Protecting Hattah–Kulkyne Ramsar Wetlands from Introduced Predators:

Final Report 2017–2018

A. Robley, L. Woodford, M. Thompson, A. Taglierini and B. Hradsky

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 291

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Citation: Robley, A., Woodford, L., Thompson, M., Taglierini, A. and Hradsky, B. (2018). *Protecting Hattah–Kulkyne Ramsar Wetlands from Introduced Predators: Final Report 2017–2018*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 291. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Front cover photo: Surveying artificial freshwater turtle nests (Malcolm Thompson); feral Cat (Alan Robley); setting fox baits (Malcolm Thompson); fox raiding artificial turtle nest (Alan Robley).

Printed by Victorian Government, Melbourne.

Edited by Organic Editing

ISSN 1835-3827 (print)
ISSN 1835-3835 (pdf))
ISBN 978-1-76077-073-0 (print)
ISBN 978-1-76077-074-7 (pdf)

Accessibility

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Protecting Hattah–Kulkyne Ramsar Wetlands from Introduced Predators:

Final Report 2017–2018

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Technical Report Series No. 291

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Acknowledgements

This project was commissioned by the Mallee Catchment Management Authority through funding from Australian Government's National Landcare Program.

Karen Moodie, David Scammell, Nicole Wishart and Louise Chapman (MCMA), and Paul Moloney (Department of Environment, Land, Water and Planning) provided assistance and support during the project. Parks Victoria, including Shane Southon, Mick Peterson and Parks Victoria staff at the Hattah–Kulkyne National Park office and depot, provided support with logistics, access to, and use of the depot facilities and information about Hattah–Kulkyne National Park. Comments from Michael Scroggie and Lindy Lumsden (ARI), and Kate McWhinney and Rian Caccianiga (MCMA) improved this report. We gratefully acknowledge these contributions.

We would also like to thank the Mildura Rural City Council for issuing a permit for taking feral Cats directly to a veterinary clinic (CRM 6352/2016).

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Context:

The Mallee Catchment Management Authority (MCMA), through funding from the Australian Government's National Landcare Program, are implementing *The Protecting Hattah Lakes Ramsar Site Values* project. Natural flooding of the Hattah Lakes in north-western Victoria has been disrupted for the past 100 years, resulting in infrequent flooding events and a substantial loss of ecological values in the lake system. A program to reinstate natural flow regimes aims to deliver a minor flood to the lakes and surrounding floodplain three times in 10 years and a major flood once every 8 to 10 years.

A subproject of the program is to implement on-ground actions to mitigate threats to the environmental benefits arising from increases in environmental flows to the Ramsar wetlands within the Hattah–Kulkyne National Park (HKNP). This project looked at the threats of predation from the introduced Red Fox ('fox', *Vulpes vulpes*) and feral Cat (*Felis catus*) on wetland assets, chiefly freshwater turtles and their nests.

Aims:

- To assess aspects of fox ecology important for refining management strategies (namely, how foxes use the landscape around the lakes system, and fox density);
- To assess fox and feral Cat activity in the park;
- To report on the feral Cat and fox control operations implemented by MCMA in 2017–2018 with comparison to previous years;
- To explore possible fox control strategies via population models developed by the University of Melbourne; and
- To provide recommendations that may guide future management actions and research.

Methods:

A baiting operation was implemented by MCMA, using 90 bait stations set 1 km apart. Baits were replaced three times per week for 7 weeks in summer 2017-18. MCMA set 34 feral Cat cage traps across the Mournpall Block of the HKNP for 5 weeks in the summer of 2017–2018. To obtain detailed information on fox movement and habitat use via data collected by GPS tracking collars 26 leghold traps were set across the park for 4 weeks in October 2017 to capture foxes. Collars were programmed to collect location data every hour for 86 days then every 4 hours for another 45 days over the summer of 2017–2018. Seventy digital cameras were deployed across the main section of HKNP for 33 days prior to fox control to assess the level of occupancy of foxes and the density of feral Cats. A spatially explicit agent-based population model was used to assess six plausible fox management scenarios, including the one implemented in this project.

Results:

There was no apparent decline in the bait-take rate over the 7-week period, suggesting that encounter rates had not slowed. This would suggest there was no significant decline in the fox population. Despite significant effort by the MCMA, no feral Cats were captured during the 5-week trapping session. As no foxes were captured GPS location data could not be collected and hence, no estimates of fox movement or home range were possible. Foxes were shown to occur at 70% of sites prior to the baiting operation, whereas only four feral Cats were detected at three camera sites. Model predictions of the reduction in fox density within the Lakes Zone (covering an area buffering the Ramsar Lakes by 1 km) and the broader national park area indicated that a parkwide baiting operation with baits spaced at 1-km intervals, replaced at either 2- or 4-week intervals throughout the year, were the most effective approach to reducing fox density in both the Lakes Zone and the broader HKNP.

Conclusions and implications:

The overall project has provided MCMA, Parks Victoria and DELWP land managers with a greater understanding of the effectiveness of short-term seasonal fox control, and increased awareness of the issues related to the implementation of fox control at HKNP. While the project has focused on with reducing predation on turtle nests, the outcomes are applicable to situations applying the same strategy for protecting other species.

While it is possible to reduce foxes, and minimise predation on Eastern Long-necked Turtle (*Chelodina longicollis*) nests to some extent, previous work has shown some control strategies used were not effective at achieving a significant and sustained reduction in foxes or reducing nest predation rates to a level that would likely have a positive population-level impact (Robley et al. 2015, 2016).

The use of predictive models (both for feral Cats in 2016 and foxes in the current study) can provide insights into the probable outcomes of various alternative management strategies and how these can be used to assess the relative effectiveness, efficiencies and costs of control actions.

Integrating control of multiple threats can potentially increase the effectiveness of control actions and biodiversity outcomes. There is current debate in Australia as to the role foxes play in suppressing feral Cats, and if reducing foxes can lead to an increase in the later (Brook et al. 2012; Morgan et al.2017), also rabbits have been shown to respond to reductions in fox abundance (Pech et al. 1992). At present we have little knowledge of how to effectively integrate control actions to maximise biodiversity gains.

General conclusions

- Based on the outcomes of this and previous studies at HKNP and of the modelling undertaken in this current study short-term, relatively small-scale, high-intensity fox control is less effective than continuous broader-scale moderate-intensity control. The conclusion is supported by the modelled predictions.

General recommendations

- Future fox control strategies to include baiting at 1-km intervals with bait replacement every 2 weeks continuously across the broader HKNP (scenario 5). This strategy is likely to benefit a broader range of species that are at risk from fox predation than just freshwater turtles.
- Assess fox density prior to commencement of control and in September each year. A direct estimate of fox density can be obtained by 'recapturing individuals identified from DNA samples collected from scats. Indirect estimates can be obtained from an index of density using camera traps to assess occupancy over an area of interest. Bait take data as an index of change only be used if no other technique can be employed.
- Use this information and fox movement and home range data from GPS location data to improve model predictions and confront the model predictions with 'real' data. Use this to update plausible management scenarios and model parameters. Implement improved management strategies as applicable.
- If feral Cat control is to be undertaken, it be done using cage traps at 1 / km^2 over no less than 50 km^2, targeting areas of specific conservation concern. Traps should be operated for a minimum of four weeks. Traps should be wired open for at least two weeks to allow feral Cats to become accustomed to their presence. Traps can be moved periodically, lures refreshed after rain and food based baits need to be kept fresh.
- Feral Cat control should be targeted at a time of year when the ratio of prey to feral Cat abundance is low resulting in feral Cats being food stressed and more likely to enter a cage trap. While we have no information on when this time is at HKNP, we suggest late autumn to mid-winter as a starting point.
- Assess the response of feral Cats and rabbits (abundance, distribution within the park, change in diet of feral Cats) to the reduction of foxes, and the impact on native species.

