Glenelg Ark 2005–2019: long-term predator and native mammal response to predator control

A. Robley, P. Moloney, L. Stringer and S. Donald

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Acknowledgment

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Front cover photo: (a) Red Fox with native prey; (b) feral Cat inspecting lure; (c) monitoring native species' response; (d) 1080 baiting sign at entrance to Glenelg Ark; (e) laying baits for fox control (photographer: DELWP).

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Glenelg Ark 2005–2019: long-term predator and native mammal response to predator control

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Summary

The Glenelg Ark project was established in 2005 to facilitate the recovery of selected native mammal species considered at risk from fox (Red Fox, *Vulpes vulpes*) predation. In 2005, the project established continuous landscape-scale fox baiting across 90 000 ha of State Forest and National Park in south-western Victoria. Three native mammal species that were present in the project area at the time (in low numbers, with patchy distributions, and at risk from fox predation) were selected for monitoring. These were the Southern Brown Bandicoot (*Isoodon obesulus*), the Long-nosed Potoroo (*Potorous tridactylus*) and the Common Brushtail Possum (*Trichosurus vulpecula*).

Aims:

- To update the previous information (from 2005–2018) on the outcomes of the fox control operation and the responses of targeted native species as at 2019
- To provide information to land managers and policy groups to inform decision-making regarding the future directions of the project

Methods:

Differences in the fox and feral cat (*Felis catus*) activity at locations with and without fox control [i.e. at treatment monitoring locations (TMLs) and non-treatment monitoring locations (NTMLs)] were assessed using Bayesian regression models. Activity assessment was based on the number of images separated by >1 hour captured per day at each site from 2013 to 2019.

We used species detection/non-detection data from hair tubes and camera traps from three TMLs and three NTMLs. The occupancy rate, growth rate and turnover rate at TMLs and NTMLs for populations of the three native mammal species were examined using multiseason occupancy models.

If the critical factor limiting the impacts of fox predation on native mammal populations is fox control, then we should expect that the occupancy rates of native mammals will increase over time at sites subject to control, and that the rate of increase in occupancy will be higher at treatment sites than control sites. The growth rate should increase and stabilise, and turnover rates (the fraction of occupied sites that are newly occupied) should be variable initially then stabilise at low numbers as suitable habitat is occupied.

Results:

Fox and feral cat activity

Fox activity was 88% higher across the NTMLs [mean ($\bar{x}$) = 0.59 images/hr, credible interval (CI) 0.51–0.68] than across the TMLs ($\bar{x}$ = 0.07, CI 0.06–0.08), based on the number of unique observations per hour on the camera traps. There was no difference in feral cat activity between NTMLs ($\bar{x}$ = 0.04, CI 0.035–0.051) and TMLs ($\bar{x}$ = 0.037, CI 0.030–0.045).

Long-nosed Potoroos

Occupancy rates have not increased consistently at TMLs and have remained less than 0.25 (25% of sites occupied) in most years but have tended to be higher at TMLs ($\bar{x}$ = 0.18) compared to NTMLs ($\bar{x}$ = 0.13). Growth rates have been flat and near one (no growth) on both TMLs and NTMLs. Turnover rates have generally been high but variable at all locations.

Southern Brown Bandicoots

Occupancy rates have not increased over time and have remained less than 0.25. Occupancy rates have generally been higher on TMNLs ($\bar{x}$ = 0.20) compared to NTMLs ($\bar{x}$ = 0.15). Growth rates have been variable, with generally uncertain estimates fluctuating above and below one in all years. Turnover rates have generally been high but variable and uncertain in all years.

Common Brush-tailed Possums

Occupancy rates increased on both TMLs and NTMLs, with occupancy generally higher at TMLs ($\bar{x}$ = 0.53) compared to NTMLs ($\bar{x}$ = 0.43). There was no trend in growth rates, and the mean difference between TMLs was 0.10 (95% CI–0.01 to 0.21). Turnover rates where high (0.70 to 0.95) and tended to increase from 2013.

Conclusions and implications:

Sustained low levels of fox activity have resulted in limited differences in occupancy rates between TMLs and NTMLs for Southern Brown Bandicoots and Long-nosed Potoroos. While Common Brush-tailed Possum occupancy rates have increased, this increase has occurred on both TMLs and NTMLs, and is mainly correlated with rainfall patterns.

The lack of a significant response in Southern Brown Bandicoot and Long-nosed Potoroo after 14 years of fox control is of concern. There are some possible reasons for this lack of change in occupancy rates that are worthy of exploration.

1. The current sampling methodology is insensitive to the scale of change in occupancy, or occupancy is an inferior metric for abundance; thus, the result is an underestimate of the scale of population change that has occurred across the landscape.
2. Landscape disturbance, e.g. the long-term effects of frequent burning (both planned and natural), has resulted in a highly fragmented landscape. Populations are now restricted to isolated refugia, and species are unable to bridge the gaps between them. Both species have now filled the available niche and are limited by competition for suitable habitat.
3. Fox densities are still too high and limit the population growth of small fragmented populations of Southern Brown Bandicoot and Long-nosed Potoroo.
4. Feral cats have replaced foxes as the main predator, with potentially similar dynamics to those of foxes.
5. Some combination of the above, or some unknown and unanticipated factors.

To address these uncertainties and possible lack of management effectiveness, the project should shift from an operational footing to a formal and appropriately funded adaptive management structure. At present, the project has a limited capacity to adapt its monitoring program and its management operations to address these uncertainties. In part, the partnership with Melbourne University fills this gap. However, there is a need for a coherent strategy, as these external projects are developed independently of a broader Program strategy.

We recommend that a Glenelg Ark strategic plan be developed that articulates the projects long-term outcomes and how these will be achieved and assessed. This plan should consider the following strategies for improving our current knowledge and aid managers in making informed decisions on the future direction of the Glenelg Ark project:

Strategy to further reduce fox density

- Increase the density of baits at TMLs, and robustly assess the outcome in terms of the fox, feral cat and native species response.

Strategy to improve understanding of native species response

- Increase the number of camera sites to improve detection rates for Southern Brown Bandicoot and Long-nosed Potoroo.
- Model the patterns in the changes in occupancy from 2005 to 2018 to investigate factors that may influence the spread of recovery.

- Develop Southern Brown Bandicoot and Long-nosed Potoroo habitat suitability surfaces for the Glenelg Ark project area (using presence/absence data) to aid in setting species response targets and to identify potential new control and/or monitoring sites.
- Using expert elicitation, describe the benefits of fox control for the Heath Mouse (*Pseudomys shortridgei*); select sites for targeted monitoring within TMLs and NTMLs.

Strategy to integrate feral cat and fox control

- Implement targeted feral cat control at selected locations with known populations of Southern Brown Bandicoot and Long-nosed Potoroo.
- Undertake feasibility analysis, including the cost for broadscale baiting of feral cats within the Glenelg Ark operational area.
- Develop a community education and engagement program for integrated predator control.

Explore alternative survey methods for foxes and feral cats

- Assess the feasibility and cost of genotyping DNA from fox scats collected using scat-detector dogs or other tools.
- Assess the feasibility and cost of genotyping DNA from hair samples collected using hair snare traps for feral cats.

Scientific support

- Develop a service agreement for the continued scientific support and advice concerning the ongoing implementation and development of Glenelg Ark.

Filling specific knowledge gaps

- Develop and support a set of potential student projects to fill identified knowledge gaps.

1 Introduction

The Glenelg Ark project has implemented continuous, landscape-scale fox (Red Fox, *Vulpes vulpes*) baiting across 90 000 ha of State Forest and National Park in south-western Victoria since 2005. To justify ongoing government commitment and community support for Glenelg Ark, its benefits to Victoria's biodiversity must be demonstrated. The monitoring and evaluation component of Glenelg Ark measures (i) the response of foxes to control activities, and (ii) the response of three native species that are at risk from fox predation to a reduced abundance of foxes.

Three native mammal species that are present in the Glenelg Ark project area in low numbers (Robley et al. 2011), have patchy distributions (Menkhorst 1995), and are also at risk from fox predation were selected for monitoring: the Southern Brown Bandicoot (*Isoodon obesulus*), the Long-nosed Potoroo (*Potorous tridactylus*) and the Common Brushtail Possum (*Trichosurus vulpecula*). All three species are known to be preyed upon by foxes (Seebeck 1978) and have been reported to respond positively to a reduction in foxes (Kinnear et al. 2002; Arthur et al. 2012).

We suggest that, in the presence of predators such as foxes, it is probable that populations can only persist in refugia that may be quite atypical of a species' actual niche requirements. In terms of the Hutchinson (1978) concept of the niche (also see Kinnear et al. 1985), fox predation affects the dimensions of a species' realised niche (i.e. where the species actually lives) by exaggerating their requirements for protective shelter and their need for food to be nearby. Niche theory predicts that a release from predation would relax the requirements for shelter and the proximity of food, and thus permit the expansion of the realised niche, as observed by Kinnear et al. (1988) for Black-flanked Rock-wallabies (*Petrogale lateralis*) when foxes were controlled.

We predict that if fox control has been effective at Glenelg Ark, the three target species should exhibit niche expansion indicated by:

1. a positive trend in the occupancy rate over time at locations with fox control. If species abundance is limited by predation, increased survival should lead to individuals occupying new sites as the population expands
2. a significant difference in occupancy rates between locations with and without fox control. If fox predation is the limiting factor, occupancy rates should be higher across locations with fewer foxes compared with locations with more foxes
3. increased rates of occupancy at fox control locations in the years immediately after implementation of control as new sites are colonised. Growth may stabilise once all possible sites are occupied
4. fluctuating turnover rates (the fraction of occupied sites that are newly occupied) on fox control sites in the years after control is implemented, while species search for new, suitable sites to occupy, then begin to stabilise as suitable habitat is filled. At locations with no fox control, turnover rates should be unstable and variable.

We assessed operational success (whether fox control has resulted in a reduction in foxes) by using an activity index to compare the differences in the relative abundance of foxes at locations with ongoing and continuous fox control with that at locations with no history of fox control. We assessed performance success (whether fox control has resulted in a positive increase in target native species) by comparing three population parameters: (i) the rate of occupancy and the derived estimates of (ii) growth rate (i.e. current occupancy rate divided by previous season's occupancy rate) and (iii) rate of turnover (the fraction of occupied sites that are newly occupied with time) of the three target species between locations with and without ongoing fox control.

This report updates the previous monitoring and evaluation report (Robley et al. 2018) by incorporating new data on the outcome of the fox control operation and native species monitoring. This report also contains recommendations on future management options and suggests areas of further research. The outcome is that land managers, policy makers and the community can now make informed, evidence-based assessments of the success of this broadscale mainland fox control operation and have the information necessary for decision-making about future directions.

2 Methods

2.1 Glenelg Ark operations area

The Glenelg Ark operations area is in far south-western Victoria, near the township of Heywood (38°07'50"S, 147°37'45"E), and includes six locations in State Forests and National Parks. The main ecological vegetation communities across all six locations are Heathy Woodland, Lowland Forest, Herb-rich Woodland, and Wet Heathland. The area receives an average annual rainfall of 700 mm, and the average minimum and maximum temperatures are 8.1°C and 17.6°C, respectively.

2.2 Monitoring and evaluation design

Three treatment monitoring locations (TMLs), i.e. locations that are subject to fox control, and three non-treatment monitoring locations (NTMLs), i.e. locations not subject to fox control (Figure 1), were used to assess the benefits of fox control to native species. These areas were matched as best as possible for ecological vegetation class and fire history (Appendix 1). There had been little fox control in the TMLs and NTMLs prior to 2005. To achieve a broadscale reduction in abundance of foxes across the public land areas, fox control was consolidated in the southern half of the overall project area (Figure 1). This meant that random allocation of treatment and non-treatment sites was not feasible.

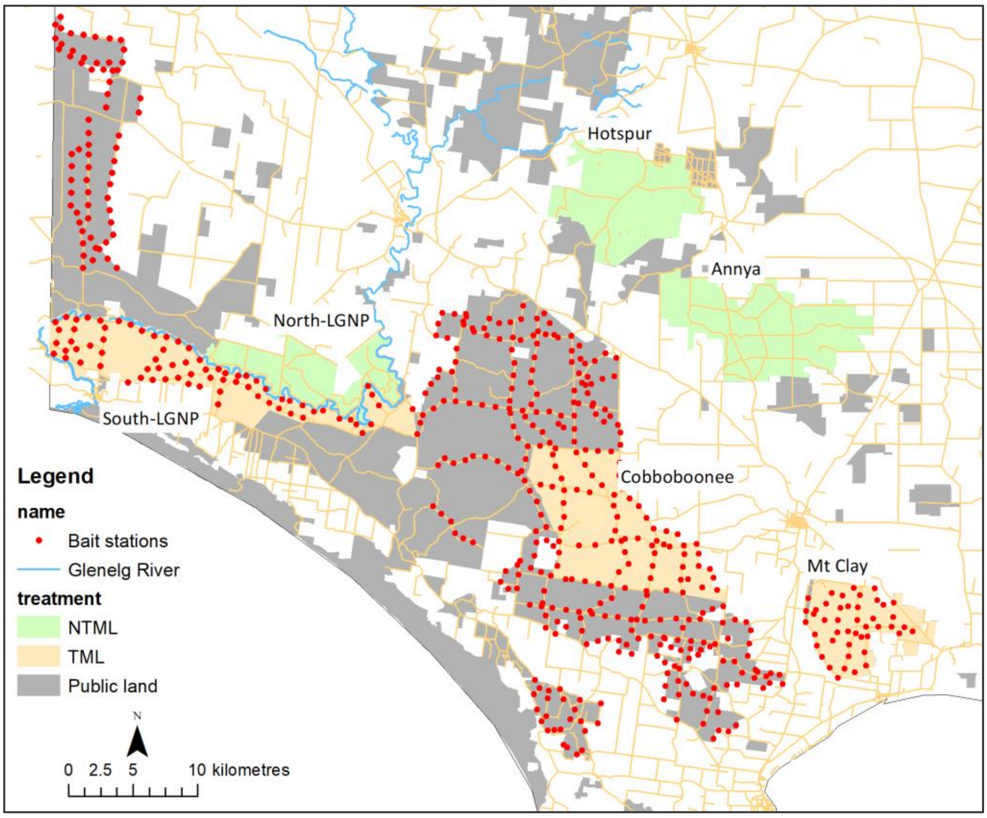

Figure 1. Glenelg Ark operations area

Red dots indicate poison bait stations. Green polygons indicate non-treatment monitoring locations (NTML). Tan polygons indicate treatment monitoring locations (TML). Fox baiting along the coast was discontinued in 2017. LGNP = Lower Glenelg National Park.

