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October 2018

Arthur Rylah Institute for Environmental Research,
Department of Environment, Land, Water and Planning

Technical Report Series No. 295

Arthur Rylah Institute for environmental research

VICTORIA State Government | Environment, Land, Water and Planning

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Report produced by: Arthur Rylah Institute for Environmental Research
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Citation: Robley, A., Moloney, P. and Pitts, D. (2018). *Glenelg Ark: benefits to biodiversity from long-term fox control, 2005–2017.* Arthur Rylah Institute for Environmental Research Technical Report Series No. 295. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Front cover photo: a) Red Fox with native prey. b) Feral Cat inspecting lure. c) 1080 baiting sign at entrance to Glenelg Ark. d) Monitoring native species' response. e) Laying baits for fox control. f) Southern Brown Bandicoot. g) Long-nosed Potoroo (photographer: DEWLP).

Printed by (Print Room, Preston)
Edited by Organic Editing

ISSN 1835-3827 (print)
ISSN 1835-3835 (pdf))
ISBN 978-1-76077-308-3 (pdf/online/MS word)

Accessibility

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Acknowledgements

Data analysis and reporting was funded by the Weeds and Pests on Public Land Initiative of the Department of Environment, Land, Water and Planning (DELWP), through the Glenelg Ark project and Parks Victoria. Wesley Burns (DELWP) provided valuable support to the project. Members of the Glenelg Ark Working Group (Richard Hill and Bernadette Hoare, among others) also provided guidance and input throughout.

The individual, spatially explicit fox population model (Foxnet) used to predict differences in fox density was developed and provided by Bronwyn Hradsky (University of Melbourne). Support in customising the model for Glenelg Ark was provided by Bronwyn and is greatly appreciated. Members of the works crew at the Heywood and Dartmoor Depot undertook invaluable project support activities, including baiting and camera set-up (Allan Duffield, Dave Grassi, Chris Hatfield and Tom McKinnon), and baiting (Ray Albert, Michael Bowd, Dwayne Hauser, Tim Hiscock, Simon Donald and Kenny Scott). Camera trapping and other field activities were performed under the research permit number 1007449 and AEC permit number AEC 15-008.

Lindy Lumsden provided comments that improved this report.

Summary

Context:

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. 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*).

This report updates the previous 2016 monitoring and evaluation report (Robley et al. 2017) by adding new data on the outcome of the fox control operation and the response of targeted native species from 2017. It also incorporates fox population modelling to investigate the likely density of foxes under the current and possible future management strategies. This report also contains recommendations for future management options and suggests areas of further research.

Aims:

This report updates the long-term predator and native mammals' response dataset and explores fox population model predictions of fox density under various management options. We sought to monitor the success of the project and, by providing information to land managers and policy groups, to inform decision-making regarding future directions.

Methods:

Differences between the level of fox activity (i.e., the number of images per camera site separated by 24 hrs) at locations with and without fox control [i.e. treatment monitoring locations (TMLs) and non-treatment monitoring locations (NTMLs)] were assessed based on the number of independent images captured on camera traps from 2013 to 2017. Differences in fox density between TMLs and NTMLs were predicted using individually based spatially explicit population models (Foxnet). The predicted fox density to be achieved from increasing the bait density from the current 1000-m spacing to 500-m spacing at TMLs was modelled using Foxnet and compared with the predicted fox density under the current baiting strategy.

The response of the three native mammal species to the reduction in foxes was examined using detection data from a total of 240 camera traps from three TMLs and three NTMLs. Analyses of the changes in native species were undertaken using multiseason occupancy models.

Results:

The number of sites occupied by Southern Brown Bandicoots increased by 67% at Mt Clay between 2016 and 2017. Long-nosed Potoroos occupied 27% more sites at locations with fox control compared with at locations with no fox control. Since 2012, Common Brushtail Possums have occupied more sites at locations with fox control. Overall, all three species occupy more sites where foxes have been controlled.

Fox activity (based on the number of independent images captured per day) was 86% lower on sites with fox control compared with on sites with no fox control. There was no strong evidence that feral Cats (*Felis catus*) were more active at locations with fox control.

Foxnet model outcomes supported the observation (based on the activity index) that fox activity was lower on treated sites (the average predicted density was 0.3/km^2, whereas on non-treatment sites it was 1.8/km^2).

Decreasing the spacing between bait stations from 1000 m to 500 m and maintaining a fortnightly bait replacement schedule decreased predicted fox density by 41% across the three TMLs compared with estimates under the current strategy (1000-m spacing and fortnightly replacement).

Conclusions and implications:

Changes in native species since 2005 have been mixed. In general, Common Brushtail Possum and Long-nosed Potoroo occupied more sites at locations with fox control. It is likely that Southern Brown Bandicoot occupied more sites at locations with fox control; however, due to the low detection rates at Lower Glenelg National Park (LGNP)-north, the model uncertainty in the number of occupied sites was high, resulting in a point estimate that was approximately in the middle of a plausible range with wide confidence limits.

To decrease the amount of uncertainty in the estimate of the number of sites occupied by Southern Brown Bandicoot in LGNP-north, we suggest the following approach. We propose running cameras at LGNP-north longer (time to be estimated) and using the improved location-specific detection rates in the 2018 analysis. Increasing the length of time over which cameras are deployed at LGNP-north will allow more time for the detection location specific detection rates to increase. This would increase the certainty in the model predictions. Altering the current baiting method by reducing the spacing of bait stations is unlikely to decrease fox density significantly from what is currently being achieved. Future investigations will explore the option of increasing the area being treated by expanding the baiting program into private land surrounding the currently treated locations, creating a buffer, and/or by treating currently untreated locations.

Activity level is a poor surrogate measure of abundance and density. Improving the estimates of fox and feral Cat response to management actions using more robust and direct measures would allow managers to make more informed decisions about the effectiveness of the current and alternative management approaches.

The following recommendations are made for improvement of the outcomes of Glenelg Ark.

Item	Recommendation	Detail
Native species' response	Increase the duration of camera surveys to improve detection rates for Southern Brown Bandicoot at LGNP-north.	Low detection rates of Southern Brown Bandicoots at LGNP-north over the past few years are creating computational problems, resulting in large amounts of uncertainty in model predictions. A longer period of camera deployment may increase the detection rate, decreasing the level of uncertainty. This in turn should provide a more robust estimate of any difference between NTMLs and TMLs.
	Model the patterns in the changes in occupancy from 2005 to 2017 to investigate whether species are dispersing into new areas or whether they are limited to certain habitat and investigate factors that may influence the spread of recovery.	Quantifying and understanding the factors that influence the rate of recovery and spatial spread of threatened species in relation to management intervention is a key 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, distance between sites, and the possibility of directional spread into account. This information will improve our understanding of the drivers and the limitations of species recovery following fox control.
	Develop bandicoot and 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.	The limited response of bandicoots and potoroos 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. Freely available remotely sensed habitat data (e.g. vegetation type, topography, fire history, distance to drainage lines, distance to forest edge, and landscape productivity data) can be combined with the information on detection and non-detection of species at sites to develop a species habitat suitability surface across the project area. This information will be useful in understanding the expected increase in species occurrence and will also identify potential new locations for monitoring and/or fox control actions.

Item	Recommendation	Detail
	Using expert elicitation describing the benefits of fox control for the Heath Mouse (*Pseudomys shortridgei*), select sites for targeted monitoring of TMLs and NTMLs.	Current monitoring sites were placed in locations based on best understanding of 'suitable' habitat for the three main target species at the time. Species distribution models have been developed in recent years. 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 changes in abundance between TMLs and NTMLs.
Fox control	Use spatially explicit individual-based population models of the reduction in fox density due to control operations, to develop strategies for increased reduction of fox populations.	Run models testing a range of baiting scenarios to assess impact on fox density. Despite decades of fox control, we have little understanding of the best strategy for maintaining and further reducing fox abundance once it reaches a low level.
Alternative survey methods for foxes and feral Cats	Assess the feasibility and cost of genotyping DNA from fox scats collected using scat-detector dogs.	Scat-detector dogs and genotyping DNA from scats have both been used successfully to enumerate fox populations before and after fox control. A similar approach could be used in Glenelg Ark to assess differences between baited and comparable unbaited areas.
Integrated predator control	Implement targeted feral Cat control at locations with known populations of Southern Brown Bandicoot and Long-nosed Potoroos.	Feral Cats may limit the response of Southern Brown Bandicoots and Long-nosed Potoroos 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.
Scientific support	Continue to source scientific support and advice concerning the ongoing implementation and development of Glenelg Ark.	Evaluation and interpretation of the monitoring data, development of new projects addressing emerging issues, and general guidance to the project from the scientific community has been instrumental in its success.
Monitoring and reporting	Continue annual monitoring, evaluation and reporting.	Continue annual monitoring, evaluation and reporting in order to closely track changes in predators and prey, thus allowing more responsive management of emerging issues, e.g. a decline in Southern Brown Bandicoots, or a change in feral Cat abundance.
Filling specific knowledge gaps	Develop a set of potential student projects to fill identified knowledge gaps.	The current monitoring program does not assess changes in small native mammals [e.g. Heath Mouse and White-footed Dunnarts (*Sminthopsis leucopus*)], or unintended consequences (e.g. the possible negative impacts on biodiversity of overabundant medium- and small-sized herbivores, e.g. Swamp Wallabies (*Wallabia bicolor*) and Common Brushtail Possums). A series of student projects could fill these knowledge gaps, taking advantage of the infrastructure that Glenelg Ark provides.

1 Introduction

The Glenelg Ark project was established in July 2005 to facilitate the recovery of selected native mammal populations considered at risk from fox (Red Fox, *Vulpes vulpes*) predation. The project established continuous landscape-scale fox baiting across 90 000 ha of State Forest and National Park in south-western Victoria. 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 (1) the response of foxes to control activities, and (2) the response of native species that are at risk from fox predation to a reduced abundance of foxes. Without such monitoring and evaluation, it would be impossible to justify the reinvestment of scarce public conservation funds, to improve management actions based on scientific information, and to maintain community support. Thus, monitoring and evaluation forms an essential part of management and is not an imposition or an adjunct to it.

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 thought to be 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*). The bandicoot (weight ~1.0 kg) and the potoroo (weight ~1.2 kg) are medium-sized ground-dwelling mammals that have high and moderate rates of fecundity, respectively (Lobert and Lee 1990). Both 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). The Common Brushtail Possum is a semi-arboreal species weighing ~3.0 kg, which has a low rate of fecundity (Kerle and How 2008) and is known to be eaten by foxes (Triggs et al. 1984) and to respond to fox control (Kinnear et al. 2002).