- Investigate a range of management tools to improve the effectiveness of feral Cat control, including:
    a. trap alert systems that can send notifications on trap status increasing efficiencies and reducing staff time.
    b. cage trap type/design, i.e., double entry versus single entry, size and shape.
    c. lure types (food, olfactory, audio/visual). The likelihood of entering a cage trap may be influenced by age and sex. Different lure types can act to entice feral Cats of different age and sex into traps, refining our understanding of lure types could potentially increase trapping efficacy.
- Acquire knowledge of feral Cat home range, movement, body condition, diet, response to fox control, and prey availability in different seasons. Use this information to improve effectiveness and efficiency of feral Cat control programs.
- Explore options to use bait products for feral Cat control when they become available following declaration of feral Cats as an established pest.
- Incorporate feral Cat responses to fox control into the spatially explicit agent based fox model.

1 Introduction

Natural flooding of the Hattah Lakes system has been disrupted for the past 100 years due to river flows being diverted for agriculture, industry, and town water supply, resulting in infrequent flooding events and substantial loss of ecological values in the lake system. A partnership program between the Federal Government and Victorian State Government aims to reinstate natural flow regimes by delivering a minor flood to the lakes and surrounding floodplain three times in 10 years and a major flood once every 8 to 10 years (Murray–Darling Basin Authority 2012).

The Mallee Catchment Management Authority (MCMA), through funding from the Australian Government's National Landcare Program, is implementing the 2013-18 *Protecting Hattah Lakes Ramsar Site Values* project. Within the broader program are a series of subprojects, with one specifically implementing on-ground actions to mitigate threats to the environmental benefits arising from increases in environmental flows to the Ramsar wetlands at Hattah–Kulkyne National Park (HKNP). One of these threats is predation from the introduced Red Fox ('fox', *Vulpes vulpes*) and feral Cat (*Felis catus*) on wetland assets, chiefly freshwater turtles and their nests.

The MCMA engaged the Arthur Rylah Institute (ARI) of the Department of Environment, Land, Water and Planning (DELWP) to prepare a Predator Management Strategy in 2013–2014 (Robley et al. 2014). The focus of the Predator Management Strategy is the effective management of introduced predators to allow affected native species to increase and persist within the Hattah Lakes Ramsar sites.

Reducing predation by introduced predators on seasonally vulnerable prey, such as nesting reptiles and bird species, is of interest to biodiversity managers around the world. In Australia, the fox is a significant predator of Eastern Long-necked Turtle (*Chelodina longicollis*) nests, destroying 96% of nests (Thompson 1983). Feral Cats are widespread across Australia and occupy most habitats. They are a significant predator of mammals, birds and reptiles and are identified as a major threat to endangered fauna. The impact of feral Cats on biodiversity is also recognised nationally in documents such as *The Action Plan for Australian Mammals 2012* (Woinarski et al. 2014). The Victorian Government has recognised predation by feral Cats as a threatening process under legislation related to threatened species, and plan to declare them an established pest species in 2018.

In 2014–2015 and 2015–2016, changes in fox predation rates on artificial nests of Eastern Long-necked Turtles were experimentally assessed using a non-randomised intervention designed to compare a short-period (3-week) but broad-scale poison baiting operation (2014–2015) with a medium period (17-week) but spatially concentrated baiting program (2015–2016) across lakes within the Mournpall Block of HKNP (Robley et al. 2016a, 2016b). These investigations found that the broad scale approach tended to reduce foxes and protect turtle nests better that the smaller scale shorter term strategy.

In 2016–2017, the fox control strategy was repeated from 2015–16, keeping the focus on the lakes system (Robley et al. 2017a). However, in this iteration we implemented a non-randomised before–after control–impact (BACI) study to assess changes in predation rates at two lakes subject to fox control and at one lake with no fox control activities. There were mixed results from this study, which indicated that at one treatment lake nest survival rates decreased but remained unchanged at the second treatment lake. While at the nil-treatment lake foxes increased and nest survival decreased.

In autumn 2016 and summer 2017, feral Cat density and the consumption rates of non-toxic bait were assessed (Robley et al. 2017b) in the Mournpall Block of HKNP. We combined our density estimates and consumption rates with movement models to assess various management scenarios (i.e. ground-based baiting and aerial baiting). Estimated abundance of cats within the 331 km^2 study area was 91 with a corresponding density estimate of 0.27 cats/km^2. Baiting transects spaced at 1 km intervals at a baiting rate of 30 baits/linear km was predicted to reduce feral Cat density by 75%.

In the current (2017–2018) project, MCMA engaged ARI to assist with implementation of the predator control program. This report details the outcomes of the fifth and final year (2017–2018) of the project. The objectives of this final year's work were to assess the outcome of the MCMA's 7-week fox control and 5-

week feral Cat control operation, to gather information on the ecology of foxes with a view to improving management strategies, and to implement a population model of foxes to assess past and possible future management scenarios.

2 Methods

2.1 Study area

This study was conducted in the HKNP in north-west Victoria (34° 38' S, 142° 23' E). The study area covered the Hattah Lakes system, which is part of the Murray River floodplain. Twelve lakes are listed under the Ramsar Convention on Wetlands (Department of Sustainability and Environment 2003) and they cover an area of ~1155 ha (Murray–Darling Basin Authority 2012). This study took place between November 2017 and April 2018.

Environmental flows were delivered to the lakes system in August 2017, filling lakes and the surrounding floodplains up to 45.5 m above sea level (ASL). At this level, surface water significantly restricted movement within the park because many tracks were submerged for several months. Access to the whole park remained sporadic throughout this study as the water receded, with full access achieved only in February 2018.

2.2 Fox and feral Cat control

Baiting operations for the control of foxes conducted by the MCMA commenced 22 February 2018 and continued until 29 March 2018, running for a total of 7 weeks. Ninety bait stations were established at 1 km intervals (Figure 1) and baited with FoxOff, with baits being checked and replaced three times per week.

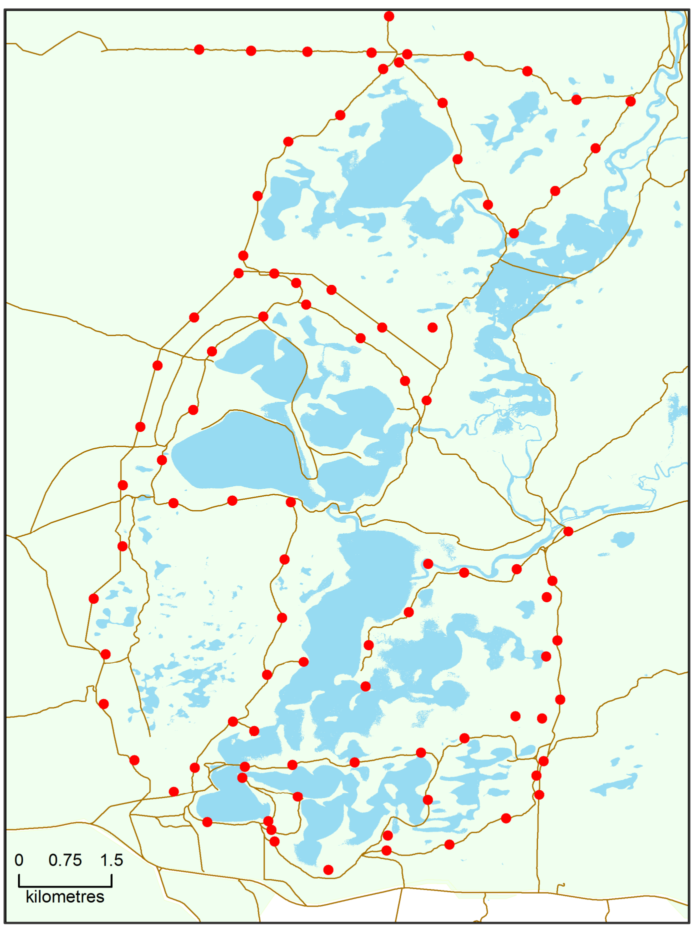

Figure 1. Location of bait stations used in the 2018 fox baiting program.
Bait stations were spaced at 1-km intervals and baits were checked and replaced three times per week for 7 weeks.