The six monitoring locations were:

1. Lower Glenelg National Park – south (LGNP-south; TML; 8954 ha)
2. Lower Glenelg National Park – north (LGNP-north; NTML; 4659 ha) (separated from LGNP-south by the Glenelg River)

3. Cobboboonee National Park (TML; 9750 ha)
4. Annya State Forest (NTML; 8520 ha)
5. Mount Clay State Forest (TML; 4703 ha)
6. Hotspur State Forest (NTML; 6940 ha).

This strategy was designed to enable the identification of any patterns of association between a reduction in foxes and an increase in targeted native species.

2.3 Measuring changes in fox and feral cat activity

We examined the difference in fox and feral cat activity between treatment and non-treatment locations from 2013 to 2019 using data generated from camera traps (see Section 2.5 for details of when and where camera traps were set). We used the number of images separated by >1 hour captured per day at each camera site to generate an index of activity for foxes and feral cats. Fox and feral cat activity were assessed using a Bayesian non-linear mixed model. The model was implemented in brms package (Bürkner 2017) in R (R Development Core Team 2018) using RStudio (RStudio Team 2015, v.1.1.463). Treatment (NTML or TML) and locations (each of the six individual locations) were set as fixed effects and year was set as a random effect. The presence of foxes was included in the feral cat model as a fixed effect to test what influence foxes might have on feral cat activity. The (log)number of cameras that operated on any given day was used as an offset in the models to allow for differing numbers of camera days per sampling period. Models were warmed up with 1000 interactions and sampled using 2000 iterations. Model comparisons were performed using approximate leave-one-out cross-validation based on the posterior likelihood in the 'loo' package (Vehtari et al. 2019).

2.4 Measuring response in native mammal species

Occupancy of the three target species (Long-nosed Potoroo, Southern Brown Bandicoot and Common Brushtail Possum) was monitored annually at 40 sites established within each TML and NTML (Figure 2). The location of the monitoring sites was based on descriptions of the habitat preferred by the target native mammal species (Menkhorst 1995) and aligned with Ecological Vegetation Classes (EVCs); the number of sites were allocated according to the proportion of preferred habitat within each TML and NTML. The position of the monitoring sites within locations was randomly allocated but constrained to be within 50 m of tracks. A site was assumed to sample the area potentially occupied by the target species, with home ranges for Southern Brown Bandicoot and Long-nosed Potoroo ranging from 2 to 4 ha (Bennett 1987; Scott et al. 1999; Ricciardello 2006; MacGregor et al. 2013).

Monitoring prior to the commencement of poison baiting was conducted in winter 2005, then usually undertaken in spring (2005, 2008–2018). In 2006, sampling was undertaken in late winter, and the spring 2007 samplings at Mt Clay and Hotspur were delayed, with monitoring undertaken in the 2007–2008 summer.

From 2005 to 2012, at each monitoring site nine 'Handiglaze' hair-tubes (Murray 2005; Figure 3) baited with peanut butter, rolled oats and golden syrup were set and checked daily for four consecutive days, with tapes being replaced each day. These daily surveys represented four repeat surveys of the monitoring site per sampling period. Beginning in spring 2013, hair-tubing was discontinued, and a single digital camera (Reconyx RapidFire HC600, Reconyx, LLP Wisconsin, USA) was set at one of four possible locations within a hair-tube grid at each monitoring site (Figure 3). A series of coin tosses determined the location of the camera within a monitoring site. Cameras were attached to the nearest tree at 20–30 cm above the ground. A lure of truffle oil, peanut butter, rolled oats and golden syrup was secured to the ground in a small, ventilated container 2 m in front of the camera. Cameras were set to take five images per trigger and operated for a minimum of 30 days, with each day representing a repeat survey of the monitoring site per sampling period.

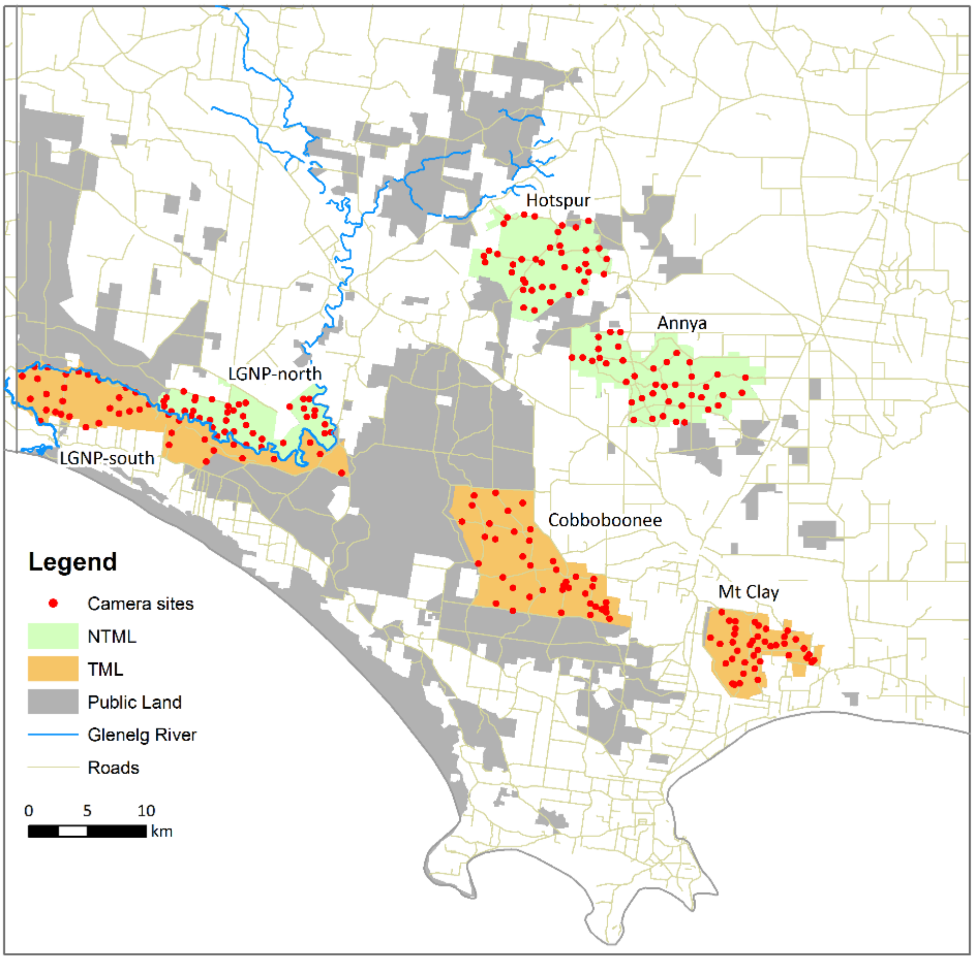

Figure 2. Monitoring sites in the treatment monitoring locations (TMLs; tan polygons) and non-treatment monitoring locations (NTMLs; green polygons) for Glenelg Ark are indicated by red dots. LGNP = Lower Glenelg National Park.

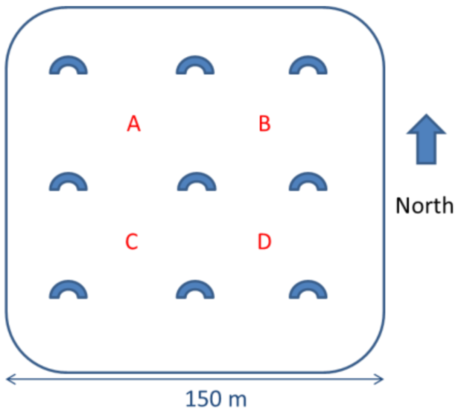

Figure 3. The layout of the nine hair-tubes and possible location (A, B, C or D) of the single digital camera at a monitoring site

2.4.1 Data analysis

Long-term site occupancy changes in native mammals

A multiseason occupancy model was used to estimate the occupancy rate (ψ), detection (p), local A multiseason occupancy model was used to estimate the occupancy rate (ψ), detection (p), local colonisation rate (γ, the probability that an unoccupied site in season γ_t is occupied in season γ_{t+1}) and local extinction rate (ϵ, the probability that an occupied site in season ϵ_t is unoccupied in season ϵ_{t+1}) (MacKenzie et al. 2003, 2006), where occupancy rate over time was estimated as:

$$\psi t = \psi_{t-1}(1 - \epsilon_{t-1}) + (1 - \psi_{t-1})\gamma_{t-1}.$$

Thus, occupancy over time is derived from successive estimates of colonisation and survivorship. The model was constructed in a Bayesian framework, using a space–state formulation (Royle and Kéry 2007). Separate models were constructed for each species of interest: Common Brushtail Possum, Long-nosed Potoroo and Southern Brown Bandicoot. Each model allowed for a difference in parameters at each of the six locations: Annya; Hotspur, Lower Glenelg National Park – North, Cobboboonee, Mt Clay and Lower Glenelg National Park – South. The first three locations have no fox control strategy, whereas the latter three do have a baiting program. The models allowed for differences in daily detection rates due to whether a hair-tube or camera was being used for detections. In addition, detection of Long-nosed Potoroo (*LNP*) and Southern Brown Bandicoot (*SBB*) using hair tubes could differ depending on whether Common Brushtail Possum (*CBTP*) was detected at the site. The rationale is that the hair-tubes could be swamped with Common Brushtail Possum hairs, and therefore *LNP* and *SBB* could be underreported.

Two derived statistics have been calculated from the posterior distributions for the number of occupied sites: growth rate and turnover rate.

The growth rate is a comparison of the current occupancy rate with the previous season's occupancy rate, i.e.

$$Growth_t = \frac{\psi_t}{\psi_{t-1}}$$

Growth rates >1 imply increasing occupancy, whereas growth rates <1 show that occupancy is decreasing, and a growth rate of 1 shows there has been no change in occupancy.

Turnover rate is the fraction of occupied sites that are newly occupied (Royle and Kéry 2007), i.e.

$$Turnover_t = \frac{(1 - \psi_{t-1})\gamma_{t-1}}{\psi_t}$$

The higher the turnover rate, the more local colonisation is occurring.

We predicted that the occupancy rate across TMLs should be higher than NTMLs. In addition, we predicted that growth rates should increase in the years following the commencement of fox control. As species escape limitation by foxes and increase in abundance, the rate of occupancy should increase as populations expand and occupy new sites. This may slow or become close to constant as suitable habitat is filled, i.e. when there are no new suitable and accessible sites to occupy. We predicted that turnover rates would be variable in the years following the commencement of fox control, then decrease and remain low and nearly constant. When species that are limited by predation expand, some degree of turnover would be expected. However, as suitable available sites become occupied, the fraction of the occupied sites that are *newly* occupied would slow down and decrease.

The models were constructed in JAGS (Plummer 2003) via R (R Core Team 2018 using the package R2jags (Su and Yajima 2015. Model chains were run until the chains converged. Convergence was defined as having all Gelman and Rubin's convergence diagnostic potential scale reduction factors being <1.05 (Gelman et al. 2004).

3 Results

3.1 Fox and feral cat activity

There was strong support from the regression model that foxes were more active at NTMLs than at TMLs (Figure 4). Fox activity between 2013 and 2019 was 88% higher across the NTMLs ($\bar{x}$ = 0.59, CI 0.51–0.68) than across the TMLs ($\bar{x}$ = 0.07, CI 0.06–0.08), based on the number of unique observations per hour on the camera traps.

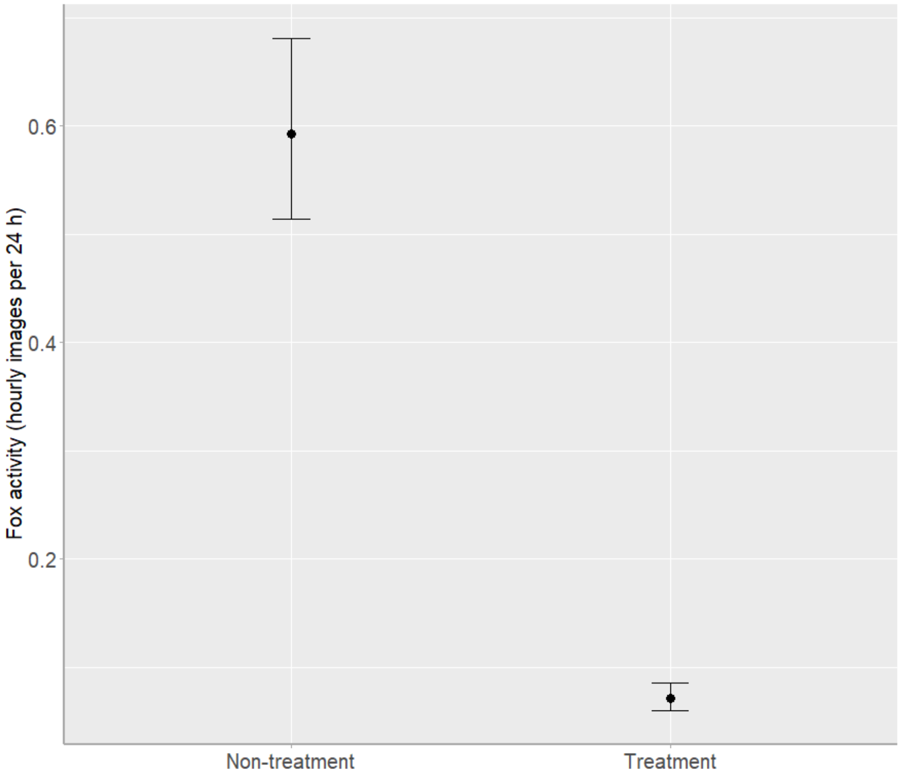

Figure 4. Fox activity at non-treatment and treatment sites (number of images separated by >1 hour/24 hours)
Error bars indicate the 95% credible intervals.

