays of up to 1 km from its home range centre (Figure 7).

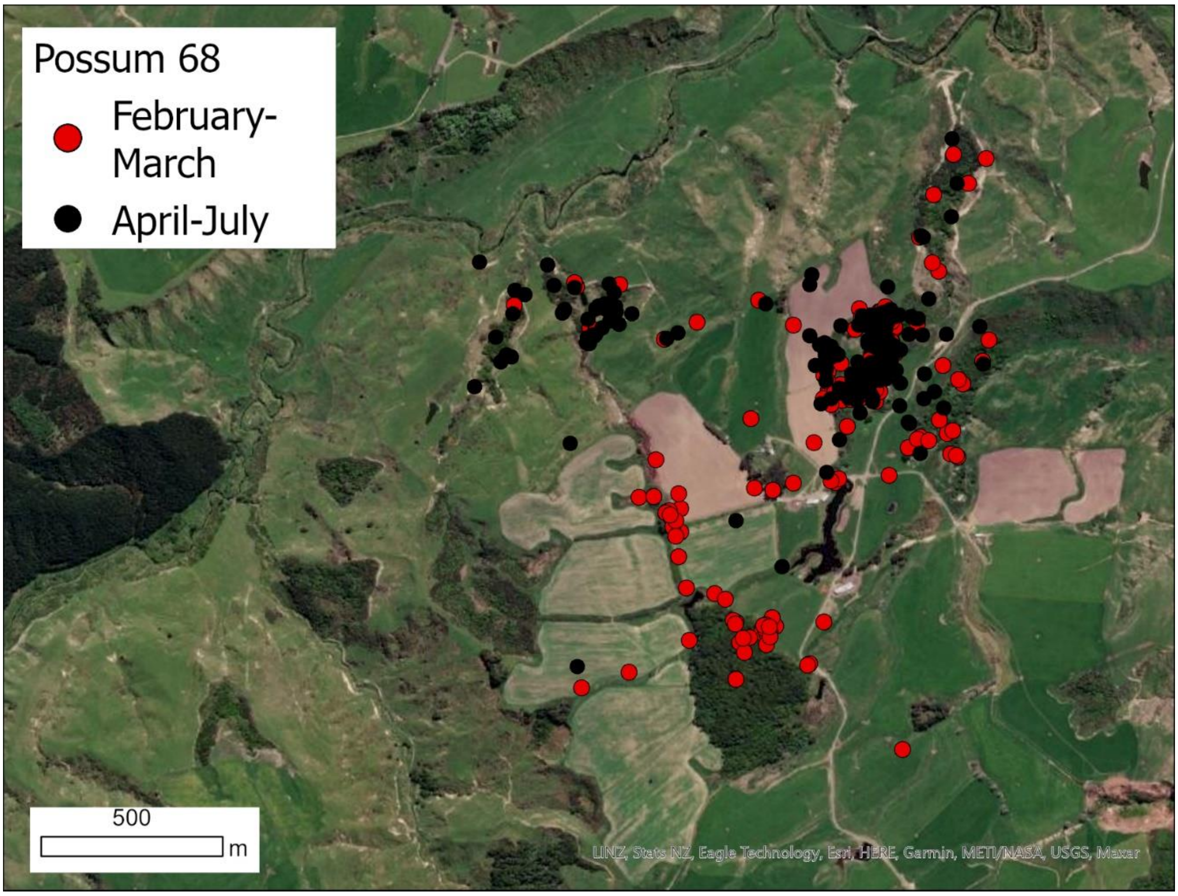

Figure 8. GPS locations for male possum GPS68 for the period from February to July (inclusive) 2021, showing a minor contraction of its home range between summer (February/March) and autumn/winter (April–July).

A similar pattern was seen in the February/March 2021 data that were excluded from the above analyses. Three farmland male possums from this period that were in areas yet to be covered by high-intensity control had a mean home range of 40.3 ha (range: 17.7–85.0 ha). That compared with 85.3 ha (range: 27–123 ha) for three farmland males where high-intensity control had been in place since March 2020.

