Glenelg Ark—2023 monitoring and evaluation update

A. Robley, P.D. Moloney and E. Le Duc

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Front cover photo: (a) Red Fox; (b) feral cat; (c) DEECA crew monitoring native species' (d) and setting bait station; (e) Long-nosed Potoroo; and (f) Southern Brown Bandicoot (photographer: Ethan Le Duc).

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Glenelg Ark—2023 monitoring and evaluation update

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Context:

Launched in 2005, the Glenelg Ark project aims to support the recovery of specific native mammal species threatened by Red Fox (*Vulpes vulpes*) predation. That year, continuous landscape-scale fox baiting was implemented across 90,000 ha of state forest and national park in south-western Victoria. Three native mammal species, identified as vulnerable to fox predation due to their low numbers, fragmented distributions, and susceptibility to fox predation, were selected for monitoring: the Common Brushtail Possum (*Trichosurus vulpecula*), Long-nosed Potoroo (*Potorous tridactylus*), and Southern Brown Bandicoot (*Isoodon obesulus*). This report provides an update on the fox control and monitoring efforts of the Glenelg Ark project for 2023. Covering the monitoring period from 2005 to 2023, this report re-evaluates the factors influencing the drivers of occupancy for the three target species, including factors other than fox control, and updates the outcomes of the monitoring program.

Aims:

The aims of this report were to:

- update information on the outcomes of the fox-control operation and the responses of target native species as of 2023
- aid land managers and policy groups in decision-making regarding the project's future directions.

Methods:

To evaluate differences in fox occurrence and native species response between areas with fox control (Fox Control Monitoring Locations, FCMLs) and without fox control (No Fox Control Monitoring Locations, NFCMLs), presence/absence data from camera traps deployed in 2023 were added to data from 2005–2022. Data collection and analysis methods matched those in Robley et al. (2023). Seven environmental factors were assessed at both fox-controlled and non-fox-controlled sites to understand their influence on the occupancy of three targeted native species. To represent habitat type we used two variables: the ecological vegetation division (EVD) Tall Mixed Forest (Eastern), and 'other EVDs', which was comprised of several other vegetation divisions where low detection rates of target species prevented the use of separate EVDs in the analysis.

We measured the success of fox control by examining four population parameters: (i) occupancy rate, (ii) colonisation rate (the rate at which new sites are occupied each year), (iii) site survival rate (the proportion of sites occupied in the previous year that are still occupied in the following year), and (iv) site growth rate (the rate at which the number of occupied sites increases over time). These metrics were compared between locations with and without ongoing fox control.

Data on native species detection from 240 monitoring sites, split between three locations with fox control and three without, were used in Bayesian multi-season occupancy models. Changes in site colonisation and survival rates of the three target native mammals were expressed as odds ratios (ORs), indicating the strength of the relationship between variables. Site growth rates for the occupied sites were then calculated. Changes in fox and feral cat activity were assessed from 2013–2023. An activity index was calculated using the number of detections at a camera site scaled to 1500 camera nights and analysed using a negative binomial regression model within a Bayesian framework. The naïve occupancy rates for a range of native species were also calculated.

Results:

Native species response

Common Brushtail Possum

The rate at which sites survived from one year to the next declined with distance to non-native vegetation in NFCLMs but tended to increase with increasing distance to non-native vegetation with fox control, while site survival increased with increasing Terrian Ruggedness Index (TRI) in fox control areas, but not in locations without fox control. Site survival declined with increases in elevation regardless of treatment.

With fox control, the odds of a site becoming occupied (colonised) was 3.33 (95% credible interval (CI): 1.76–6.73) higher in Tall Mixed Forest than in other vegetation types. In the absence of fox control, there was no detectable difference in colonisation between vegetation groups.

Since 2009, the difference in the average annual rate of sites increasing (site growth rate) between locations with and without fox control has been very close to zero (0%, 95% CI: -1–1%), suggesting that most available suitable habitat has been occupied.

Long-nosed Potoroo

Fox control improved the odds of an occupied site remaining occupied by a factor of 2.9 (95% CI: 1.0–8.6) when keeping distance from water at its average value. Incorporating distance from water decreased site survival at locations without fox control but site survival remained constant with increasing distance to water with fox control. Terrain wetness had a positive effect on site survival regardless of the presence of fox control.

Fox control had a positive effect on site colonisation, with site colonisation being higher in the 'other EVDs' group than in Tall Mixed Forest and increasing with elevation. Without fox control site colonisation rates were consistently low and did not differ between forest types or vary with elevation.

Fox control resulted in an increase in the average annual site growth rate by +3.1% (95% CI: -0.00–6.5%).

Southern Brown Bandicoot

When keeping all variables at their mean values, fox control had a positive effect on occupancy by a factor of 3.2 (95% CI: 2.0–5.3).

Including the environmental variables indicated that higher rates of site survival were associated with increasing distance to water (without fox control), and higher elevation (with fox control). Site survival declined with increasing time-since-fire, regardless of treatment.

Colonisation increased with distance to non-native vegetation and decreased with time-since-fire in both FCMLs and NFCMLs

The annual average difference between FCMLs and NFCMLs in bandicoot occupancy growth rate was 0.08% (95% CI: -4.0–2.0%). This effectively indicates that there was no growth in site occupancy by Southern Brown Bandicoots from 2005 to 2023.

Other native species

Twenty-six native species were detected on cameras between 2013 and 2023. Of these, the Short-beaked Echidna (*Tachyglossus aculeatus*) tended to be detected more frequently across the ten years at fox-control sites (n=760) compared with no-fox-control sites (n=540). This observation is worth further investigation in the next round of analysis, as echidnas are known to form part of the fox diet.

The differences in fox and feral cat activity between locations with and without fox control and over time

Overall, the fox activity index at locations without fox control was 3 times higher (95% CI: 1.7–5.0) than the fox activity index at locations with fox control in 2023.

The feral cat activity index varied between locations and over time. Our models provide some support for a reduced feral cat activity index in locations with fox control and indicate a slight decline in the feral cat activity index across locations over time, except for 2022–2023 when cat activity increased at all locations.

Conclusions and implications:

The Glenelg Ark program highlights the positive effects of reducing fox populations on native species such as the Common Brush-tailed Possum, Southern Brown Bandicoot and Long-nosed Potoroo.

The program's adaptive management framework allows for ongoing research and strategic planning to address knowledge gaps and unintended consequences. Further studies, particularly on feral cat management and the response of species like the endangered Heath Mouse (*Pseudomys shortridgei*), are crucial for guiding future management strategies and funding priorities.

Here we provide some recommendations on possible next steps in the monitoring program.

1. Continue the current monitoring to improve the estimates and model predictions for better informed management.
2. Review the variables used in the modelling and update with both site-specific data and more representative remotely sensed variables, e.g. the fraction of absorbed photosynthetically active radiation (FAPAR) as a more informative measure of changes in productivity.

3. Improve our assessment of fox and feral cat densities across all sites, through (i) data derived from genetic material collected from scats, and/or (ii) the use of distance-sampling using data collected from camera traps.
4. Commence planning for the integration of feral cat control. A possible design for the rollout of feral cat control is provided in Robley et al. (2019). This approach would continue to add to the current long-term monitoring dataset, but would allow for the integration of feral cat control.
5. Look for opportunities to assess the response of small mammals to fox control, in particular the Heath Mouse.
6. Include Short-beaked Echidna response in the 2024 data analysis.

1 Introduction

The Red Fox (*Vulpes vulpes*, hereafter the fox) has 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).

Since its inception in 2005, the Glenelg Ark project has implemented continuous, large-scale Red Fox baiting over 90,000 ha of state forest and national park in south-western Victoria. The project's monitoring and evaluation efforts have focused on assessing the impact of fox control on fox activity and the occupancy rates of three native mammal species at risk from fox predation: the Common Brushtail Possum (*Trichosurus vulpecula*), Long-nosed Potoroo (*Potorous tridactylus*), and Southern Brown Bandicoot (*Isoodon obesulus*). These species were selected for monitoring due to their low numbers in the area (Robley et al. 2011), patchy distributions (Menkhorst 1995), and susceptibility to fox predation (Seebeck, 1978). Studies have shown that these species respond positively to reduced fox presence (Kinnear et al. 2002; Arthur et al. 2012).

The presence of predators, such as foxes, likely forces these species to persist in refuges that may not reflect their typical habitat needs. According to Hutchinson's (1978) niche concept and further supported by Kinnear et al. (1988), fox predation alters a species' realised niche by increasing its need for protective shelter and nearby food. When predation pressure is removed, these requirements lessen, allowing for niche expansion, as observed in the Black-flanked Rock-wallaby (*Petrogale lateralis*) when foxes were controlled (Kinnear et al. 2002). This relaxation may be reflected in various occupancy metrics over time.

Environmental factors also play a role in species distribution (MacKenzie et al. 2017). To account for these influences, several explanatory variables were included in the Glenelg Ark's dynamic spatial occupancy models (Royle and Kéry 2007) to evaluate the native species' response to fox control.

We measured the success of fox control by examining four population parameters: (i) occupancy rate, (ii) colonisation rate (the rate at which new sites are occupied each year), (iii) survival rate (the rate at which previously occupied sites remain occupied), and (iv) growth rate (the rate at which the number of occupied sites increases over time). These metrics were compared between locations with and without ongoing fox control.

We predicted that effective fox control at Glenelg Ark would lead to niche expansion in the target species, indicated by:

1. higher colonisation rates associated with fox control, suggesting that reduced predation pressure allows populations to expand into new sites
2. higher site survival rates in areas with fewer foxes, indicating better survival rates
3. greater overall growth rates at locations with fox-control compared to those without fox control.

This fourteenth annual report provides an update on the Glenelg Ark project, building on the previous report (Robley et al. 2023), and highlighting the project's progress in managing fox threats and monitoring the responses of three native species vulnerable to fox predation.

This report includes new data from the 2023 monitoring of the fox-control operation and target native species. It introduces a revised occupancy modelling approach that incorporates plausible environmental variables to explore the drivers of species responses to reduced predation risk. Additionally, future directions for the monitoring and evaluation of Glenelg Ark are suggested, providing land managers, policymakers, and the community with the information needed to make informed decisions about the success and future of this large-scale fox control initiative.

2 Methods

Descriptions of the study site, fox control operation, data collection and analytical approach used are summarised below, for a full description see Robley et al. (2023).

2.1 Location

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 encompasses 90,000 hectares of public land (Figure 1).

Fox control efforts have been concentrated in the southern half of the operations area to broadly reduce fox numbers across public lands. Ideally, random allocation of fox control across public land blocks would have enhanced the assessment's rigor by better isolating the impact of fox control ('the treatment') on native species occurrence ('the response'). However, this was not possible for operational and logistic reasons.

Fox baiting was conducted using commercial shelf-stable baits containing either sodium fluoroacetate (1080) or para-aminopropiophenone (PAPP). These baits were buried at designated bait stations (Figure 1). The stations were checked, and any taken baits were replaced, every two weeks throughout the year.

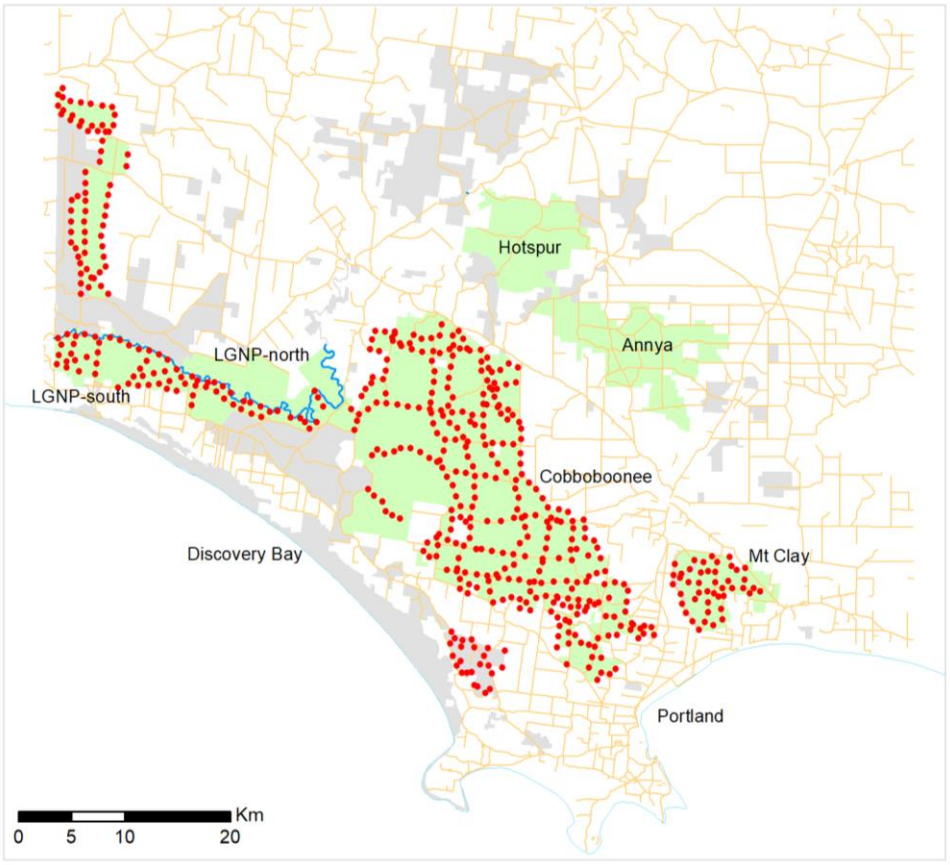

Figure 1. Glenelg Ark operational areas.
Green = Glenelg Ark operational areas; red dots indicate poison bait stations; pale grey = other public land.

2.2 Monitoring and evaluation design

Three fox-control monitoring locations (FCMLs) and three no-fox-control monitoring locations (NFCMLs) were used to assess the benefits of fox control to native species (Figure 2). There had been no fox control in the FCMLs and NFCMLs before 2005.