The MCMA operated 34 feral Cat cage traps (Figure 2) for 5 weeks from 13 November 2017 to 15 December 2017 at or near locations where feral Cats had been previously recorded on camera traps (Robley et al. 2016a).

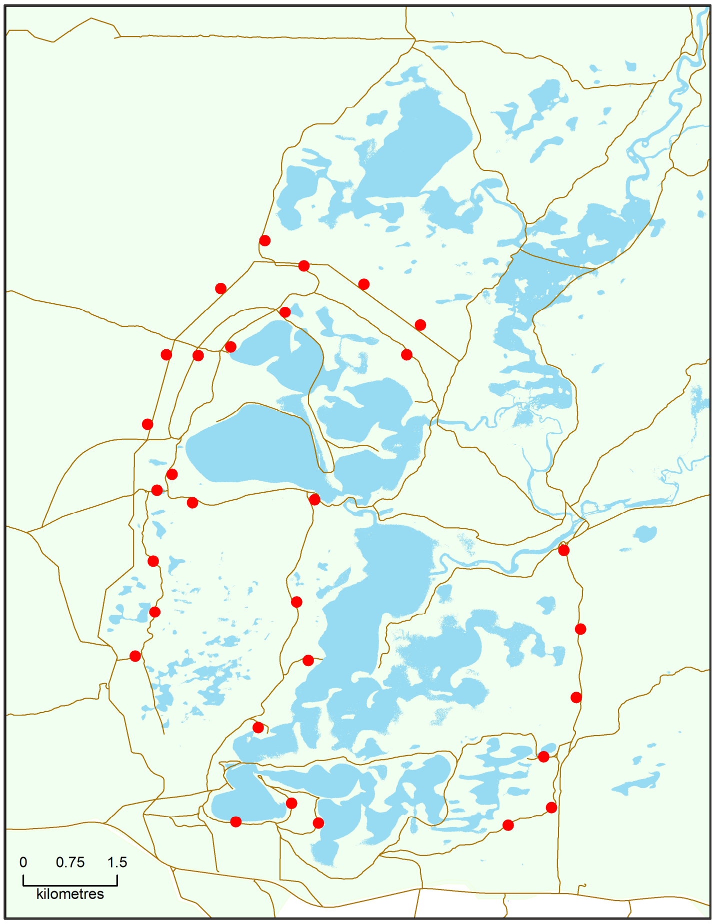

Figure 2. Location of feral Cat cage traps in 2017-2018 near locations were feral Cats had previously been recorded on camera traps.

Cage traps were baited with commercially available fresh chicken pieces, and were supplemented with an audio lure and a visual lure, i.e., reflective tinsel and bird feathers. Cages were wrapped in plastic and covered with vegetation and placed at or near the base of a shrub or fallen log (Figure 3). Cage traps were set on Monday mornings, then checked (and reset if necessary) each morning until the following Friday. Traps were wired open over weekends and left baited to allow feral Cats to become accustomed to them.

Figure 3. Feral Cat cage trap set up at Hattah–Kulkyne National Park.

2.3 Assessment of fox home range and movement

To assess fox home range and movement patterns around the lake system, the plan was to capture and fit GPS tracking collars (Telenax TGB-325/311, Playa del Carmen, Mexico; Figure 4) to 10 foxes, capturing the foxes by using Victor Soft Catch #1.5 (Western Trapping Supplies, Toowoomba QLD) (Figure 5). Twenty-six traps were set approximately 1 m from the edges of roads and tracks, had a lure of fox urine, and were checked daily for a minimum of 4 weeks beginning in mid-September 2017. Upon capture, we intended to sedate each fox with an intramuscular injection of Domitor (0.2/mg/kg), fit it with a GPS tracking collar, and record its sex and body weight, before reviving it with an intramuscular injection of Antisedan (2.5/mg/kg) and releasing it at the point of capture.

Tracking collars were scheduled to take a GPS location record every 60 minutes for the first 86 days, and then every 4 hours for the remaining 45 days. The collars were programmed to operate from 10 October 2017 to 18 February 2018, after which time they would automatically drop off. The collars would then be retrieved via tracking each collar’s unique VHF signal.

Figure 4. Telenax GPS collar for foxes at Hattah–Kulkyne National Park.

Figure 5. Setting a soft-jawed leghold trap for foxes at Hattah–Kulkyne National Park.

To assess home range and movement of GPS-collared foxes, the plan was to use the biased random bridge (BRB) method (Benhamou and Cornelis 2010, Benhamou 2011). BRB is a movement-based kernel method that links successive GPS fixes and then interpolates between them to develop a smoothed kernel density estimate for each interpolated location (Durr and Ward 2014). See Benhamou (2004) for full details of this process. Analysis would have been implemented using statistical software R 3.4.3 in the adehabitatHR package (Calenge 2006).

2.4 Modelling fox control strategies

Population parameters for foxes obtained from similar ecosystems elsewhere in Australia (Appendix 1) were incorporated into a spatially explicit, agent-based model (ABM) built and run in the open-source software Netlogo (version 6.0.2; Wilensky 1999) and R version 3.4.0 (R Core Team 2017). The model has a spatial resolution of 1 ha and runs over an area of 9967 km^2 on the Victorian side of the Murray River. This provided a buffer of 45+ km around HKNP to capture >95% of dispersing females and >90% of dispersing male foxes that might reach the park, assuming an average home range size of 4000 ha and dispersal distances that scale accordingly (Trewhella et al. 1988). The Murray River was assumed to be a complete barrier to fox movement.

Models were 'burnt in' for 15 years to allow populations to stabilise in the absence of baiting and remove any founding effects. Fox density was then estimated over a five-year period (e.g. 2018 – 2022). A baseline scenario without any baiting was conducted to compare with the changes arising from six plausible management scenarios (Table 1). Thirty replicates were run for the unbaited and each of the six baited scenarios. The model parameters are listed in Appendix 1.

Table 1. Six plausible management scenarios for the control of foxes at Hattah–Kulkyne National Park

Scenario	Baited area	Bait spacing	Bait replaced	Baiting duration	Baiting commenced	No. bait stations
S1	Lakes Zone	330 m	every 2 weeks	16 weeks	8 Oct 2018	225
S2	Lakes Zone	330 m	every 4 weeks	16 weeks	8 Oct 2018	225
S3	Lakes Zone	1 km	3× per week	12 weeks	22 Oct 2018	90
S4	HKNP	1 km	3× per week	12 weeks	22 Oct 2018	215
S5	HKNP	1 km	every 2 weeks	continuous	1 Jan 2018	215
S6	HKNP	1 km	every 4 weeks	continuous	1 Jan 2018	215

Prediction in the changes in fox density over a five-year period arising from these scenarios were made over two regions: (i) the Lakes Zone – a 1-km-wide buffer around the core lakes within HKNP (53 km^2), and (ii) the HKNP (437 km^2) (Figure 6). Scenarios S1–S3 operated only in the Lakes Zone, whereas Scenarios S4–S6 operated across the entire HKNP including the Lakes Zone. For all scenarios we calculated fox density in both the Lakes Zone and the wider HKNP. Fox control within the Lakes Zone impacts the overall density of foxes across the Park by creating a sink into which dispersing animals move.