Fox activity was significantly higher on all three individual NTMLs compared with the three TMLs (Table 1; Figure 5), indicating that the impact of fox control was similar across the TMLs. There was a trend in declining fox activity from 2013 to 2019 across all three NTMLs (Figure 5), but this was not significant (Figure 5).

Table 1. Fox activity across all monitoring locations

Mean = number of images separated by >1 hour in a 24-hour period. SE = standard error, LCI and UCI = lower and upper credible intervals, respectively.

Treatment	Location	Mean	SE	LCL	UCL
NTML	Annya	0.67	1.13	0.53	0.87
NTML	Hotspur	0.85	1.19	0.60	1.20
NTML	LGNP-north	0.82	1.19	0.58	1.15
TML	Cobboboonee	0.11	1.22	0.08	0.17
TML	LGNP-south	0.10	1.22	0.07	0.15
TML	Mt Clay	0.11	1.22	0.07	0.16

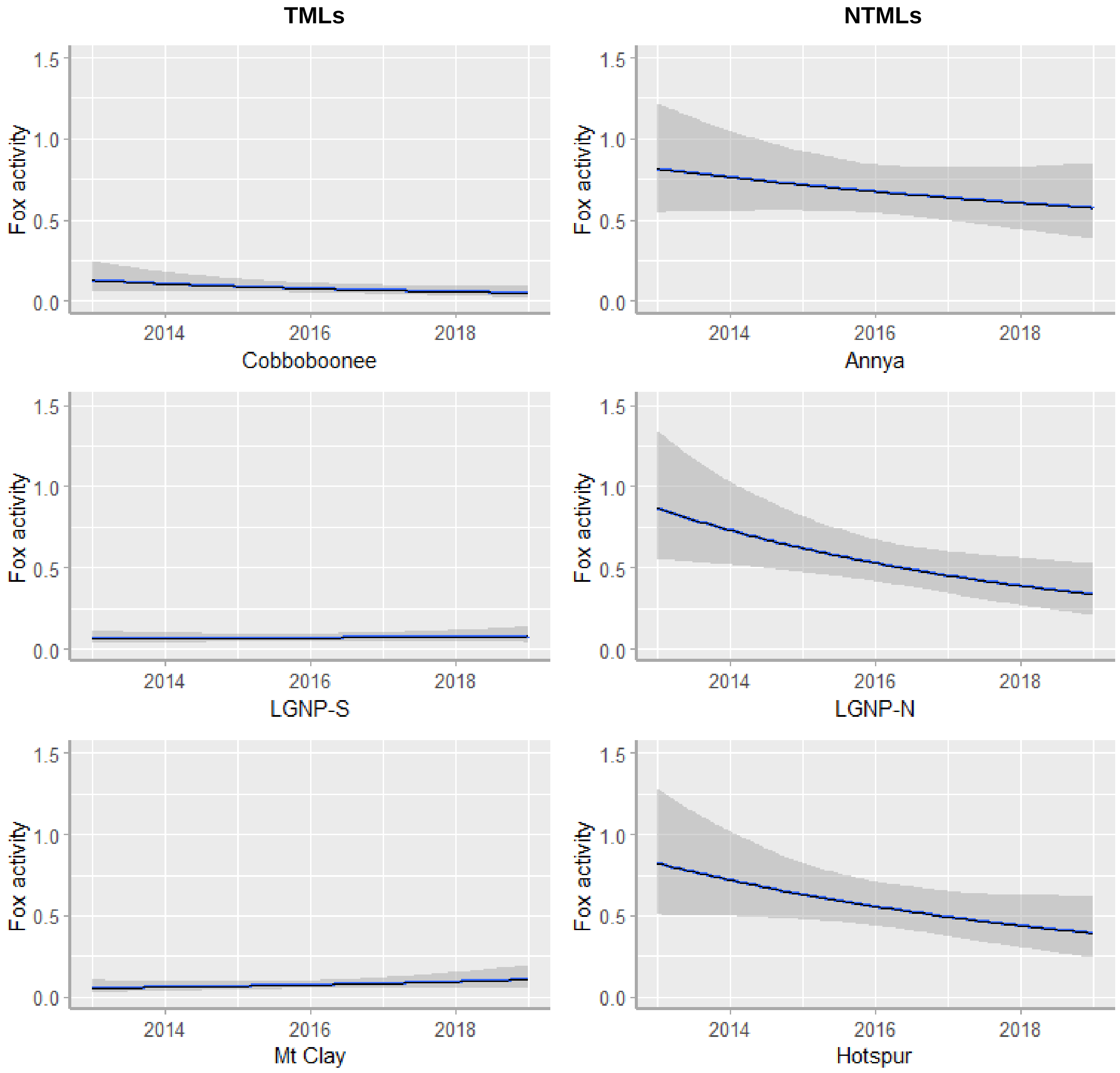

Figure 5. Fox activity at individual sites (number of images separated by >1 hour)
Treatment Monitoring Locations (TMLs) = Cobboboonee, Lower Glenelg National Park – south (LGNP-south) and Mt Clay. Non-treatment Monitoring Locations (NTMLs)= Annya, Hotspur and Lower Glenelg National Park – north (LGNP-north). Grey shading indicates the 95% credible intervals.

There was no support in the regression models for the hypothesis that feral cat activity was higher at locations treated for fox control. Between 2013 and 2019, there was no difference in feral cat activity between NTMLs ($\bar{x}$ = 0.25, SD 0.74) and TMLs ($\bar{x}$ = 0.25, SD 0.70).

There was considerable variation in feral cat activity between locations: LGNP-north (TML) and LGNP-south (NTML) had the highest levels of feral cat activity, and Annya (NTML) and Mt Clay (TML) had the lowest levels of feral cat activity (Figure 6). Feral cats showed signs of decline from 2013 to 2019 at three of the six locations, with the most substantial declines being observed at LGNP-south. Feral cat activity trended upwards at Cobboboonee and Annya.

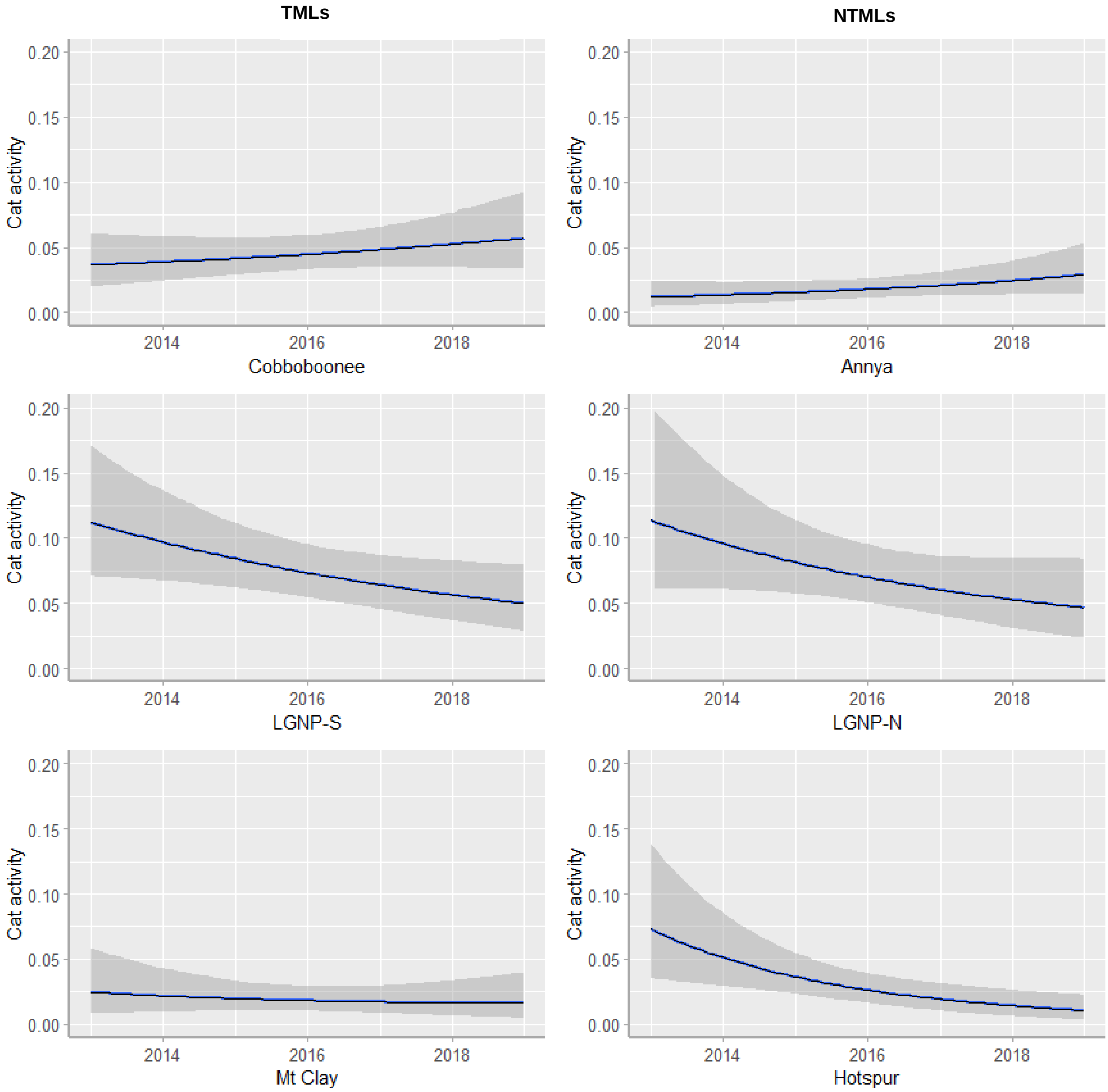

Figure 6. Feral cat activity at individual sites (number of images separated by >1 hour)
Treatment Monitoring Locations (TMLs) = Cobboboonee, Lower Glenelg National Park – south (LGNP-south) and Mt Clay. Non-treatment Monitoring Locations (NTMLs) = Annya, Hotspur and Lower Glenelg National Park – north (LGNP-north). Grey shading indicates the 95% credible intervals.

3.2 The response of selected native mammals 2005–2019

Overall, Common Brushtail Possums occupied the most sites, and their occurrence showed a clear difference between TMLs and NTMLs. Long-nosed Potoroo and Southern Brown Bandicoot occupied more sites across TMLs compared with NTMLs, but the difference was not significant. The differences in site occupancy were not uniform, and there was considerable variation between locations.

3.2.1 Common Brushtail Possum

Occupancy rate

In general, the occupancy rates of the Common Brushtail Possum were higher at TMLs (Figure 7), with 7 of the last 9 years having occupancy rates higher at TMLs.

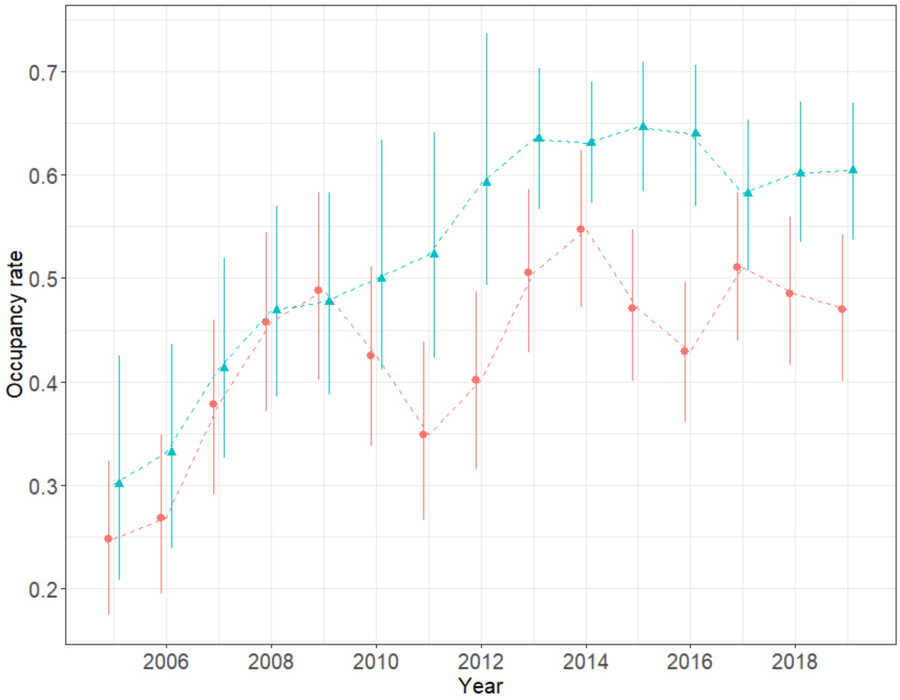

Figure 7. Occupancy rates for Common Brushtail Possum over time on TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations)

Red circles = posterior median occupancy rates at TMLs, aqua triangles = posterior median occupancy rates at NTMLs, lines represent the 95% high-density intervals.

Occupancy rates for Brush-tailed Possums varied between locations. The occupancy rate was generally higher at Cobboboonee NP, LGNP-south and LGNP-north, compared with Mt Clay and Annya, with moderate rates of occupancy at Hotspur (Figure 8).