The monitoring locations were:

1. Annya State Forest (NFCML; 8520 ha)
2. Hotspur State Forest (NFCML; 6940 ha)

3. Lower Glenelg National Park – North (LGNP-north; NFCML; 4659 ha) (separated from LGNP-south by the Glenelg River)
4. Cobboboonee National Park (FCML; 9750 ha)
5. Lower Glenelg National Park – South (LGNP-south; FCML; 8954 ha)
6. Mount Clay State Forest (FCML; 4703 ha).

2.3 Data collection

Monitoring was first conducted in winter 2005, before the commencement of poison baiting, and then was usually undertaken in spring (2005, 2008–2023). In 2006, sampling for monitoring was conducted in late winter, and the spring 2007 samplings at Mount Clay and Hotspur were delayed until the 2007–2008 summer.

Within each of the six locations, 40 monitoring sites were established (Figure 2). The placement of the monitoring sites was chosen 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 within an EVC was proportional to the size of the preferred habitat within each FCML and NFCML. The positions of the monitoring sites within locations were randomly assigned but constrained to be within 50 m of tracks. From 2005 to 2012, at each monitoring site, nine 'Handiglaze' hair-collection tubes (Murray 2005) 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 tape replacements represented four repeat surveys of the monitoring site per sampling period. Microscopic examination of hairs allows for the identification to species level.

Hair-tubing was discontinued from spring 2013, and a single digital camera (Reconyx RapidFire HC600, Reconyx, LLP Wisconsin, USA) was randomly set at one of four possible points within a hair-tube grid at each monitoring site. Cameras were attached to the nearest tree 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.

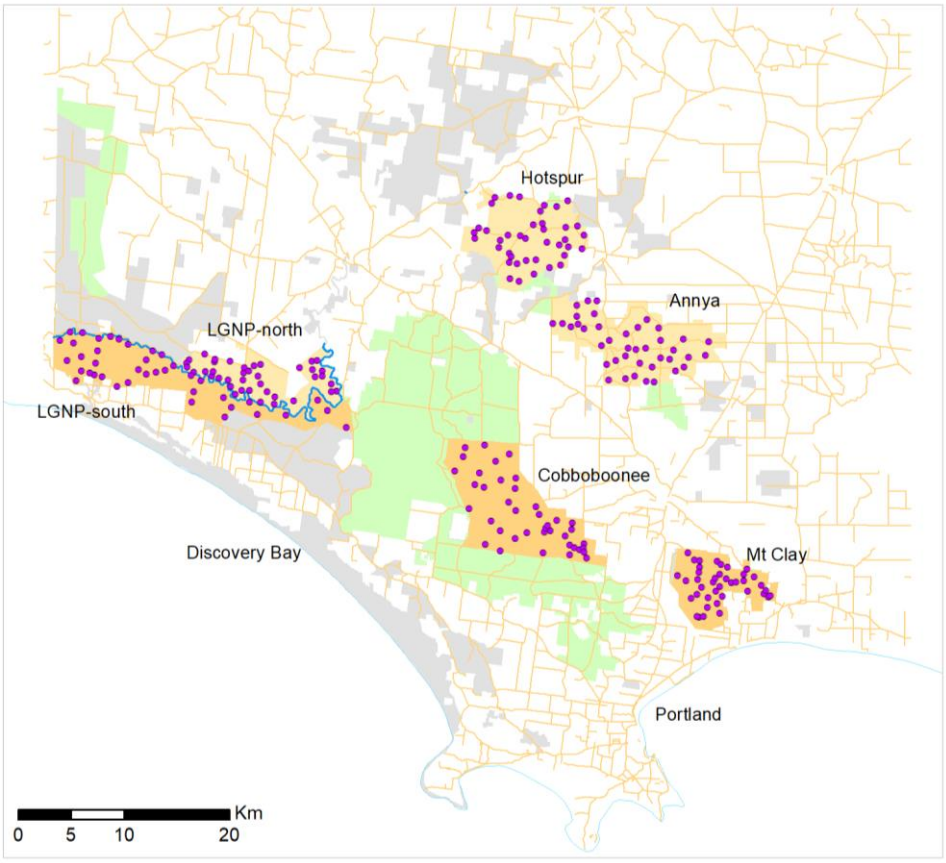

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Figure 2. Monitoring sites in the 'fox-control monitoring locations' (FCMLs; dark-tan areas) and 'no-fox-control monitoring locations' (NFCMLs; pale-tan areas) are indicated by purple dots.
LGNP = Lower Glenelg National Park.

2.4 Species occupancy

A multi-season occupancy model (MacKenzie et al. 2017) was utilised to estimate occupancy (ψ), detection (p), local colonisation (γ), and local survival (η) rates for the Common Brushtail Possum, Long-nosed Potoroo, and Southern Brown Bandicoot. The model was developed in a Bayesian framework using a space-state formulation (Royle and Kéry 2007) and considered six locations, three with fox control (Cobboboonee National Park, Mount Clay State Forest, and Lower Glenelg National Park – South) and three without (Annya State Forest, Hotspur State Forest, and Lower Glenelg National Park – North) with all six locations considered fixed effects in the model.

The models included several site-level covariates affecting the local survival and colonisation rates (Table 1). The model comparisons and analyses were performed using Bayesian methods to determine the impact of these covariates on the occupancy dynamics of the target species.

If there was evidence that the covariate was important (i.e. the 95% high-density interval or 95% confidence interval excluded 0), then that covariate was included in a combined model for that rate. Only the final combined model has been reported (see Table A2 for definitions of model parameters).

Table 1. Description of the site-level covariates used in the multi-season occupancy models.

Covariate	Description
Distance to non-native vegetation (DTNV) patches of >30 ha	Distance in metres to the nearest patch (>30 ha) of non-native vegetation, e.g. pine plantation, open pasture. Invasive predators prefer edges, so the distance to substantial non-native vegetation was considered (DELWP 2019; Geary et al. 2020).
Distance to water (DTW)	The distance to the nearest stream, river or permanent wetland from the camera monitoring station (in metres). Reflects habitat complexity and productivity, influencing shelter and food availability (Beven and Kirby 1979).
Elevation	The elevation above sea level of the camera station. Influences rainfall, moisture, and temperature gradients, affecting resource availability.
Vegetation group	Two categories were used to describe vegetation groups representing habitat – one was the EVD Tall Mixed Forest (Eastern) and the second comprised of a grouping of all other ecological vegetation divisions (‘other EVDs’).
Terrain ruggedness index (TRI)	A measure of the difference in elevation between a centre cell and the eight cells directly surrounding it. The eight elevation differences were squared and averaged. The square root of this average result was a TRI measurement for the centre cell. High ruggedness can limit predator movement and predation rates (Hohnen et al. 2016; McDonald et al. 2017; Stobo-Wilson et al. 2020).
Time-since-fire (TSF)	Time (in years) since the camera site was last recorded as being burnt. Used to account for the time since the last fire, impacting habitat structure and resources (food and shelter).
Topographic wetness index (TWI)	A quantitative measure of the terrain-driven variation in soil moisture. TWI is calculated as log to the base e (specific catchment area/slope) and estimates the relative wetness at a camera site. TWI impacts vegetation and food sources (Beven and Kirkby 1979; Lobert 1990; Riley et al. 1999; Gallant and Austin 2012; Nuske et al. 2017; DELWP 2020).
Treatment	A binary variable that indicates whether or not fox control occurred at a location: 0 = no fox control, 1 = fox control.

The models accounted for variations in daily detection rates depending on whether a hair-tube or camera was used for detection. Additionally, they considered differences in Long-nosed Potoroo and Southern Brown Bandicoot detection based on whether Common Brushtail Possums were detected at the site in a hair-tube. This adjustment was made because hair-tubes could be overwhelmed with Common Brushtail Possum hairs, potentially hindering the collection of hair from other species, and leading to the

underreporting of Long-nosed Potoroos and Southern Brown Bandicoots when Common Brushtail Possums were present.

Odds ratio

The model calculates colonisation and survival equations in the log-odds (logit) scale, which can range from negative to positive infinity. These parameters are transformed into a more interpretable scale when discussing their effects by using the odds ratio (OR). The OR measures the strength of the association between an explanatory variable and an outcome and can range from zero to infinity. It represents the ratio of the odds of an outcome occurring given a particular event to the odds of the outcome not occurring. An OR less than 1 indicates a decrease in the odds of the event occurring, while an OR greater than 1 indicates an increase. An OR of 1 suggests no detectable effect. For instance, if the chance of detecting a bandicoot at a location without fox control is 20%, the odds would be 0.25:1. If the chance at a location with fox control is 60%, the odds would be 1.5:1. Comparing these odds, the OR for detection at a fox-control site would be 6, implying a six-fold increase in the odds of detection compared to a no-fox-control site. Applying this OR to a different area where the detection rate without fox control is 10% (=0.111 odds), we would expect a 40% (=0.666 odds) chance of detection at a fox-control site.

Growth rate

We derived the growth rate from the posterior distributions for the number of occupied sites. The growth rate compares the current occupancy rate with the previous season's rate:

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

A growth rate greater than 1 indicates increasing occupancy, while a rate less than 1 indicates decreasing occupancy. A rate of 1 shows no change. To assess the impact of fox control on growth rates, we converted the average growth rate to a percentage and calculated the difference between locations with and without fox control. For instance, if the annual growth rates at a fox control location were 110%, 120%, 110%, 90%, 100%, and 110%, the net change would be 144%, with a geometric mean of 106.2%, indicating a 6% annual increase in site occupancy.

The models were constructed in JAGS (Plummer 2003) via R (R Core Team 2022) using the package R2jags (Su and Yajima 2015). Convergence was achieved when the Gelman-Rubin convergence diagnostic (scale reduction factor) was less than 1.05 for all parameters (Gelman et al. 2004). Model selection involved running models with each variable separately and including a variable in the final model if its 95% confidence interval excluded 0, indicating its importance.

2.5 Fox and feral cat activity

From 2013 to 2023, we used presence and absence data from 40 camera traps in three fox-controlled (FCMLs) and three non-fox-controlled monitoring locations (NFCMLs) to calculate an activity index for foxes and feral cats.

The annual activity index was scaled to a per 1500 camera nights basis and analysed using a negative binomial regression within a Bayesian framework (McCarthy, 2007; Hilbe, 2011). Five models were developed to explore differences between locations and temporal changes.

1. Null Model: Assumes the activity index is constant across all locations and years.
2. Location Model: Assumes the activity index varies by location but is constant over years.
3. Independent Location and Year Model: Assumes the activity index varies independently across locations and years.
4. Interacting Location and Year Model: Assumes the activity index varies by year for each location separately.
5. Location and Year Model: Assumes that there is no interaction between years and fox-control status, with the activity index varying independently across locations and years.

Model comparison was done using leave-one-out cross-validation, with significance determined by 95% credible intervals excluding zero. Bayesian models were constructed in STAN using (Carpenter et al. 2017) the brms package (Bürkner 2017) in R (R Core Team, 2021), with non-informative priors and No-U-Turn sampling. Convergence was confirmed visually and with the Gelman-Rubin diagnostic (Gelman et al. 2004), ensuring model adequacy through residual plots and posterior predictive checks.

3 Results

3.1 Initial occupancy, survival, colonisation, and growth rates

Several environmental variables were included in the final model for the three target native mammal species. There was no single or set of common environmental variables that consistently explained relationships with the odds of a site being occupied, surviving, or being colonised for any of the three species. The presence of fox control at locations was positively associated with the odds a site was both colonised and endured for Long-nosed Potoroos and Southern Brown Bandicoots, and in combination with other variables for Common Brush-tailed Possums.

3.1.1 Common Brushtail Possum

Occupancy

None of the modelled covariates were important for determining initial occupancy, i.e., occupancy in 2005 pre-baiting (Table A3-A).

The number of occupied sites increased steadily from 2005–2009 across all locations, before decreasing from 2009–2011 across all locations, and then increasing and remaining steady from 2018 to 2020, with another drop in 2021 and signs of recovery since then. However, there was clear separation between FCMLs and NFCMLs from 2015, with the occupancy rate of Common Brush-tailed Possums being higher at sites in FCMLs (Figure 3).

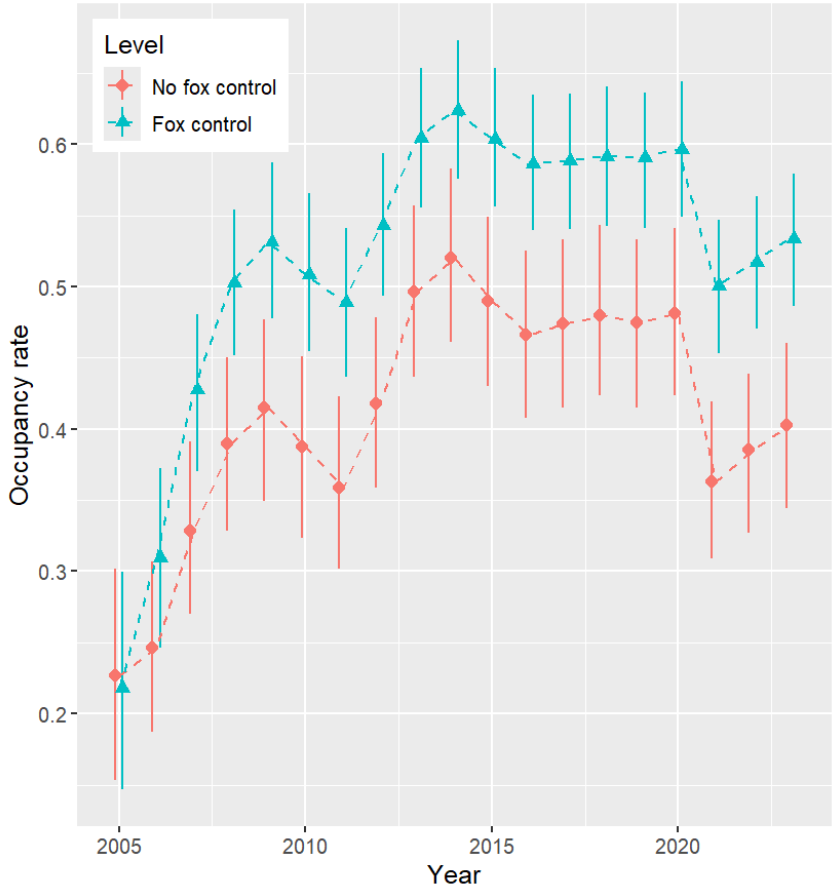

Figure 3. Occupancy rates for the Common Brushtail Possum over time by fox control status.