Home range shape was generally circular for pre-control, forest-dwelling possums, but home ranges were much more irregular for possums on farmland during both pre- and post-control periods (Figures 6 & 7). They generally reflected the spatial pattern of woody vegetation, with some ranges elongated along water courses containing scattered scrub and forest patches, and possum activity concentrated in those patches (Figure 7). Most centres of activity, even in small patches on the edges of home ranges, represent multiple visits spread over several months (unpubl. data).

In general, possums did not frequent open pasture; locations recorded in open areas were few and scattered and most likely represent travel between habitat patches. Individual possums visited habitat patches up to 250 m away from the nearest adjacent patch within their home range (Figure 7).

All seven VHF collars fitted to possums in May 2019 (pre-control sample) were relocated in September 2019 and none had made long-range dispersal movements. The mean distance between initial capture and relocated positions was 162 m (range 10–394 m). Visual inspection of the GPS data revealed that none of the 26 GPS-monitored possums made long-range dispersal movements during the study, as they utilised all or nearly all of their home range throughout the period they were monitored. One farmland male (GPS68) made a slight change to the area utilised while being monitored when it stopped using the southern end of its home range after March 2021 (Figure 8).

6 Conclusions

6.1 Possum abundance and survival

Pre-control possum abundance was extremely variable. It was near zero in some areas, as anticipated given the history of possum control, but moderate (11% trap-catch) in some forest areas (e.g. Grandy Lakes pine forest and along the eastern border of the Māhia Peninsula Scenic Reserve). Possum abundance declined markedly at Grandy Lakes after initiation of intensive possum control, at least in those areas trapped during post-control collar deployment and retrieval. Trap-catch was 97% lower in November 2021 than in May 2019 across all trapped forested areas. The one post-control possum in forest died two months after collaring.

The initial roll-out of intensive possum control appears to have been less successful in farmland habitats. Trap-catch declined there by just 60% between May 2019 and November 2021, although, as previously stated, the November 2021 trap-catch may be biased high because trapping was targeted at sites where possums were collared the previous January. Farmland possums that we collared in January 2021 were relatively invulnerable to toxic bait stations and the wireless traps. Only one of three of these possums that were collared prior to the initiation of intensive control died, with the other two surviving about seven months to the end of the study. All four farmland possums that were collared after intensive control was rolled out survived for at least five months, with at least three surviving the 10 months to the end of the study. If these survivors had remained near their capture locations throughout the post-control period (since March/April 2020, 9–10 months before they were collared), then three of them would have survived up to 20 months in the presence of intensive possum control.

The wireless trap network from Te Kahika Forest northward (Figures 3 & 4) caught no possums during the 11-month post-control period we monitored. One possum was caught on Pongaroa Station in a podiTRAP, a trap designed to kill small predators, during this time. The fact that possums were present throughout this period suggests the wireless trap network, which has set, un-lured leg-hold possum traps placed about 1.2 m above the ground, was insensitive to survivors. That is likely to be due in part to the network within our study areas following public roads, which pass through few possum-habitat patches. However, some survivors of intensive control were trappable in ground-set leg-holds: we caught 12 in 2021, five of them twice.

The presence of long-term survivors during intensive bait-station poisoning indicates the need for alternative control methods to be incorporated into the possum eradication effort, at least in those areas (such as our study area) where the mop-up phase has yet to be implemented. The use of trail cameras and possum-tracking dogs has been initiated on the southern part of the peninsula and is planned to be rolled out more extensively in the coming months. Depending on the results, our work indicates that the use of ground-set leg-hold traps may be a useful addition, particularly if costs are minimised by targeting traps to sites where possums have recently been detected (e.g. by dogs, trail cameras or chewcards). Catch rates are likely to be maximised if traps are set with a lure blaze, white back-board or flat chewcard mounted behind the trap and flour lure is placed on the ground around the trap (Warburton et al. 2021). Consideration should be given to targeting woody habitat patches, particularly along waterways, for any further extension of the wireless leg-hold trap network (primarily used as a monitoring tool to date) and trail cameras. All additional monitoring and control efforts would be most effectively employed by targeting such sites.

The lack of juvenile possums captured during post-control trapping suggests that young animals are more suspectable than adults to the poison bait-station network, at least in farmland habitats. The residual adults may be bait- or bait-station shy, having been exposed to bait stations for several years. If so, then shyness may be an artifact of the annual servicing of bait stations, meaning that they were either empty for most of the time, inducing possums to ignore them, or they frequently contained degraded bait or small residues that induced shyness in possums that investigated them. Different bait formulations and/or different models of bait station and location might be required to overcome any existing shyness issues.