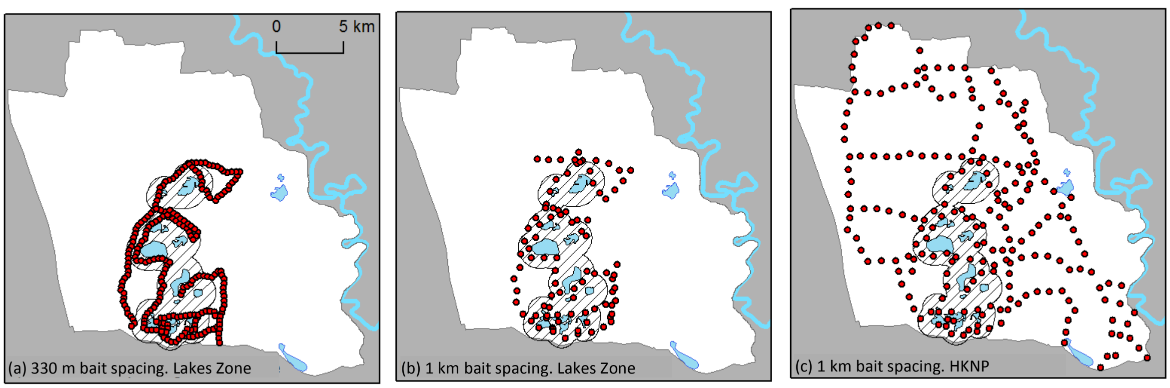

Figure 6. Layout of bait stations for (a) Scenarios S1 and S2, (b) S3 and S4 and (c) Scenarios S5 and S6. Bait stations are shown as red dots.

For all scenarios, fox density was monitored in the (i) Lakes Zone (black hatching) and (ii) HKNP (white polygon). It was assumed that foxes did not inhabit the lakes or cross the Murray River.

Average density estimates were made both for mid-September (after the birth of cubs and just prior to turtle nesting season) and across the peak of the turtle nesting season (i.e. mid-November to mid-January) in both the Lakes Zone and the wider HKNP.

2.4.1 Costs of control operations

The costs of the control operations for each scenario were provided by the MCMA. These were used to estimate the cost–benefit ratio for each scenario on a per-hectare basis.

Salaries:	$355/day for each person (including all on-costs)
Travel:	$0.66 per km of travel
Fox bait:	$2.00 per bait
Travel distance:	150 km round trip to service all scenarios
Time:	1 person-day per to set up and service S1–4 and 2 person-days per to set up and service S5–6

2.5 Fox and feral Cat occurrence

We used motion-sensing digital cameras (Reconyx RapidFire, Reconyx, LLP Wisconsin, USA) to collect presence/absence data at 74 sites for assessing indices of fox and feral Cat abundance. A commercial predator lure (Fox Frenzy Lure, Mark Junes Lures Inc., Texas USA) applied to absorbent cloth was placed in a small, ventilated PVC cowling and secured to the ground (using a 30-cm steel peg) 2 m in front of each camera (Figure 7). Cameras were operated for a minimum period of 30 days in January 2018, with each day representing a repeat survey of the monitoring site per sampling period. Images were organised following the methods outlined by Harris et al. (2010) and Sanderson and Harris (2014).

Figure 7. Motion-sensing digital camera set-up at Hattah–Kulkyne National Park.

Cameras were placed across the survey area at 700-m intervals in a grid pattern (Figure 8). This spacing was chosen to ensure that individuals could potentially be detected at multiple camera-trap locations within their estimated home range.

Feral Cat density was assessed using spatial mark-resight models following the method of Ramsey et al. (2005). Detections of individuals at multiple locations can produce spatially correlated detections, which are essential for obtaining unbiased estimates of population density when the population is totally or partially unmarked (Ramsey et al. 2005).

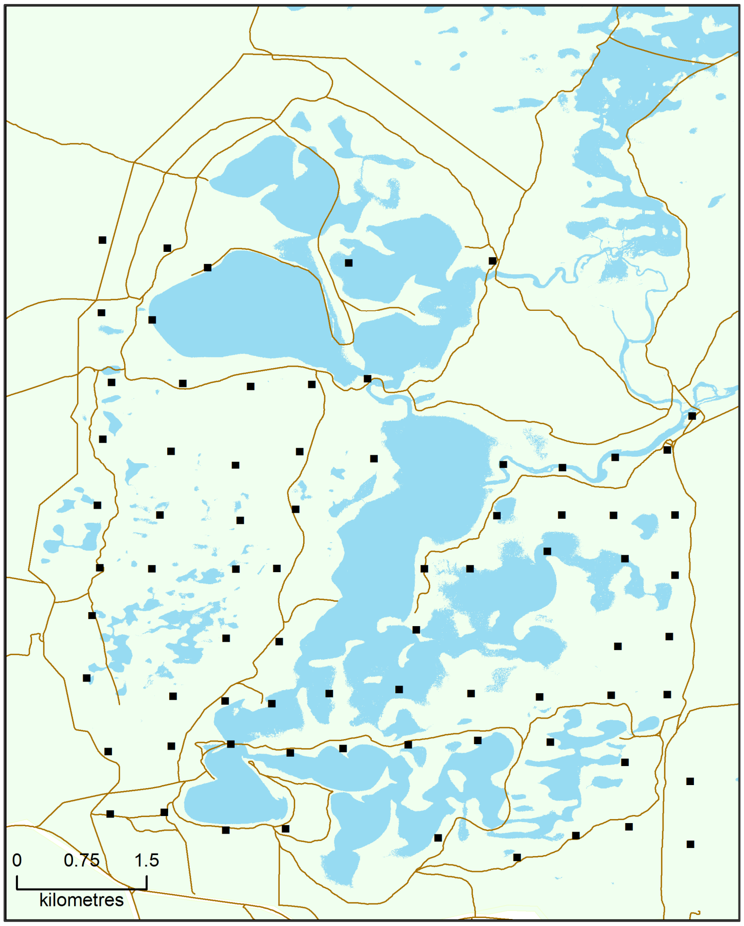

Figure 8. Locations of motion-sensing digital cameras used to assess indices of fox and feral Cat abundance.

The average distance between cameras was 700 m. Cameras were set for a minimum of 30 days in January 2018.

An alternative analytical approach is to use occupancy modelling, and allowing for spatial autocorrelation (Hines et al. 2010), to assess the rate of site occupancy across the park by both foxes and feral Cats, and to explore possible spatial interaction between the two species.

3 Results

3.1 Fox home range

We set 26 Victor Soft Catch #1.5 traps (Western Trap Supplies, Toowoomba QLD) on accessible tracks over a period of 4 weeks, beginning in mid-October 2017 (Figure 9). Traps were checked daily, and lures were refreshed every third or fourth day, or after a rain event.

