

Impact of removal on occupancy patterns of the invasive rainbow lorikeet (*Trichoglossus moluccanus*) in Tasmania

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Abstract Introduced species may threaten both biodiversity and agriculture, necessitating an understanding on the factors that influence their distribution, and the efficacy of control measures. In Tasmania, Australia, the introduced rainbow lorikeet (*Trichoglossus moluccanus*) may be widespread, but data on where they occur and the efficacy of control methods are limited. We used an occupancy modelling framework (presence–absence data) to undertake a survey of two populations of invasive rainbow lorikeets to: (i) understand their distribution across the north and south of the island, and (ii) evaluate the impact of removing birds from the southern population by quantifying occupancy before (2016) and after (2018) removal. The best model explaining occupancy in both populations included a negative relationship with distance from central urban areas. We found no change in site occupancy or detectability in the southern population after removal of 208 birds (potentially comprising >50% of their original population size). This result may be explained by one of three possibilities: (i) the population is larger than previously thought, (ii) the population recovered quickly after reduction, or (iii) removal of birds reduced population density but not area of occupancy. We highlight the importance of urban habitats for the invasive rainbow lorikeet and suggest that alternative methods (e.g. abundance/density-based monitoring) may better detect impacts of removal.

Key words: biological invasion, invasive species, lethal control, occupancy, parrot, pest monitoring, trapping.

INTRODUCTION

Long-term control or eradication is a primary objective in many management programmes for invasive species (Simberloff 2009). Successful eradication depends on understanding the ecology of the target species and monitoring to evaluate the impact of control measures on key demographic parameters (e.g. Hoffmann 2015). A lack of knowledge and biological understanding can result in resource-intensive actions that fail to meet objectives (e.g. Shine & Doody 2011; Garrock *et al.* 2014; Doherty & Ritchie 2017). Adaptive management allows actions to be changed if they fail to achieve outcomes. The best cases of management of invasive species are comparable to ecological experiments (Myers *et al.* 2000), in which ecological processes can be examined and controls may be evaluated through continued monitoring of key demographic parameters of the target species (Blossey 1999).

Effective monitoring is an essential element of species management programmes (Goldsmith 1991; Probert *et al.* 2011), and rigorous monitoring provides data crucial for adaptive management. Monitoring that uses presence–absence data has been commonly employed to study invasive species (e.g.

Havel *et al.* 2002; Jones 2011; Guillera-Arroita & Lahoz-Monfort 2012). Occupancy-based approaches are a relatively low-cost way to survey large areas rapidly for mobile and cryptic species (Webb *et al.* 2014; Crates *et al.* 2017). Occupancy data reveal species habitat–occupancy relationships while accounting for imperfect detection (e.g. Dugger *et al.* 2011; Pearl *et al.* 2013). This type of information is essential for planning, management and targeted control efforts for invasive species (e.g. Bled *et al.* 2011; Gormley *et al.* 2011). Failing to account for imperfect detection can lead to inaccurate representations of species distribution patterns and skew inferences (MacKenzie 2005). Estimating detection probabilities can also have important management implications (MacKenzie *et al.* 2002), particularly if efficacy of control efforts depends on high likelihood of detection. In invasive species management, population control will have (often unmeasured) impacts on invader behaviour (Côté *et al.* 2014), which may also affect detectability and occupancy. This has been documented in species where repeated capture creates avoidance behaviour or increased vigilance, hindering future control (Côté *et al.* 2014; Pecorella *et al.* 2016). The occupancy framework (MacKenzie *et al.* 2006) provides a simple way to evaluate changes in occupancy and detection in context of management,

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which may reveal potential behavioural aversion of target species from managed areas.

Here, we use an occupancy modelling framework to investigate the distribution of the introduced rainbow lorikeet *Trichoglossus moluccanus* in Tasmania, Australia. Introduced as escaped/released caged birds, the population may be growing. Rainbow lorikeets are capable of inhabiting diverse urban habitats and have been successfully introduced to Perth, Australia (Chapman 2005); Auckland, New Zealand (Polkanov & Greene 2000); and Singapore (Lin Neo 2012). The species is aggressive and is known to dominate other bird species that utilise the same resources (Higgins 1999). The species may displace native species and is considered a serious pest of agricultural assets (Chapman 2005). Introduced rainbow lorikeet populations are rarely studied, and thus, their habitat associations and patterns of distribution in novel habitats remain unknown. We aim to provide new information about the status and control options for the invasive rainbow lorikeet by asking two questions:

1. Does opportunistic lethal control (removal) of rainbow lorikeets change site-level occupancy and detection probability?
2. What are the patterns of contemporary rainbow lorikeet occupancy across Tasmania?