6.2 Possum movement patterns

6.2.1 Previous studies

Undisturbed adult possums are sedentary (Cowan & Clout 2000). Possum home range size and overlap increase when density is reduced through population control (Efford et al. 2000; Ramsey et al. 2002; Pech et al. 2010; Rouco et al. 2016; Margetts et al. 2020). Reported mean home range sizes in post-control populations are as large as 99 ha for forest-dwelling males and 91 ha for farmland males, with individual ranges up to 192 ha (Sweetapple et al. 2016). The corresponding figures for adult female possums are 61 and 35 ha for forest and farmland habitats, respectively. These compare with just 1–4 ha typical of uncontrolled possums in forests (Cowan & Clout 2000).

Individual possums isolated by control are likely to make long-range dispersal or exploratory movements to find breeding partners, although the evidence is largely anecdotal. Elsewhere, for example, several isolated foci of possum activity detected four to six months post-control could no longer be detected at those locations 3 to 12 months later, suggesting that surviving possums had moved elsewhere (Nugent et al. 2008; Sweetapple et al. 2014). High fecundity among adult females (87% with pouch young throughout the year) in a population reduced to near zero (trap-catch = 0.05%) in the Hauhungaroa Range suggests considerable mobility among the residual possums (Sweetapple & Nugent 2009). Direct measurements of post-control possum movements are rare, but include: a radio-collared male in deep forest that moved at least 2.3 km in two or more shifts over 12 months to its recapture location close to an adult female (Sweetapple & Nugent 2009); two farmland possums that moved 600–1600 m after a 90% population reduction (Brockie et al. 1997); and two adult possums, one male and one female, that gradually shifted their home range centres by 0.5 to 1.0 km over several months (Sweetapple et al. 2014).

6.2.2 Conclusions from this study

All monitored possums were sedentary during the study: they did not move the location of their home ranges or make long-range dispersal or exploratory movements. Pre-control home range size was larger for farmland than forest possums, probably reflecting the lower possum abundance in farmland habitats at that time (Figure 5), but it might also be partly attributable to habitat-specific movement patterns. Farmland possums did not significantly expand their home range size following control as might be expected. This probably reflects the low pre-control abundance, the apparently lower impact of initial intensive control there, and our small sample sizes. Forest possums were, potentially, more likely to have expanded or shifted their home ranges during the post-control period, because their pre-control home range sizes were relatively small, and their abundance was markedly reduced by intensive control. However, we could not measure that effect as the only forest possum for which we had post-control movement data died shortly after it was collared.

The density at which farmland possums are forced to shift their home ranges in order to find conspecifics might be lower than that achieved by the end of our study. Alternatively, those possums already under intensive control for 9–10 months when collared in January 2021 might have already reaggregated into breeding groups since initiation of intensive control. Our limited data suggest that at the end of the study there was little or no need for them to move to find breeding partners. Six of the eight possums captured at the end of the study were paired with members of the opposite sex. Furthermore, one of the two potentially lone males captured was at a site where an adult female was present 5 months earlier and may well have still been present. The apparent ability of both male and female possums to greatly expand their home range size following population control means that residual mean density needs to be extremely low (below 0.01/ha) before possums become totally isolated from potential mates.

Given the absence of shifts or large-distance movements among the possums we monitored, our study did not directly reveal movement corridors used by dispersing possums. Activity patterns of farmland possums, which generally mirrored the distribution patterns of woody vegetation in this study and elsewhere (Sweetapple et al. 2014), provide insight as to where these corridors might lie. Such corridors in farmland are likely to be along streams with patchy or continuous woody vegetation, or other parts of the landscape with a network of closely-spaced habitat patches. Our data suggest that movement is most likely along routes where habitat patches are less than 250 m apart. Our study provides no insight into potential movement routes in continuous forest, but elsewhere dispersing juvenile possums most frequently settled near rivers (Byrom et al. 2015), and possums immigrating into a recently controlled forest in the Hauhungaroa Range followed a large stream (Sweetapple & Nugent 2020). Water courses, therefore, are also likely routes of possum movement in continuous forest on Māhia Peninsula.