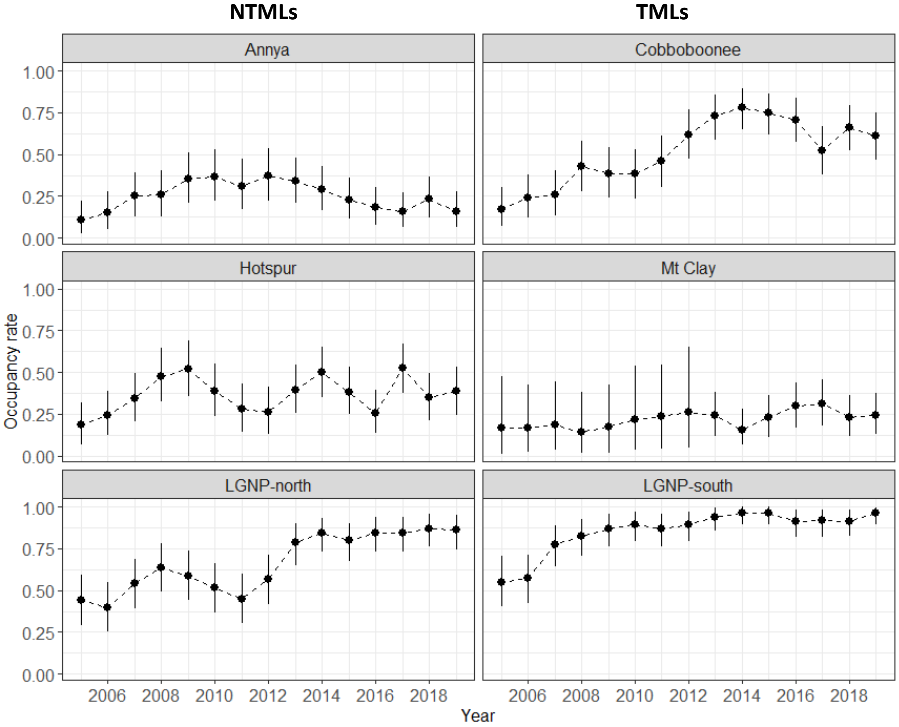

Figure 8. Occupancy rates for Common Brushtail Possum in each monitoring location over time at individual sites

The dots represent the median occupancy rates, and the lines represent the 95% high-density intervals

NTMLs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Growth rates

The mean growth rate at TMLs was 1.05 (95% CI 0.91–1.24) and did not differ from that at NTMLs (1.06, 95% CI 0.82–1.41) (Figure 9). Overall, the growth rate for the Common Brushtail Possum has slowed and tended to decrease at both TMLs and NTMLs, with no difference being found between NTMLs and TMLs. There was no trend in growth rates, and the mean difference between TMLs was 0.10 (95% CI –0.01 to 0.21).

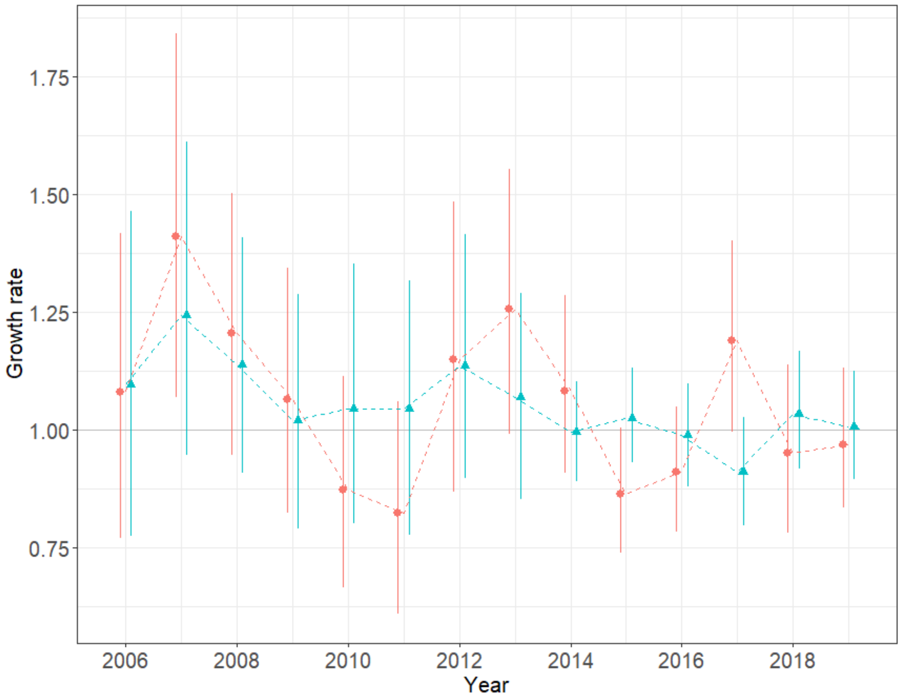

Figure 9. Growth rate for Common Brushtail Possum over time on TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations).

Red circles = median growth rates at TMLs, aqua triangles = median growth rates at NTMLs, and the lines represent the 95% high-density intervals.

There has been no substantial change in growth rate (proportional increase in occupied sites between years) at any of the site locations since baiting began in 2006 (Figure 10).

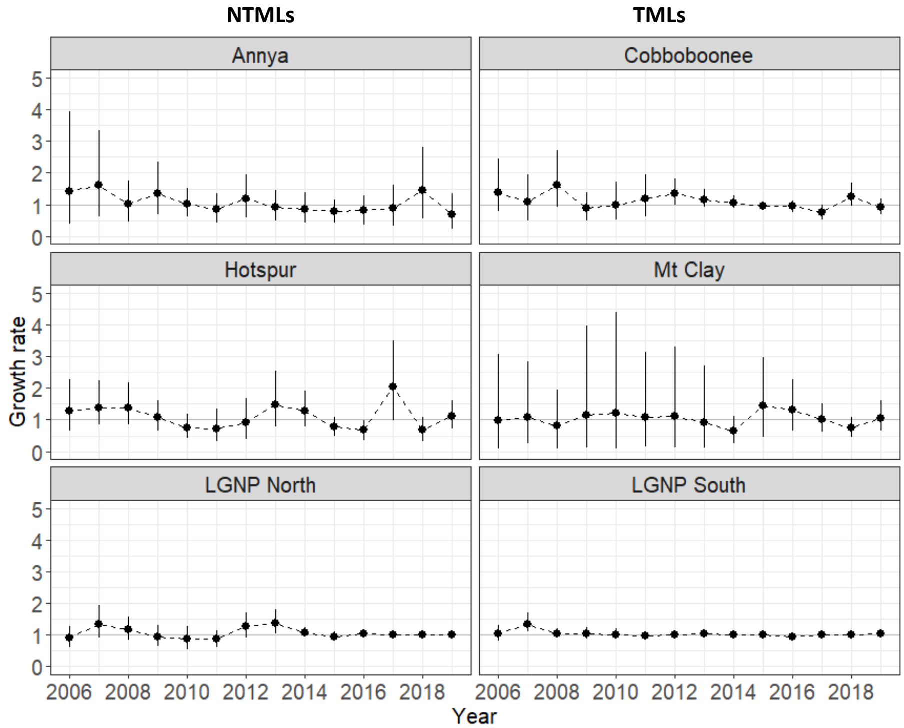

Figure 10. Growth rate (as percentage change) for Common Brushtail Possum in each monitoring location over time

The dots represent the median growth rates, and the lines represent the 95% high-density intervals.
NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Turnover rates

Overall turnover rates tended to be higher at NTMLs, with an increase in rates on both TMNLs and NTMLs from around 2012. Nearly 90% of occupied sites at NTMLs were newly occupied sites from around 2014. (Figure 11).

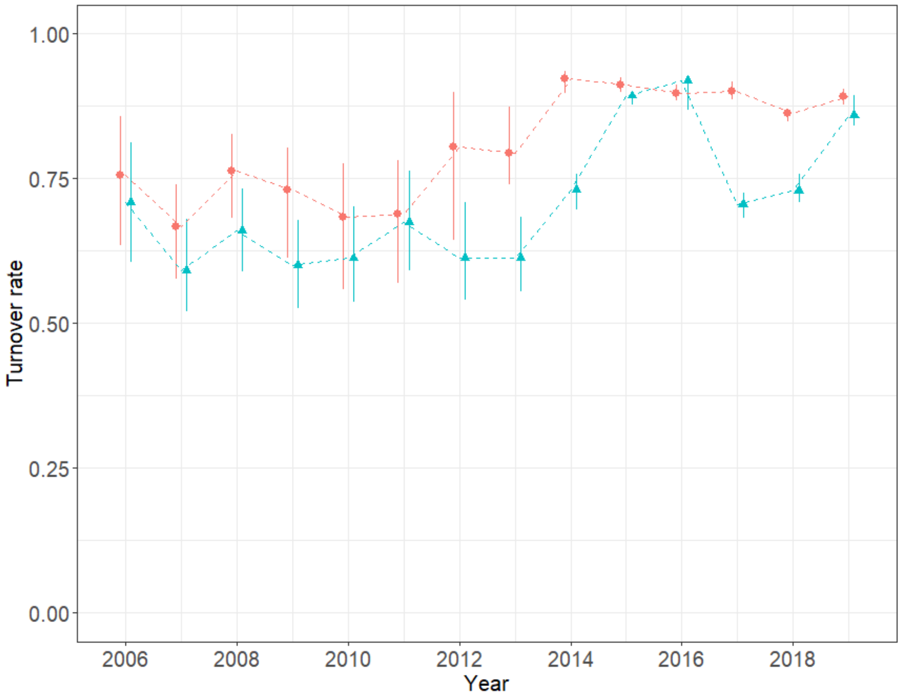

Figure 11. The turnover rates for Common Brush-tailed Possum at TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations)

Red circles = median turnover rates at TMLs, aqua triangles = median turnover rates at NTMLs, and the lines represent the 95% high-density intervals.

Turnover rates (the fraction of occupied sites that are *newly* occupied in any year) have been variable and uncertain. Average turnover at TMLs was 0.30 (95% CI 0.06–0.56) compared with NTMLs, 0.36 (95% CI 0.07–0.50). At Cobboboonee, turnover stabilised at generally low levels from 2012, and at LGNP-north turnover stabilised from around 2014. Turnover has always been low at LGNP-south (Figure 12).

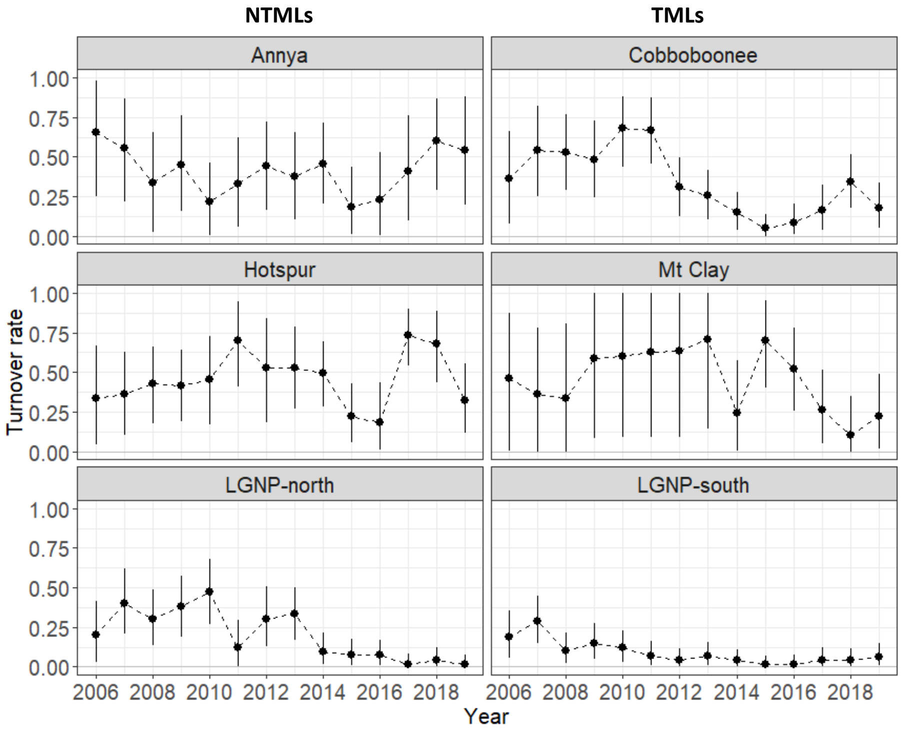

Figure 12. The turnover rate for Common Brushtail Possum in each monitoring location over time
The dots represent the median turnover rates, and the lines represent the 95% high-density intervals.
NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Detection

Detection rates were lower with cameras, but more precise, while hair-tubes had higher daily detection rates but were less precise. Daily detection rates for the Common Brushtail Possum varied between locations with both devices (Figure 13). LGNP-south had the highest detection rate with either device, and significantly more than all other locations. Mt Clay had the smallest detection rates using either device.

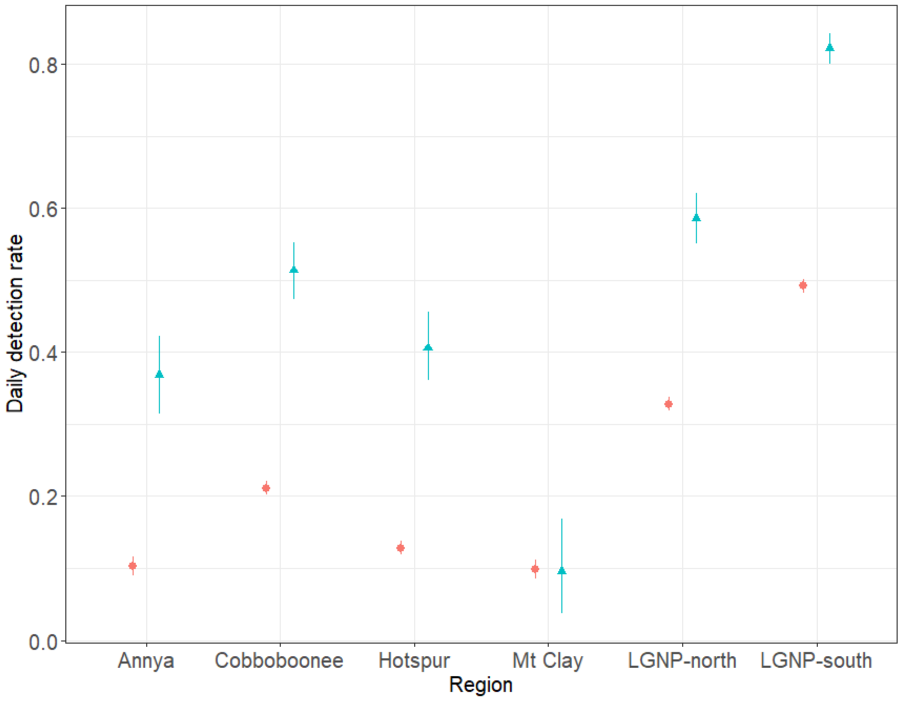

Figure 13. Detection rates for Common Brushtail Possum, derived using hair-tubes and cameras

Aqua triangles represent hair tube detections, red dots represent camera detections, and the lines represent the 95% high-density intervals.