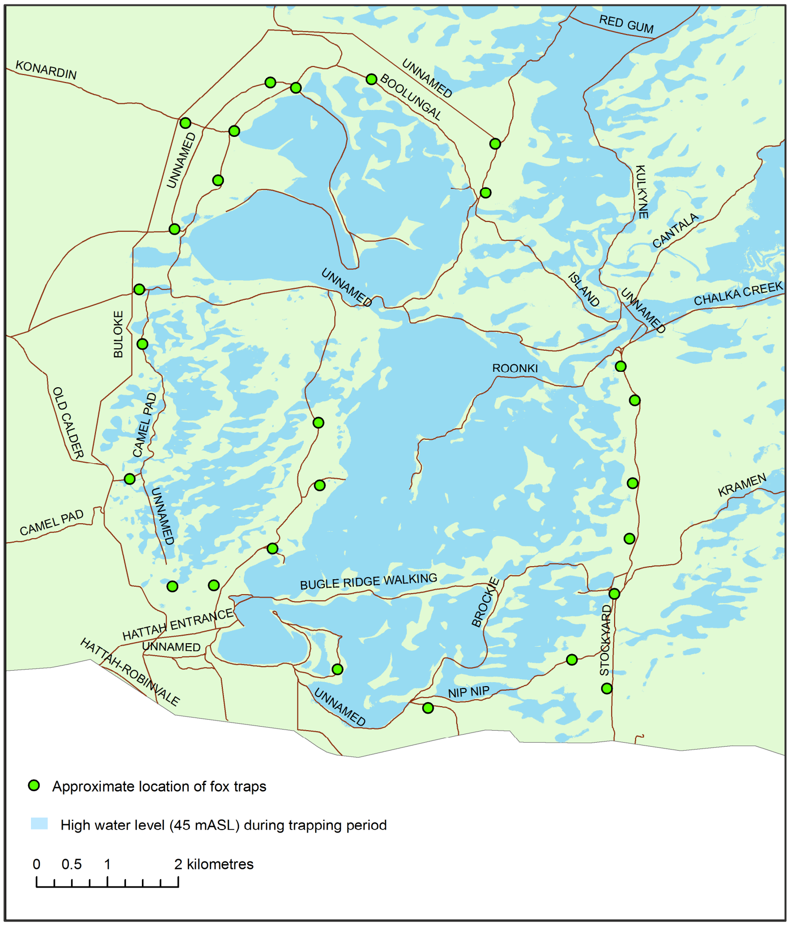

Figure 9. Locations of fox traps at Hattah–Kulkyne National Park.

Despite undertaking trapping for over 1000 trap-nights, no foxes were captured. Hence, it was not possible to determine home range size and movement patterns of foxes. Several steps were taken to improve trapping success, including moving selected traps to new locations, changing the lure type, and refreshing or resetting traps after moderate rain which occurred twice during the trapping period.

3.2 Fox and feral Cat occurrence

Foxes were detected at 43 sites (58%) using camera traps in January 2018; many of these were juvenile foxes, most likely born in the previous spring. It was not possible to distinguish individuals, and activity was mainly confined to night-time (hence, black and white images), with only two foxes being detected in daylight hours.

Analysis of the probable number of sites occupied, taking into account imperfect detection indicated that 70% (95% confidence limit 54–82%) of sites were occupied by foxes.

Feral Cats were detected at only three sites. The markings on these feral Cats indicated that four individual Cats were present. However, due to the small sample size and low number of resightings, conclusions about density, abundance, or interactions with foxes were not possible.

3.3 Fox control program

The MCMA operated 90 bait stations for 7 weeks. A total of 327 (17% of) baits were taken. The percentage of baits taken daily ranged from 1.5% to 23%. There was an overall tendency for bait-take to increase with time (Figure 10).

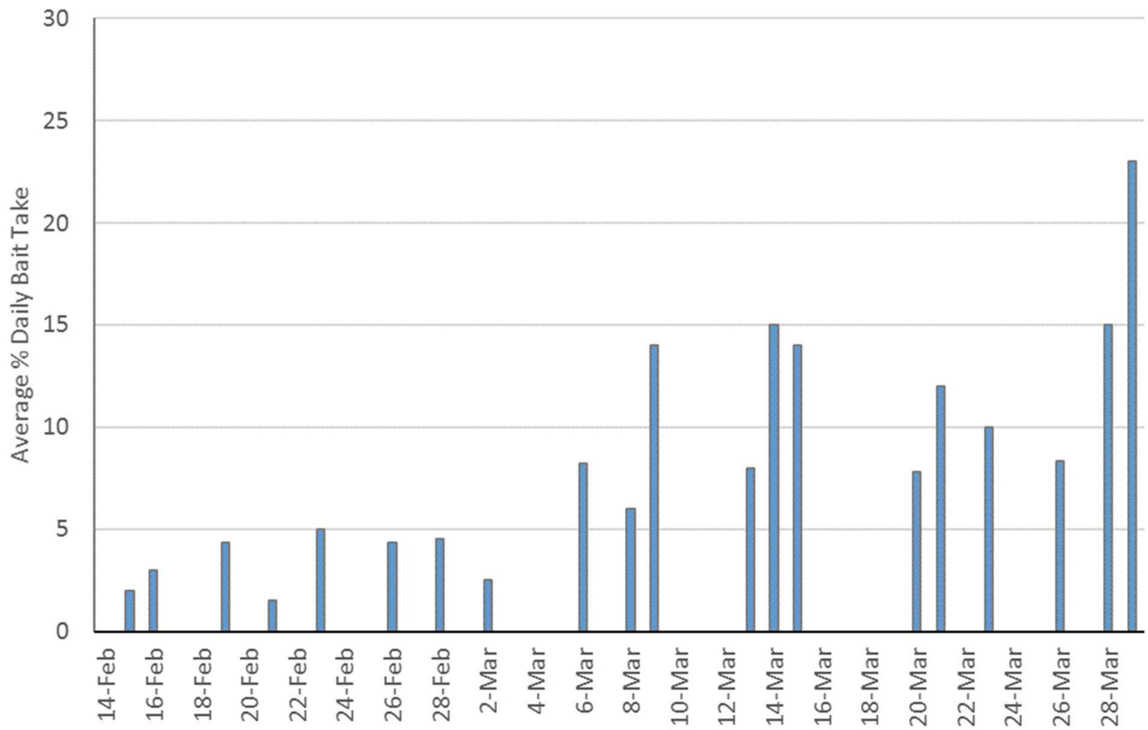

Figure 10. Daily bait-take at Hattah–Kulkyne National Park over 7 weeks, from 14 February to 29 March 2018.

3.4 Feral Cat control program

Cage traps were operated for 900 nights. No feral Cats were caught during this period. Several steps were taken to increase the probability of trapping feral Cats, including moving selected traps to new locations, changing the lure type, and refreshing or resetting traps after moderate rain which occurred twice during the trapping period.

3.5 Modelled fox control strategies

The model predicted that the most effective baiting scenarios would be Scenarios S5 and S6, i.e., baiting continuously at 1 km intervals with baits replaced at 2 week (S4) or 4 week (S6) intervals. These scenarios produced the lowest average and lowest maximum fox densities in both the Lakes Zone and across the entire HKNP (Figure 11; Table 2).

In an unbaited scenario, fox densities at HKNP were predicted to fluctuate annually between a maximum of 1.5 ± 0.2 foxes km^{-2} (after the birth of the cubs in mid-September) and a minimum of 0.8 ± 0.1 foxes km^{-2} (immediately prior to the next breeding season). For the 8-week period between mid-November and mid-January (i.e. the peak of the turtle breeding season), the unbaited fox density was predicted to average 1.2 ± 0.1 foxes km^{-2} across both the Lakes Zone (Figure 11b) and the entire national park (Figure 11d).