The symbols indicate the median fitted values, and the bars represent the 95% credible intervals.

Site survival

Survival declined with distance to non-native vegetation in NFCLMs but tended to increase with increasing distance-to-non-native-veg in FCLMs, while survival increased with increasing TRI in fox control areas but

not in NFCLMs. Site survival declined with increases in elevation regardless of treatment (Table A3-B; Figure 4).

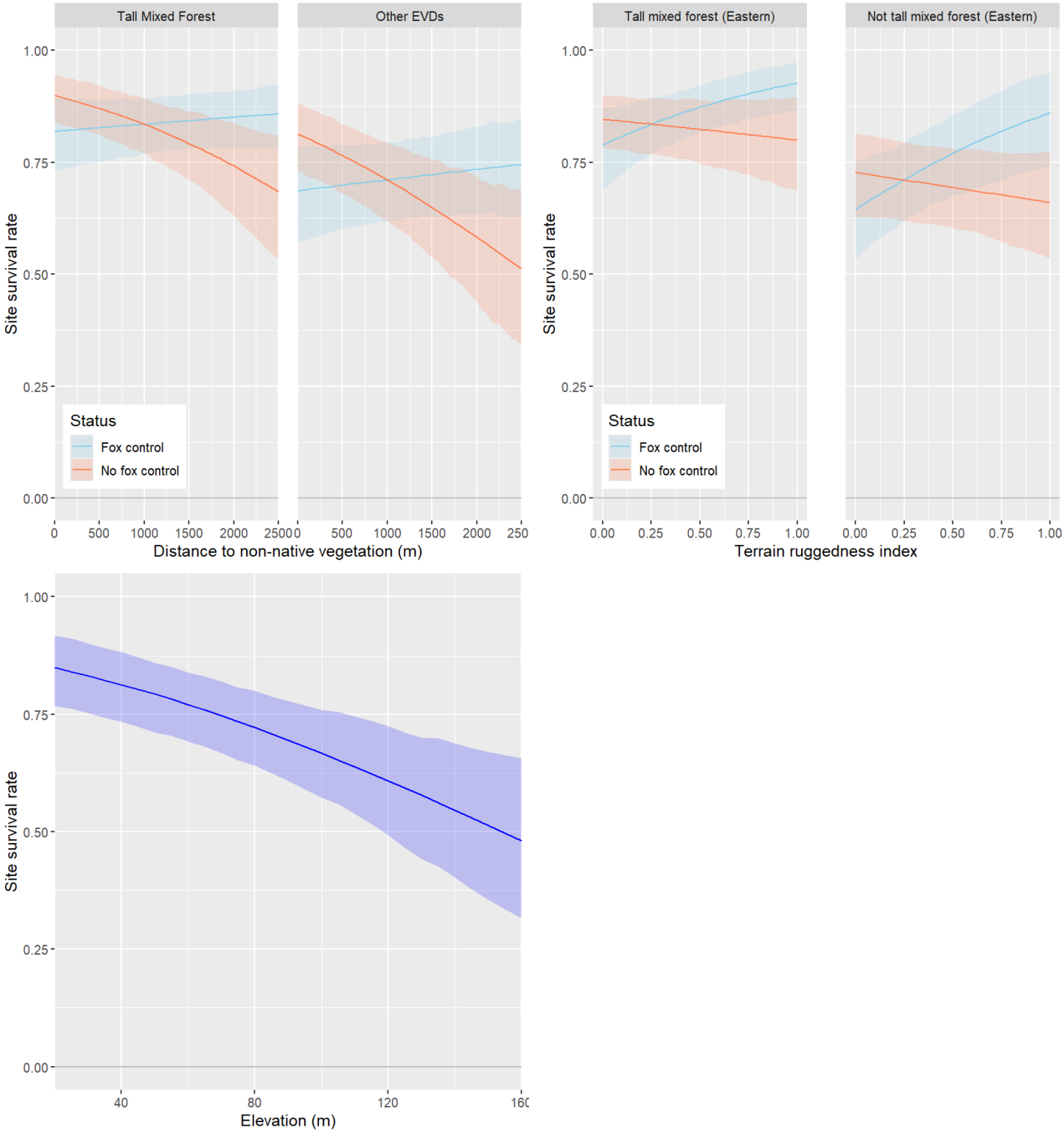

Figure 4. Estimated site survival rates for the Common Brushtail Possum in relation to distance to non-native vegetation, terrain ruggedness, ecological vegetation division, and elevation given all other covariates were held at their mean values.

The lines indicate the median fitted values, and the shaded area represent the 95% credible intervals.

Site colonisation

In FCMLs, the odds of an unoccupied site becoming occupied was 3.33 (95% credible interval (CI): 1.76–6.73) higher in Tall Mixed Forest than in 'other EVDs'. In the absence of fox control, there was no detectable difference in colonisation between EVD classifications.

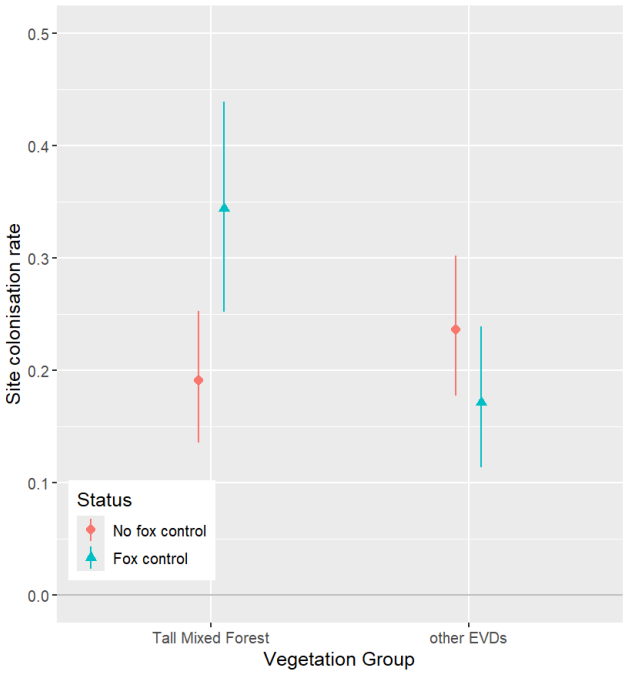

Figure 5. Estimated site colonisation rates for the Common Brushtail Possum in relation to ecological vegetation division, given all other covariates were held at their mean values.

The symbols indicate the median fitted values, and the bars represent the 95% credible intervals.

Growth rates

The annual average growth rate of Common Brushtail Possum occupancy in NFCMLs was 101% (95% CI: 100–103%), while in FCMLs the growth rate was 101% (95% CI: 100–107%). There was no difference in average annual growth rate (0%, 95% CI: -1–1%) at sites in FCMLs compared to at sites in NFCMLs.

3.1.2 Long-nosed Potoroo

Occupancy

None of the modelled covariates were important for determining initial occupancy (Table A4-A).

The number of occupied sites has remained steady in both FCMLs and NFCMLs over time. There is strong evidence that the average occupancy rate for Long-nosed Potoroo in FCMLs was greater than in NFCMLs and has been so since 2008 (Figure 6).

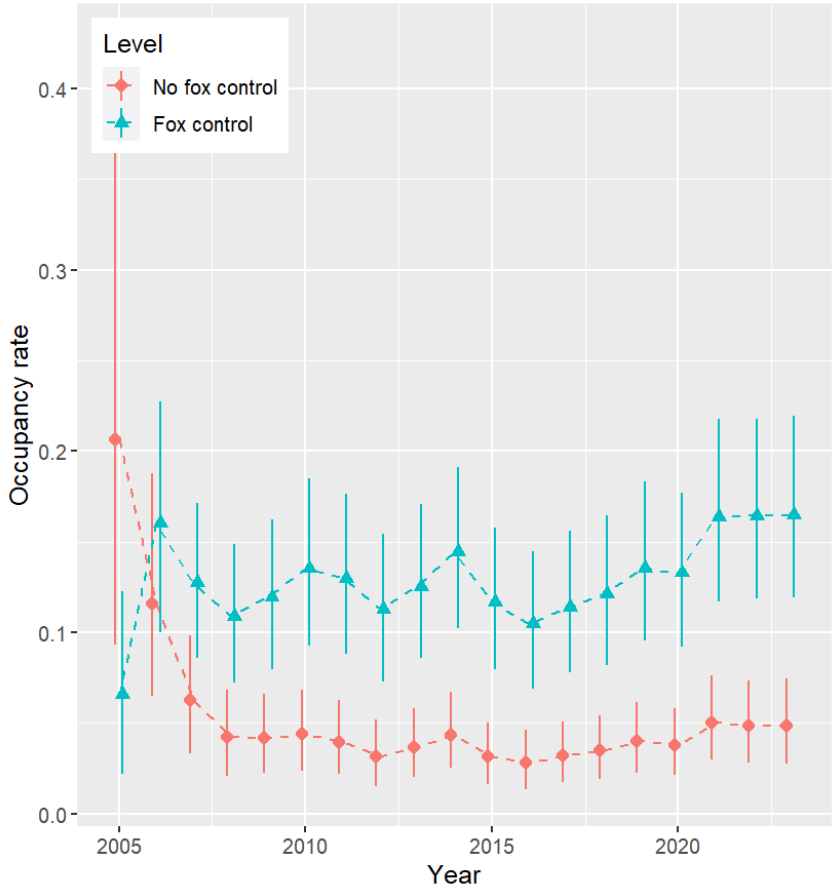

Figure 6. Occupancy rates for the Long-nosed Potoroo over time by fox control status and the difference in that occupancy.

The symbols indicate the median fitted values, and the bars represent the 95% credible intervals.

Site survival

Site survival decreased with distance to water in NFCMLs but was constant with increasing distance to water FCMLs (Table A4-B; Figure 7).

At the average distance to water, the odds of an occupied site remaining occupied was larger by a factor of 2.9 (95% credible interval 1.0–8.6) in FCMLs than in NFCMLs.

Site survival rates increased with increasing TWI regardless of the presence of fox control (Figure 7).

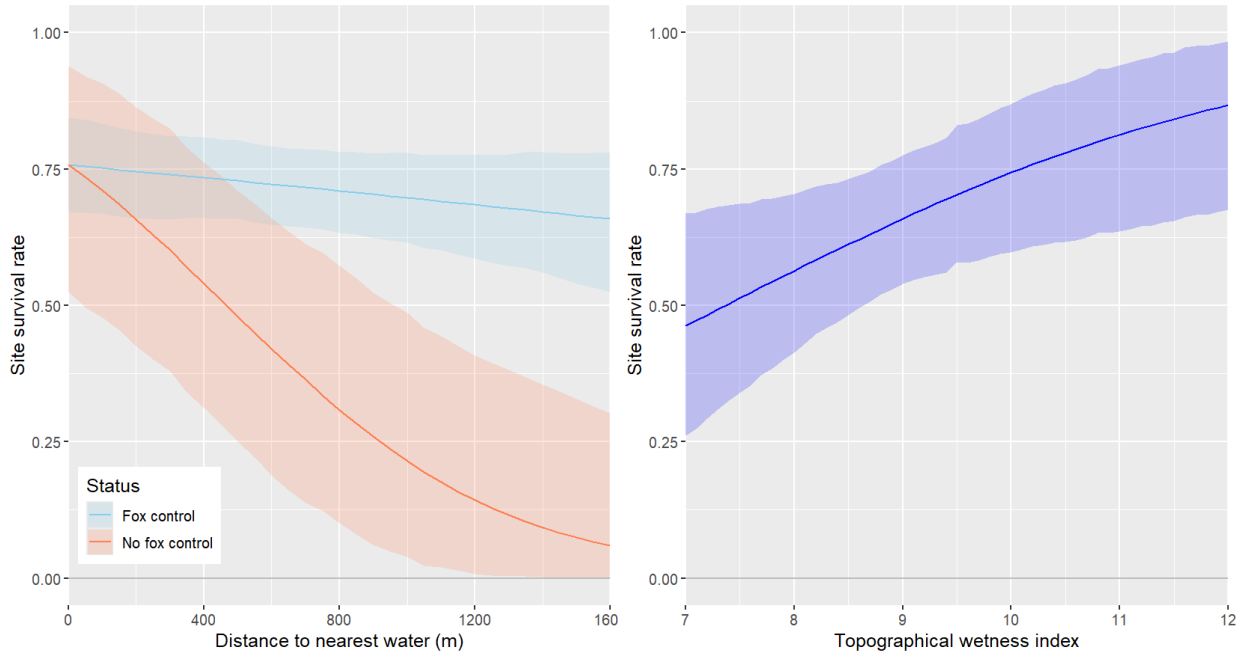

Figure 7. Estimated site survival rates for the Long-nosed Potoroo in relation to distance to nearest water, by fox-control status, and topographical wetness index, given all other covariates were held at their mean values.

The lines indicate the median fitted values, and the shaded areas represent the 95% credible intervals.

Colonisation

At sites in FCMLs, the odds of an unoccupied site becoming occupied was larger by a factor of 25 (95% CI: 11–62) than at an equivalent site in NFCMLs.

In FCLMs, site colonisation was higher in other EVDs than in Tall Mixed Forest and increased with increasing elevation. Colonisation rates were consistently low and did not differ between vegetation types or vary with elevation in NFCLMs (Table A4-C; Figure 8).