3.2.2 Long-nosed Potoroo

Occupancy rate

Long-nosed Potoroo occupancy rates did not increase consistently, but were generally higher at TMLs, and they have slowly but steadily declined at NTMLs. This slow decline accounts for the differences observed between the TMLs and NTMLs (Figure 14).

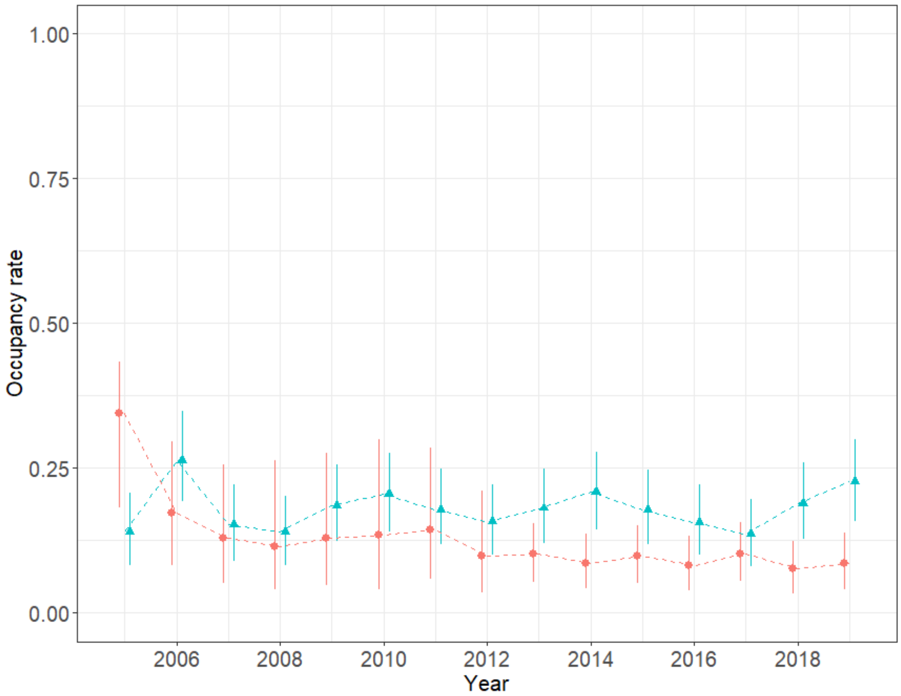

Figure 14. Occupancy rates for Long-nosed Potoroo over time on TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations).

Red circles = median occupancy rates at TMLs, aqua triangles = median occupancy rates at NTMLs, and the lines represent the 95% high-density intervals.

Occupancy rates have fluctuated more at TMLs, while at NTMLs they have generally been more constant (Figure 15).

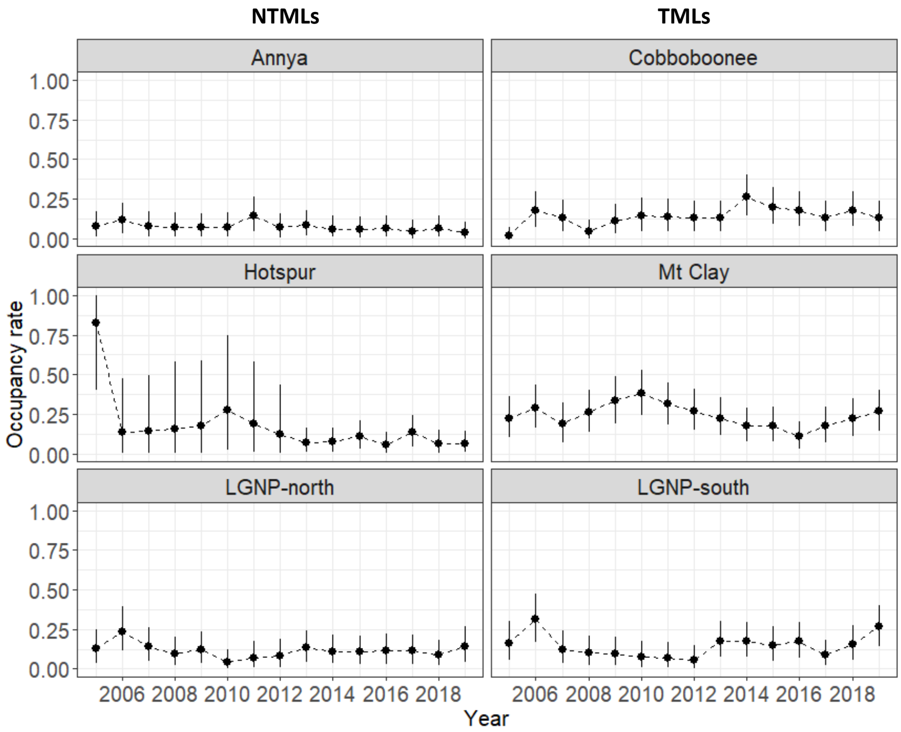

Figure 15. Occupancy rates for Long-nosed Potoroo in each monitoring location over time
The dots represent the median occupancy rates, and the lines represent the 95% high-density intervals.
NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Growth rates

Overall growth rates (the proportional increase in occupied sites between years) at TMLs were 1.08 (95% CI 0.58–1.88) and at NTMLs 0.93 (95% Cl 0.53–1.24) (Figure 16). There was no trend in growth rates, and the mean difference between TMLs and NTMLs was 0.07 (95% CI 0.02 – 0.14). Estimating growth rates is challenging when occupancy rates are low, the result is wide confidence estimates.

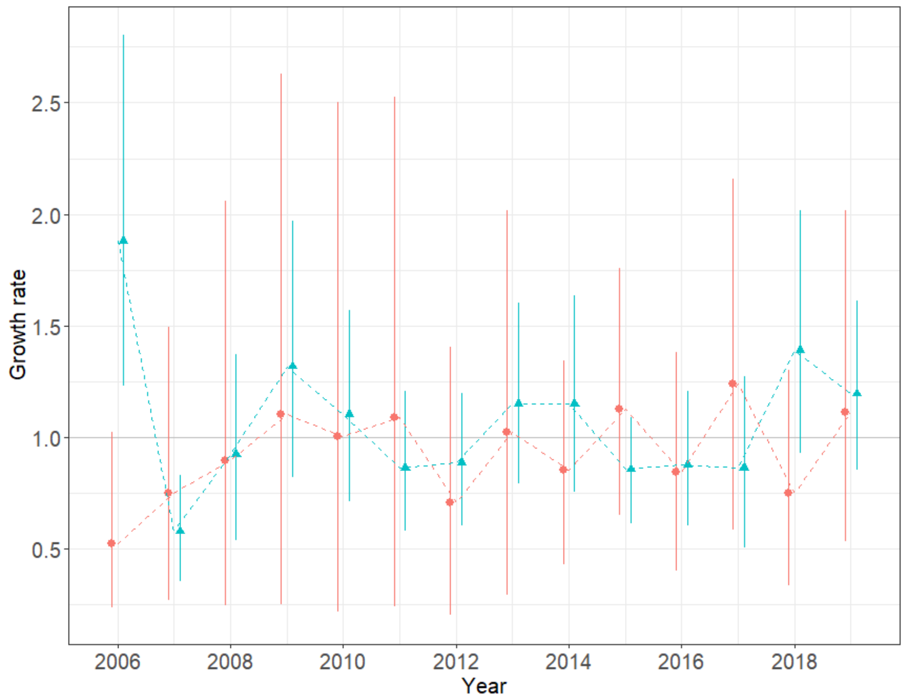

Figure 16. Growth rate for Long-nosed Potoroo over time on TMLs (Treatment Monitoring Locations) and NTMLs (Non-treatment Monitoring Locations) .

Red circles = median growth rates at TMLs, aqua triangles = median growth rates at NTMLs. The lines represent the 95% high-density intervals.

Growth rates at individual locations reflected the general similarity between TMLs and NTMLs (Figure 17). The rate at Cobboboonee in 2006 is off the scale to allow most data points to be more visible and reflects the small number of sites and low occupancy rates.

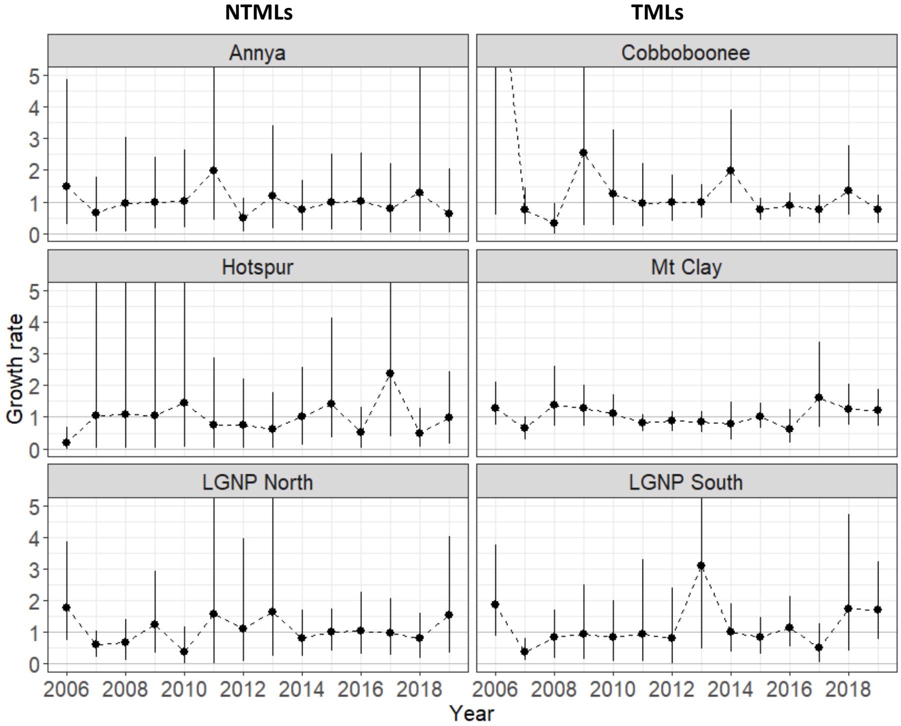

Figure 17. Growth rates for Long-nosed Potoroo in each monitoring location over time
The dots represent the median growth rates, and the lines represent the 95% high-density intervals.
NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Turnover rates

Turnover rates tended to be unstable, and generally lower at TMLs. In 2014, turnover rates increased at TMLs and concurrently decreased at NTMLs. (Figure18).

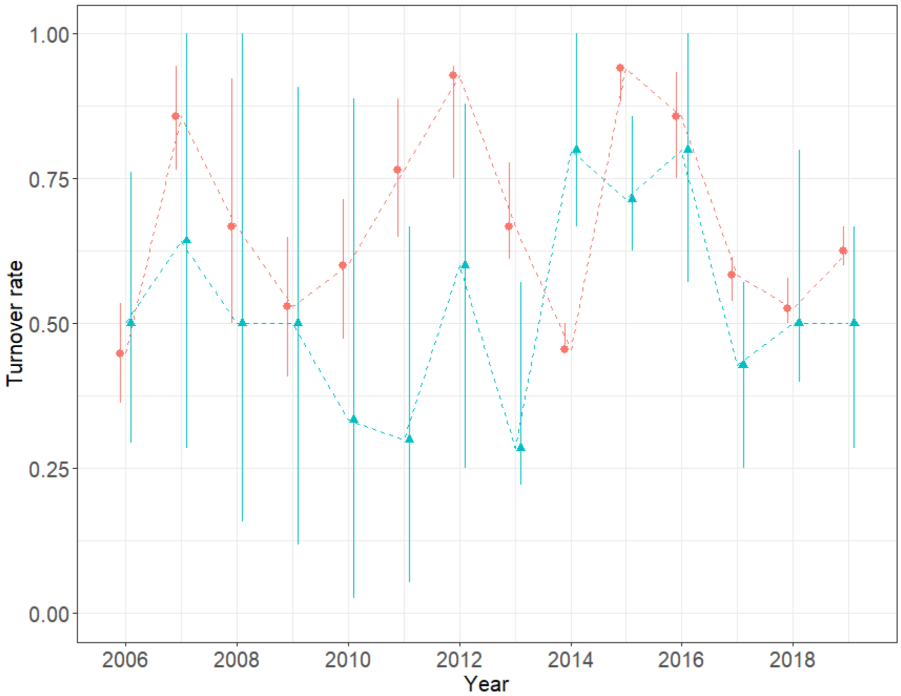

Figure 18. The turnover rates for Long-nosed Potoroos at TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations).

Red circles = median turnover rates at TMLs, aqua triangles = median turnover rates at NTMLs. The lines represent the 95% high-density intervals.

Turnover rates have generally been high but variable and uncertain at all locations (Figure 19). The exceptions are Mt Clay, which has shown generally lower turnover, and Cobboboonee where turnover has tended to be low since 2015.