Foxes have played a role in the decline and extinction of Australian mammals (Short and Smith 1994; Salo et al. 2007), and there are examples of mammal recovery following sustained reduction in fox abundance (McLeod et al. 2008). Based on our knowledge of the initial status of the targeted prey species, it was reasoned that once fox numbers had been reduced, the prey species would be able to escape the limitation imposed by predation, and the number of sites occupied by the targeted prey species should increase. We assessed changes in foxes and feral Cats (*Felis catus*) by comparing their activity (number of independent images captured by a digital camera at a monitoring site) at locations having an ongoing history of continuous fox control (with fortnightly replacement baiting) with that at locations having no history of fox control. We assessed the response of the native species to the reduction in foxes by comparing the number of monitoring sites occupied by the native species at locations with and without ongoing fox control.

The response of native species to the reduction in fox abundance at sites in Glenelg Ark was assessed each spring, using detections resulting from species contact with hair-tubes from 2005 to 2012, and using detections by digital cameras from 2013 to 2017.

We examined the differences (if any) in the occupancy and detection estimates of Common Brushtail Possums, Long-nosed Potoroos and Southern Brown Bandicoots from 2005 to 2017 at the six monitoring locations within the Glenelg Ark project area.

This report updates the previous monitoring and evaluation report (Robley et al. 2017) by incorporating new data on the outcome of the fox control operation, and modelled estimates of fox density and of the response of the targeted native species from 2013 to 2017. This report also contains recommendations on future management options and suggested 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 broad-scale mainland fox control operations, and have the information needed for decision-making about future directions.

2 Methods

2.1 Glenelg Ark operations area

The Glenelg Ark operations area is located 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 monitoring areas, known as 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) (Fig. 1), were used to assess the benefits of fox control. There had been little fox control in the TMLs and NTMLs prior to 2005. To achieve a broad-scale reduction in foxes across the public land areas, fox control was consolidated in the southern half of the overall project area (Fig. 1). This meant that a random allocation of treatment and non-treatment sites was not feasible.

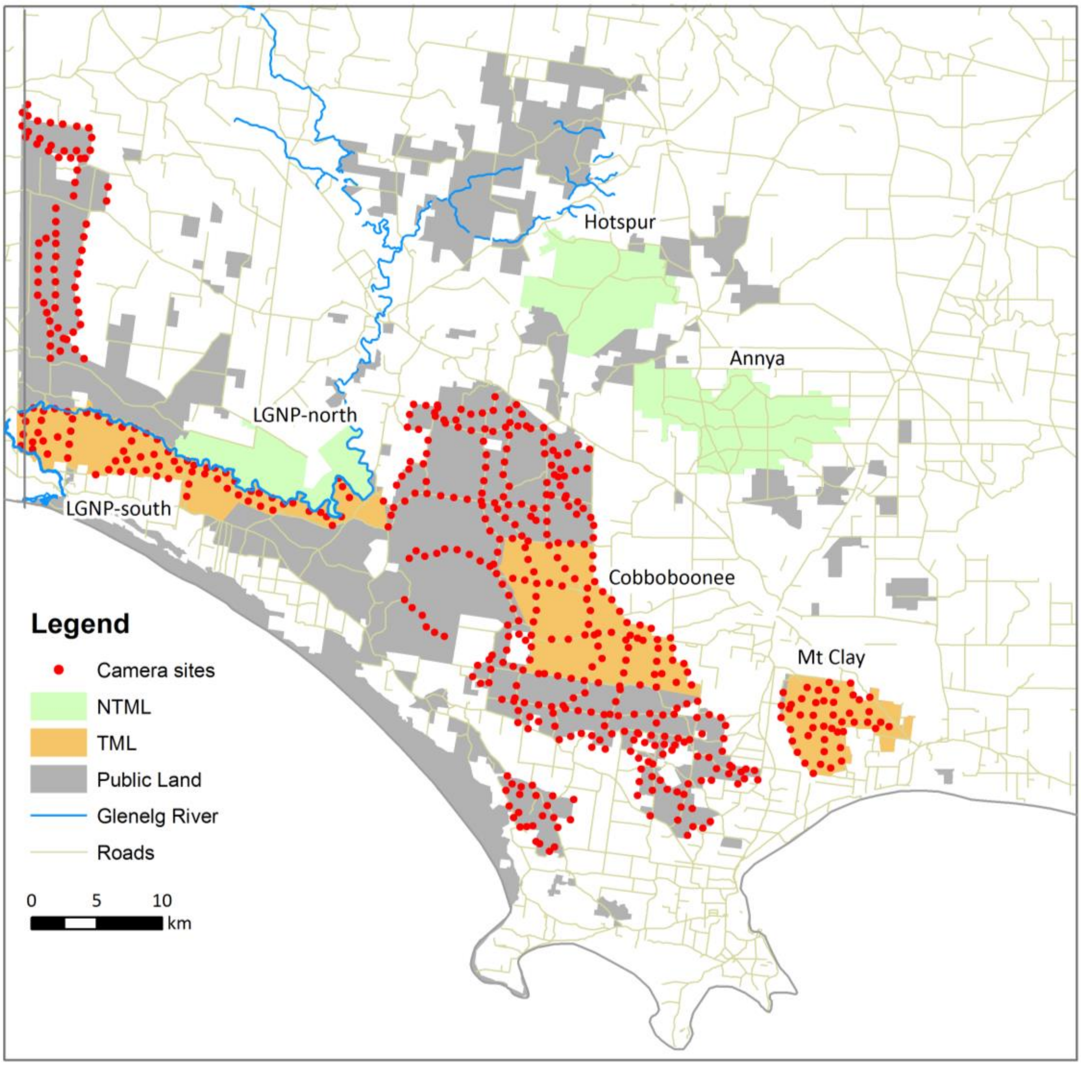

Figure 1. Glenelg Ark operations area. Red dots = poison bait stations. Tan areas = TMLs. Pale green areas = NTMLs. Fox baiting along the coast was discontinued in 2017.

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 but does not allow any statistical interpretation of causality (Lande et al. 1994).

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 2017 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 independent 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 was assessed using a Bayesian non-linear mixed model, with treatment set as a fixed effect and year set as a random effect in the fox and feral Cat models; the presence of foxes was included in the feral Cat model as a fixed effect to test the 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 model to allow for differing numbers of camera days per sampling period.

2.4 Modelling differences in fox density

A spatially explicit, agent-based model (ABM; Hradsky et al. in press) was built and run in the open-source software Netlogo (version 6.0.2; Wilensky 1999) and R (R Development Core Team 2016). The model was run at 1-ha resolution over an ~89 000 ha landscape. This allowed for a buffer of ~30 km around monitoring locations within the Glenelg Ark operations area, to capture >95% of dispersing female and >90% of dispersing male foxes that might reach the areas of interest, assuming an average home range size of 4000 ha and dispersal distances that scale accordingly (Trewhella et al. 1988).

Fox density was monitored in two regions: (i) the three treatment locations (total 23 407 ha), and (b) the three non-treatment locations (total 21 119 ha) (Fig. 2). Model parameters are shown in Appendix 1.

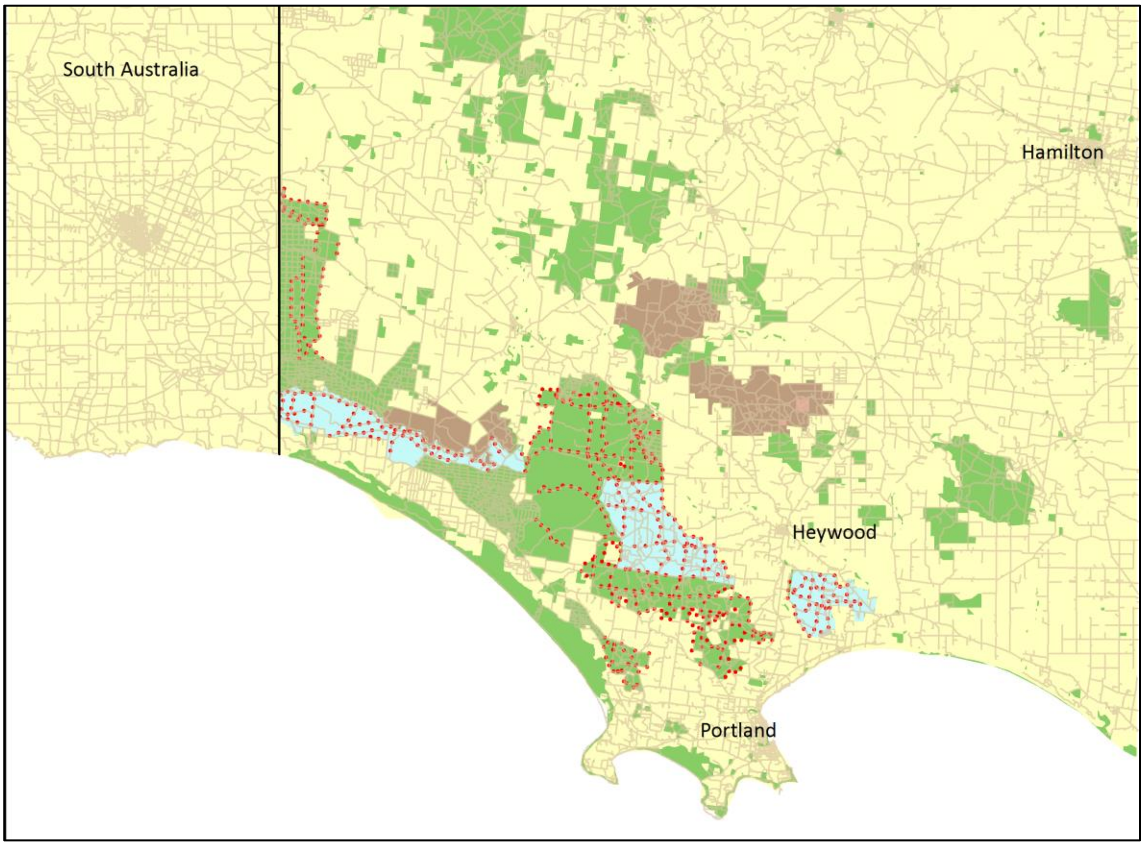

Figure 2. Landscape configuration for the agent-based model. The fox population model estimated density across this entire landscape covering a 30km buffer around the monitoring sites. Changes in fox density was monitored across (a) the three TMLs, shown in pale blue and (b) the three NTMLs, shown in pale brown. Green = public land. Yellow = other. Red dots = poison bait stations. Foxes were not able to access areas shown in white (i.e. the ocean). Public land parcels in SA not shown.