METHODS

Study area

We focused on the two main centres of rainbow lorikeet occurrence in Tasmania, Australia, based on records in the Atlas of Living Australia (www.ala.org.au, accessed September 2018). Historical records and other evidence (Shukuroglou & McCarthy 2006) were used to define our two study areas in the north and south of the island, and we assumed these populations were isolated from one another. We focused on cities and surrounding areas where rainbow lorikeet records were clustered. We identified two discrete populations. The northern coastal population (Fig. 1) comprised the urban areas and nearby suburbs of Burnie, Ulverstone and Devonport (we have no reason to believe these northern subpopulations are isolated from one another). The southern Hobart population (Fig. 2) comprised the southern suburbs of Hobart southward to Kettering. The study areas were predominantly suburban with scattered patches of native vegetation among urban and peri-urban habitats.

Aim 1: To determine if opportunistic removal of adult rainbow lorikeets lowered site-level occupancy and detection probability of introduced lorikeets

The southern population of rainbow lorikeets are subject to intermittent lethal control (hereafter: removal) by the

Tasmanian Government to curtail the species establishment. In 2017, 208 rainbow lorikeets were removed from the southern population during the autumn/winter (March to August), potentially comprising >50% of the local population (based on an estimated population of ~350 individuals, D.S., unpublished data, 2016). To examine the effect of this removal, we undertook surveys during the breeding season both before (2016) and after (2018) removal. Both surveys were conducted within September to control for a potential seasonal effect. We established 177 sites of 200 m diameter in a grid pattern over the southern study area. Sites were spaced >250 m apart and contained at least one *Eucalyptus* tree, that is potential rainbow lorikeet habitat. If ground-truthing indicated there were no trees at that location, the site was moved to the nearest location with a tree. We undertook at least two repeated five-minute presence-absence surveys (mean 3.5 surveys per site, max 4 surveys). In 2016, surveys were conducted by four skilled observers, and in 2018, MC undertook all surveys. The species is conspicuous (highly vocal and identifiable), so we assumed a reliable detectability between observers, but in both periods we undertook field calibration among observers to ensure detection of birds was consistent. We controlled for potential effects of weather on detection probability by only surveying in fine conditions (i.e. no wind or rain). We also collected the following habitat variables at each site: (i) presence-absence of *Eucalyptus* spp., (ii) *Grevillea* spp., (iii) *Banksia* spp., (iv) *Acacia* spp., (v) urban/planted gardens, (vi) *Eucalyptus* spp. flowers, and (vii) distance from central urban area. We selected these plant species as they represent important resources for the rainbow lorikeet (Higgins 1999). We also recorded distance from city centres as previous studies have found lorikeets are more abundant in peri-urban areas (Veerman 1991; Shukuroglou & McCarthy 2006).

Aim 2: To determine the patterns of contemporary rainbow lorikeet occupancy across northern Tasmania

We followed the same site selection and survey procedure as above in the northern study area. In 2018, we surveyed 135 sites across the three focal urban areas (mean 45 sites per city). Sites were surveyed three times each during the breeding season (October/November). All northern surveys were undertaken by MC.

Statistical analysis

We provide our code and summarise the data in RMarkdown script provided in Appendix S1. For both aims, we followed MacKenzie *et al.* (2006) and fitted single-season occupancy models using the package ‘*unmarked*’ (Fiske & Chandler 2011) in R (R Core Team 2019) to estimate occupancy and detection probability. To account for potential impacts of time of day on detection probability, we fitted a model containing this variable in the detection component as a factor, with constant occupancy for the 2018 surveys. Based on the results of this model (below), we assumed that detection probability was constant in all other models because we controlled for factors (inclement weather) that could influence detection. For both aims, we fitted a