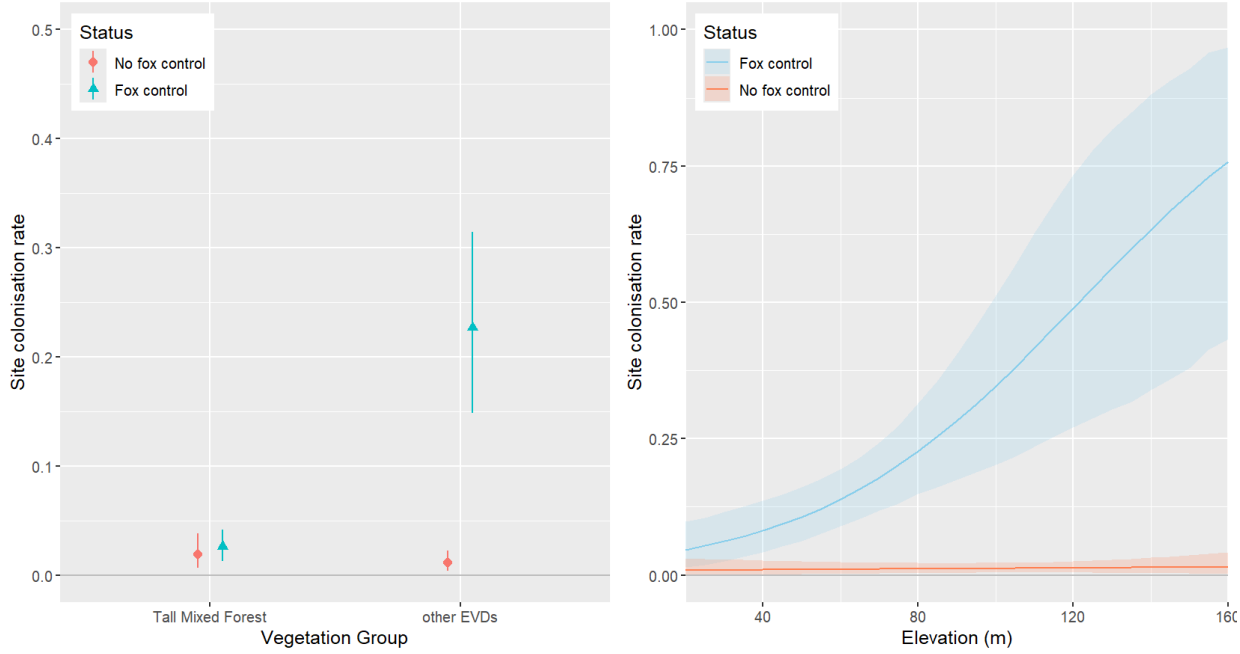

Figure 8. Estimated site colonisation rates for the Long-nosed Potoroos in relation to vegetation group and elevation, by fox-control status, given all other covariates were held at their mean values.

The lines (blue – fox control, red – no fox control) indicate the median fitted values, and the shaded areas represent the 95% credible intervals.

Growth rate

Growth rates in both FCMLS and NFCMLs have remained around zero (no relative change in population). However, the growth rate at FCMLs has been consistently greater than in NFCMLs. The annual average growth rate in NFCMLs was 99% (95% CI: 95–102%), while the growth rate in FCMLs was 102% (95% CI: 99–104%), with the difference being a net annual average increase of +3.1% (95% CI: 0.00–6.5%).

3.1.3 Southern Brown Bandicoot

Occupancy

The only covariate that influenced initial occupancy rates was elevation in FCMLs (Table A5-A). At sites with greater elevation, the initial occupancy rate was higher in NFCMLs and lower in FCMLs.

Overall occupancy rate (considering all important covariates) has been consistently higher in FCMLs than in NFCMLs since 2006. It has also been relatively consistent through time, with indications of two years of increases in 2022 and 2023 across both FCMLs and NFCMLs (Figure 9).

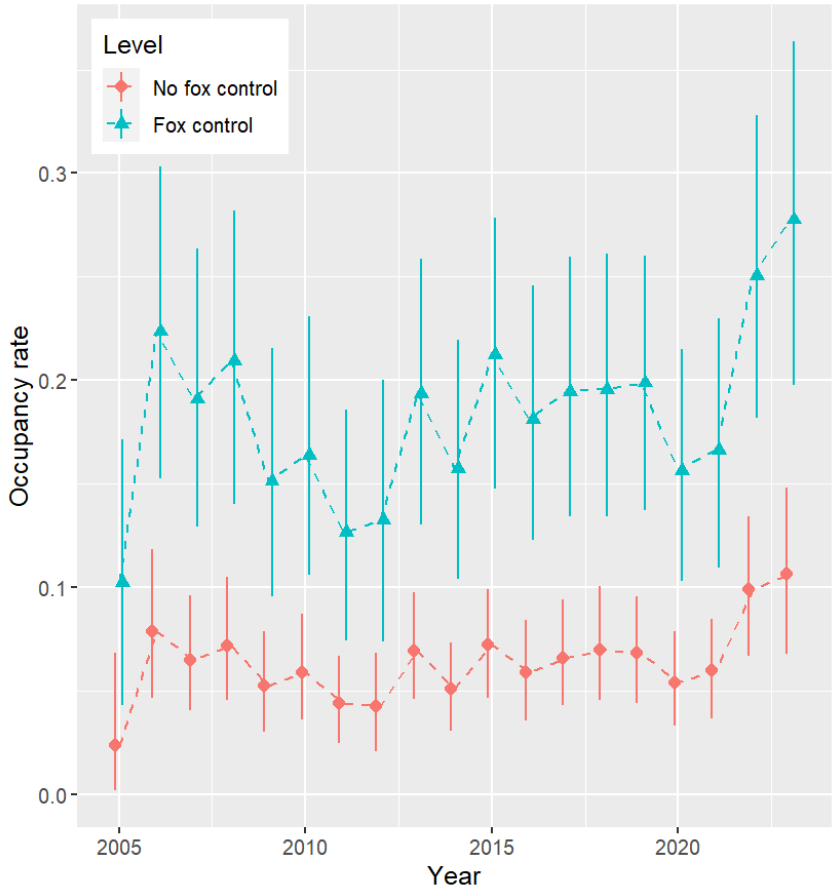

Figure 9. Occupancy rates for the Southern Brown Bandicoot over time by fox control status.

The line is the median occupancy rate, and the vertical bars represent the 95% high density interval.

Site survival

The probability that a site survived declined with increasing time-since-fire in both FCMLs and NFCMLs (Table A5-B; Figure 10).

At sites further away from water in FCMLs, the probability a site survived tended to decline. At sites in NFCMLs, the opposite occurred, with the probability of site survival increasing further form water.

At sites in FCMLs, sites with higher elevation were associated with higher local survival, whereas the opposite occurred at sites in NFCMLs.

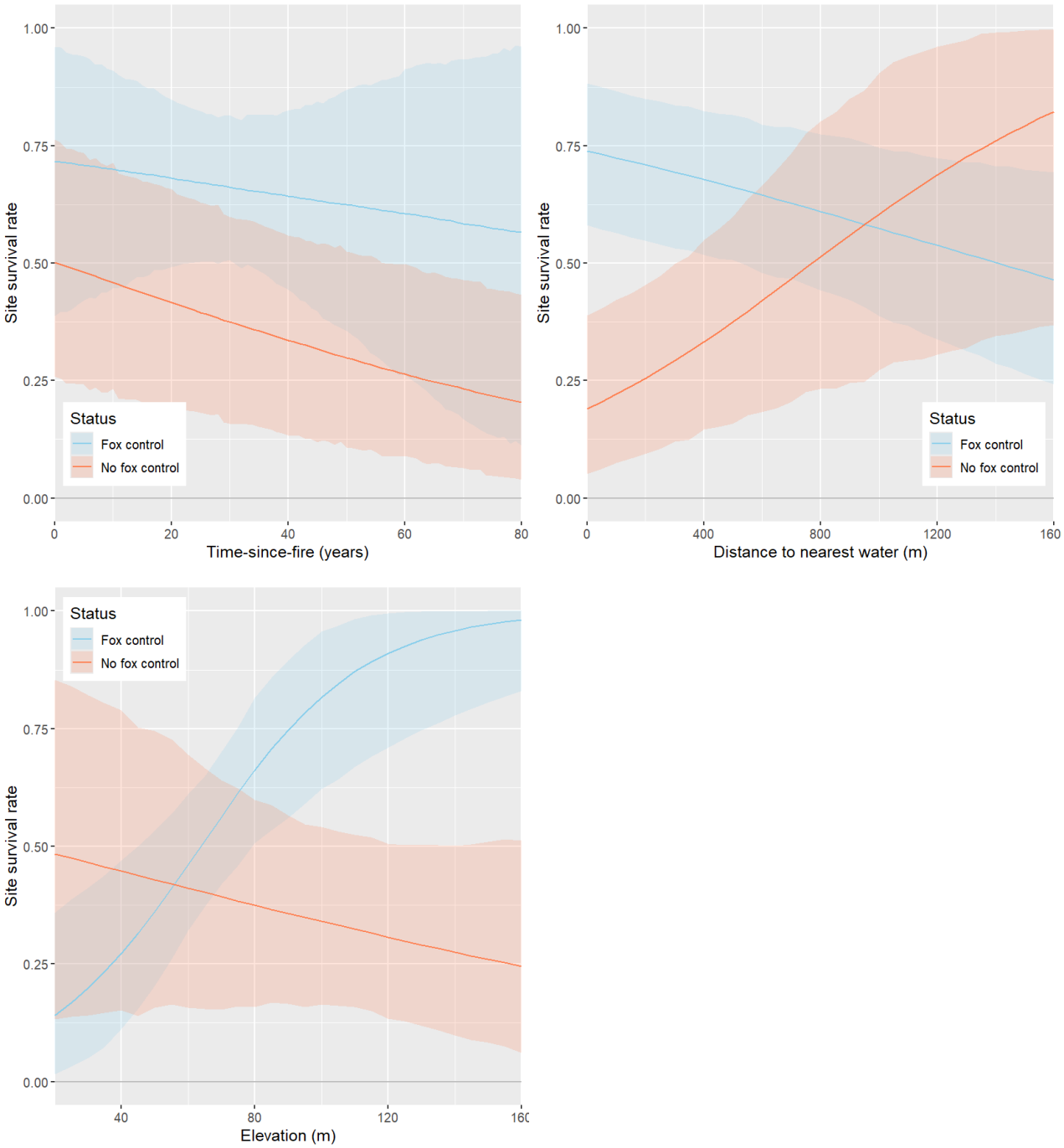

Figure 10. Site survival rate for the Southern Brown Bandicoot across different times-since-fire, distances to nearest water and elevations separated by fox control status, given all other covariates were average.

The line is the median fitted value and the shaded areas represent the 95% high density interval.

Site colonisation

The odds of an unoccupied site becoming occupied were consistently larger in FCMLs than in NFCMLs, by a factor of 3.2 (95% CI: 2.0–5.3). Colonisation increased with distance to non-native vegetation and decreased with time-since-fire in both FCMLs and NFCMLs (Table A5-C; Figure 11).

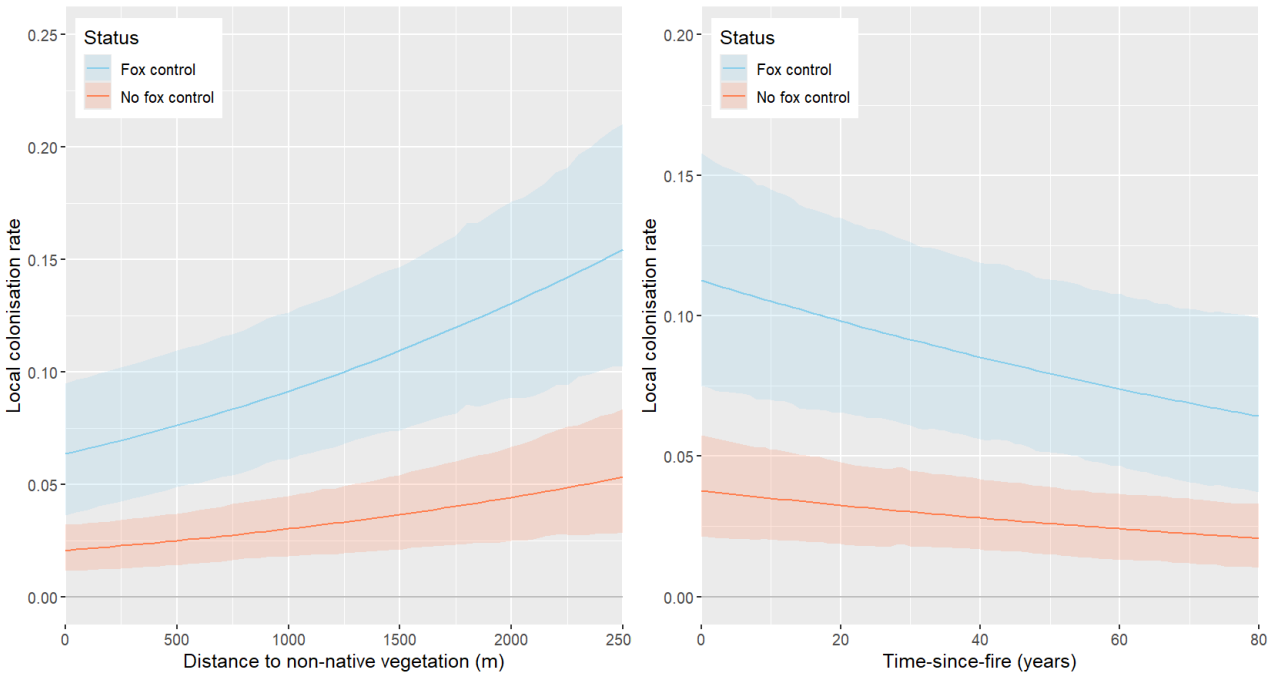

Figure 11. Estimated local colonisation rate for the Southern Brown Bandicoot related to distance to non-native vegetation and time since last fire, separated by fox control status.