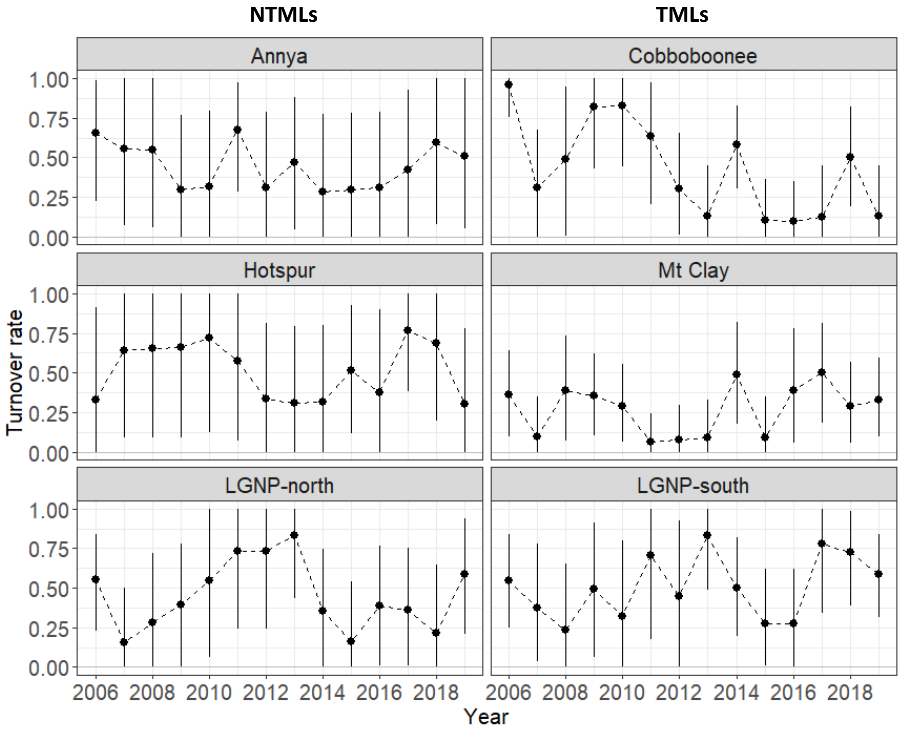

Figure 19. The turnover rates for Long-nosed Potoroo in each monitoring location over time
The dots are the median turnover rates, and the lines represent the 95% high-density intervals.
NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Detection

The hair-tube results for detection rates of Long-nosed Potoroo varied between locations and with the presence of the Common Brushtail Possum (Figure 20). There was strong evidence that LGNP-north and LGNP-south had reduced detection rates when Common Brushtail Possum were present. Most other locations had a similar result, but without enough evidence to be convincing. However, there was substantial evidence that Mt Clay had an *increased* detection rate when Common Brushtail Possum were detected. Using the camera trap data, daily detection rates for Long-nosed Potoroo varied between locations. Cobboboonee and Mt Clay had higher detection rates than the other locations.

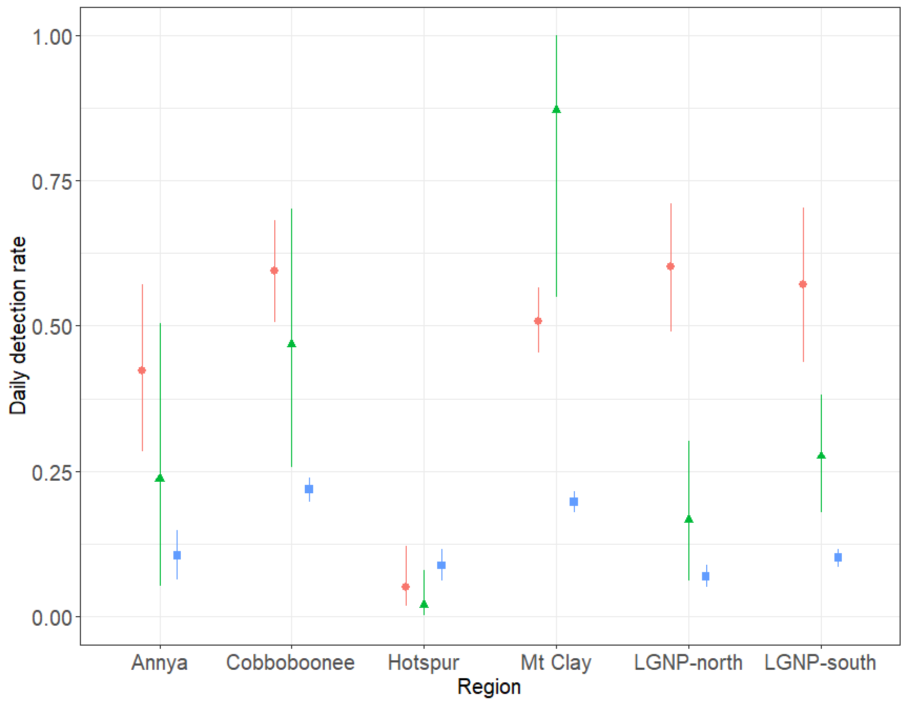

Figure 20. Daily detection rates from hair-tubes and cameras for Long-nosed Potoroo

Red dots represent hair tube data, green triangles represent hair tube detection adjusted for Common Brushtail Possum presence, and blue dots represent camera data.

3.2.3 Southern Brown Bandicoot

Occupancy rate

Southern Brown Bandicoot occupancy rates have generally been higher at TMLs, except for 2013 (Figure 21). The high degree of uncertainty in the estimates means it is not possible to state whether occupancy is higher at TMLs, statistically.

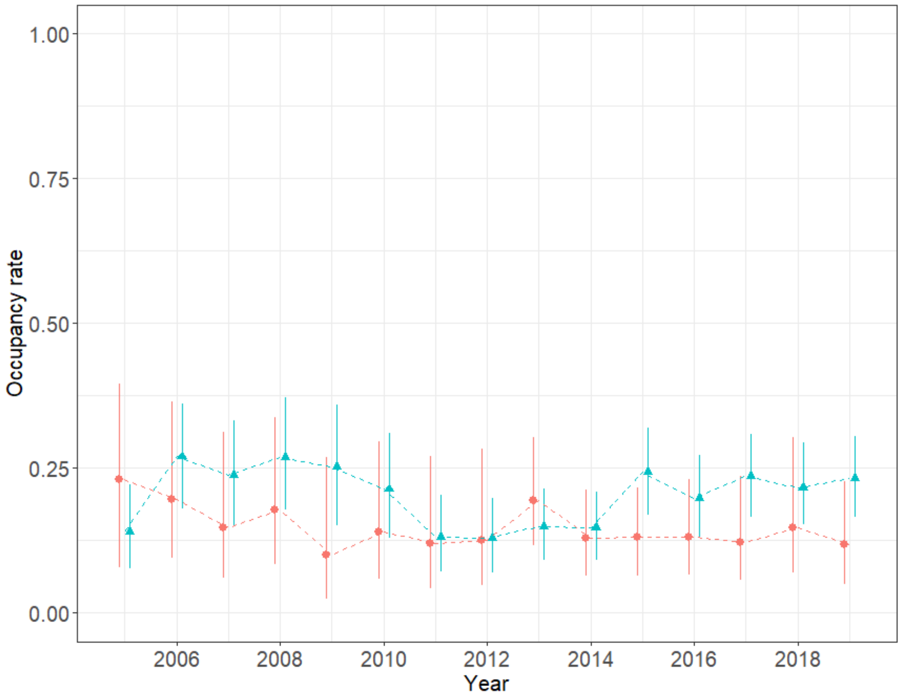

Figure 21. Occupancy rates for Southern Brown Bandicoot over time on TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations).

Red circles = median occupancy rates at TMLs, aqua triangles = median occupancy rates at NTMLs. The lines represent the 95% high-density intervals.

The was no clear pattern in the differences in occupancy rates between NTMLs and TMLs (Figure 22).

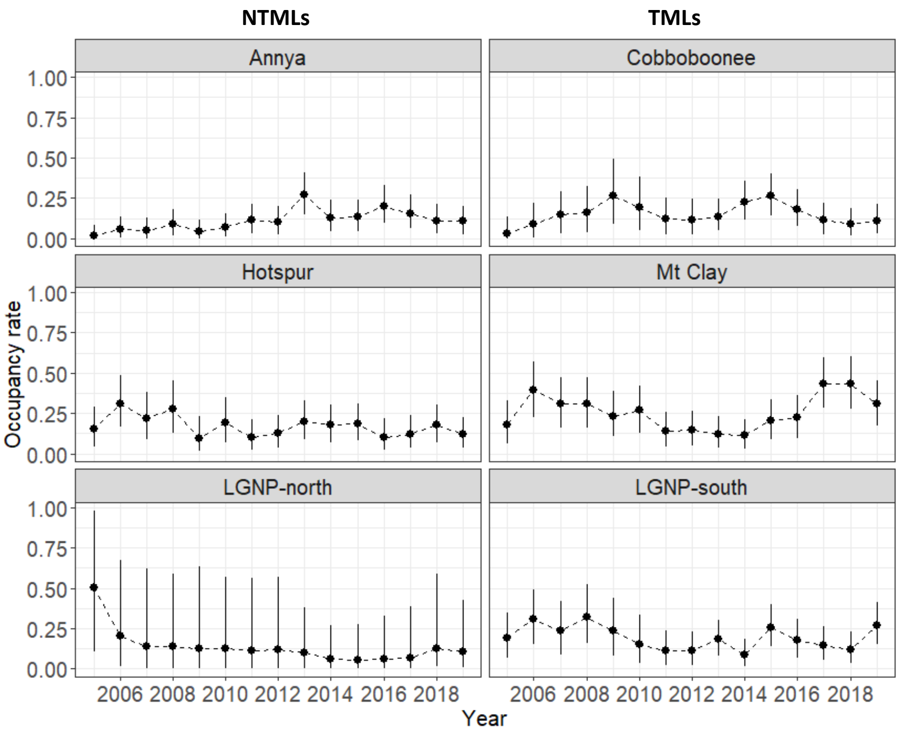

Figure 22. Occupancy rates for Southern Brown Bandicoot in each monitoring location over time
The dots represent the median occupancy rates, and the lines represent the 95% high-density intervals. NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Growth rates

Overall growth rates were similar between TMLs (1.08, 95% CI 0.61–1.91) and NTMLs (1.0, 95% CI 0.57–1.56) (Figure 23). There was no trend in growth rates with a mean difference between TMLS and NTMLs of 0.06 (95% CI –0.05–0.14).

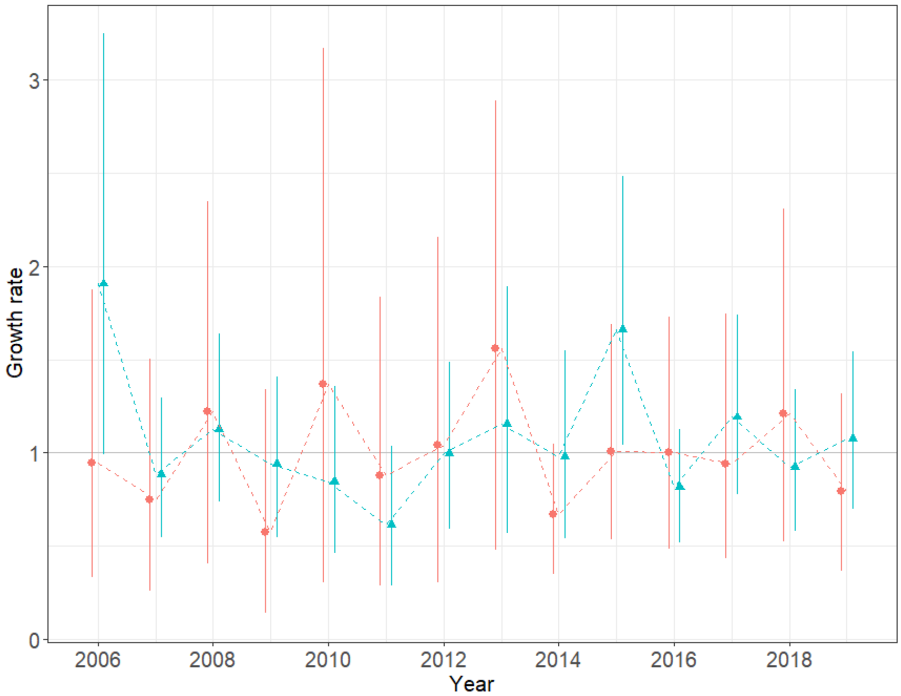

Figure 23. The growth rates for Southern Brown Bandicoot over time by TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations).

Red circles represent median growth rates at TMLs, aqua triangles represent median growth rates at NTMLs, and the lines represent the 95% high-density intervals.

Growth rates were low and variable, with no positive trend over time or differences between the TMLs or NTMLs. (Figure 24).