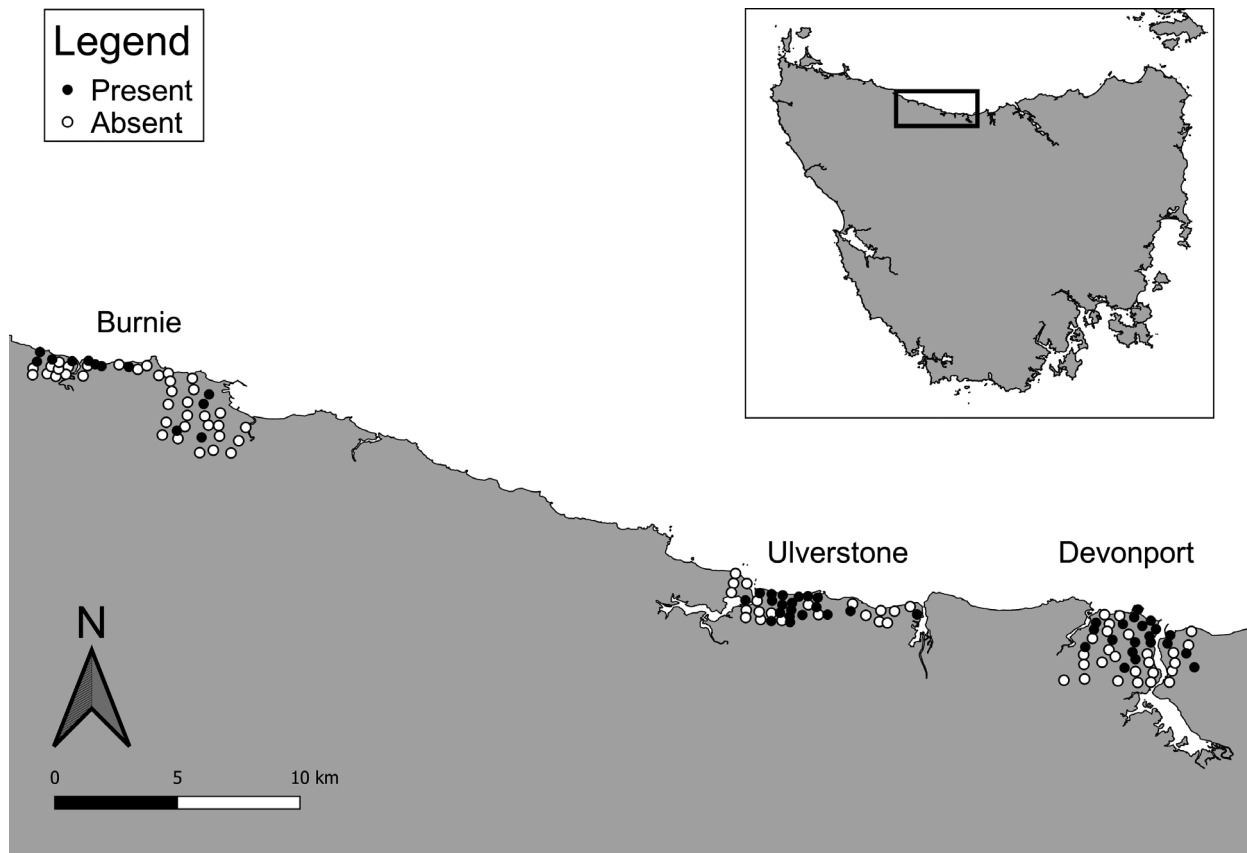


Figure 1. Northern study area showing survey sites where rainbow lorikeets were present and absent in 2018.

constant occupancy model as well as the site-level vegetation and distance covariates in the occupancy component of models (limiting individual models to single terms to avoid overfitting). We selected the best model based on $\Delta\text{AIC} < 2$ (Buckland *et al.* 1997) using the function ‘*modSel*’. For aim one, we compared the occupancy and detection estimates (and confidence intervals) from the best fitting models for each year to evaluate whether the removal of birds affected these parameters. We expect that if there was an effect of removal, modelled estimates and confidence intervals should have minimal overlap. For aim two, we pooled data from all sites into the same analysis across the three cities as it did not appear that these populations were isolated. We made this assumption based on the close proximity of all three cities in the north of Tasmania (< 22 km between cities – Fig. 1) and the mobility of the species (Chapman 2005).