All baiting scenarios were predicted to reduce fox density in the Lakes Zone (Figure 11a and b, Figure 12a) and across the entire national park (Figure 11c and d, Figure 12b). However, Scenarios S5–S6, which involved baiting across the entire national park, were more effective at reducing fox densities across the entire national park, including the Lakes Zone, than Scenarios S1–S3, in which baiting was only conducted in the Lakes Zone (Figure 11b, Figure 12b).

Baiting year-round (Scenarios S5 and S6) maintained a continuously low density of foxes, with fox densities always ≤0.5 foxes km^{-2} in the Lakes Zone and across the park (Figure 11; Figure 12). In contrast, baiting only during the turtle breeding season (Scenarios S1–S4) allowed fox populations to partially recover each year due to fox dispersal in autumn and breeding in September (Figure 11a and b, Figure 12).

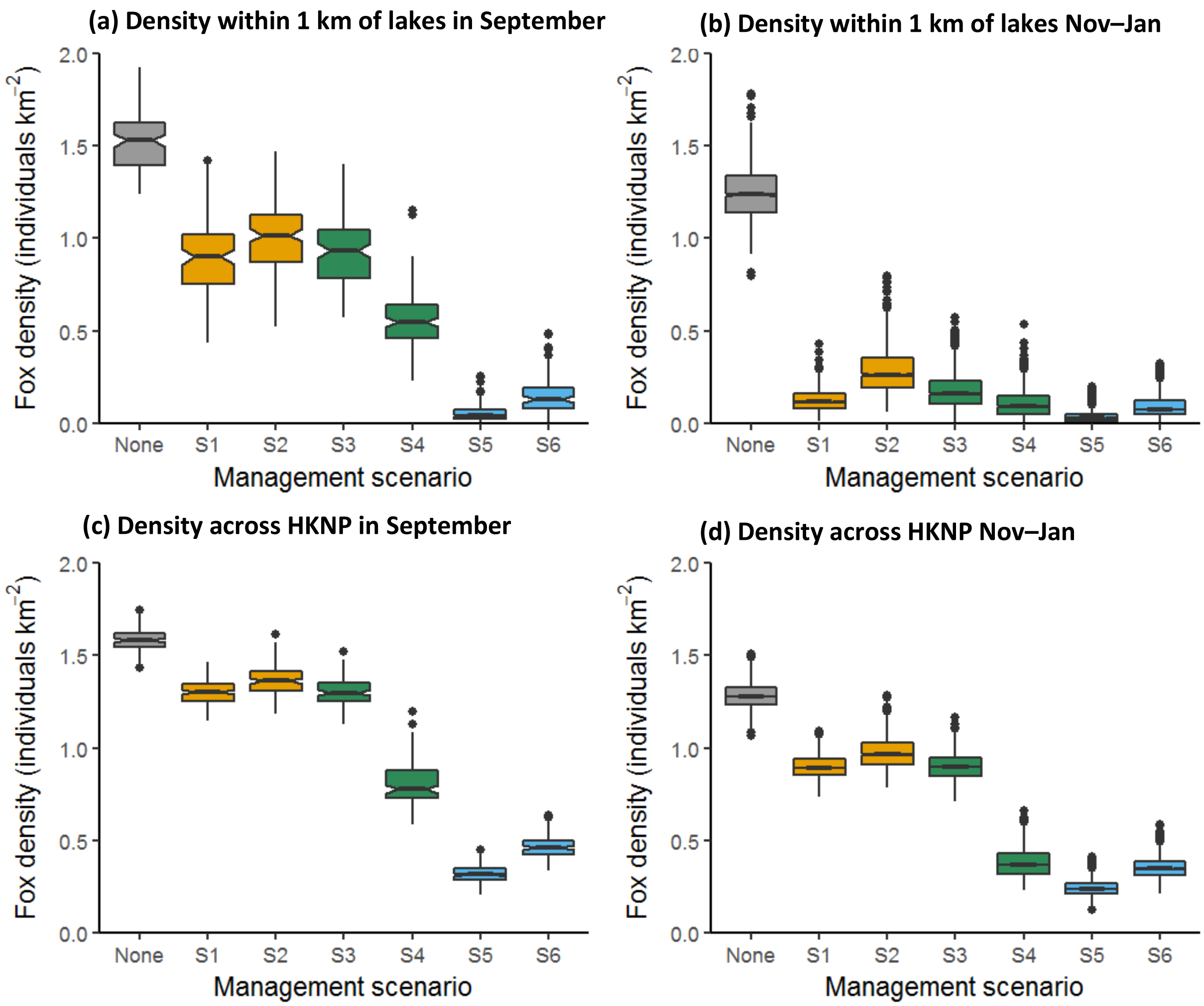

Figure 11. Density of foxes within a 1-km zone of the lakes at Hattah–Kulkyne National Park (a and b) and across the national park (c and d) for alternative baiting scenarios.
Fox densities are shown for mid-September, when fox cubs are born (a and c), and for mid-November to mid-January (b and d).

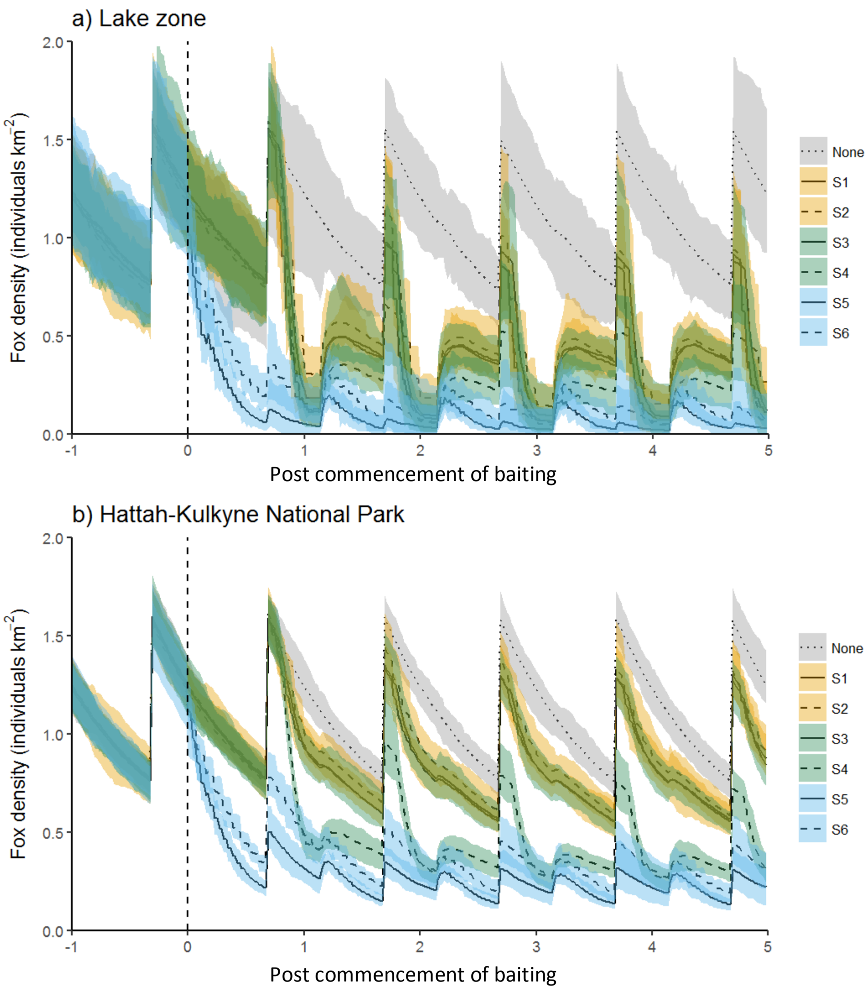

Figure 12. Predicted fox population trajectories for (a) a 1-km zone around the lakes and (b) Hattah–Kulkyne National Park for 1–5 years post commencement of baiting.
Peaks in density are associated with the birth of cubs from resident foxes (early spring) and dispersal from surrounding areas (autumn). Lines show mean with shaded bars indicating minimum and maximum predicted values.