2.5 Measuring site occupancy changes in mammal species

Site 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 (Fig. 3). The positioning of monitoring sites was based on descriptions of the habitat preferred by the target native mammal species (Menkhorst 1995) and stratified according to the proportion of preferred habitat within each TML and NTML.

Monitoring was typically undertaken in spring (2005, 2008–2017). Initial sampling, prior to the commencement of poison baiting, was conducted in winter 2005. 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; Fig. 4) (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 (Fig. 4). The location of the camera within a monitoring site was determined by a series of coin tosses. 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 operated for a minimum of 30 days, with each day representing a repeat survey of the monitoring site per sampling period.

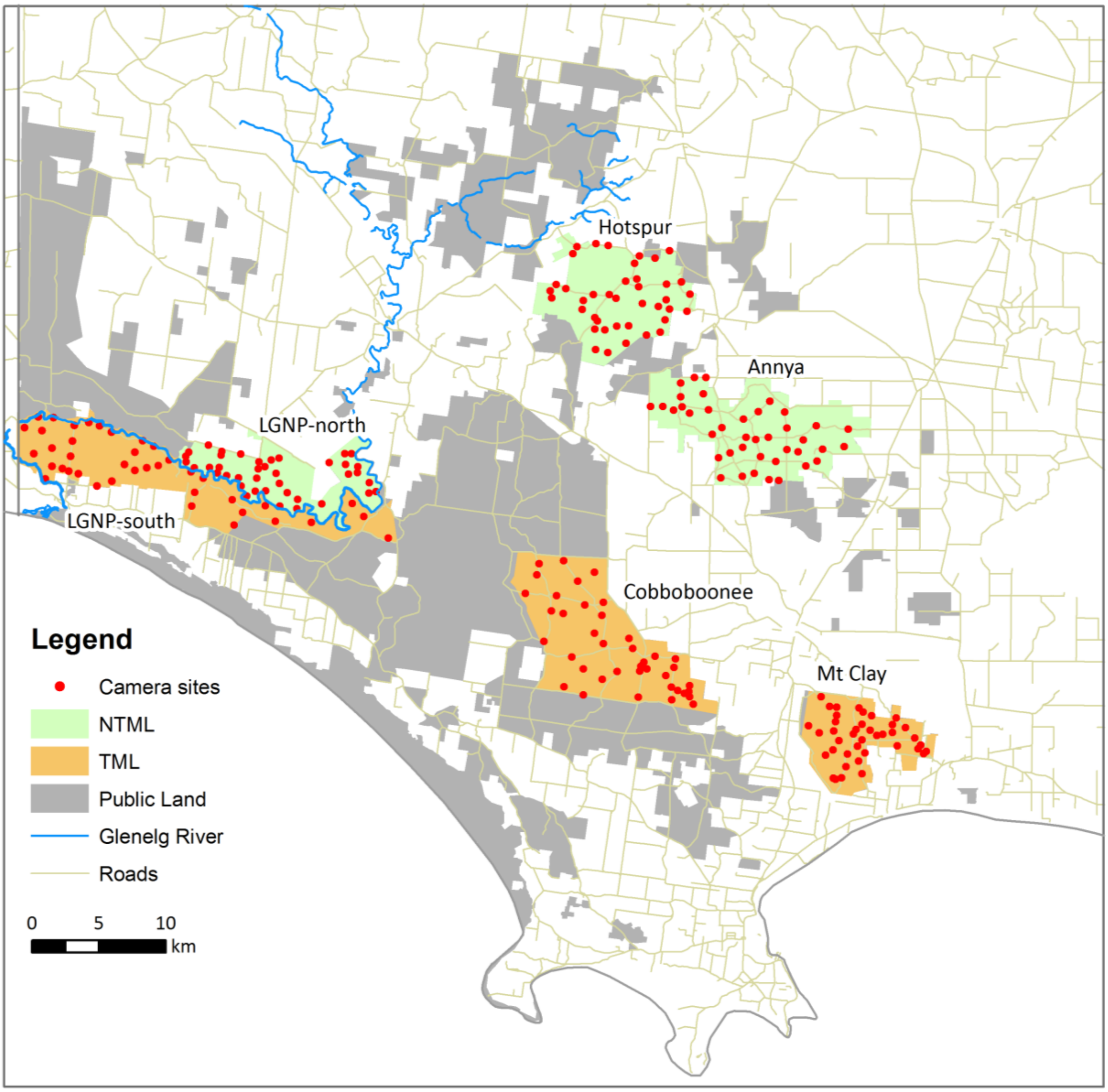

Figure 3. Monitoring sites in the TMLs (treatment monitoring locations; tan polygons) and NTMLs (non-treatment monitoring locations; green polygons) of Glenelg Ark are indicated by red dots. LGNP = Lower Glenelg National Park.

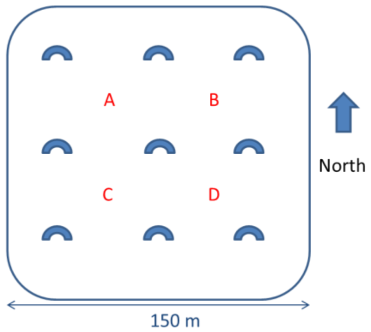

Figure 4. Layout of nine hair-tubes and possible location (A, B, C or D) of the single digital camera at a monitoring site.

2.5.1 Data analysis

Long-term site occupancy changes in native mammals

To assess the long-term responses of the selected native mammals, we used multiseason occupancy models to estimate the occupancy (ψ), detection (p), local colonisation (γ) and local survivorship (ε) for monitoring sites within a location from 2005 to 2017 (MacKenzie et al. 2003, 2006). The models were constructed in a Bayesian framework (Kéry 2010), using a space–state formulation (Royle and Kéry 2007).

A separate model was constructed for each of the native species of interest. The data for each species were summarised for each monitoring site. Each model allowed for differences in parameters at each of the six locations: Annya, Hotspur and LGNP-north (NTMLs); and Cobboboonee, Mt Clay and LGNP-south (TMLs). Hair-tube detection of Long-nosed Potoroos and Southern Brown Bandicoots differed depending on whether Common Brushtail Possums were detected at the site, and this was considered by the models. Hair analysis from the tubes indicated that the sticky-tapes were being swamped with possum hairs (B. Triggs, pers. comm.), and therefore potoroos and bandicoots could have been under-reported.

3 Results

3.1 Rainfall

Mean annual rainfall (recorded at the Portland Airport, ~20 km from the project area centre) varied substantially over the period 1983–2017 (Fig. 5). The years 1994–2001, prior to the commencement of this study saw consistently below-average rainfall. For the period covering this study (2005-2017), eight of the thirteen years were below average; however, 2011, 2014 and 2017 were the three highest rainfall years over the 34 year period, with rainfall 30.9%, 42.7% and 23.6% above the 34-year average.

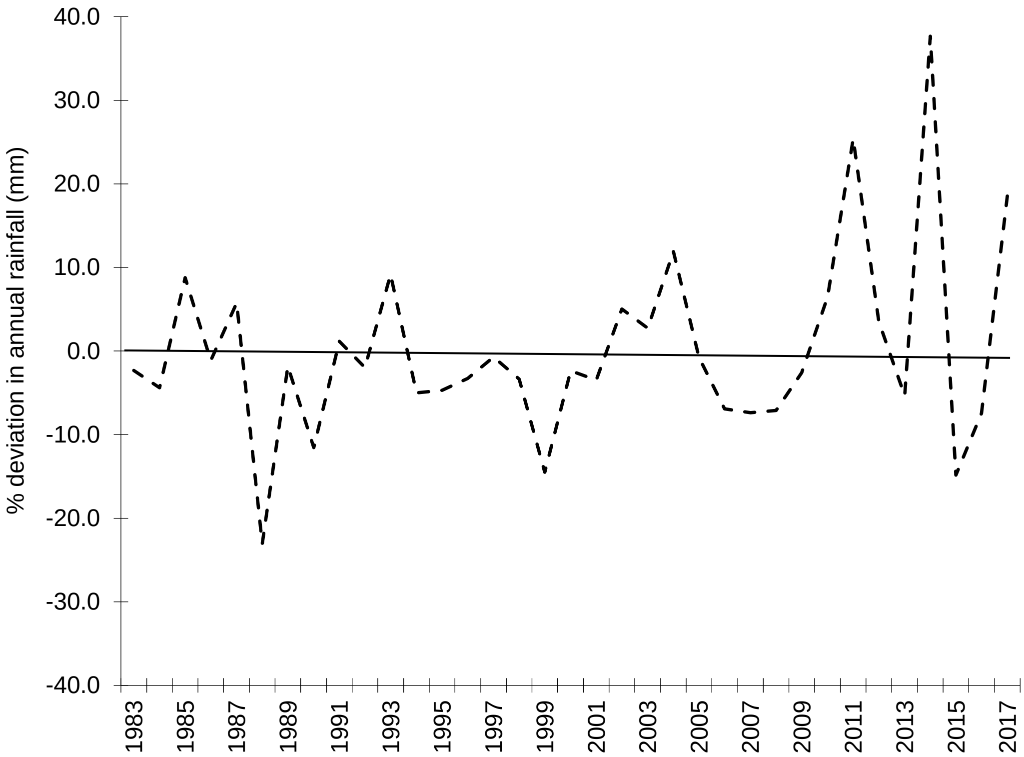

Figure 5. Deviation in mean annual rainfall from the 1983–2017 average. Data from the rainfall station at Portland Airport.

3.2 Fox and feral Cat activity

3.2.1 Fox activity

Fox activity was significantly higher (86%) across non-treated locations (mean 13.7, 95% confidence interval [CI] 11.7–16.1) compared with treated locations (mean 1.8, 95% CI 1.5–2.2) between 2013-2017. (Fig. 6).