The line is the median fitted value and the shaded areas represent the 95% high density interval.

Growth rate

Growth rates in both FCMLs and NFCMLs remained around zero (i.e. there were no relative changes in population) except for in 2022, when they were clearly positive at all locations. However, the reduced growth rate in 2023 could have just been an artifact of the model. The proportion of sites that were estimated to be occupied in 2023 may change once the 2024 data is included. For example, consider the case where a site was occupied in 2022, but Southern Brown Bandicoots were not detected in 2023, then there would be a fraction of the posterior distribution for that site that would be unoccupied. Then, if in 2024 that site detected Southern Brown Bandicoots, the fraction of the posterior distribution for that site that was unoccupied would decrease, because it may be more likely that it was occupied from 2022 to 2024 and not detected in 2023 rather than going from occupied to unoccupied to occupied over the same period.

There was no real difference in average growth rate between fox control treatments (0.8%, 95% CI: -0.4-0.2%), with the annual growth rate in NFCMLs being 103% (95% CI: 100–106%) and the annual growth rate in FCMLs being 102% (95% CI: 100–105%). This effectively indicates that there has been a slight increase in the population growth rate of Southern Brown Bandicoots from 2005 to 2023 in both FCMLs and NFCMLs.

3.2 Predator activity

3.2.1 Fox activity

Over the 11 years of camera trapping, foxes were never detected at 7.5% to 17.5% of sites within the FCMLs (Table 2). However, foxes were detected at least once in nearly all sites inside the NFCMLs. It should be noted that in 2023, foxes were detected for the first time at eight camera sites in FCMLs, including by five cameras (12.5% of cameras) at Mt Clay. The overall fox index in NFCMLs was greater than in FCMLs.

Table 2. Summary of fox detections across all years by location.

Treatment	Location	No foxes detected (% of sites)	Total fox detections	Fox activity index
Fox control	Cobboboonee	7.5	232	22.5
Fox control	Mount Clay	10.0	196	19.1
Fox control	LGNP-south	17.5	154	14.2
No fox control	Annya	2.5	1,143	109.0
No fox control	Hotspur	0.0	957	85.8
No fox control	LGNP-north	0.0	882	88.7

LGNP-north: Lower Glenelg National Park – North; LGNP-south: Lower Glenelg National Park – South.

The fox models showed a preference for the treatment interacting with time model (Table A6). That model showed there was a difference between the locations, with fox activity higher but declining in NFCLs, while remaining consistently low in FCMLs (Figure 12 and Table A6).

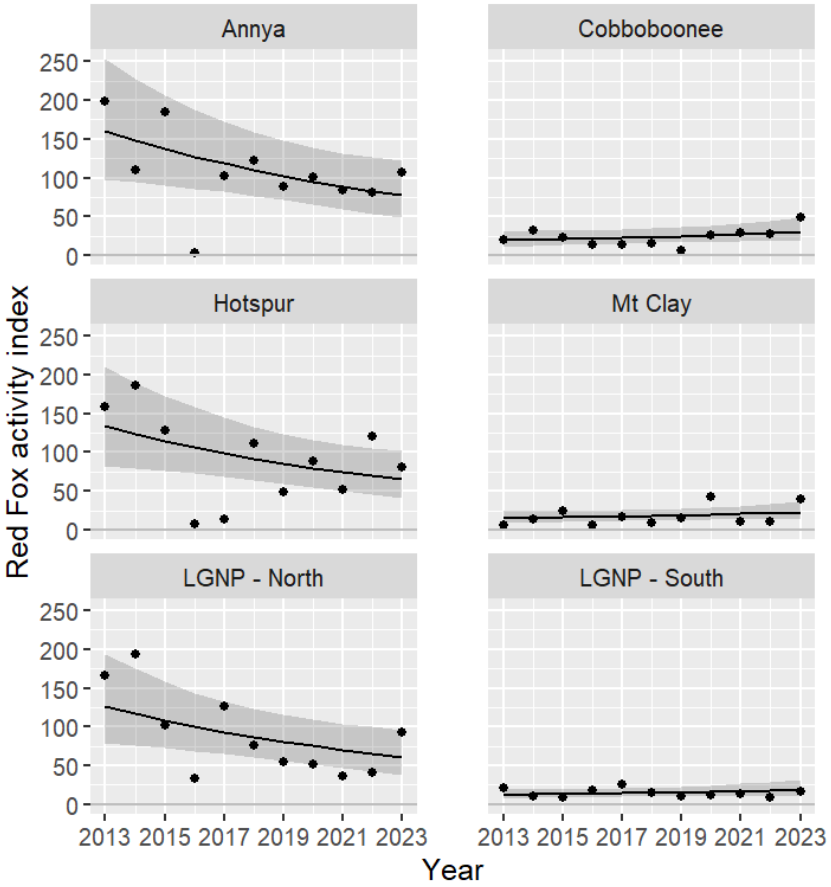

Figure 12. The modelled fox activity index in each FCML and NFCML over time.

The dots indicate the observed fox activity indices, the lines represent the model medians, and the shaded regions represent the 95% credible intervals. The left-hand panels show data for NFCMLs, and the right-hand panels show data for FCMLs.

On average, the fox activity index in NFCMLs declined by 7% per annum (95% CI: 1–12%). In comparison, there was no evidence of a change in FCMLs over time (increase of 4% per annum, with 95% CI: -2–12%). However, given the fox activity index was initially (in 2013) 9.5 times larger (95% CI: 5.5–15.6) in NFCMLs than in FCMLs, they were still 3.0 times larger (95% CI: 1.7–5.0) in 2023.

3.2.2 Feral cat activity

Over the 11 years of camera trapping, feral cats were never detected at less than 25% of sites outside of LGNP North and South. Rather, they were detected at least once at 97.5% (39 out of 40) of sites in the LGNP-North and 87.5% (35 out of 40) of sites in the LGNP-South (Table 3). In 2023, six camera sites – two camera sites each at Annya, Mt Clay and LNGP-South – detected feral cats for the first time. The overall feral cat index varied greatly between locations.

The feral cat models showed a preference for the independent location and year model; however, there was also some support for the location only model (Table A7). The best model showed that there was a difference between the locations and that feral cat activity declined at locations over time until 2021, before increasing again (Figure 13).

Table 3. Summary of feral cat detections across all years by location.

Treatment	Location	No feral cats detected (% of sites)	Total feral cat detections	Feral cat activity index
Fox control	Cobboboonee	27.5	96	8.6
Fox control	Mount Clay	55.0	53	4.7
Fox control	LGNP-south	12.5	169	14.5
No fox control	Annya	47.5	55	4.8
No fox control	Hotspur	32.5	90	7.5
No fox control	LGNP-north	2.5	199	18.5

LGNP-north: Lower Glenelg National Park – North; LGNP-south: Lower Glenelg National Park – South.

There were differences in the feral cat activity index across locations (Figure 13), but these differences did not relate to treatment. The feral cat activity index was similar in the average FCMLs and NFCMLs, with the former being 9% larger (95% CI: -20–47%).

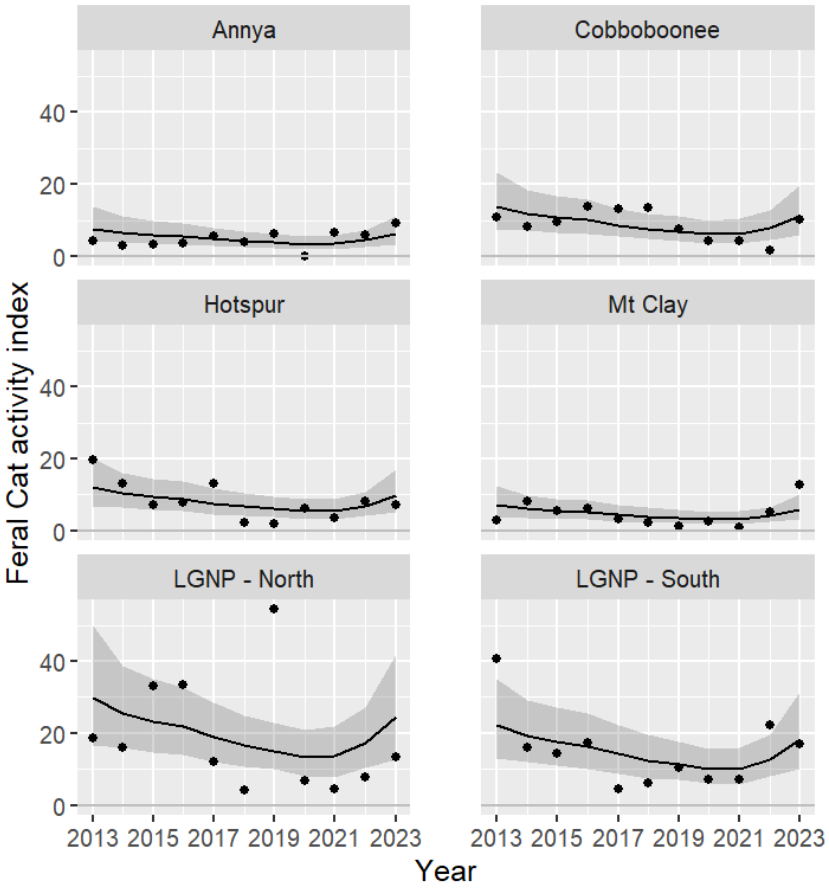

Figure 13. The modelled feral cat activity index at each location over time.

The dots indicate the observed feral cat activity indices, the lines represent the model medians, and the shaded regions represent the 95% credible intervals.

3.4 Other species' naïve occupancy

Forty native and introduced species (not including the three native target species, foxes or feral cats) were detected on cameras from 2013 to 2023, including four introduced mammal, 6 marsupial, 1 monotreme, 1 rodent, 1 reptile, and 23 bird species (Figure A1). Several other species were also detected intermittently during this time; however, we only presented data for species that were detected for at least 6 of the 11 years of camera trapping. The mean naïve occupancy (percentage of sites at which a species was detected) was higher at fox-control sites for Short-beaked Echidna (*Tachyglossus aculeatus)* (Figure A1). The mean naïve occupancy was higher at sites in NFCMLs than at sites in FCMLs for Koalas (*Phascolarctos cinereus*). In comparison, the mean naïve occupancy percentages for all other species were highly variable over time and did not clearly differ between FCMLs and NFCMLs.

4 Discussion

All three target species had higher rates of occupancy across locations subject to 19 years of fox control compared to locations without fox control. Growth rates of occupied sites across all locations were stable over the longer-term, with short term fluctuations likely driven by responses to factors other than predation pressure from foxes. Fox activity was substantially lower where there was long term control in place.

The Glenelg Ark monitoring program employs an occupancy modelling approach to explore the dynamics influencing changes in site occupancy for three native species. Changes in site occupancy can mirror changes in abundance, with site colonisation and persistence likely to reflect birth and survival rates when surveys are conducted over a short period (MacKenzie et al. 2017). By evaluating these rates alongside the factors affecting them, we can gain insights into how reduced predation risk might impact habitat use by the target species.

We made three predictions about the response of the target species to fox control at Glenelg Ark. The first two were:

1. higher colonisation rates associated with fox control, suggesting that reduced predation pressure allows populations to colonise new sites
2. higher survival rates associated with fox control, suggesting that reduced predation pressure allows populations to persist.

These predictions held true for the survival and colonisation rates of Long-nosed Potoroos and the colonisation rates of Southern Brown Bandicoots, with these rates being significantly positively influenced by fox control. Common Brush-tailed Possums tended to use aspects of habitat differently in the presence of fox control. All three species exhibited distinct responses to various biotic and abiotic factors, indicating that reduced predation pressure enables these species to overcome limitations and expand their occupied habitats.

Possum survival and colonisation rates were higher and tended to increase in Tall Mixed Forest with fox control compared to in other EVDs with fox control and as TRI increased. This likely indicates a habitat preference for Tall Mixed Forest, which is more likely to provide shelter (hollows, nesting sites and better food quality; eucalypt leaves account for 72% of the diet of possums in New South Wales [Kerle 1984]). Our findings support those of Pickett et al. (2005) who investigated the influence of predation risk on the foraging behaviour of brushtail possums across a range of fox densities in eucalypt forest and cypress-pine stands. They found no effect of fox removal on behaviour, body condition or reproduction in eucalypt-dominated forests. By contrast, in cypress-pine (more open habitat, poorer food quality), possums travelled further on the ground, used a greater number of feeders, and had remained at feeders longer in low-fox-density areas than in high-fox-density areas.

In areas without fox control, possum survival rates declined as the distance to non-native vegetation and TRI increased, irrespective of the EVD group – with no difference in colonisation rates between EVD types without fox control. It is possible that foxes prefer Tall Mixed Forest, close to non-native vegetation in low TRI areas. Modelling fox occurrence in relation to environmental variables could clarify the effects of distance and EVD in locations without fox control.

Fox control generally resulted in higher survival rates for Southern Brown Bandicoots. While survival and colonisation rates typically declined with increasing time-since-fire, they tended to be higher in areas with fox control. The negative relationship between time-since-fire and colonisation for bandicoots appears counterintuitive. As vegetation recovers post-wildfire, habitat complexity increases, shifting from low complexity immediately post-fire to a more structurally complex forest in later years (Coop et al. 2000), which should provide protection against fox predation. Arthur et al. (2012) observed that bandicoots (*Isoodon obesulus* and *Perameles nasuta* combined) presence initially increased with rising shrub cover post-fire (up to 25 years), but then declined more rapidly than expected, likely due to interactions with feral cats rather than foxes. This relationship with fire is consistent with our findings, where bandicoot colonisation probability was high initially before declining over time, and while the model outcome did not include fox control as a substantial influence, colonisation rates were generally higher in areas with fox control.

Distance to water and distance from non-native vegetation influence bandicoot survival and colonisation. Research indicates that foxes preferentially utilise ecotones or edges, selecting human-modified habitats such as reservoirs, forest edges, and roads (Hradsky et al. 2017). These areas are both productive and offer ample hunting opportunities (Storch et al. 2005). The tendency of bandicoots to colonise new sites away

from open non-native vegetation, such as farm paddocks and pine plantations, suggests an avoidance of areas with higher predation risk.