Table 2. Comparison of alternative baiting scenarios

Table compares the predicted densities and reductions of foxes from 6 plausible management scenarios along with estimated costs.

Number of baits deployed each year, the number of visits required per year, the maximum fox density during the turtle breeding season (mid-November to mid-January), the percentage reduction in the fox population relative to an unbaited scenario, baiting efficiency (percentage reduction in fox population per 500 baits deployed) and cost per hectare. The 'best' scenario for each measure of success is shown in bold, the 'worst' in italics.

			Maximum fox density		Percentage reduction		Baiting efficiency		
Scenario	Baits /year	Visits/ year	Lakes zone	HKNP	Lake zone	HKNP	Lakes zone	HKNP	Operation Cost/ha
S1	1800	8	0.43	1.09	90 %	*30 %*	25 %	8 %	$1.78
S2	900	4	0.80	1.29	*77 %*	*24 %*	**43 %**	**13 %**	$0.90
S3	3240	36	0.57	1.16	86 %	30 %	13 %	*5 %*	$6.07
S4	7740	36	0.54	0.66	91 %	70 %	*6 %*	*5 %*	*$7.78*
S5	5590	26	0.20	0.41	**97 %**	**81 %**	9 %	7 %	$0.68
S6	2795	13	0.33	0.56	93 %	72 %	17 %	13 %	**$0.34**

4 Discussion

4.1 Effectiveness of the predator control program 2014–2018

This project has implemented a range of fox and feral Cat control strategies since 2014 to protect natural values that are likely to be at risk from fox predation (e.g. Eastern Long-necked Turtle nests and eggs). In addition, a fox population model was applied to the 2017-2018 data that explored the likely outcome of a range of past and possible future management scenarios.

Broader-scale baiting is more effective at reducing foxes both across the park and around the Lakes Zone. In 2014, the short-period broad-scale baiting (3-week) operation reduced sites occupied by foxes by 41%; however, this was not sufficient to have any detectable positive effect on turtle nest survival.

In the following years (2015 and 2016), the length of the baiting operation was extended (12 weeks) to cover the nesting period of Eastern Long-necked Turtles. There were indications that nest predation rates were similar pre- and post-baiting at lakes with fox control, but more severe at lakes with no fox control, suggesting that control had minimised the degree of predation. However, there was either no detectable reduction in foxes, or there was an increase in foxes post-baiting. This was most likely due to immigration from dispersing foxes from elsewhere in the park. Although this was not consistent between controlled and uncontrolled sites, with increases at the control site post-baiting but not at the uncontrolled site.

While we were unable to formally assess changes in foxes in 2017-18, the bait-take rates were higher in the second half of the 7-week baiting period, suggesting that there was no slowing of the bait encounter rate. There was no assessment of what species were taking bait, so the lack of decline in bait take can be confounded by either individual foxes taking and caching multiple baits and non-target species removing baits. Change in bait take rate has been used in other studies to infer a decline in fox populations, however due to the factors noted above it is unreliable and an imprecise metric.

Short-term, localised and spatially intense baiting operations (2015-16 and 2016-17) were unable to overcome the potential for rapid inwards movement of foxes from outside the baited area. Also, the probability of foxes encountering baits in what may have been only a small proportion of their home range may not have been sufficient to induce a population-level reduction in foxes.

These results are supported by the modelling outcomes, which showed that annual, broad-scale, moderately-intensive baiting over the entire park is predicted to result in a substantial reduction in fox density, both within 1 km of the lakes and more broadly across the Park, whereas short-term control focused only on the Lakes Zone is predicted to be less effective. What remains unclear is the density foxes would need to reduce to for a significant increase in the survival rate of Eastern Long-necked Turtle nests. Without this information, a precautionary approach would be to maximise the reduction in fox density and minimise the cost.

Foxes are likely to prey upon a range of native and introduced (rabbits) species other than Eastern Long-necked Turtles and their eggs, and it is possible that the fox control has resulted in other benefits to the Park. Anecdotal observations over the past 5 years indicate that the number of Emu (*Dromaius novaehollandiae*) chicks that survive to sub-adult stage has increased, with mobs of 10–15 being observed in 2017, compared with groups of just 2–3 in 2014–2015 (Robley pers. obs.).

The feral Cat control program was undertaken using the only tool currently available—cage trapping. Cage trapping is known to have limited and transient impacts at a population level and is generally expensive to implement. While several feral Cats were removed in 2015–2016, none were captured in 2017. The costs are mainly associated with the requirements to check traps daily and to deliver feral Cats to a local council or veterinarian for disposal. Proposed changes to the status of free-roaming Cats, declaring them an established pest, will remove the requirement to offer up caught Cats to councils, significantly reducing costs. In addition, the development of new technologies alerting operators to when a trap has been sprung, will also greatly reduce costs. These changes will allow land managers to potentially operate more traps in a single trapping session, increasing the efficiency of this method of control.

Environmental flows into the lake system complicated the assessment of the outcomes of fox control operations in most years. The flood levels in 2015 and 2017 each peaked at 45.5 m ASL, and coincided with the timing of field work for those years. This not only restricted access to lay baits, but also significantly reduced access for monitoring of sites.

The initial aim of this project was to assess the effectiveness of relatively small-scale, targeted fox control implemented over a short period to protect a specific asset, i.e., Eastern Long-necked Turtle nests. The difficulty in gaining access to the littoral zone, flooding events, and operating in a culturally and environmentally sensitive environment resulted in compromises in the delivery of the fox control strategies. Also, current State Government regulations and policy limiting the use of bait products not registered in Victoria curtailed the implementation of alternative approaches that may have had increased success. To a lesser extent, the delivery of the proposed strategies was not achieved due to limitations in the land managers' capacity and available resources to undertake the required control actions.

For example, placing eggs impregnated with 1080 (a registered bait product in WA but not in Victoria) close to the edges of lakes was not possible due to current State Government legislation specifically prohibiting the use of bait products not currently listed under the CaLP Act. In addition, repeated visits by the small side-by-side vehicles needed to undertake the operation would have resulted in damage to sites with both environmental and cultural importance. Frequent bait replacement (2 or 3 times per week) was not always possible, and the duration of the baiting operation was not always as recommended due to limitations on the land managers capacity.

4.2 Impacts on monitoring and evaluation of outcomes

In 2017-18, no foxes were captured for the fitting of GPS collars. It is unclear why this was the case. However, there are several possible factors that may have reduced the probability of capturing foxes: (i) low density of foxes across the park resulting from low abundance of rabbits (often a staple source of prey for foxes). Rabbits had been reduced to very low numbers by the introduction of rabbit haemorrhagic disease, in addition to the regular rabbit control activities over the past several years; also, the preceding months were hot and very dry, possibly reducing broader prey abundance; (ii) cubs may not have emerged from dens, restricting the range of the vixens' movements, and (iii) the high-water levels (peaking at 45.5 m ASL) may have pushed some foxes outside the study area. At its peak, water covered ~80% of the Mournpall Block.