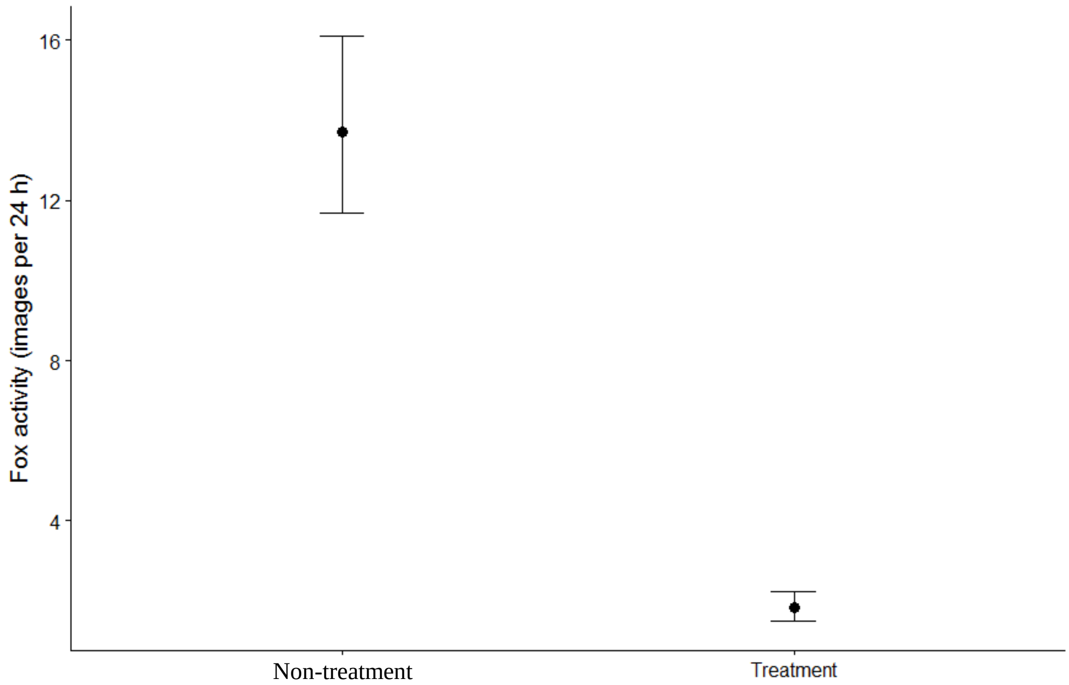

Figure 6. Difference in fox activity (images per 24 h) between non-treatment and treatment monitoring locations. Bars are 95% confidence limits.

Fox activity was significantly higher on all three non-treatment locations compared with the three treatment locations (Fig. 7), indicating that, in general, fox activity is significantly higher at locations without fox control.

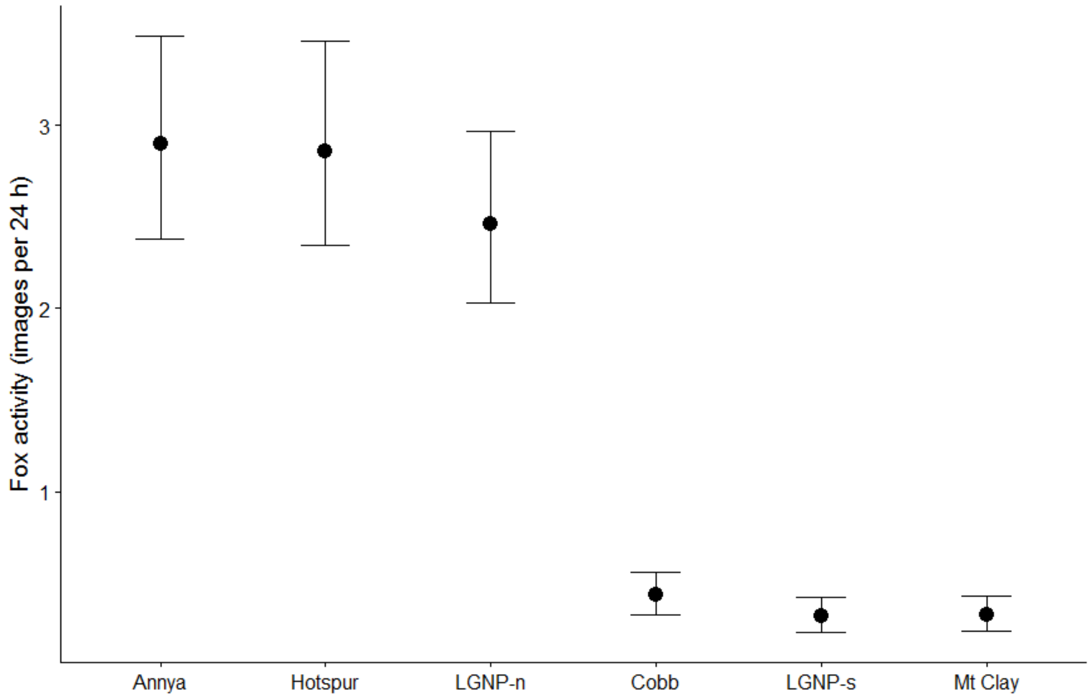

Figure 7. Fox activity (images per 24 h) at each of the six monitoring locations. Non-treatment locations = Annya, Hotspur and Lower Glenelg National Park-north (LGNP-n); treatment locations = Cobboboonee (Cobb), Lower Glenelg National Park-south (LGNP-s) and Mt Clay.

The average fox activity varied little between years on treatment locations but was highly variable between years on non-treatment sites (Fig. 8). There is some suggestion in the data that at Hotspur and Annya fox activity declined over time, while remaining constant at LGNP-north.

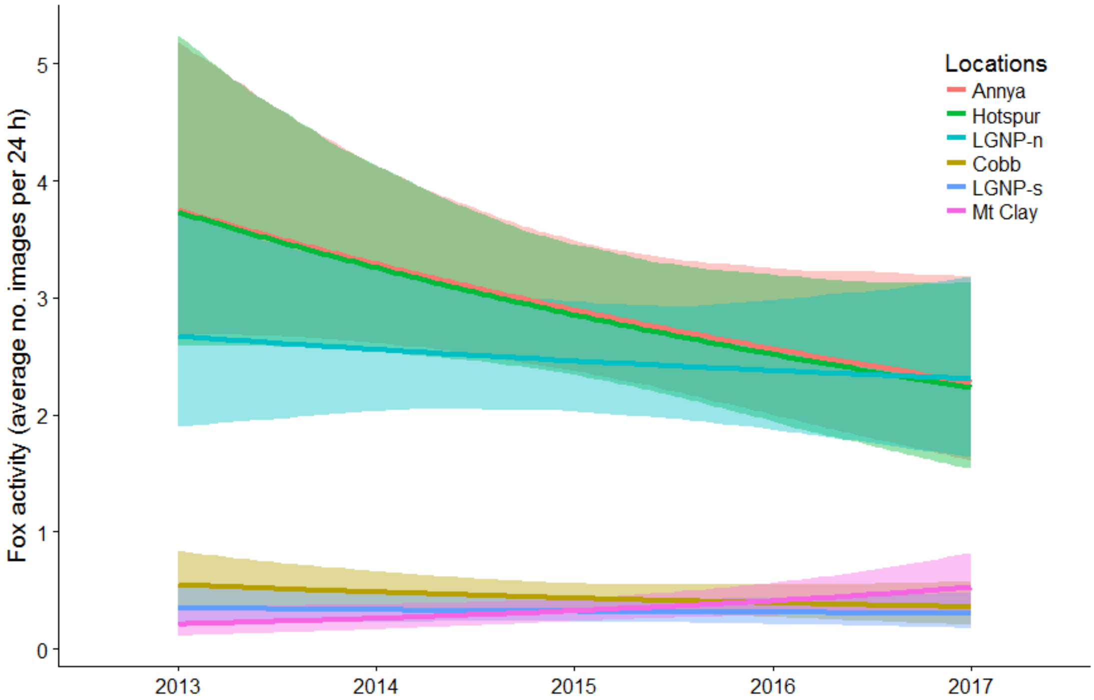

Figure 8. Fox activity (average number of images per 24 h) over time. Non-treatment sites = Annya, Hotspur and Lower Glenelg National Park-north (LGNP-n); treatment sites = Cobboboonee (Cobb), Lower Glenelg National Park-south (LGNP-s) and Mt Clay.

3.2.2 Feral Cat activity

There was no support in the models for the hypothesis that feral Cat activity was higher at locations treated for fox control. There was considerable variation in feral Cat activity between sites: LGNP-n (treatment site) and LGNP-s (non-treatment site) had the highest levels of feral Cat activity, and Annya (treatment site) and Mt Clay (non-treatment site) had the lowest levels of feral Cat activity (Fig. 9).

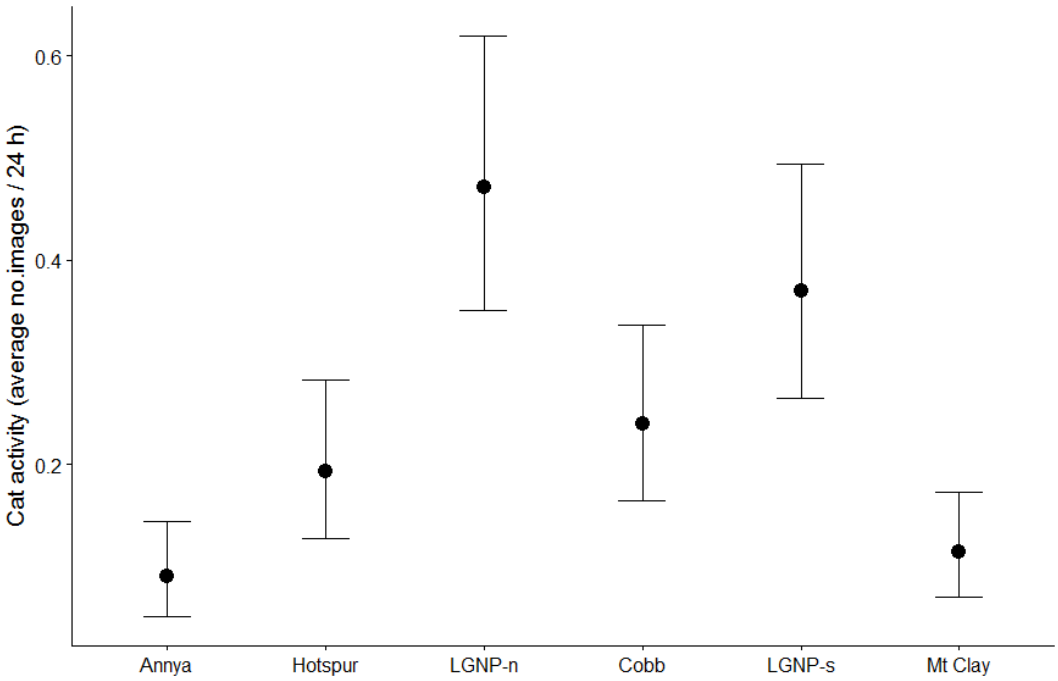

Figure 9. Feral Cat activity across the six monitoring locations at Glenelg Ark. Non-treatment sites = Annya, Hotspur and Lower Glenelg National Park-north (LGNP-n); treatment sites = Cobboboonee (Cobb), Lower Glenelg National Park-south (LGNP-s) and Mt Clay. Bars are 95% confidence limits.