Potoroos exhibited significantly higher colonisation rates in vegetation communities outside of Tall Mixed Forest under fox control, while colonisation rates were very low and showed no variation between EVD groupings at sites without fox control. This pattern likely reflects a habitat preference for areas outside Tall Mixed Forest and suggests that foxes may limit colonisation within this EVD. According to Bennett (1993), Long-nosed Potoroos are associated with dense ground and shrub vegetation across their geographic range. However, Bennett's study also found that potoroos were present in areas with varied vegetation compositions and densities and were not strongly tied to a specific vegetation type or structural feature. This mosaic of dense and open habitats provided both shelter from predators and abundant food resources in more open areas (Bennett 1993). To better understand the local drivers affecting both potoroos and bandicoots, the collection of detailed site-specific habitat variables from each camera site is recommended.

The relationship between elevation, potoroo and bandicoot parameters remains unclear. Landscape position has been shown to influence the presence of both foxes and Long-footed Potoroos (Lumsden et al. 2012). Lumsden et al. (2012) found that foxes were more likely to occur at sites with either high or low elevation and easterly aspects, but less likely on steep, mid-slope habitats. Conversely, Long-footed Potoroos were somewhat more likely to occur at sites with intermediate elevations, higher stream density, and easterly aspects. The elevation range at our sites was relatively small (sea level to 160 m). Elevation was included as a proxy for soil moisture and temperature gradients, which affect resource availability. However, this may be a poor proxy in our study, and a more informative variable could provide deeper insights. We recommend using the fraction of absorbed photosynthetically active radiation (FAPAR; Qin et al. 2018), which characterises the energy absorption capacity of vegetation canopies and is crucial for estimating the net primary production of terrestrial ecosystems. This variable could help interpret patterns in site occupancy, such as the peaks and troughs observed in Southern Brown Bandicoots, which roughly coincided with significant rainfall events in 2010-2011 and 2020.

The third prediction we made about the target species response was that there would be greater overall growth rates at sites with fox control than at those without fox control.This prediction held true only for potoroos, and even then, to a limited and variable extent. After 19 years of fox control, the growth of occupied sites has stabilised across locations with fox control and remains lower but constant in locations without fox control, resulting in minimal differences between the two. This may indicate that fox abundance has not been sufficiently reduced to eliminate growth limitations, or that other factors, or a combination of factors, such as the availability of suitable habitat, are restricting growth.

In 2005 (pre-fox control), the occurrence of all three species overlapped across all locations, with each species exhibiting distinct responses. Common Brush-tailed Possum occurrence increased at a similar rate across both treated and untreated locations, but with higher rates at treated sites. Long-nosed Potoroo occurrence decreased at untreated sites while initially increasing at treated sites before stabilising. Southern Brown Bandicoot occurrence initially increased at all locations, with higher rates at treated sites, before also stabilising. This suggests that while occurrence is higher at locations with fox control, the populations are now responding to drivers other than reduced fox densities.

An exception to this was the uplift in Southern Brown Bandicoot occupancy from 2021 to 2023. This increase occurred across all locations except LGNPN and was generally more pronounced at locations with fox control. The observation that occupancy and overall growth increased in 2022 but not in 2023 is likely an artifact of the modelling process. Sites occupied in 2022 where bandicoots were undetected in 2023 may have been reoccupied in 2024, leading the model to predict these sites as occupied in 2023, and therefore increasing the predicted number of occupied sites for that year.

Variable selection

The static variables incorporated into our model offer valuable insights into the habitat characteristics influencing species presence. For instance, Tall Mixed Forest appears crucial for possums and potoroos, particularly in tandem with fox control, while proximity to water bodies emerges as significant for bandicoots and potoroos, again in areas with fox control. Selecting the most informative predictors for modelling species response presents a challenge. Ideally, factors directly impacting population growth, survival, distribution, or relevant biotic and abiotic processes should be prioritised (Phillips et al. 2006). While our analysis considered these criteria, future refinement may involve reviewing and potentially adding or removing variables to elucidate any disparities in habitat use between locations with and without fox control.

Time-varying variables, such as time-since-fire, provide insight into temporal changes in species occurrence. Increasing time-since-fire, for instance, emerged as significant for Southern Brown Bandicoots, but not for other species. Another potentially informative variable could reflect changes in productivity. Terrain Wetness Index (TWI), serving as a proxy for soil moisture and vegetation productivity (Kopecky and Cizkova 2010), and Terrain Ruggedness, representing microhabitat diversity (Dilts et al. 2023), offer broad representations

of underlying conditions. However, TWI was found to be only significant for potoroo colonisation. Another promising variable is FAPAR, as previously discussed.

Native species

Twenty-seven native species other than the target species have been detected by camera traps since 2013. Among these, the Short-beaked Echidna has been detected more frequently at locations with fox control, suggesting that either this species has responded positively to the reduction in foxes, or that it was always more common at these locations. This is something that is worth further investigation, and we propose to include the Short-beaked Echidna in next year's analysis. While no other native species has been detected more often across the fox-control locations, this does not necessarily mean they have not benefited from the reduction in foxes.

Foxes and feral cats

The weight of the available evidence indicates that foxes are at lower levels across locations with fox control than at locations without fox control (this report, Rees et al. 2023). Determining the threshold fox density below which prey species populations are no longer limited by predation, remains challenging. For example, FoxNet modelling was incorporated into occupancy models to investigate the impact of the 2019–2020 bushfires in Gippsland (Robley et al. 2022). This work showed that fox density significantly affected the occurrence of Long-footed Potoroo (*Potorous longipes*), the probability of which was zero at a site when fox density was higher than 0.5/km^2. Habitat structure and diversity also influence species survival, highlighting the complexity of predator-prey dynamics.

The fox activity results indicate a slow decline in fox activity at untreated sites, possibly due to long-term control efforts. This is possible because the Annya, Hotspur and LGNPN (no fox control) locations are within probable movement and dispersal distances for foxes (Robley et al. 2016) to the Cobboboonee and Mt Clay (fox control) locations. This trend could be further explored using spatially explicit population models, such as FoxNet (Hradsky et al. 2019).

Predator interactions and the availability of habitat refugia play significant roles in prey mortality rates through interference, competition, or cooperative predation (Stallings and Dingeldein 2012). Furthermore, habitat modifications, such as planned burning, can escalate predator activity (McGregor et al. 2017), posing challenges for management strategies. Feral cats, known for their substantial impact on native wildlife, exhibit heightened densities in areas subject to fox control (Rees et al. 2019), although the relationship is multifaceted. Nevertheless, there is little uncertainty regarding the deleterious effects of feral cats on native fauna within the Glenelg Ark operations area.

Emerging tools like Curiosity® feral cat bait offer promising avenues for landscape-scale feral cat management. Integrated predator control has demonstrated positive outcomes for native species elsewhere. For instance, Comer et al. (2020) documented favorable responses from both the Western Ground Parrot (*Pezoporus flaviventris*) and the Chuditch (*Dasyurus geoffroii*) following five years of integrated fox and feral cat control at a coastal south-western Australian site.

General summary

The findings of the Glenelg Ark program underscore the beneficial impacts of fox reduction on species such as Southern Brown Bandicoots and Long-nosed Potoroos. The results also provide evidence for the potential of habitat quality to interact with the outcome of the fox control effort. Changes to ground vegetation and tree species composition resulting from wildfire or planned burning (Rees et al. 2023a) or the presence of feral cats (Rees et al. 2023b) are factors that most likely influence the degree of fox impact on native species, and the success of fox control in benefiting biodiversity.

We advocate for the initiation of landscape-scale feral cat control planning, slated to commence in the financial year 2025–2026. Robley et al. (2019) offer a potential framework for the implementation of feral cat control. This approach not only contributes to the ongoing long-term monitoring dataset, but also facilitates the integration of feral cat control measures.

The primary objective of the Glenelg Ark project is to mitigate the threat of fox predation on native species, thereby safeguarding or enhancing biodiversity. This project stands out as one of the few long-term (19 years) fox control initiatives in Australia that incorporates ongoing monitoring and encompasses areas both actively managed for foxes and those left untreated. This unique approach provides an unparalleled opportunity to investigate the enduring shifts in prey and predator dynamics and the underlying drivers of these changes. Such comprehensive monitoring programs are vital for yielding ecological insights and are indispensable for advancing the management of ecosystems and natural resources (Lindenmayer et al. 2009).

There are only a handful of extensively documented instances where fox control has resulted in the increased abundance of native species, particularly within open systems (Reddiex and Forsyth 2006). Most

of the success stories originate from fenced areas where foxes (and feral cats) have been eradicated from within enclosures (de Torres and Marlow 2012; Dickman 2012), or from insular habitats such as islands (Jones et al. 2016). Notably, in a review of pest control operations in Australia, only 2.5% of 627 fox control initiatives involved treatment and non-treatment areas and monitored both prey and predator responses, with the Glenelg Ark project being among this small fraction (Reddiex and Forsyth 2006).

The program's adaptive management framework, characterised by its flexibility, enables ongoing research and strategic planning to tackle knowledge gaps and unintended consequences. Further studies, especially regarding the impact of feral cat management and the response of species like the endangered Heath Mouse (*Pseudomys shortridgei),* listed as Endangered in Victoria (DELWP 2022) and Vulnerable under the Environment Protection and Biodiversity Conservation Act 1999 (Cwlth), hold promise for informing future management strategies and funding priorities.

Recommendations

Here we provide some recommendations on possible next steps in the monitoring program.

1. Continue the current monitoring to improve the estimates and model predictions to better inform management.
2. Review the variables used in the modelling and update with both site-specific data and more representative remotely sensed variables, e.g., FAPAR as a more informative measure of changes in productivity.
3. Improve our assessment of fox and feral cat densities across all sites, through (i) data derived from genetic material collected from scats, and/or (ii) the use of distance-sampling using data collected from camera traps.
4. Model fox occurrence in relation to environmental variables to determine whether fox's habitat preferences interact with prey species responses.
5. Commence planning for the integration of feral cat control. A possible design for the rollout of feral cat control is provided in Robley et al. (2019). This approach would continue to add to the current long-term monitoring dataset but allow for the integration of feral cat control.
6. Look for opportunities to assess the response in small mammals to fox control, in particular the Heath Mouse.
7. Include Short-beaked Echidna response in the 2024 data analysis.

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Appendix

Table A1. Ecological vegetation classes within each FCMLs' and 'NFCMLs.

Location	Ecological Vegetation Division (EVD)	Area (ha)	%	Ecological Vegetation Class (EVC)	Area (ha)	%
Mt Clay State Forest	Other EVDs	1597	36.3	Heathy Woodland/Damp Heathy Woodland/Damp Heathland Mosaic	1597	35.6
(fox control)	Tall Mixed Forest	2797	63.7	Herb-rich Foothill Forest	847	18.9
				Lowland Forest	1950	43.4
LGNP-South	Tall Mixed Forest	1319	16.5	Damp Sands Herb-rich Woodland	1319	14.9
(fox control)	Other EVDs	6654	83.5	Damp Sands Herb-rich Woodland/Heathy Woodland Mosaic	2855	32.2
				Damp Sands Herb-rich Woodland/Heathy Woodland/Sand Heathland Mosaic	972	11
				Heathy Woodland/Limestone Woodland Mosaic	2827	31.9
Cobboboonee National Park	Tall Mixed Forest	7557	79.9	Lowland Forest	7557	79.9
(fox control)	Other EVDs	1035	11.0	Wet Heathland/Heathy Woodland Mosaic	1035	11
Hotspur State Forest	Tall Mixed Forest	5332	91.5	Heathy Woodland	2235	32.9
(no fox control)	Other EVDs	493	8.5	Lowland Forest	3097	45.6
				Wet Heathland	493	7.3
LGNP-North	Tall Mixed Forest	2021	45.1	Damp Sands Herb-rich Woodland	2021	43.5
(no fox control)	Other EVDs	2458	54.9	Damp Sands Herb-rich Woodland/Heathy Woodland Mosaic	417	9
				Wet Heathland/Heathy Woodland Mosaic	2041	43.9
Annya State Forest	Tall Mixed Forest	6810	100.0	Damp Sands Herb-rich Woodland	1106	13.5
(no fox control)				Lowland Forest	5704	69.8

Table A2. Parameters and their definitions used in the multi-season occupancy model.

Parameter	Description
t	The survey period since the initial survey in 2005
$Y_{i,t,j}$	Observation status of a species at site i in period t on the j observation: 1 (detected), 0 (otherwise)
$Z_{i,t}$	True occupancy status of a species at site i in period t: 1 (occupied), 0 (otherwise)
$\psi_{i,t}$	The occupancy rate for a species at site i in period t
p_{D_j}	The daily detection rate of a species depending on the device D used on day j at a site, given the site is occupied
$x_{i,t,h}$	Variable of interest h at site i in period t
$\gamma_{i,t}$	Colonisation rate at site i in period t
$\eta_{i,t}$	Survival rate at site i in period t
$\varepsilon_{C,t}$	Random variation in colonisation rates in period t
$\varepsilon_{S,t}$	Random variation in survival rates in period t
σ_C	Standard deviation in the random variation in colonisation rates between periods
σ_S	Standard deviation in the random variation in survival rates between periods

Table A3. Parameter estimates (posterior median and 95% credible limits) and corresponding odds ratios for initial occupancy, local survival and colonisation for the Common Brushtail Possum.