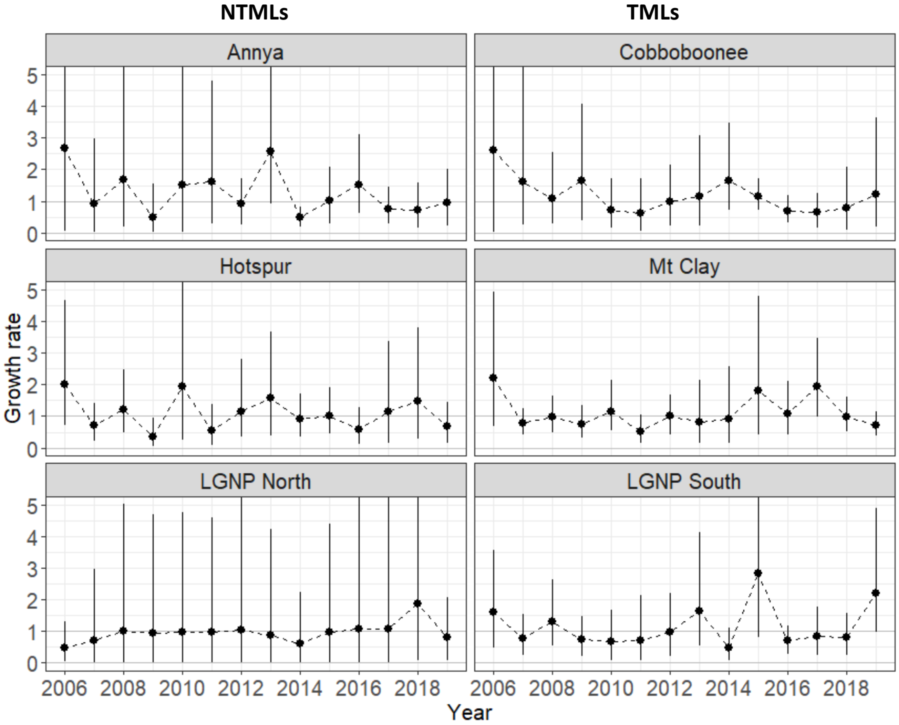

Figure 24. Growth rates for Southern Brown Bandicoot in each monitoring location over time
The dots represent the median growth rates, and the lines represent the 95% high-density intervals. NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Turnover rates

Overall, turnover rates were highly variable and uncertain, and tended to be higher at NTMLs, with the notable exception of 2014. (Figure 25).

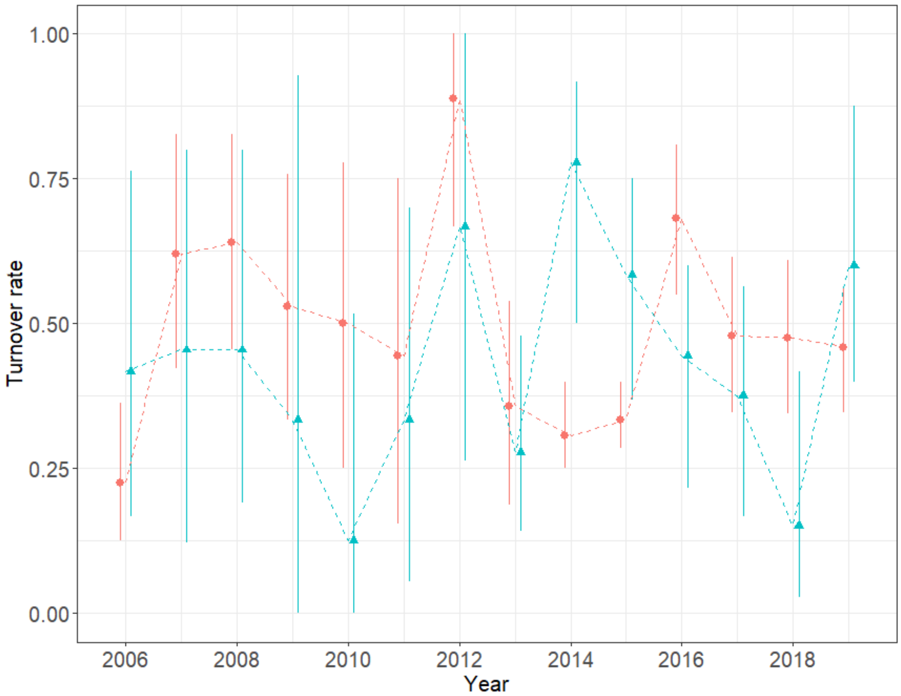

Figure 25. The turnover rates for Southern Brown Bandicoot at TMLs (Treatment Monitoring Locations) and NTMLs (Non-Treatment Monitoring Locations).

Red circles represent the median growth rates at TMLs, aqua triangles represent the posterior median estimated growth rates at NTMLs, and the lines represent the 95% high-density intervals.

Turnover rates (the fraction of sites that are newly occupied in any year) have generally been high, although variable and uncertain at all locations (Figure 26).

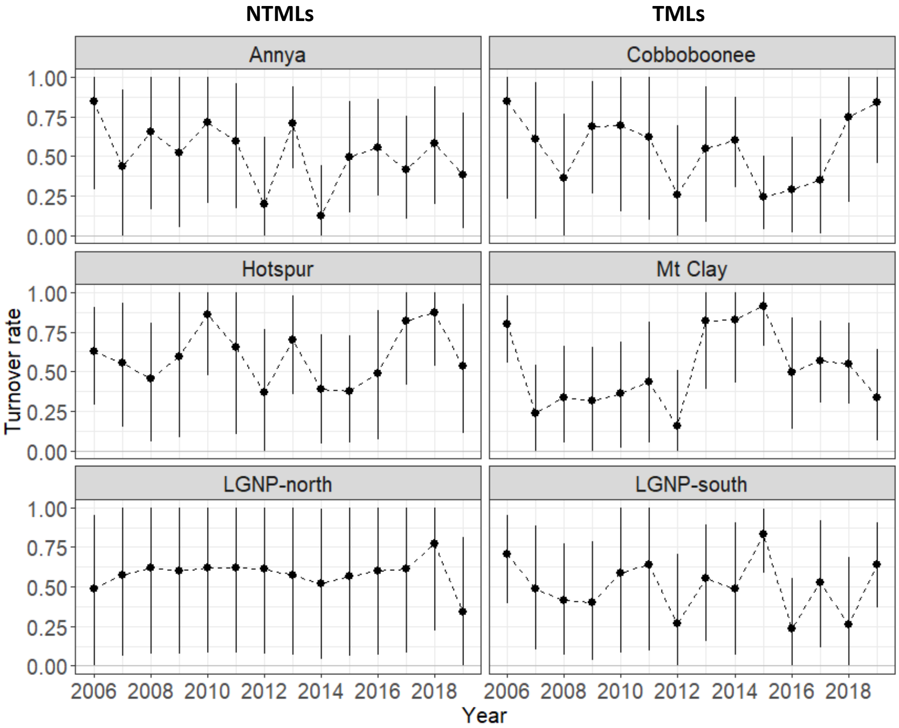

Figure 26. The turnover rates for Southern Brown Bandicoot in each monitoring location over time
The dots represent the median turnover rates, and the lines represent the 95% high-density intervals.
NTLMs = Non-treatment Monitoring Locations, TLMs = Treatment Monitoring Locations

Detection

Daily detection rates from hair-tubes for Southern Brown Bandicoot varied between some locations and depending on the presence of Common Brushtail Possum (Figure 27). There was strong evidence that Hotspur, Mt Clay, LGNP-north and LGNP-south had reduced detection rates when Common Brushtail Possum were present. Daily detection rates from camera traps for Southern Brown Bandicoot varied between locations. Annya had higher detection rates than the other locations, while LGNP-north was lower than other locations.

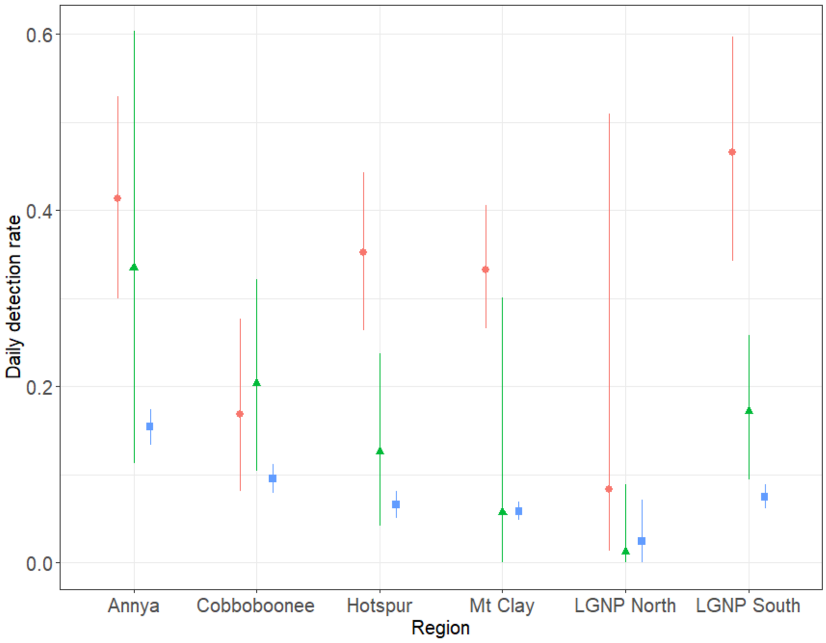

Figure 27. Daily detection rates for Southern Brown Bandicoot, based on data from hair tubes and cameras
Red dots represent hair tube data, green triangles represent hair tube detection adjusted for Common Brushtail Possum presence, and blue dots represent camera data.

4 Discussion

After 14 years of fox control undertaken by the Glenelg Ark project, which has reduced the level of fox activity significantly, there is only a small positive change in occupancy rates of Long-nosed Potoroo and Southern Brown Bandicoot. Contrary to our expectations, at TMLs we have observed no sustained positive trend in occupancy rate, generally flat growth rates, and high and variable turnover rates for bandicoots and potoroos, and a limited difference in occupancy rates between TMLs and NTMLs. It is possible that the lack of a widespread or significant response by these two species is due to them being limited to refugia (Kinnear et al. 2002; Long et al. 2005) at TMLs and that predation is still limiting at NTMLs. Alternative plausible explanations are still possible, i.e., spatial variation in habitat suitability, limited connectivity to unoccupied habitat, or other biotic interactions (other than predation) that constrain the range of locations occupied by these species.

Stoddart and Braithwaite (1979) identified a lack of predation, high longevity and (presumed) synchronous invasion of a newly created habitat was resulting in a 3-year wave-like replacement of male Southern Brown Bandicoots at the Royal Botanic Gardens Annex, Cranbourne. Increases and decreases in small mammal populations can be driven by endogenous factors (density dependence, competition for food and space, etc.) as well as exogenous factors (predation, change in habitat, etc.). Arthur et al. (2012) showed that for Southern Brown Bandicoot and Long-nosed Potoroo, population response was linked to changes in canopy following a fire, while rainfall had no detectable influence on population growth. What the underlying differences in conditions at TMLs and NTMLs might be and just how these differences might act to affect bandicoot and potoroo abundance is not known and warrants further investigation.

Common Brushtail Possums had a positive rate of increase in occupancy that was higher at TMLs, but growth rates tended to decline over time at these sites, suggesting that all suitable sites were becoming occupied, and that further expansion was limited by other factors. Turnover rates were relatively stable from 2005 to until 2013, then increased. The high rates of occupancy at LGNP-south (TML), Cobboboonee (TML) and LGNP-north (NTML) by Common Brushtail Possums may have been driven by factors other than fox predation. Geary (2017) modelled the distribution of Common Brushtail Possums across the Glenelg Ark monitoring locations over the same period against a range of environmental variables and found that climate, proximity to farmland, and topography were more influential on their distribution than predator control.

Similar responses by native species considered to be at immediate risk from fox predation have been reported elsewhere. When reviewing a 15-year fox control program at Booderee National Park, New South Wales, Lindenmayer et al. (2018) reported an increase in Common Brushtail Possums and macropods, and an initial increase in abundance of Long-nosed Bandicoot (*Perameles nasuta*) that was followed by a decline. Wayne et al. (2017) reported a decline in Woylie (*Bettongia penicillata*) at sites in south-west Western Australia after the implementation of intensive fox control. In that study, predation by feral cats was implicated in the decline; however, Lindenmayer et al. (2018) reported a very low number of feral cats at Booderee National Park and were unable to explain the drivers of the observed declines.

Stable site occupancy rates observed at NTMLs could reflect a stable predator–prey relationship (Sinclair 1996). This could come about if bandicoots and potoroos are the alternative prey of foxes that primarily live on other common and relatively abundant species. For example, the Common Ringtail Possum (*Pseudocheirus peregrinus*) is an important and stable component of fox diet and is common at most Glenelg Ark sites (Robley et al. 2016). It could be assumed that at NTMLs the constant high-density fox population feeds opportunistically on bandicoots and potoroos. The small populations of bandicoots and potoroos at these sites are unable to increase fast enough to build up numbers that are greater than can be removed by the resident foxes. The result is stable numbers of bandicoots and potoroos from year to year, as seen at each of the NTMLs. Alternatively, these species may have occupied the portion of the habitat that is highly suitable and are not expanding into non-suitable habitat.

In general, across all locations, populations of Southern Brown Bandicoots and Long-nosed Potoroos appear to be small and fragmented. This could potentially expose these populations to the effects of small population sizes (e.g. genetic bottlenecks, or Allee effects), compounding the risk of local extinction. Further investigation is needed to define what actions, if any, can be taken to improve the distribution and long-term viability of these two species across the Glenelg Ark project area.

There are five plausible explanations for the general lack of significant change in the occupancy of these species at the TMLs in the Glenelg Ark area.

1. The current sampling methodology is insensitive to the scale of change in occupancy, or occupancy is an inferior metric for abundance; thus, the result is an underestimate of the scale of change that has occurred across the landscape.
2. Fox densities are still too high and limit the population growth of small fragmented populations of Southern Brown Bandicoot and Long-nosed Potoroo.
3. Feral cats have replaced foxes as the main predator, with potentially similar dynamics to those of foxes.
4. Landscape disturbance, e.g. the long-term effects of frequent burning (both planned and natural), has resulted in a highly fragmented landscape. Populations are now restricted to isolated refugia, and species are unable to bridge the gaps between them.
5. Some combination of the above.

Several potential effects flow from these possible explanations.

Some redesigning of the sampling method is required to address the potential sampling issue outlined above. The combined cumulative probability of detection per site in 2019 for both Southern Brown Bandicoot and Long-nosed Potoroo was very low (P = 0.16 and 0.24, respectively), meaning that there was only a 16% chance of detecting a Southern Brown Bandicoot at a site in 2019 if one was present. To increase the probability of species being detected, there are two possible alternatives: (i) increase the number of sites surveyed or (ii) increase the duration of the surveys. MacKenzie and Royal (2005) provide an overview of designing occupancy studies and recommend that, for rare species, it is more efficient to sample more sites less intensively. This is because species need to be detected to calculate a robust estimate of occupancy. A species can only be detected at a site where it is present; hence, when occupancy is low, increasing the number of sites surveyed is likely to increase the number of sites where the species is detected.