3.3 Fox density

Using the ABM to predict fox densities under different management strategies the average predicted fox density following 10 years of baiting on the TMLs was 0.3/km^2 compared with 1.8/km^2 on the NTMLs. Fox density was predicted to be on average 41% lower when baits were replaced fortnightly and spaced at 500-m intervals (mean = 0.30/km^2 vs 0.26/km^2) over 10 years compared to the current management strategy. While it is unknown whether this difference is significant in terms of the impact of fox predation on native species response, this does suggest an improved outcome in relation to reducing the threat.

In contrast, decreasing the frequency of bait replacement to monthly resulted in a predicted fox density of 0.41/km^2, an increase of 26% over the 10 years, compared with fortnightly bait replacement. Decreasing and increasing the spacing of bait stations had minimal effect on fox density (Fig. 10).

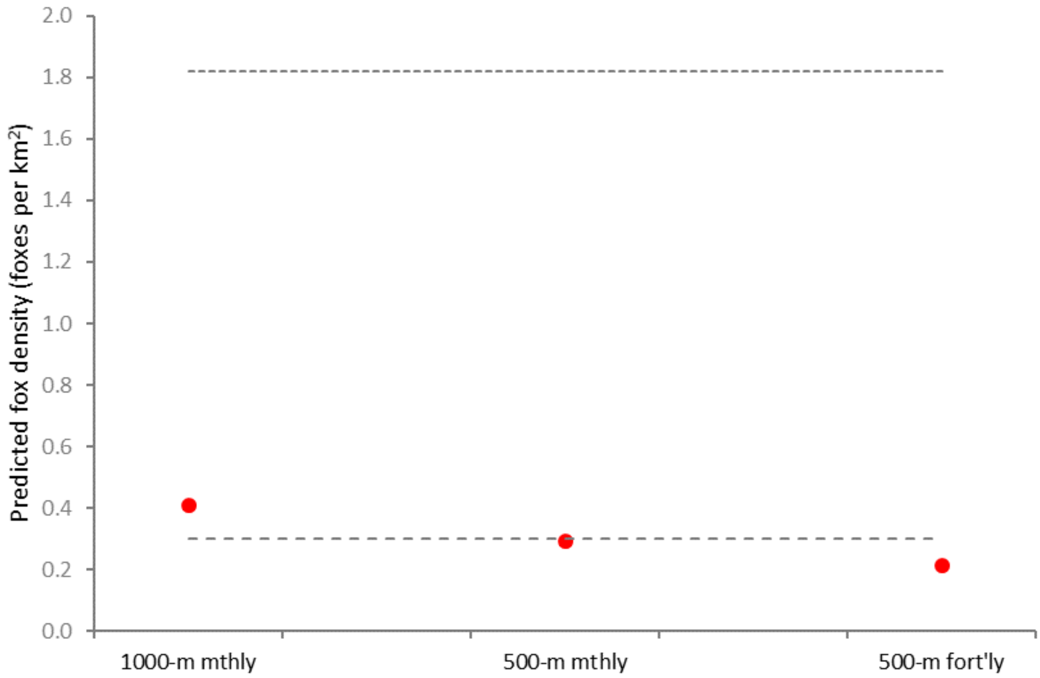

Figure 10. Predicted fox densities arising from different baiting frequencies and spacing's using the agent-based model. Dotted line = average fox densities at NTMLs over 10 years. Dashed line = average fox densities at TMLs under current baiting strategy (fortnightly baiting at 1000-m intervals). Error bars are 95% confidence limits.

3.4 Changes in the number of sites occupied 2005–2017

3.4.1 Common Brushtail Possums

The number of sites assessed as occupied by the Common Brushtail Possum has declined at Annya since 2012. Occupancy at Hotspur has fluctuated but has remained in a similar range from 2015 to 2017, while there has been a general increase in occupancy at LGNP-north (Fig. 11).

The number of occupied sites at locations with fox control rose at Cobboboonee from 2011 and is showing signs of a decline in 2017, whereas at LGNP-south the number of occupied sites has remained high and constant since 2007. Occupancy has remained constant and unchanged at Mt Clay (Fig. 11).

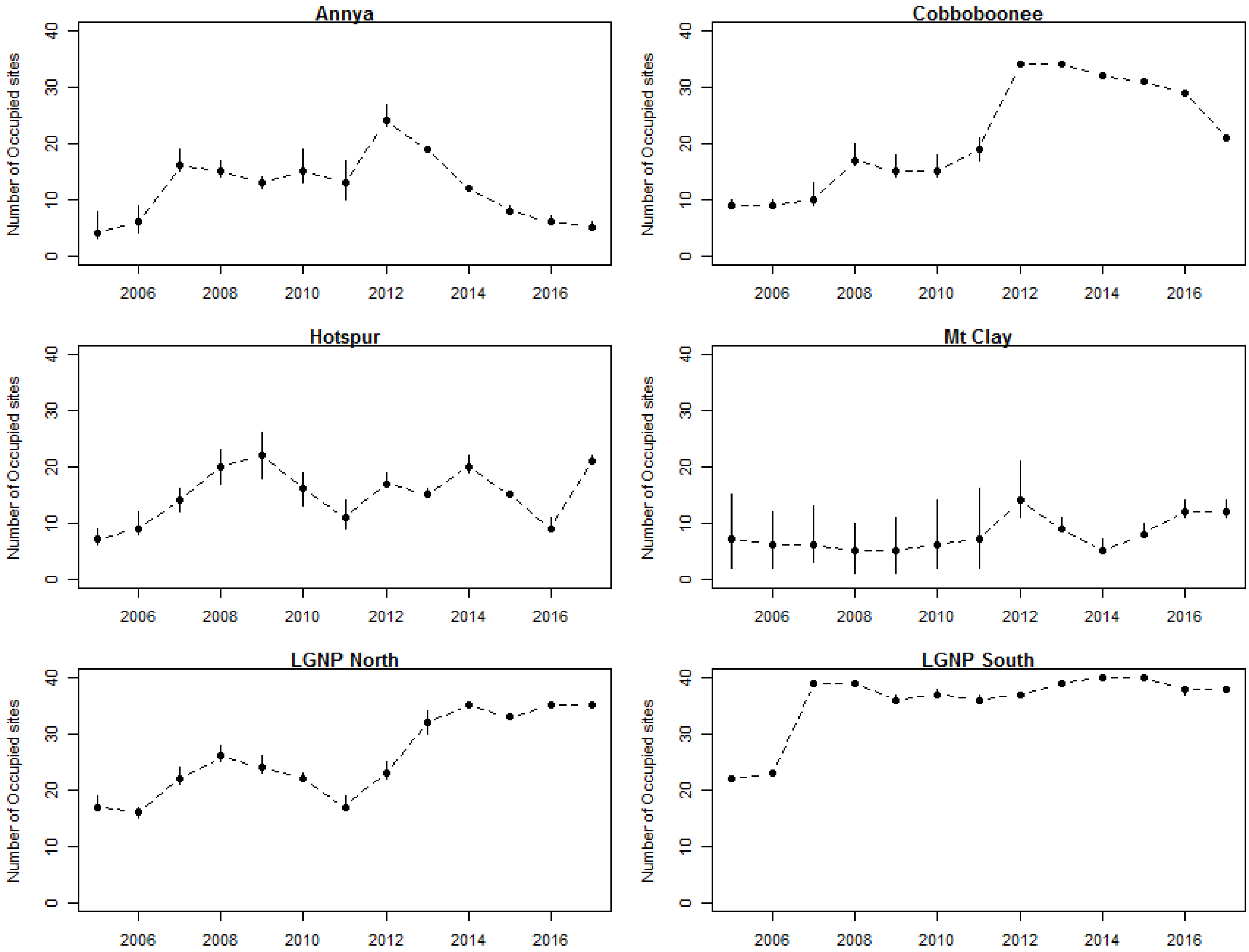

Figure 11. Estimated numbers of sites occupied by Common Brushtail Possums. NTML on left and TML on right.

Overall, the number of sites occupied by Common Brushtail Possums is higher at locations with fox control (Fig. 11).

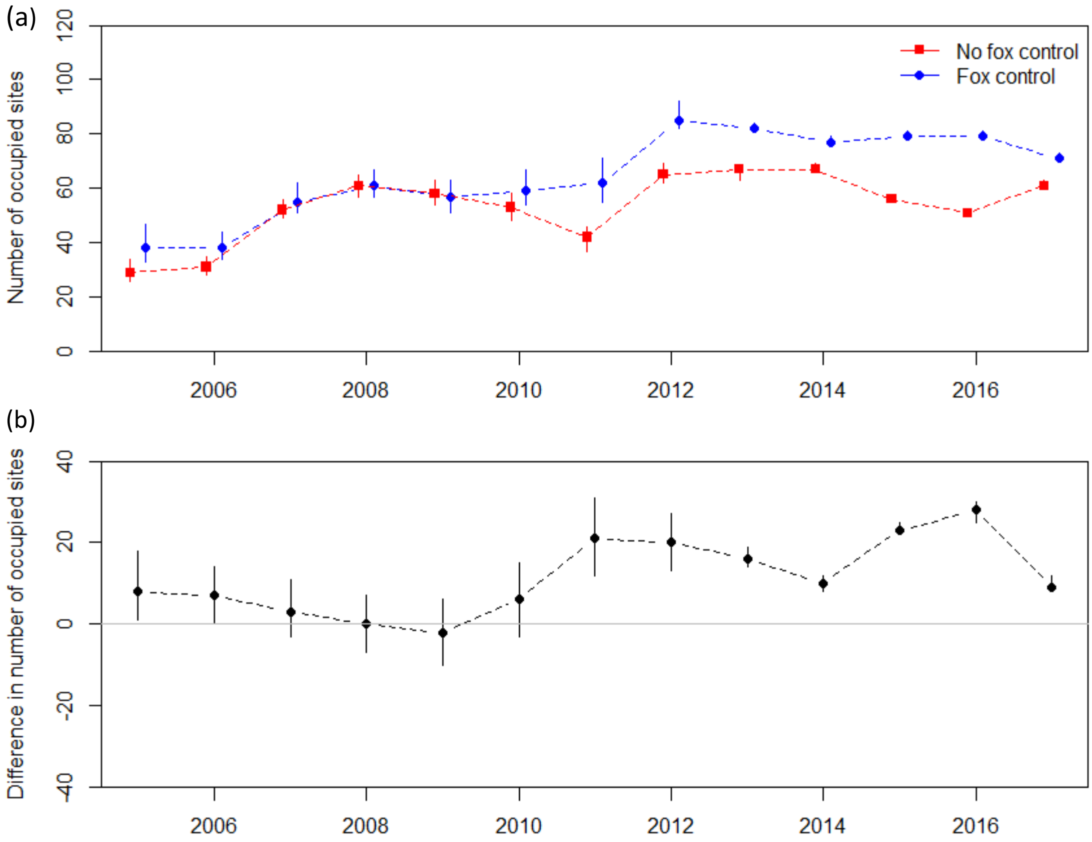

Figure 11. The overall occupancy of Common Brushtail Possums: (a) the estimated number of sites occupied by Common Brushtail Possum over time with presence (blue dotted line) or absence of fox control (red dotted line), and (b) the difference in the number of occupied sites between treatment and non-treatment locations. Vertical lines = 95% credible interval estimates.