RESULTS

Aim 1: To determine if opportunistic removal of adult rainbow lorikeets lowered site-level occupancy and detection probability of introduced lorikeets

We recorded rainbow lorikeets at 44 of 177 sites in the southern survey area in 2016 (naïve overall

occupancy 0.25), and at 49 of 166 sites in 2018 (naïve overall occupancy 0.30). Some sites (11) were removed from the 2018 survey due to changed accessibility between the two years surveyed. The best fitting model of rainbow lorikeet occurrence in both 2016 and 2018 included distance from central urban area (Table 1). The two best models (within $\Delta\text{AIC} < 2$) included distance in the detection parameter and time of the day in the detection component of one of them. Because these models are both plausible ($\Delta\text{AIC} < 2$; Burnham & Anderson 2002), we chose the model with constant detection probability for prediction. The confidence intervals of the occupancy estimates from 2016 and 2018 closely overlapped for all distances from the urban centre (Fig. 3 shows estimates and confidence intervals from the best models for 2016 and 2018), indicating no impact of removal on site-level occupancy.

Aim 2: To determine the patterns of contemporary rainbow lorikeet occupancy across northern Tasmania

We recorded rainbow lorikeets at 52 of 135 sites in the northern survey area in 2018 (naïve overall

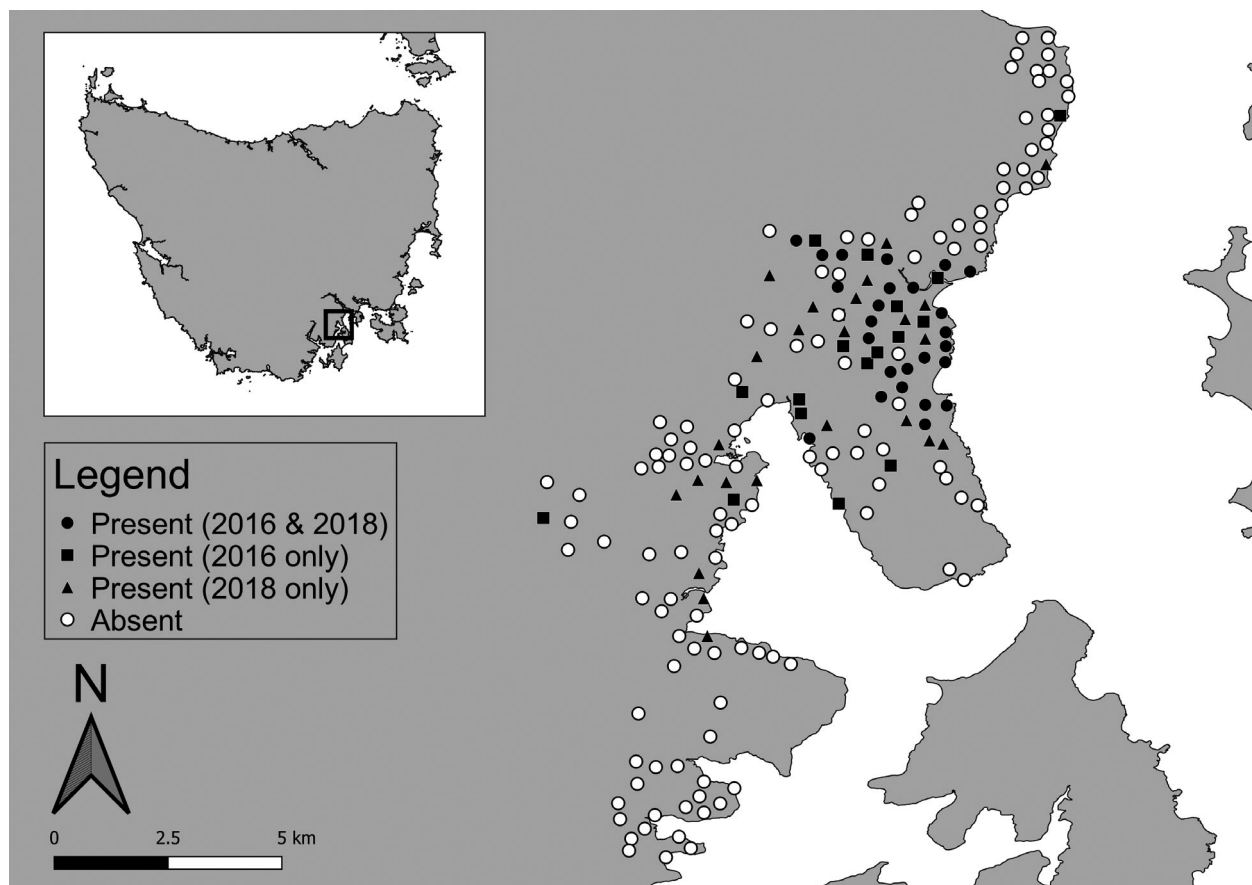


Figure 2. Southern study area showing survey sites where rainbow lorikeets were present and absent in 2016 and 2018.