4.3 Management implications and cost–benefit ratios

The 'best' management option depends on the measure of success. Scenario S5 (which deployed baits at 1-km intervals across the HKNP, with baits replaced every 2 weeks) was predicted to reduce the fox populations by 97% in the Lakes Zone and by 81% across HKNP. Scenario S5 was thus the 'best' management strategy if the aim was to achieve the maximum reduction in fox populations, and it was the second cheapest on a per-hectare basis (Table 2). In contrast, Scenario S2 was the least effective, in terms of reducing fox density, but the most efficient in terms of fox suppression per 500 baits deployed, required the least number of visits to replace baits, and was only 25% more expensive on a per-hectare basis (Table 2).

Depending on management priorities and the relationship between fox density and turtle predation, a compromise between effectiveness and efficiency (such as Scenario S6) may be optimal: Scenario S6 achieved good reduction in density in the Lakes Zone (93%) and across the park (72%), but it required fewer visits, was more efficient in terms of population reduction per 500 baits deployed, and was 50% cheaper to deliver than Scenario S5.

Scenario S4, which involved baiting three times per week for 12 weeks over the turtle breeding season at 1-km intervals across the entire HKNP, was consistently less effective, required more site visits, was less efficient than Scenarios S5 and S6, and was the most expensive.

Scenario S1, which closely matched previous control strategies, achieved a good level of reduction around the Lakes Zone, but was not very efficient and was the third-most expensive strategy to implement.

We note that our conclusions depend on assumptions about fox home range size (based on the literature relating to similar habitat), dispersal behaviour, and bait-take rates. Changes to these values may affect our conclusions about both the absolute density of foxes and the relative changes in fox populations with alternative baiting scenarios.

4.4 Conclusion

The primary aim of the project was to undertake activities to protect environmental values associated with the Ramsar wetlands within HKNP during the restoration of appropriate water regimes. A range of predator control strategies were implemented, the effectiveness of those strategies was assessed on both predators and Eastern Long-necked Turtles, and strategies adapted in response to environmental conditions, logistical, and operational constraints. In addition, a modelling approach was implemented to assess the relative benefits of possible alternative predator control strategies, leading to testable recommendations about future strategies.

The key link between fox density and prey response (in this case freshwater turtles) remains unknown and until this link is better understood, strategies should aim to minimise fox population sizes. The role of alternative prey species (e.g., rabbits) in supporting fox populations in also unclear at HKNP.

Changes to the regulations for the management of feral Cats are due to be passed by the Victorian Government mid-2018. These changes will allow for the humane destruction of feral Cats at the point of capture on certain public land tenures, removing the current requirement to present captured Cats to a local council or veterinarian. While this will significantly reduce the operational costs, the feral Cat control tools available to land managers will not change in the foreseeable future, i.e. they will remain limited to cage trapping and shooting.

If cage trapping is to be implemented as a feral Cat population control tool in HKNP, control activities should be undertaken in such a way as to optimise the capturing of feral Cats, i.e. using optimal lure type, cage trap type, and time of year, all of which can all play a role in improving trap effectiveness. The use of new technologies should also be encouraged when available.

4.2.1 Recommendations

- Future fox control strategies to include baiting at 1-km intervals with bait replacement every 2 weeks continuously across the broader HKNP (scenario 5). This strategy is likely to benefit a broader range of species that are at risk from fox predation than just freshwater turtles.
- Assess fox density prior to commencement of control and in September each year. A direct estimate of fox density can be obtained by 'recapturing individuals identified from DNA samples collected from scats. Indirect estimates can be obtained from an index of density using camera traps to assess occupancy over an area of interest. Bait take data as an index of change only be used if no other technique can be employed.
- Use this information and fox movement and home range data from GPS location data to improve model predictions and confront the model predictions with 'real' data. Use this to update plausible management scenarios and model parameters. Implement improved management strategies as applicable.
- If feral Cat control is to be undertaken, it be done using cage traps at 1 / km^2 over no less than 50 km^2, targeting areas of specific conservation concern. Traps should be operated for a minimum of six weeks. Traps should be wired open for two of those weeks to allow feral Cats to become accustomed to their presence. Traps can be moved periodically, lures refreshed after rain and food based baits need to be kept fresh.
- Feral Cat control should be targeted at a time of year when the ratio of prey to feral Cat abundance is low resulting in feral Cats being food stressed and more likely to enter a cage trap. While we have

no information on when this time is at HKNP, we suggest late autumn to mid-winter as a starting point.

- Assess the response of feral Cats and rabbits (abundance, distribution within the park, change in diet of feral Cats) to the reduction of foxes, and the impact of native species.
- Investigate a range of management tools to improve the effectiveness of feral Cat control, including:
    a. trap alert systems that can send notifications on trap status increasing efficiencies and reducing staff time.
    b. cage trap type/design, i.e., double entry versus single entry, size and shape.
    c. lure types (food, olfactory, audio/visual). The likelihood of entering a cage trap may be influenced by age and sex. Different lure types can act to entice feral Cats of different age and sex into traps, refining our understanding of lure types could potentially increase trapping efficacy.
- Acquire knowledge of feral Cat home range, movement, body condition, diet, response to fox control, and prey availability in different seasons. Use this information to improve effectiveness and efficiency of feral Cat control programs.
- Explore options to use bait products for feral Cat control when they become available following declaration of feral Cats as an established pest.
- Incorporate feral Cat responses to fox control into the spatially explicit agent based fox model.

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Appendices

Appendix 1. Parameters for the agent-based model

Parameter	Unit	Value	Source	Source location	Source ecosystem
Spatial resolution	ha	1			
Landscape size (accessible to foxes)	km^2	9966.66	45 km buffer around HKNP		
Lake Zone size	km^2	53.31			
HKNP size	km^2	437.16			
Time step	weeks	1			
Time limit	weeks	1040	20 years (15 unbaited, 5 baited)		
Initial fox density	No. km^{-2}	1.5			
Average home range size	km^2	4	(Towerton et al. 2016)	Dubbo, NSW	Dry sclerophyll forest: calllitris, red gum, ironbarks
Home range kernel	%	100	As above	As Above	As Above
Productivity Mallee: lakeside	Ratio	1:1	As above	As Above	As Above
Annual survival (<1-year-old)	Proportion	0.39	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: Sheep, Cattle
Annual survival (1–2 years)	Proportion	0.65	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: Sheep, Cattle
Annual survival (2–3 years)	Proportion	0.92	(Marlow et al. 2000; Devenish-Nelson et al. 2013)	Carnarvon, WA	Rangeland: Sheep, Cattle
Annual survival (>3 years)	Proportion	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)	Orange, NSW	Rangeland
Fecundity	Cubs per fox family	3.74	(McIlroy et al. 2001)	Orange, NSW	Rangeland
Sex ratio at birth	Proportion 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)	Yathong, NSW	Semi-arid rangeland
End of dispersal season	Week of year	21 (late May)	As above	As Above	As Above
Female dispersal rate	Proportion	0.700	(Coman et al. 1991)	Metcalfe, VIC	Pasture (Sheep, Cattle), woodland
	Proportion	0.999	(Coman et al. 1991)	Metcalfe, VIC	Pasture (Sheep, Cattle), woodland

Bait efficacy index (based on Pr(death per 1 bait and 100 ha home range))	Proportion	<0.3	Derived from (Robley et al. 2016a)	HKNP, VIC	Mallee floodplain
Commence baiting	Year no.	16			

HKNP: Hattah–Kulkyne National Park.

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