3.4.2 Long-nosed Potoroos

The number of sites occupied by the Long-nosed Potoroo declined at Hotspur since 2005 but has remained steady since then (Fig. 12). Occupancy at Annya declined from 2005 to 2017 and fluctuated but remained relatively unchanged at LGNP-north. The number of sites occupied at treated locations varied over time. There has been a slight increase since 2005 at Cobboboonee, a slight overall decrease at LGNP-south, and at Mt Clay Long-nosed Potoroos have fluctuated but remain relatively constant in the numbers of sites occupied (Fig. 12).

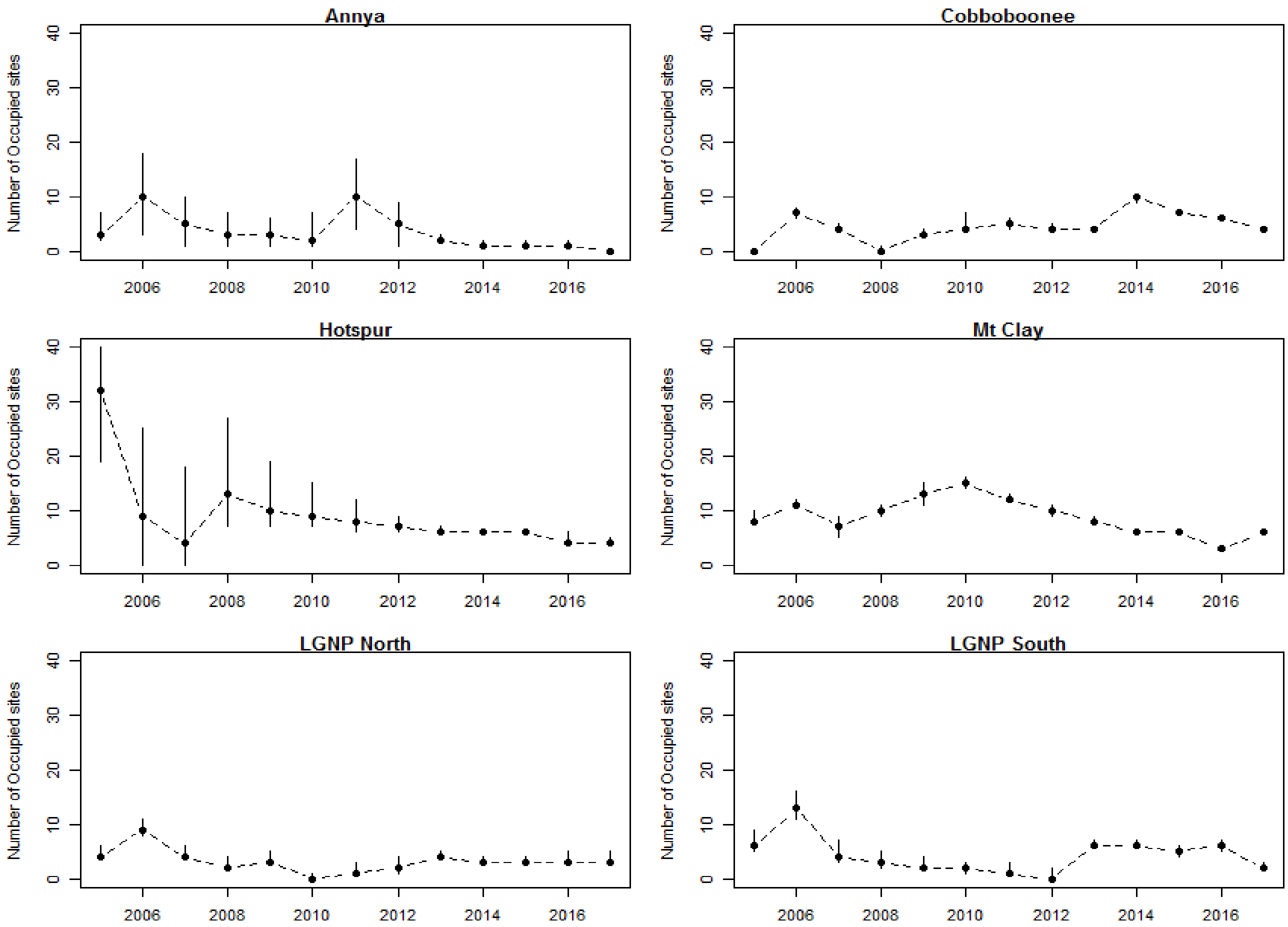

Figure 12. Estimated numbers of occupied sites for Long-nosed Potoroo in each region over time. The vertical lines represent the 95% credible interval estimates. NTMLs on right and TMLs on left.

As a result, overall, the number of sites occupied by Long-nosed Potoroo has been higher since 2012 at locations with fox control compared with at sites without fox control (Fig. 13).

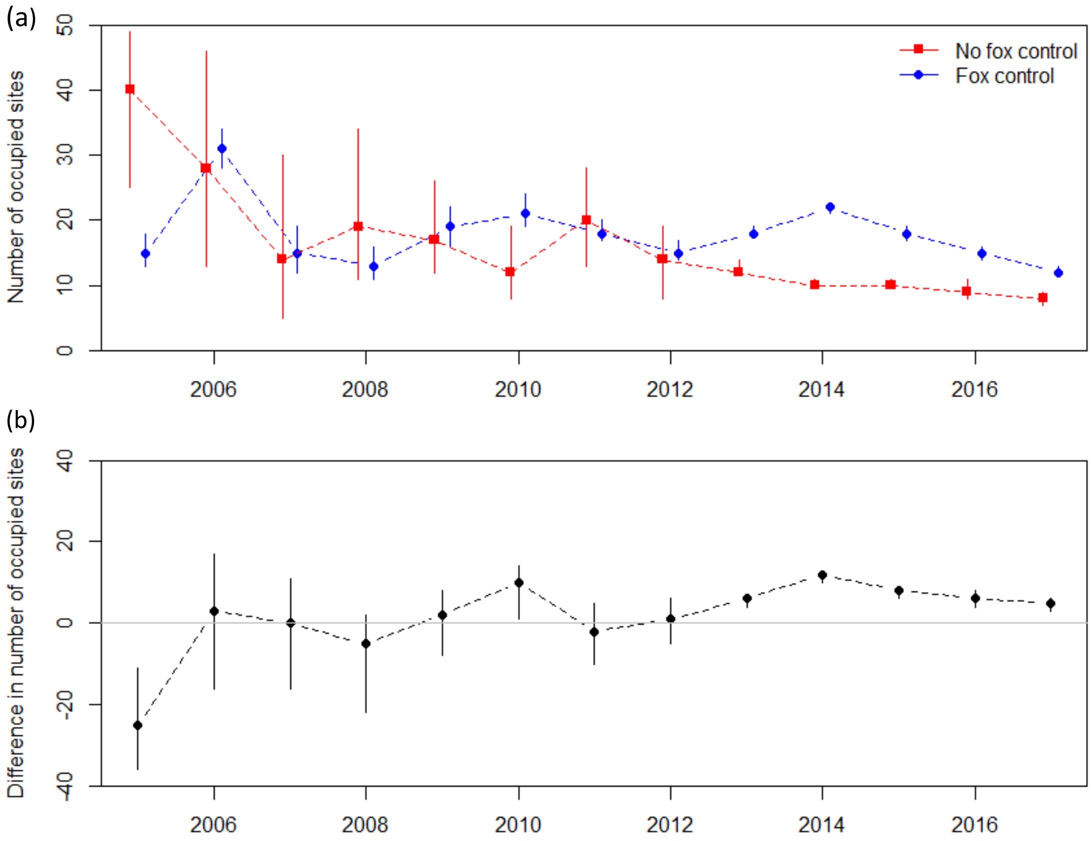

Figure 13. The overall occupancy of Long-nosed Potoroos: (a) the estimated number of sites occupied by Long-nosed Potoroos over time with presence (blue dotted line) or absence of fox control (red dotted line), and (b) the difference in the number of occupied sites between treatment and non-treatment locations. Vertical lines = 95% credible interval estimates.

3.4.3 Southern Brown Bandicoots

The number of sites occupied by the Southern Brown Bandicoot has increased slightly at Annya (no fox control) between 2005 and 2006, but generally remained constant from 2006 to 2017. At Hotspur, the number of sites occupied was higher between 2006 to 2008 than in 2005 between 2010 and 2017 they have remained relatively stable at 2005 levels. Southern Brown Bandicoot were effectively extinct from LGNP-north sites from 2007 to 2012 but have shown some signs of recovery in 2013–2014. The large confidence intervals around the estimates of the numbers of occupied sites reflect the low levels of detection, which in turn affect the model predictions. Only one site was recorded as having Southern Brown Bandicoot in 2015–2017, and as a result, the model prediction (using previous years detection rates) is that anywhere from 1 to 35 sites may have Southern Brown Bandicoot present, with a point estimate roughly in the middle of this interval estimate.