Large home range sizes, and potential dispersal movements of isolated residual possums, have implications for ongoing possum control at Māhia Peninsula. Most possums will eventually be exposed to monitoring or control devices, even within a sparse network of devices. Clusters of farmland possums at Māhia would, conservatively, all be exposed to detection devices spaced 500 m apart. A similarly sparse detection network (trail cameras set at 500 m x 700 m) was successfully used to achieve and maintain possum freedom over c. 11,642 ha of continuous forest in the Whataroa Catchment, South Westland (Cook & Mulgan 2022).

Although we have no post-control movement data for possums in extensive forest, the very low post-control possum abundance there, and similar home range sizes of low-density farmland and forest possums elsewhere (e.g. Sweetapple et al. 2016), suggest similar device spacing in forest at Māhia will also be appropriate. Those networks can be further minimised by targeting the parts of the landscape that are most likely to be used by possums, especially on farmland. Furthermore, large proportions of the landscape are, eventually, likely to have no possum activity (e.g. Sweetapple & Nugent 2009, 2020) so that, given a sufficient monitoring network, control can be halted over much of the landscape. However, if lean detection/control networks are used, they will need to be long-life devices needing infrequent servicing that are highly sensitive to possums. One low-cost option is chewcards with a durable bait (e.g. Possum Dough, Kiwicare Holdings Ltd, or Smooth Lure, Connovation), which could be set for 1–3 months at best sign in small clusters, at widely spaced detection foci.

If labour-intensive methods (e.g. detector dogs, spot-lighting, leg-hold trapping) are to be used during mop-up operations, the costs of control will be minimised by targeting sites where possum activity has recently been detected (e.g. by trail cameras or chewcards). However, that control will need to be either actioned immediately to maximise the probability the possum/s is/are still present, or it will need to be applied over an area around the detection site that is commensurate with the large post-control home range size (c. 100 ha).

The importance of high mobility of residual possums will increase the closer that possum numbers get to zero. Eventually most remaining possums will be isolated and may abandon their established home ranges in search of conspecifics. Some may range over areas of many hundreds of hectares or more (e.g. Nugent et al. 2013; Sweetapple & Nugent 2020). This appeared to happen in the Hauhungaroa Range once the 7-night chewcard index fell below 3% and possum density was measured at less than 0.01/ha

(Sweetapple & Nugent 2020). During this final phase of the eradication programme, detection networks will need to be extensive and close to real time, with follow-up control very responsive if roving possums are to be captured. An alternative strategy could be to halt control for a period (e.g. 6–12 months) to allow residual possums to reaggregate into stable breeding groups (e.g. Sweetapple & Nugent 2016), making mop-up easier. Any reaggregated breeding groups detected will need to be intensively treated to eliminate them without triggering another round of isolated-possum dispersal and new breeding cluster establishment.

Some possums may maintain relatively small home-range sizes at very low possum densities. For example, one post-control female (GPS58) had a home range of just 4.2 ha, although it made occasional forays of up to 1 km from that home range and was located within the home range of an adult male. Such possums are likely to coexist with others that have much bigger home range sizes, or if they become isolated by the removal of their more mobile neighbours, expand their home range size or move their home range centres. Device spacing does not, therefore, need to be set to target these less-mobile individuals. They will still be exposed to the mop-up efforts that are targeted around the detection sites of their more mobile neighbours. If they survive those targeted efforts and become isolated, and fail to find conspecifics, they will not compromise the eradication effort because they will eventually die without further breeding.

7 Recommendations

- The mop-up of possums under the WMPFM programme should continue to be expanded across the northern half of Māhia Peninsula and include alternative control methods in addition to the intensive poison bait station network.
- Consideration should be given to more extensive use of lured, ground-set leg-hold traps, targeted to sites with recent possum detections, for possum mop-up operations.
- Long-term monitoring devices (trail cameras, wireless leg-hold trap networks, chewcards or waxtags), and mop-up effort, should be targeted at key possum habitats, predominantly native woody vegetation patches along waterways, if practical.
- Long-term monitoring devices located 500 m apart in possum habitat will place monitoring devices within each residual possum breeding cluster on farmland during mop-up operations. Intensive possum control should be undertaken over about 100 ha of habitat centred on each possum detection site.

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