Parameter	Median (95% CI)	Odd ratio (95% CI)	Interpretation
A: Initial occupancy			
Distance to water	-0.31 (-0.95, 0.31)	0.73 (0.39, 1.35)	No influence of initial occupancy
Tall Mixed Forest (Eastern)	0.82 (-0.78, 2.68)	2.27 (0.46, 14.7)	No influence of initial occupancy
Distance to water in fox control area	0.671 (-0.05, 1.471)	1.96 (0.95, 4.35)	No influence of initial occupancy
Tall Mixed Forest (Eastern) in fox control area	9.277 (0.63, 19.9)	10689 (1.88, >4 mil)	Highly uncertain positive relationship with initial occupancy and Tall Mixed Forest in fox control locations
Fox control area	-5.92 (-12.9, 0.08)	0.00 (0.0, 1.09)	No influence of initial occupancy
B: Site survival			
Distance to non-native vegetation	**-0.56 (-0.9, -.22)**	0.57 (0.41, 0.80)	**43% decline in site survival as distance increases**
Terrain ruggedness index	-0.16 (-0.45, 0.12)	0.85 (0.64, 1.13)	No influence on the probability a site remains occupied through time
Tall Mixed Forest (Eastern)	**0.60 (0.16, 1.05)**	**1.83 (1.17, 2.87)**	**An 83% increase in local survival in Tall Mixed Forest (Eastern) compared to in other EVDs**
Elevation	**-0.52 (-0.80, -0.22)**	**0.60 (0.45, 0.80)**	**A 40% decline in local survival with every 40 m increase in elevation**
Distance to non-native vegetation in fox control area	**0.68 (0.25, 1.11)**	**1.98 (1.28, 3.02)**	**98% increase in the odds a site survives compared to in non-fox control areas for every 1 km closer to native vegetation**
Terrain ruggedness index in fox control area	**0.77 (0.22, 1.38)**	**2.16 (1.25, 3.99)**	**For every 500 m change in TRI, the odds slightly more than double compared to in non-fox control areas**
Fox control area	0.12 (-0.28, 0.54)	1.13 (0.75, 1.72)	No influence on the probability a site remains occupied through time
C: Site colonisation			
Terrain ruggedness index	0.11 (-0.11, 0.33)	1.12 (0.90, 1.40)	No influence on the probability a site becomes occupied through time
Elevation	-0.23 (-0.47, 0.02)	0.80 (0.63, 1.02)	No influence on the probability a site becomes occupied through time
Tall Mixed Forest (Eastern)	-0.27 (-0.65, 0.13)	0.76 (0.52, 1.14)	No influence on the probability a site becomes occupied through time
Terrain ruggedness index in fox control area	0.48 (-0.03, 1.0)	1.61 (0.94, 2.73)	No influence on the probability a site becomes occupied through time
Tall Mixed Forest (Eastern) in fox control area	**1.20 (0.56, 1.91)**	**3.33 (1.76, 6.73)**	**A 3.3-fold increase in the odds a site is colonised in Tall Mixed Forest compared to at non-fox control sites**
Fox control area	-0.40 (-0.91, 0.06)	0.67 (0.40, 1.06)	No influence on the probability a site becomes occupied through time

Bold type indicates evidence that the covariate was important. All estimates are on the logit scale. CI = credible interval.

Table A4. Parameter estimates (posterior median and 95% credible limits) and corresponding odds ratios for initial occupancy, local survival and colonisation for the Long-nosed Potoroo.

Parameter	Median (95% CI)	Odd ratio (95% CI)	Interpretation
A: Initial occupancy			
Tall Mixed Forest (Eastern)	1.46 (-1.10, 5.25)	4.31 (0.33, 189.81)	No relationship with sites in Tall Mixed Forest (Eastern)
Tall Mixed Forest (Eastern) in fox control area	(-10.00, -4.15)	0.00 (0.00, 0.02)	No relationship with EVD and fox control
Fox control area	-7.29 (-23.49, 2.01)	0.00 (0.00, 7.47)	No relationship with fox control locations
B: Local survival			
Distance to water	**-1.22 (-2.10, -0.32)**	**0.30 (0.12, 0.73)**	**Local survival declines by 70% with every 500 m from water**
Topographic wetness index	**0.81 (0.01, 1.62)**	**2.25 (1.01, 5.05)**	**With every 2 units of TWI there is a 2.25-fold increase in local survival**
Tall Mixed Forest (Eastern)	-0.32 (-2.10, 1.56)	0.73 (0.12, 4.76)	No relationship with Tall Mixed Forest (Eastern)
Time-since-fire	0.33 (-0.23, 0.86)	1.39 (0.79, 2.36)	No relationship with time-since-fire
Distance to water in fox control area	**1.07 (0.18, 2.05)**	**2.92 (1.20, 7.77)**	**Nearly 3-fold increase in local survival with every 500 m from water in fox control areas compared with in non-fox control areas**
Topographic wetness index in fox control area	-0.41 (-1.37, 0.41)	0.66 (0.25, 1.51)	No relationship with TWI
Tall Mixed Forest (Eastern) in fox control area	-0.70 (-2.63, 1.21)	0.50 (0.07, 3.35)	No relationship with EVD
Time-since-fire in fox control area	-0.22 (-0.92, 0.48)	0.80 (0.40, 1.62)	No relationship with TSF
Fox control area	**1.06 (0.04, 2.16)**	**2.89 (1.04, 8.67)**	**A nearly 3-fold increase in local survival in fox control areas**
C: Local colonisation			
Elevation	0.14 (-0.51, 0.84)	1.15 (0.60, 2.32)	No relationship with change in elevation
Tall Mixed Forest (Eastern)	0.51 (-0.50, 1.64)	1.67 (0.61, 5.16)	No relationship with EVD
Tall Mixed Forest (Eastern) in fox control area	**-2.90 (-4.14, -1.64)**	**0.05 (0.016, 0.19)**	**A 95% increase in the odds a site is colonised if in Tall Mixed Forest at fox control sites**
Elevation in fox control areas	**1.03 (0.06, 1.97)**	**2.81 (1.06, 7.15)**	**Nearly a 3-fold increase in the odds a site is colonised with each 50 m increase in elevation**
Fox control area	**3.22 (2.39, 4.13)**	**24.95 (10.94, 62.11)**	**Fox control has a significant influence on colonisation**

Bold type indicates evidence that the covariate was important. All estimates are on the logit scale. CI = credible interval.

Table A5. Parameter estimates (posterior median and 95% credible limits) and corresponding odds ratios for initial occupancy, local survival and colonisation for the Southern Brown Bandicoot.

Parameter	Median (95% CI)	Odd ratio (95% CI)	Interpretation
A: Initial occupancy			
Terrain ruggedness index	-5.13 (-9.07, -0.99)	0.01 (0.0, 0.37)	Uncertain slightly negative relationship
Elevation	3.27 (-0.18, 7.38)	26.39 (0.83, 1603.59)	No relationship with elevation
Terrain ruggedness index in fox control area	5.95 (2.08, 9.98)	383.75 (8.02, 21655.18)	Highly uncertain positive relationship with TRI in fox control locations
Elevation in fox control area	-4.65 (-9.42, -0.21)	0.01 (0.0, 0.81)	Uncertain negative relationship with elevation in fox control locations
Fox control area	2.27 (-13.65, 20.35)	9.69 (0.0, >6 million)	No relationship with fox control locations
B: Site survival			
Time-since-fire	**-0.43 (-0.83, -0.03)**	**0.65 (0.44, 0.97)**	**Local survival declines by 35% with each year since fire**
Tall Mixed Forest (Eastern)	0.23 (-0.95, 1.42)	1.26 (0.39, 4.14)	No relationship with EVD
Distance to water	**0.93 (0.02, 1.88)**	**2.53 (1.02, 6.55)**	**A 2.5-fold increase in the odds a site will persist with each 500 m closer to water**
Elevation	-0.30 (-1.05, 0.41)	0.74 (0.35, 1.51)	No relationship with elevation
Time-since-fire in fox control area	0.04 (-0.49, 0.57)	1.04 (0.61, 1.77)	No relationship with TSF
Tall Mixed Forest (Eastern) in fox control area	-0.59 (-1.95, 0.87)	0.55 (0.14, 2.39)	No relationship with EVD in fox control locations
Distance to water in fox control area	**-1.30 (-2.26, -0.27)**	**0.27 (0.10, 0.67**	**73% decline in local survival with every 500 m away from water**
Elevation in fox control area	**1.95 (0.56, 3.37)**	**7.03 (1.75, 29.08)**	**A 7-fold increase in the odds a site would survive with every 50 m increase in elevation**
Fox control area	**1.18 (0.01, 2.33)**	**3.25 (1.01, 10.28)**	**Just over 3-fold increase in local survival at fox control sites compared with at non-fox control sites**
C: Site colonisation			
Distance to non-native vegetation	**0.39 (0.19, 0.59)**	**1.48 (1.21, 1.80)**	**48% increase in the odds a site is colonised with each km away from non-native vegetation**
Tall mixed Forest (Eastern)	0.39 (-0.16, 0.96)	1.48 (0.85, 2.61)	No relationship with EVD
Time-since-fire	**-0.19 (-0.35, -0.05)**	**0.83 (0.70, 0.95)**	**A 17% decrease in the odds a site is colonised with each year since the last fire**
Tall mixed Forest (Eastern) in fox control area	-0.60 (-1.33, 0.12)	0.55 (0.26, 1.13)	No relationship with EVD in fox control areas
Fox control area	**1.17 (0.67, 1.67)**	**3.22 (1.95, 5.31)**	**> 3-fold increase in the odds a site is colonised in fox control areas compared with non-fox control areas**

Bold type indicates evidence that the covariate was important. All estimates are on the logit scale. CI = credible interval.

Table A6. Summary of the fox activity index model comparisons.

Model	Weight
Location + Year + Treatment:Year	0.720
s(Year) + Location	0.213
Null	0.067
Location + Year	0.000
Location	0.000
Location * Year	0.000

Table A7. Summary of the feral cat activity index model comparisons.

Model	Weight
Year + Location	0.785
Location	0.215
Location + Year	0.000
Location * Year	0.000
Location + Year + Treatment:Year	0.000

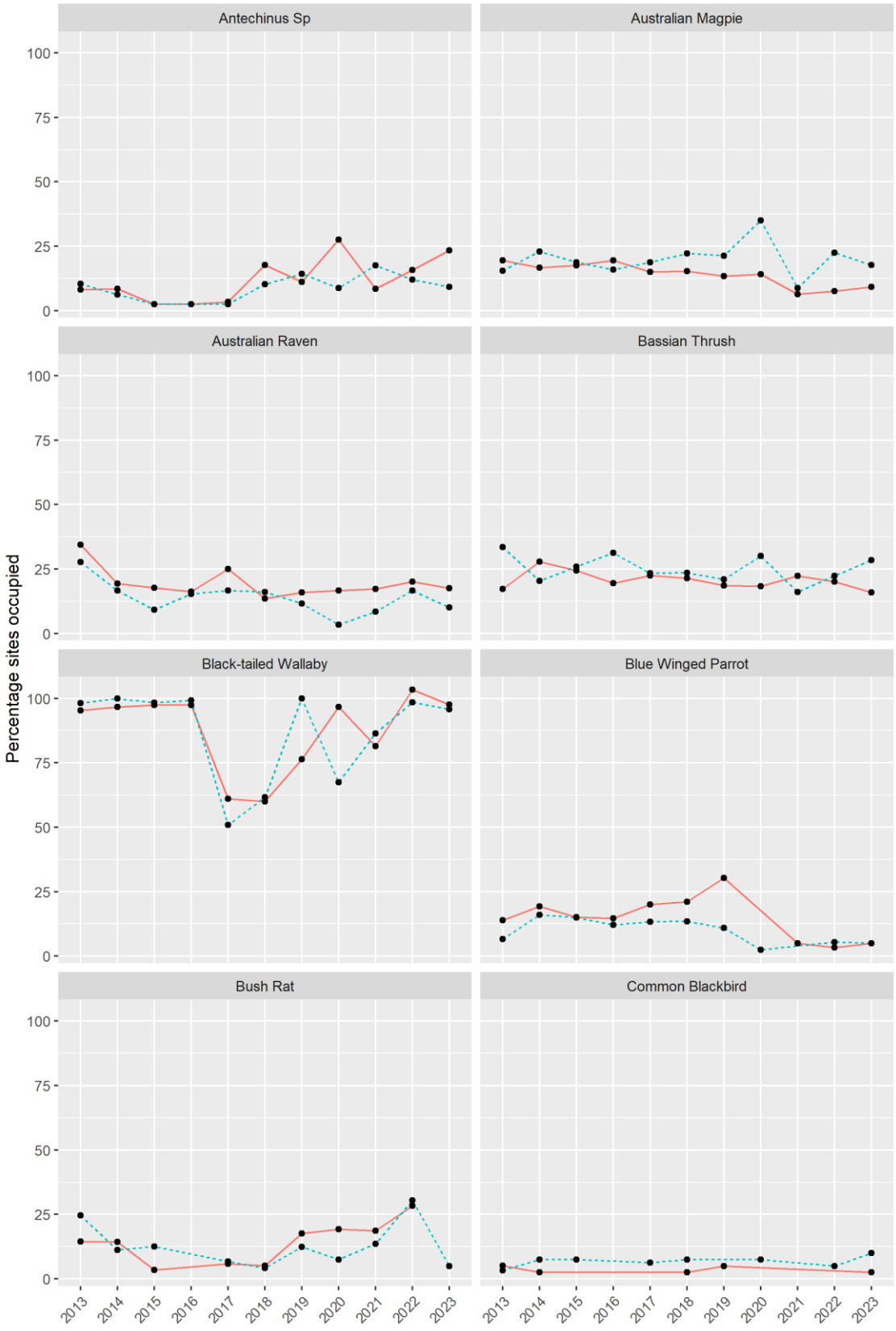

Figure A1. The average naïve occupancy (percentage of sites occupied) of native and introduced species at Glenelg Ark FCMLs' and 'NFCMLs' from 2013 to 2023.

Red solid lines: treated locations; aqua dashed lines: untreated locations.