Both the activity index and spatial population models presented in Robley et al. (2018) indicated that abundances of foxes are significantly lower in areas with fox control. The mean density of foxes predicted by those models ranged between 0.2 and 0.7 foxes/km^2 after 9 years of baiting. This would roughly equate to 180–450 remaining foxes being resident within the operations area of Glenelg Ark. Given these estimates, the fox control operation has been successful at reducing foxes to low numbers.

Foxes may have not been reduced below a threshold that allows bandicoots and potoroos to escape limitation. If this is the case, then reducing foxes further should allow for an increase in occupied sites. Model predictions (Robley et al. 2017) suggest that a decrease in bait spacing to 500 m, with continued replacement at fortnightly intervals, could further reduce fox density. These models could be extended to include fox control on private land, under various plausible scenarios, e.g. to create buffers around public land blocks, to examine the potential efficacy of this strategy in further reducing fox densities. Regardless of the strategy implemented (i.e., increase sampling effort or further reduce foxes), measuring the outcome (both in terms of any further reduction in foxes and response in native species) requires additional effort.

Within the Glenelg Ark operations area, the sustained reductions in fox populations may have resulted in increased activity (and possibly abundance) of feral cats. Although the feral cat activity index was not significantly different between TMLs and NTMLs, the point estimates suggest a higher level of activity at TMLs. Robley et al. (2010) showed that the number of sites occupied by feral cats was higher at LGNP-south (ψ = 0.69 ± 0.10 SE) compared with the NTML of LGNP-north (ψ = 0.050 ± 0.13 SE). Feral cat density has been estimated to be inversely related to fox activity, based on data from Cobboboonee, Mt Clay, Annya and Hotspur (Mathew Rees, pers. comm.). Several studies elsewhere have also described increases in feral cat abundance following reductions in fox numbers (Algar and Smith 1998; Catling and Reid 2003). A similar effect has been described following local declines in Dingo (*Canis lupus dingo*) abundance in Queensland (Pettigrew 1993). Catling and Burt (1995) also reported that the abundance of feral cats was negatively correlated with both foxes and Dingoes at a site in New South Wales. Read and Bowen (2001) did not manipulate predator populations but reported that feral cat abundance peaked when fox numbers were low and when rabbit numbers were relatively high. There is a critical need for a better understanding of how feral cats respond to fox control operations in mesic habitats in south-eastern Australia.

The recent declaration of feral cats as a pest species in Victoria and the registration of Curiosity® feral cat bait provides the opportunity to explore the integration of fox and feral cat control at some locations. A possible strategy for landscape-scale feral cat control at Glenelg Ark was outlined in Robley et al. (2018). This included fox and feral cat control at two existing TMLs (Cobboboonee and Mt Clay), and only fox control at one (LNGP-south), with no changes to the NTMLs.

Robley et al. (2018) also outlined a range of projects that are currently being undertaken by the University of Melbourne investigating aspects of the interaction between fire, predation and native species. One project, due for completion in 2022, is investigating whether fox control affects native mammal resilience to planned burning events. This project compares recovery rates of native mammals following planned burn operations in locations with and without fox control. This project builds on previous investigations at Glenelg Ark, which found significant declines in floristic composition and diversity, habitat structure, and mammal occurrence, and shifts in the diet of foxes following planned burn operations (Robley et al. 2016). A second project (due for completion in 2021) is investigating the development of a species distribution model for Southern Brown Bandicoot in the Glenelg region, and uses spatially explicit metapopulation modelling to explore the potential effects of fire and predator management on this species. A third project (due for completion in 2022) is developing a rapid genomic test to estimate fox density from DNA extracted from fox scats. Robust fox density estimates are needed for evaluation of fox control programs and the development of efficient and effective management approaches.

The Glenelg Ark monitoring program has focused on changes in three medium-sized mammal species in response to a reduction in fox abundance across the landscape. Other species that are present in the Glenelg Ark area, such as the Heath Mouse (*Pseudomys shortridgei*), may also respond to fox control. The Heath Mouse is a small endemic rodent restricted to heaths and heathy woodlands in southern Australia (Menkhorst 1995). A substantial part of the Heath Mouse distribution in Victoria occurs within the Glenelg Ark operations area. The population responses of the Heath Mouse are currently not being monitored within Glenelg Ark, in part because there has been no standard survey protocol. A protocol is now available (R. Hill, DELWP, pers. comm.) and should be implemented to assess the relative status of this species across TMLs and NTMLs. Another native species that should respond positively to effective fox control is the Common Ringtail Possum. It might be expected that owls such as the Australian Masked Owl (*Tyto novaehollandiae*) and the Powerful Owl (*Ninox strenua*) might also respond positively to effective fox control as a result of increases in native prey such as possums.

The Glenelg Ark monitoring program has provided information to DELWP and Parks Victoria land managers and policy groups, highlighting the complexity of predator–prey responses to fox control. It has adopted new approaches to monitoring and is providing insights into other factors that may contribute to the long-term sustainability of the target species and other components of the ecosystem. Glenelg Ark is in a strong position to adapt its focus in the light of these insights. In addition, the project provides a framework and infrastructure through which other management-focused research questions can be addressed (e.g. the response of other small mammals, and the impact of possible unintended consequences, such as changes in the feral cat population). Currently, investigations into these issues are happening in a largely *ad hoc* fashion. A refocus of the direction and purpose of the project, including the development of a project-specific strategic plan, within an adaptive management framework, would provide a clear avenue for prioritisation and future funding.

4.1 Recommendations

To address the above issues (effectiveness of control and monitoring program, drivers for lack of clear species response etc.) and improve management outcomes, we suggest the following actions. These actions can be undertaken as stand-alone activities or in various combinations, to explore the issues more fully and to fill knowledge gaps, thus enabling improved management.

Table 2: Recommendations for Glenelg Ark

Item	Recommendation	Detail
Strategic plan	That the Glenelg Ark Project and the WPPL Program develop a project-specific strategic plan Timing: before June 2022 Responsibility: Project Officer, Program and project partners	In the absence of a strategic plan, monitoring and research have developed in an ad hoc fashion. There is a need to provide longer-term direction to the project that articulates the expectations for the introduced and native species outcomes, and the trigger points for changes to the operations and monitoring programs.
The plan should consider (but not be restricted to) the following strategies.		
Strategy to further reduce fox density	Increase the density of baits at TMLs, and robustly assess the outcome in terms of the fox, feral cat and native species response. Timing: before June 2022 Responsibility: Project Officer	Modelled predictions of changes in fox density in response to an increase in bait density undertaken in 2017–2018 show a further decline in foxes is likely. To make informed management and investment decisions, any outcomes from changes to management need to be robustly assessed.
Strategy to improve understanding of native species response	Increase the number of camera sites to improve detection rates for Southern Brown Bandicoot and Long-nosed Potoroo. Timing: before June 2022 Responsibility: Project Officer and ARI	Low detection rates of both species may reflect an actual low abundance of these species, or the low occupancy rates may be an artefact of the sampling effort. Deploying more cameras within a location may resolve this dichotomy, by either increasing detection rates and increasing accuracy of occupancy estimates or decreasing the level of uncertainty (i.e. determining that occupancy is indeed very low and that other management actions need to be considered). This would also allow examination of reasons why some sites are occupied within a block and others are not.
	Model the patterns in the changes in occupancy from 2005 to 2018 to investigate factors that may influence the spread of recovery. Timing: before June 2022 Responsibility: ARI, Project Officer and Project partners	Quantifying and understanding the factors that influence the rate of recovery and spatial spread of threatened species in relation to management intervention is a vital issue in conservation biology. Recovery at a landscape scale may depend on characteristics such as the preferred direction of spread and the distance between 'suitable' locations. Studying these characteristics is essential for making appropriate management decisions. We propose using a hierarchical model that takes spatial structure, the distance between sites, and the possibility of directional spread into account. This information improves our understanding of the drivers and the limitations of species recovery following fox control.

	Develop Southern Brown Bandicoot and Long-nosed Potoroo habitat suitability surfaces for the Glenelg Ark project area (using presence/absence data) to aid in setting species response targets and to identify potential new control and or monitoring sites. Timing: before June 2022 Responsibility: ARI, University of Melbourne and Project Officer	Use in conjunction with the first recommendation. The limited responses of the Southern Brown Bandicoot and Long-nosed Potoroo may be due to a lack of suitable habitat for these species. We propose that the site occupancy information be used to explore this possibility. Remotely sensed habitat data (e.g. vegetation type, topography, fire history, distance to drainage lines, distance to forest edge, and landscape productivity data) could be combined with detection and non-detection data to develop a species habitat suitability surface. This information will be useful in determining the expected increase in species occurrence and will also identify potential new locations for monitoring and/or fox control actions.
	Using expert elicitation, describe the benefits of fox control for the Heath Mouse (*Pseudomys shortridgei*); select sites for targeted monitoring of TMLs and NTMLs. Timing: before June 2022 Responsibility: ARI and Project Officer	Current monitoring sites were placed in locations based on the best understanding of 'suitable' habitat for the three main target species at the time. Heath Mouse species distribution models have been developed, and these could be used to select sites more likely to have the Heath Mouse present. If fox control has delivered a positive benefit, there should be a detectable difference in abundance between TMLs and NTMLs.
Strategy to integrate feral cat and fox control	Implement targeted feral cat control at selected locations with known populations of Southern Brown Bandicoot and Long-nosed Potoroo. Timing: before 2022 sampling year Responsibility: Project Officer/ARI	Feral cats may limit the response of Southern Brown Bandicoot and Long-nosed Potoroo to fox control. With the recent declaration of feral cats as a pest species, it is now possible to implement targeted control at specific locations with the currently available tools (cage trapping, shooting). Based on the results of the recommended actions listed above, model species habitat and distribution and select areas for targeted control action.
	Undertake feasibility analysis, including the cost for broadscale baiting of feral cats within the Glenelg Ark operational area. Timing: before June 2022 sampling year Responsibility: Project Officer/ARI	Planning for when, where and how to use Curiosity® feral cat bait should commence soon to ensure timely implementation can occur once regulatory and policy approvals and community support are in place.
	Develop a community education and engagement program for integrated predator control. Timing: implement before June 2022 Responsibility: Project Officer/Regional Communications team	The Glenelg Ark project has experienced some negative interactions with a small section of the community around the use of 1080 baits. A communications and engagement strategy would assist in developing the needed community acceptance and licence to undertake integrated predator control.
Explore alternative survey methods for foxes and feral cats	Assess the feasibility and cost of genotyping DNA from fox scats collected using scat-detector dogs or other tools. Timing: before June 2022 sampling year Responsibility: Project Officer	The University of Melbourne project developing a rapid genomic test of DNA extracted from fox scats is due to be completed in 2021. Building on the outcomes of that project, develop and cost a proposal to implement this approach across the remaining Glenelg Ark areas. Develop a monitoring program using this approach.

	Assess the feasibility and cost of genotyping DNA from hair samples collected using hair snare traps for feral cats. Timing: before June 2022 sampling year Responsibility: Project Officer	Genotyping DNA from hair samples has been used successfully to enumerate feral cat populations. A similar approach could be used in Glenelg Ark to assess differences between baited and comparable unbaited areas. However, attracting cats to hair snare traps requires an effective lure. Undertake trials to assess lure types and their relative effectiveness at different times of the year. Also, assess the quality and feasibility of this approach.
Scientific support	Develop service agreement for the continued scientific support and advice concerning the ongoing implementation and development of Glenelg Ark. Timing: current agreement to June 2022 Responsibility: Project Officer	Evaluation and interpretation of the monitoring data, development of new projects addressing emerging issues, and general guidance from the scientific community have been instrumental in the success of the program.
Filling specific knowledge gaps	Develop and support a set of potential student projects to fill identified knowledge gaps. Timing: before June 2021 Responsibility: Project Officer/ARI	The current monitoring program does not assess changes in small native mammals [e.g. Heath Mouse and White-footed Dunnart (*Sminthopsis leucopus*)] or unintended consequences (e.g. the interactions between small native mammals, fox control, feral cat control and fire). A series of student projects could fill these knowledge gaps, taking advantage of the infrastructure that Glenelg Ark provides. Where these might already be occurring, continue to provide logistical and in-kind support. Look for opportunities to provide financial support.

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Appendix

Appendix 1. Ecological Vegetation Classes within each treatment and non-treatment location, and the number of cameras allocated to each location

Monitoring area	Ecological Vegetation Class	Area (ha)	%	No. of cameras
Mt Clay State Forest (treatment)	Lowland Forest	1950	44	18
	Heathy Woodland/Damp Heathy Woodland/Damp Heathland Mosaic	1597	35	14
	Herb-rich Foothill Forest	847	20	8
Hotspur State Forest (non-treatment)	Lowland Forest	3097	51	20
	Heathy Woodland	2235	37	15
	Wet Heathland	493	11	4
Cobboboonee National Park (treatment)	Lowland Forest	7557	84	34
	Wet Heathland/Heathy Woodland Mosaic	1035	15	6
Annya State Forest (non-treatment)	Lowland Forest	5704	70	32
	Damp Sands Herb-rich Woodland	1106	18	7
LGNP-south (treatment)	Damp Sands Herb-rich Woodland/Heathy Woodland Mosaic	2855	34	14
	Heathy Woodland/Limestone Woodland Mosaic	2855	34	14
	Damp Sands Herb-rich Woodland	1319	17	7
	Damp Sands Herb-rich Woodland/Heathy Woodland/Sand Heathland Mosaic	972	14	6

LGNP-north (non-treatment)	Wet Heathland/Heathy Woodland Mosaic	2041	45	18
	Damp Sands Herb-rich Woodland	2021	44	18
	Damp Sands Herb-rich Woodland/Heathy Woodland Mosaic	417	10	4

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