Southern Brown Bandicoot occupancy has fluctuated at Cobboboonee since 2005, and currently site occupancy is slightly higher compared with the occupancy in 2005. The number of sites occupied at Mt Clay has increased sharply since 2016 and is currently at its highest since the beginning of the project, with an estimated increase from 5 sites occupied to 15 sites occupied (67%). The number of sites occupied at LGNP-south has fluctuated through time but is currently at the same level as in 2005 (Fig. 13).

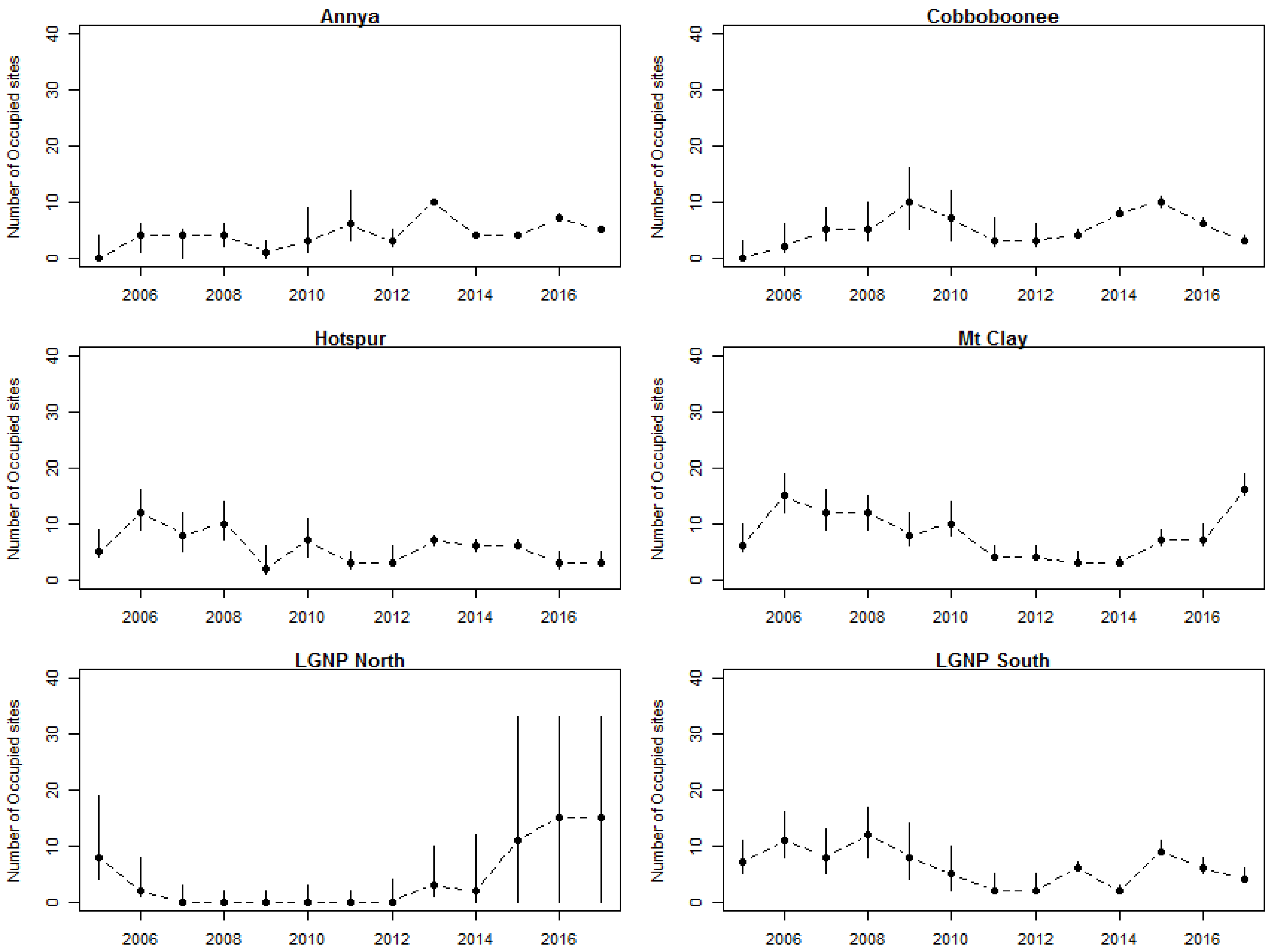

Figure 13. Estimated number of occupied sites for Southern Brown Bandicoot in each region over time. The vertical lines represent the 95% high-density intervals.

Overall, the number of sites occupied by Southern Brown Bandicoots is likely to be higher at locations with fox control. The large uncertainty around the estimates for locations with no fox control indicate that it is likely there are fewer sites occupied at these locations compared with at locations with fox control (Fig. 14).

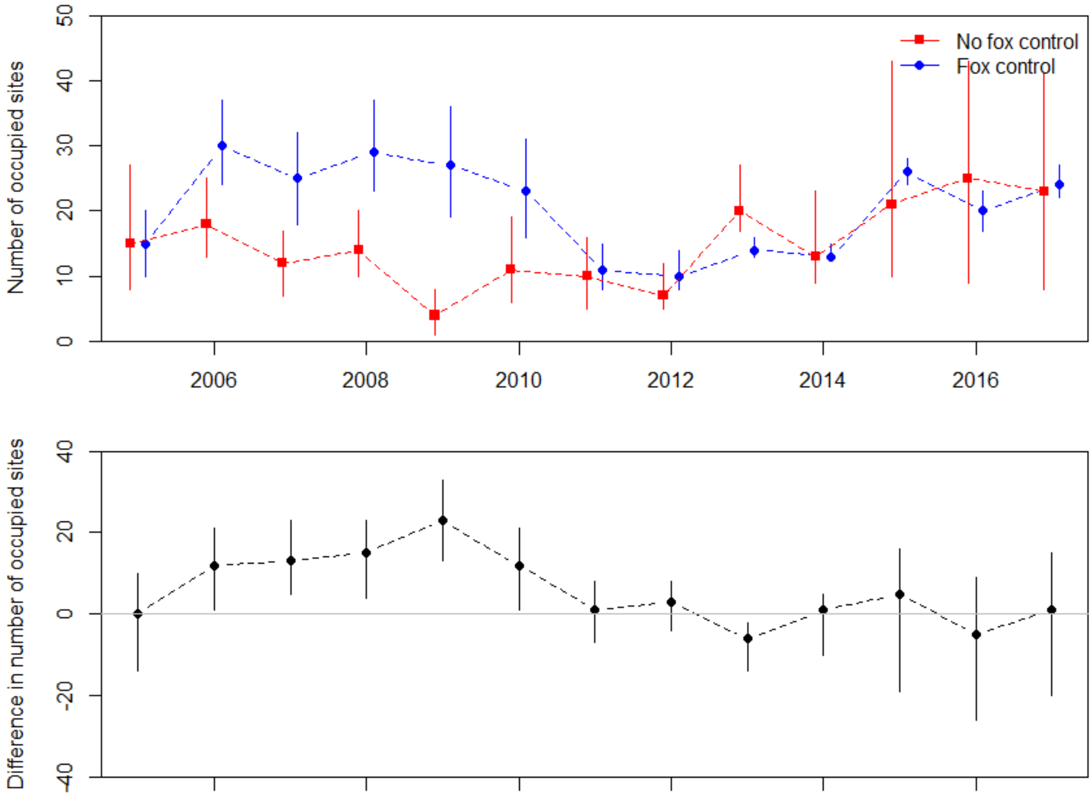

Figure 14. The overall occupancy of Southern Brown Bandicoots: (a) the estimated number of sites occupied by Southern Brown Bandicoots over time with presence (blue dotted line) or absence of fox control (red dotted line), and (b) the difference in the number of occupied sites between treatment and non-treatment locations. Vertical lines = 95% credible interval estimates.

4 Discussion

Overall, site occupancy for Common Brushtail Possum, Long-nosed Potoroo and Southern Brown Bandicoot remains higher at TMLs than at NTMLs. Fox activity remains significantly lower on treatment sites compared with on non-treatment sites, while feral Cat activity was not significantly associated with treatment effect. Predicted fox densities across the TMLs were consistently lower compared with pre-treatment densities and densities at NTMLs, and consistent with the observed differences indicated by the camera trap monitoring.

However, the responses of the native species were mixed within the suite of treatment locations. Attempting to determine the effect of fox control on species' responses by comparing the numbers of sites occupied by native species in TMLs with those in NTMLs assumed that individual locations were ecologically similar. However, occupancy within individual location types (TML or NTML) varied, suggesting that conditions (e.g. resources [food, shelter], or density of foxes and/or feral Cats) were not uniform within a location type. What the underlying differences in conditions might be and just how these differences might act to affect native species abundance is not known and warrants further investigation. The number of sites occupied by Common Brushtail Possums at LGNP-south doubled in 2007 compared to 2006 numbers, possibly because of declines in fox abundance; however, at Cobboboonee, the same level of change did not occur until 2012, and that change corresponded with the previous 2 years (2010–2011) of above-average rainfall (BOM 2017). Long-nosed Potoroos at all three TMLs showed signs of a positive response in 2006, with increases and decreases over time at Cobboboonee and Mt Clay (although there was a general decline at LGNP-south). The overall number of sites occupied by Southern Brown Bandicoots doubled in approximately the first 1–4 years, with rates declining and again increasing to more than double the initial occupation rate at Cobboboonee and Mt Clay, but generally declining and remaining lower at LGNP-south.

Similar responses by native species considered to be at direct risk from fox predation have been reported elsewhere. When reviewing a 15-year fox control program at Booderee National Park, NSW, Lindenmayer et al. (2018) reported an increase in Common Brushtail Possums and macropods, but an initial increase in abundance of Long-nosed Bandicoots (*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 very low number of feral Cats at Booderee NP and were unable to explain the drivers of the observed declines.

Glenelg Ark has been in operation for 13 years, and the initial response of the targeted native mammal species indicated that they responded positively to the reduction of foxes. It could be that these species have reached a new equilibrium with a lowered level of background fox predation and that a different factor (e.g. food, habitat, predation by feral Cats) may now be the key limiting mechanism. Several potential effects flow from this hypothesis.

First, to refute this hypothesis, reducing the remaining fox population should result in increased survival in the native mammal population, thus increasing the number of sites occupied by them. Reviewing the current fox control strategy and exploring options aimed at further reducing the fox population are warranted. Model predictions suggested that a decrease in bait spacing to 500-m, with continued replacement at fortnightly intervals, could further reduce fox density. These models will also be extended to include fox control on private land under different plausible scenarios, to create buffers around the public land blocks to examine the potential efficacy of this strategy in further reducing fox densities.