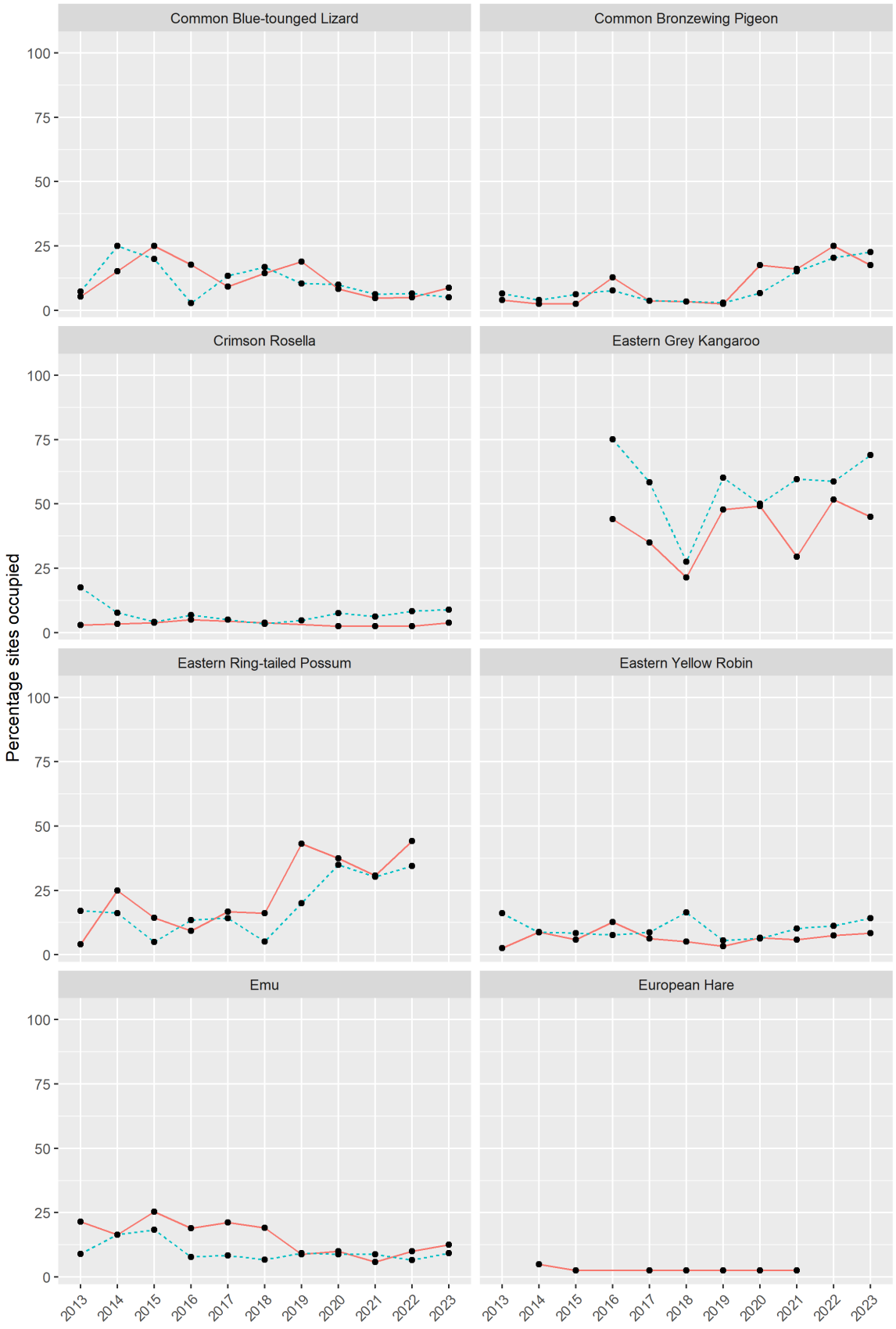

Figure A1 continued. The average naïve occupancy (percentage of sites occupied) of native and introduced species at Glenelg Ark FCMLs' and 'NFCMLs' from 2013 to 2023.

Red solid lines: treated locations; aqua dashed lines: untreated locations.

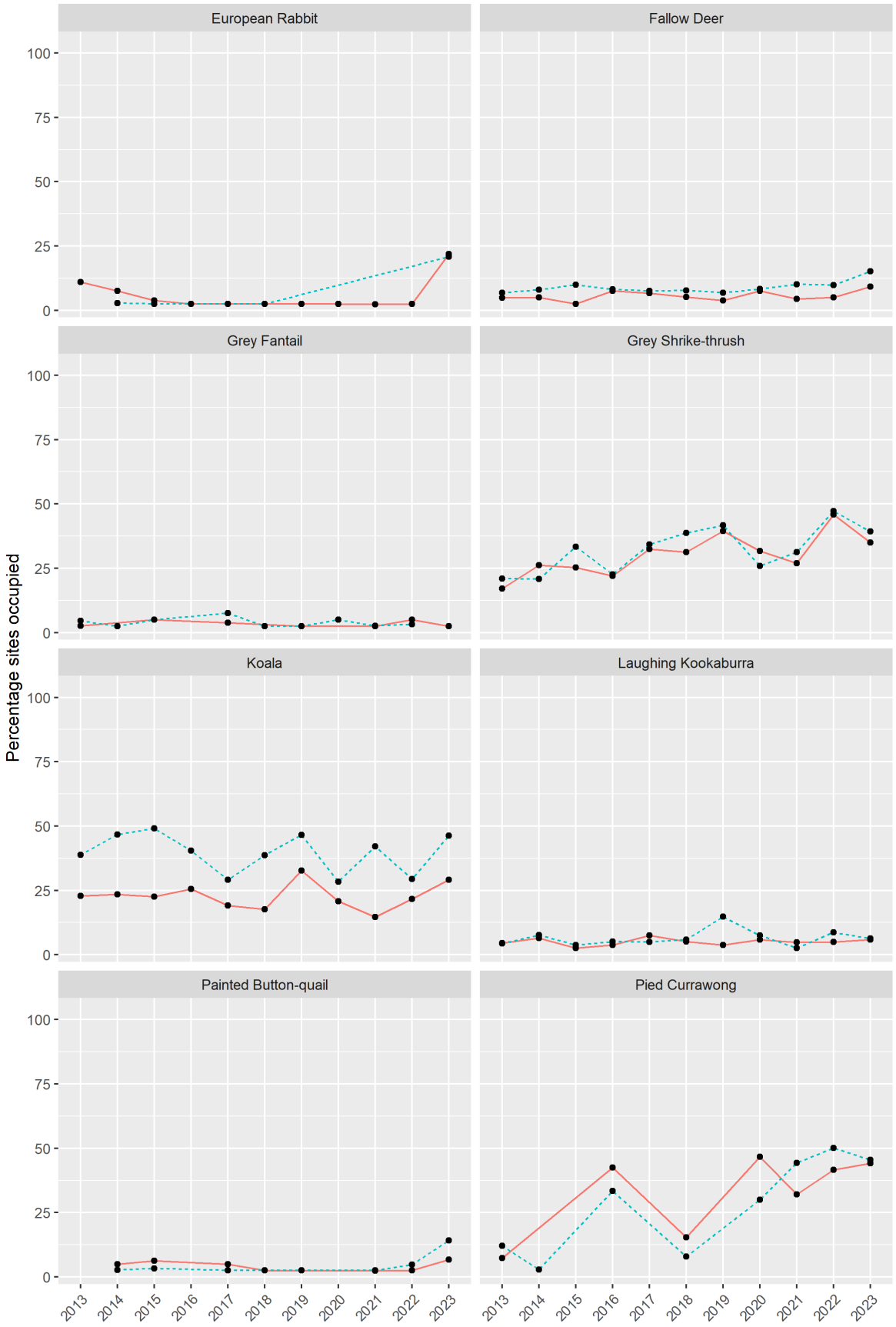

Figure A1 continued. The average naïve occupancy (percentage of sites occupied) of native and introduced species at Glenelg Ark FCMLs' and 'NFCMLs' from 2013 to 2023.

Red solid lines: treated locations; aqua dashed lines: untreated locations.

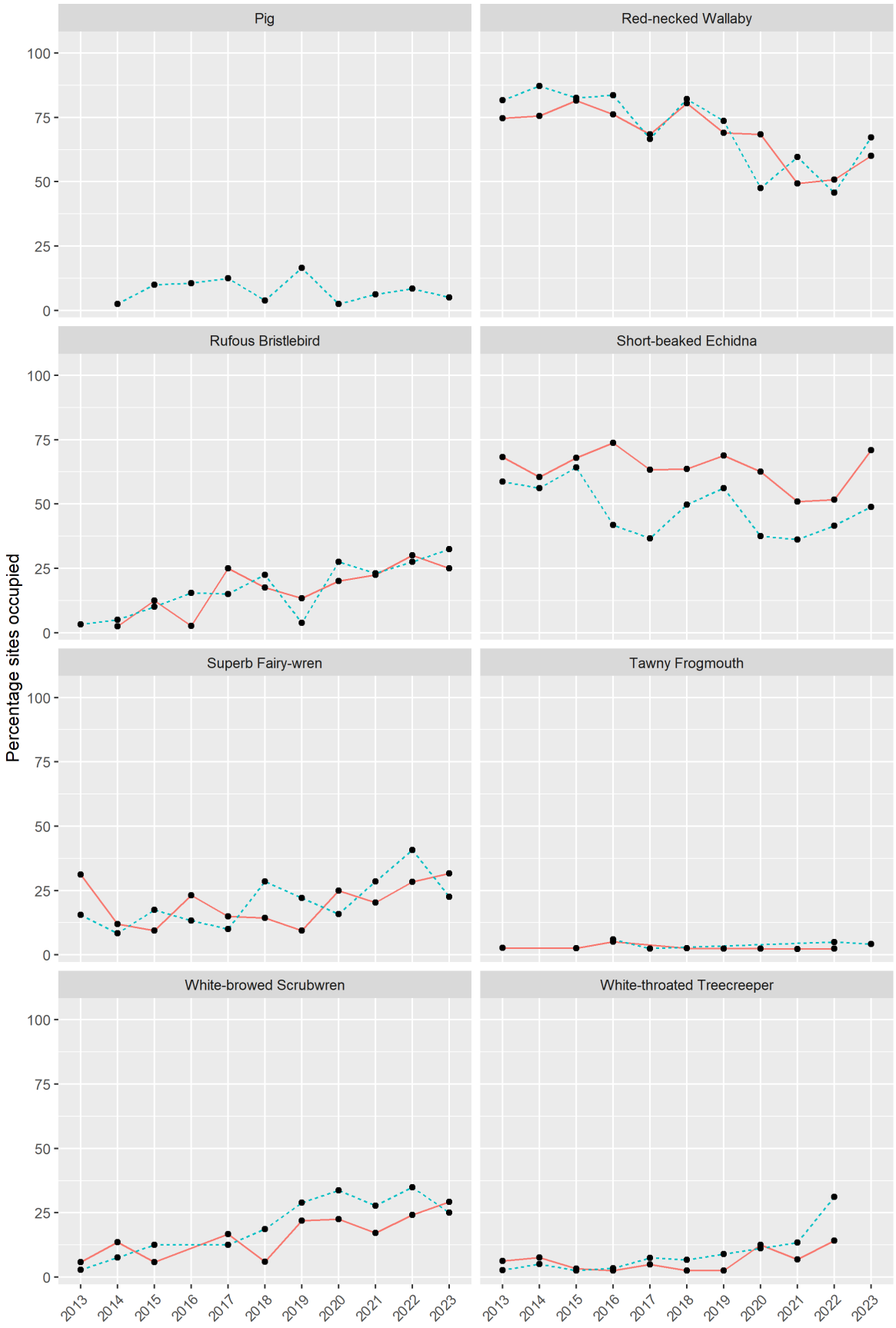

Figure A1 continued. The average naïve occupancy (percentage of sites occupied) of native and introduced species at Glenelg Ark FCMLs' and 'NFCMLs' from 2013 to 2023.

Red solid lines: treated locations; aqua dashed lines: untreated locations.

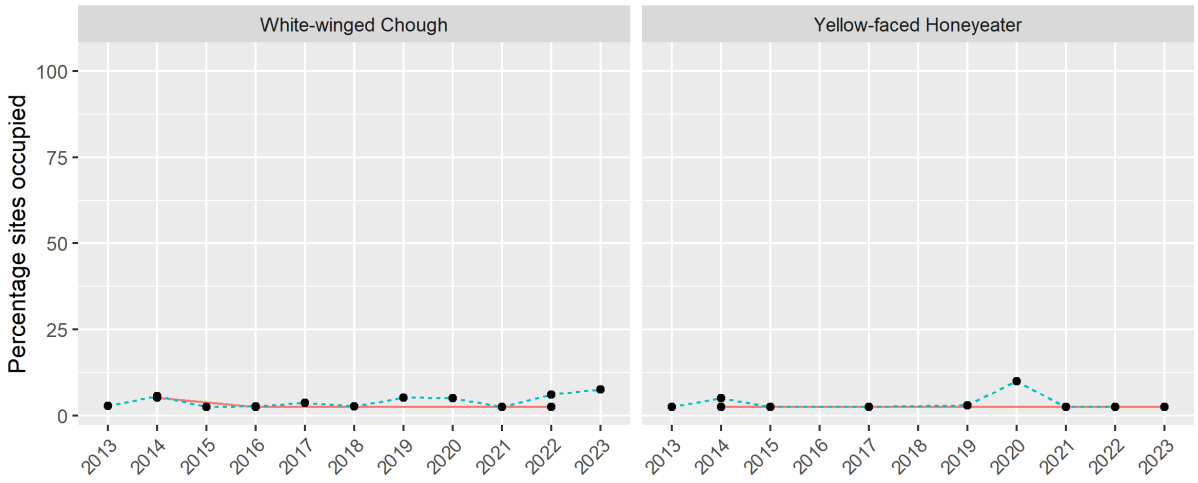

Figure A1 continued. The average naïve occupancy (percentage of sites occupied) of native and introduced species at Glenelg Ark FCMLs' and 'NFCMLs' from 2013 to 2023.

Red solid lines: treated locations; aqua dashed lines: untreated locations.

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