occupancy 0.39). We preferred the simplest model based on AIC, which included distance from central urban area (Table 2). As in the southern survey area, the model that included time of day on detection

probability was the second best model, and as they are both plausible, we again chose the simplest one for prediction. Modelled occupancy estimates and confidence intervals from the preferred model are presented in Figure 4.

Table 1. 2016 and 2018 modelled occupancy (Ψ) and detection (p) probability of rainbow lorikeets (southern survey area). Top five models ranked by AIC

| Model | <i>n</i> Pars | AIC | Δ AIC |
|---|---------------|--------|--------------|
| 2016 | | | |
| $\Psi(\text{distance}); p(.)$ | 3 | 337.38 | 0 |
| $\Psi(\text{banksia}); p(.)$ | 3 | 384.42 | 47.04 |
| $\Psi(.); p(.)$ | 2 | 386.42 | 49.04 |
| $\Psi(\text{garden}); p(.)$ | 3 | 387.02 | 49.64 |
| $\Psi(\text{flower}); p(.)$ | 3 | 387.10 | 49.72 |
| 2018 | | | |
| $\Psi(\text{distance}); p(.)$ | 3 | 393.08 | 0.00 |
| $\Psi(\text{distance}); p(\text{time})$ | 4 | 394.99 | 1.91 |
| $\Psi(\text{banksia}); p(.)$ | 3 | 437.20 | 44.12 |
| $\Psi(.); p(.)$ | 2 | 439.28 | 46.20 |
| $\Psi(\text{garden}); p(.)$ | 3 | 440.51 | 47.43 |
| $\Psi(.); p(\text{time})$ | 3 | 441.25 | 48.17 |

*n*Pars, number of parameters.

DISCUSSION

Our study reveals higher occupancy estimates for the introduced rainbow lorikeet at sites in the north of Tasmania than in the south. We also demonstrate a negative effect of distance from central urban areas on site-level occupancy across both populations (Figs 3 and 4). We found no change in occupancy or detectability estimates in the southern population despite removal of 208 individuals from the population. While opportunistic live-trapping in urban areas may reduce population size, our results suggest that occupancy is not affected by this management intervention. There are several possibilities that may explain results: (i) the population size is so large that current trapping intensities are trivial, (ii) the population was able to rapidly recover after birds were