An outstanding issue in assessing the effectiveness of the fox control is the relationship between relatively cost-effective and simple measures such as activity (the number of camera images/day), and more expensive and difficult measures of abundance, e.g., mark-recapture estimates of abundance from individual identifications using DNA sampling from scats. The relationship between activity and abundance has been assumed to be linear (i.e. it has been assumed that a unit decline in activity is linearly related to a unit decrease in actual abundance); however, this is almost certainly not the case. Thus, while fox activity may have decreased, it remains unclear what relationship this has with the abundance of foxes. This lack of understanding clouds the interpretation of the native species monitoring results, and of the effectiveness of the fox control strategies.

Second, reducing foxes may have resulted in an overabundance of native herbivores. For example, Common Brushtail Possums occupy more than 80% of sites, and wallaby species are anecdotally reported to have increased substantially in the last 10 years. This may have led to overbrowsing, thus changing the composition and structure of the habitat. Dexter et al. (2013) found that overbrowsing due to an overabundance of wallabies (linked to their fox control operations) caused a shift in the vegetation community structure at Booderee National Park in New South Wales. This is an issue requiring further investigation.

Third, within the Glenelg Ark operations area, the sustained reductions in fox populations may have resulted in increased activity (and possibly abundance) of feral Cats. While the camera surveys indicated that there was no significant difference in feral Cat activity between TMLs and NTMLs, the point estimates suggest a higher level of activity at TMLs. Several studies have described increases in feral Cat abundance following reductions in fox numbers resulting from fox control operations (Algar and Smith 1998; Catling and Reid 2003). This effect has also 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. Based on the Glenelg Ark ongoing management initiative, a PhD candidate of the University of Melbourne is looking at the variation in feral Cat density across the TMLs and NTMLs.

Feral Cats have recently been declared a pest species in Victoria under the *Catchment and Land Protection Act 1994*, obligating public land managers to manage this pest. Under the new arrangements, management strategies in Victoria are limited to cage-trapping and shooting. The deployment of toxic baits from the air or on the ground, and the capture and destruction of feral Cats in leg-hold traps are not permitted. These restrictions limit the capacity of public land managers to develop and implement effective management practices in Victoria.

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, in particular smaller mammals 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, DEWLP pers. comm.) and should be implemented to assess the relative status of this species across TMLs and NTMLs. Other native species that in theory should respond positively to a reduction in foxes are Common Ringtail Possums (*Pseudocheirus peregrinus*), and owls such as Australian Masked Owl (*Tyto novaehollandiae*) and Powerful Owl (*Ninox strenua*), which have all been reported in the Glenelg region. Contrary to expectations, however, Lindenmayer et al. (2018) reported a decline in large forest owls at Booderee National Park after fox baiting.

The Glenelg Ark monitoring program has continued to operate effectively, providing information to land managers and to DELWP and Parks Victoria policy groups on the response of the targeted native mammal species. 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 of 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 over browsing and changes in the feral Cat population).

5 Recommendations

The following recommendations are made for improvement of the outcomes of Glenelg Ark.

Item	Recommendation	Detail
Native species' response	Increase the duration of camera surveys to improve detection rates for Southern Brown Bandicoot at LGNP-north.	Low detection rates of Southern Brown Bandicoots at LGNP-north over the past few years are creating computational problems, resulting in large amounts of uncertainty in model predictions. A longer period of camera deployment may increase the detection rate, decreasing the level of uncertainty. This in turn should provide a more robust estimate of any difference between NTMLs and TMLs.
	Model the patterns in the changes in occupancy from 2005 to 2017 to investigate whether species are dispersing into new areas or whether they are limited to certain habitat and investigate factors that may influence the spread of recovery.	Quantifying and understanding the factors that influence the rate of recovery and spatial spread of threatened species in relation to management intervention is a key 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, distance between sites, and the possibility of directional spread into account. This information will improve our understanding of the drivers and the limitations of species recovery following fox control.
	Develop bandicoot and 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.	The limited response of bandicoots and potoroos 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. Freely available remotely sensed habitat data (e.g. vegetation type, topography, fire history, distance to drainage lines, distance to forest edge, and landscape productivity data) can be combined with the information on detection and non-detection of species at sites to develop a species habitat suitability surface across the project area. This information will be useful in understanding the expected increase in species occurrence and will also identify potential new locations for monitoring and/or fox control actions.
	Using expert elicitation describing the benefits of fox control for the Heath Mouse (*Pseudomys shortridgei*), select sites for targeted monitoring of TMLs and NTMLs.	Current monitoring sites were placed in locations based on best understanding of 'suitable' habitat for the three main target species at the time. Species distribution models have been developed in recent years. 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 in abundance between TMLs and NTMLs.
Fox control	Use spatially explicit individual-based population models of the reduction in fox density due to control operations, to develop strategies for increased reduction of fox populations.	Run models testing a range of baiting scenarios to assess impact on fox density. Despite decades of fox control, we have little understanding of the best strategy for maintaining and further reducing fox abundance once it reaches a low level.
Alternative survey methods for foxes and feral Cats	Assess the feasibility and cost of genotyping DNA from fox scats collected using scat-detector dogs.	Scat-detector dogs and genotyping DNA from scats have both been used successfully to enumerate fox populations before and after fox control. A similar approach could be used in Glenelg Ark to assess differences between baited and comparable unbaited areas.
Integrated predator control	Implement targeted feral Cat control at locations with known populations of Southern Brown Bandicoot and Long-nosed Potoroos.	Feral Cats may limit the response of Southern Brown Bandicoots and Long-nosed Potoroos 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.
Scientific support	Continue to source scientific support	Evaluation and interpretation of the monitoring data, development

	and advice concerning the ongoing implementation and development of Glenelg Ark.	of new projects addressing emerging issues, and general guidance to the project from the scientific community has been instrumental in its success.
Monitoring and reporting	Continue annual monitoring, evaluation and reporting.	Continue annual monitoring, evaluation and reporting in order to closely track changes in predators and prey, thus allowing more responsive management of emerging issues, e.g. a decline in Southern Brown Bandicoots, or a change in feral Cat abundance.
Filling specific knowledge gaps	Develop a set of potential student projects to fill identified knowledge gaps.	The current monitoring program does not assess changes in small native mammals [e.g. Heath Mouse and White-footed Dunnarts (*Sminthopsis leucopus*)], or unintended consequences (e.g. the possible negative impacts on biodiversity of overabundant medium- and small-sized herbivores, e.g. Swamp Wallabies (*Wallabia bicolor*) and Common Brushtail Possums). A series of student projects could fill these knowledge gaps, taking advantage of the infrastructure that Glenelg Ark provides.

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Personal communications

Barbara Triggs, mammal hair specialist, 'Dead Finish', via Genoa, Victoria.

Richard Hill, DELWP, pers. comm.

Appendix 1: Parameters for the fox agent-based population model

Parameter	Unit	Value	Source	Source location	Source ecosytem
Spatial resolution	ha	1			
Landscape size (accessible to foxes)	km²	9100	30-km buffer around Glenelg Ark operations area		
Treated region size	km²	23.4			
Non-treated region size	km²	21.2			
Time-step	weeks	2			
Time limit	weeks	780	15 years (5 unbaited, 10 baited)		
Initial fox density	no./km²	3			
Average home range size	km²	4	(Towerton et al. 2016)	Dubbo, NSW	Dry sclerophyll forest: *Calllitris*, River Red Gum (*Eucalyptus camaldulensis*), Ironbark (*E. sideroxylon*)
Home range kernel	%	100			
Productivity Forest: Farm	ratio	1:2			
Annual survival (<1 year)	propn.	0.39	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: sheep (*Ovis aries*), cattle (*Bos taurus*)
Annual survival (1–2 years)	propn.	0.65	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: sheep, cattle
Annual survival (2 – 3 years)	propn.	0.92	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: sheep, cattle
Annual survival (>3 years)	propn.	0.18	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: sheep, cattle
Cubs born	week of year	37 (mid-Sept.)	(McIntosh 1963; McIlroy et al. 2001)		
Fecundity	cubs per fox family	3.74	(McIlroy et al. 2001)	Orange, NSW	Rangeland
Sex ratio at birth	propn. female	0.5	(McIntosh 1963; McIlroy et al. 2001)	ACT; Orange, NSW	Rangeland
Age at independence	Weeks	12	(McIntosh 1963; McIlroy et al. 2001)	ACT; Orange, NSW	Rangeland
Start of dispersal season	week of year	9 (early March)	(Pech et al. 1992)	Modelled	
End of dispersal season	week of year	21 (late May)	(Pech et al. 1992)	Yathong, NSW	Semi-arid rangeland
Female dispersal rate	propn.	0.700	(Coman et al. 1991)	Metcalfe, Victoria	Pasture (sheep, cattle), woodland
Pr(death | 1 bait and 100-ha home range)	propn.	<0.3			
Commence baiting	Year no.	5			

Appendix 2: Fox and feral Cat activity model output

Table A2.1. Bayesian non-linear mixed-model parameter estimates for fox activity by treatment. Family: negative binomial (log). Formula: count ~ treat – 1. Number of observations: 240; samples: 4 chains, each with iteration = 2000; warm-up = 1000; thin = 1; total post–warm-up samples = 4000. l-95% CI = Lower 95% confidence interval; u-95% CI = upper 95% confidence interval.

Fixed effects	Estimate	Estimate error	l-95% CI	u-95% CI
Fox control	0.60	0.10	0.41	0.80
No fox control	2.62	0.08	2.46	2.78
Family-specific parameters:				
Shape	1.46	0.20	1.10	1.89

Table A2.2. Bayesian non-linear mixed-model parameter estimates for fox activity by treatment location. Family: negative binomial (log). Formula: count ~ location – 1. Number of observations: 240; samples: 4 chains, each with iteration = 2000; warm-up = 1000; thin = 1; total post–warm-up samples = 4000. l-95% CI = lower 95% credible interval; u-95% CI = upper 95% credible interval.

Fixed effects	Estimate	Estimate error	l-95% CI	u-95% CI
Annya	2.69	0.14	2.42	2.96
Hotspur	2.67	0.14	2.40	2.96
LGNP-north	2.51	0.14	2.24	2.79
Cobboboonee	0.78	0.17	0.43	1.13
LGNP-south	0.47	0.18	0.11	0.81
Mt Clay	0.54	0.18	0.18	0.91
Family-specific parameters:				
Shape	1.44	0.20	1.09	1.87

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