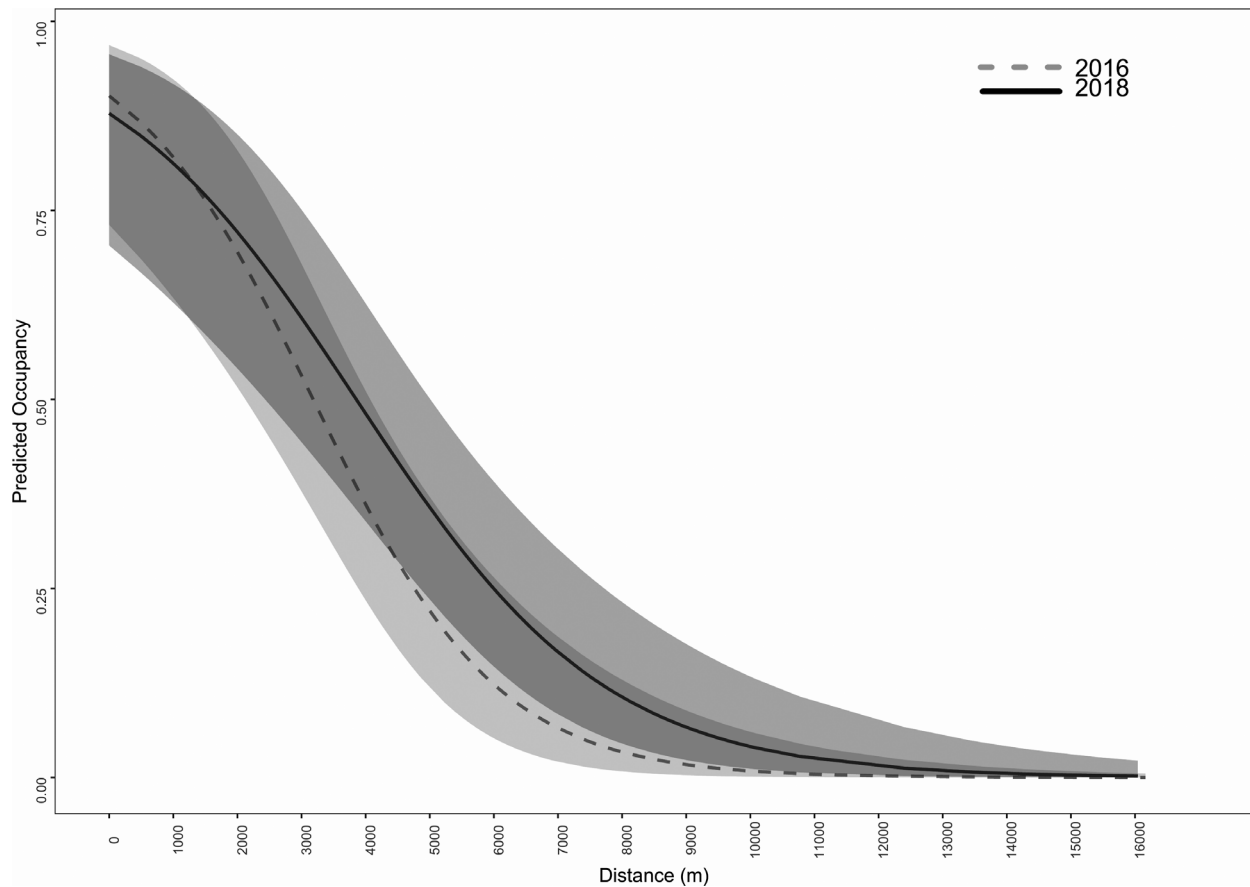


Figure 3. Modelled rainbow lorikeet occupancy relative to distance from a central urban area in southern survey area, surveyed before (2016) and after (2018) removal (shaded areas represent 95% confidence interval).

Table 2. Modelled occupancy (Ψ) and detection (p) probability of rainbow lorikeets (northern survey area). Top five ranked by AIC

| Model | n Pars | AIC | Δ AIC |
|---|----------|--------|--------------|
| $\Psi(\text{distance}); p(.)$ | 3 | 360.23 | 0.00 |
| $\Psi(\text{distance}); p(\text{time})$ | 4 | 361.02 | 0.79 |
| $\Psi(\text{garden}); p(.)$ | 3 | 369.09 | 8.86 |
| $\Psi(\text{eucalypt}); p(.)$ | 3 | 371.39 | 11.16 |
| $\Psi(.); p(.)$ | 2 | 371.78 | 11.55 |
| $\Psi(.); p(\text{time of day})$ | 3 | 372.53 | 12.30 |

n Pars, number of parameters.

removed, or (iii) removal of birds lowers population density but not the area of occupancy. More effort is required to test these hypotheses, and density or abundance-based approaches (e.g. use of count data or distance sampling, Buckland *et al.* 2001) may be more informative than occupancy for evaluating removal impacts on population size.

Our results also reveal that there is higher occupancy of sites in the north than in the south of

Tasmania. This may be a consequence of initial propagule pressure at that population, and there is anecdotal evidence that large numbers of birds were released in Ulverstone, northern Tasmania (S.R., unpublished data, 2018). The northern population has not been subject to removal, and in combination with higher founding population size, this may explain the higher site-level occupancy of this population. The northern population may also occasionally experience immigration from continental Australia (supported by evidence of self-introduced rainbow lorikeets on the Bass Straight Islands, D.S. and S.R., unpublished data, 2019). The southern population is unlikely to experience regular immigration (other than via accidental releases of captive-born birds from which the wild founders likely originated themselves), so a smaller founding population and lack of immigration plus lethal control may depress growth of the southern population and potentially explain their lower site-level occupancy estimates.

The importance of urban areas in our study supports previously demonstrated habitat preferences of the rainbow lorikeet in its native distribution

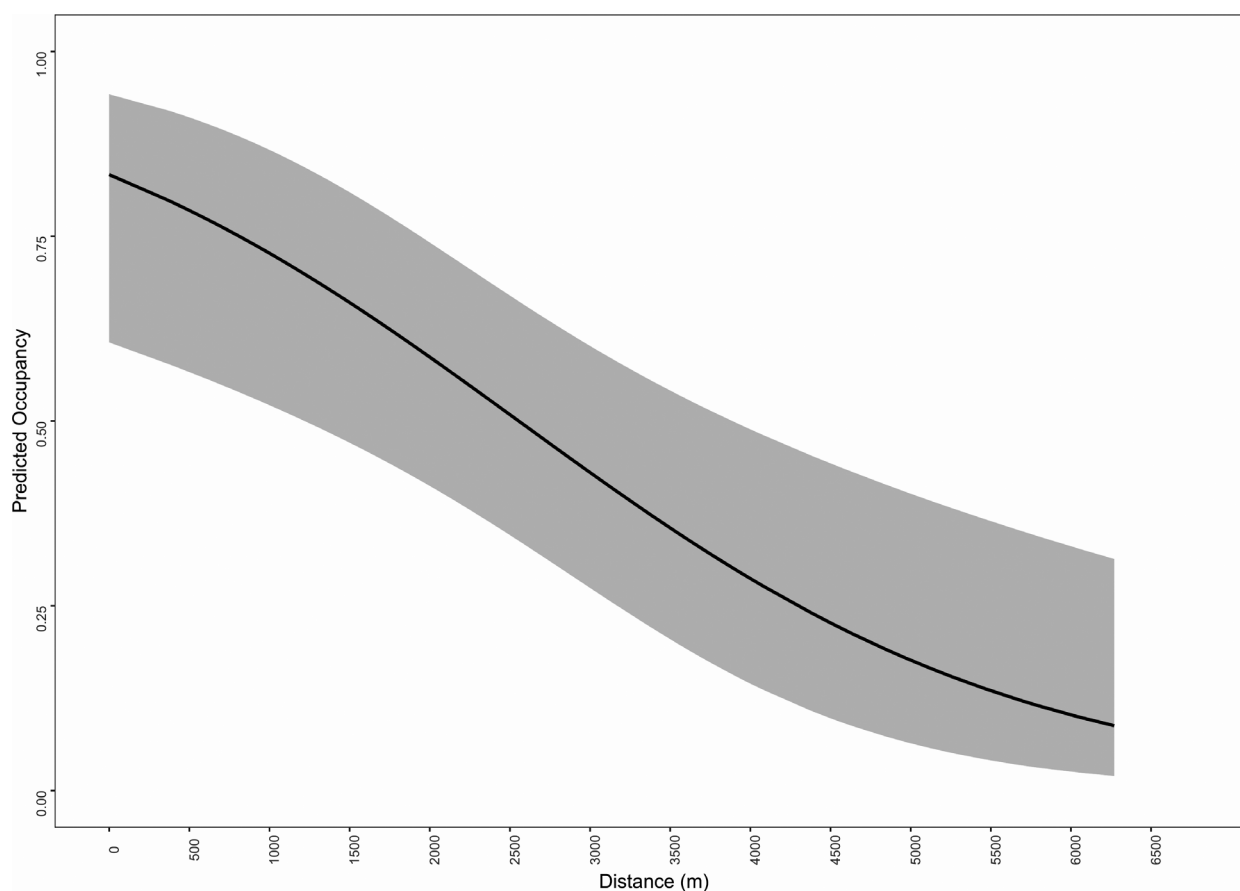


Figure 4. Modelled rainbow lorikeet occupancy relative to distance from a central urban area in northern survey area, surveyed in 2018 (shaded areas represent 95% confidence interval).

(Shukuroglou & McCarthy 2006). Reliable food sources and roosting sites are believed to be the resources preferred in urban areas, but detailed data on habitat preferences and utilisation of urban habitats are scarce (Shukuroglou & McCarthy 2006). It is possible that the occupancy patterns we found in Tasmania do not reflect optimal habitat preferences. Instead, their contemporary distribution may simply reflect where the initial introductions of the species occurred. If the latter is true, potential expansion of the population beyond the current urban limits of their range is possible as population size and propagule pressure grow, resulting in occupancy of new habitats. The habitat covariates we modelled did not predict rainbow lorikeet occupancy in our study, but other less obvious habitat features should be considered in future work. For example, food availability (feeders, flowering plants) or availability of suitable trees for evening roosts could be important in understanding rainbow lorikeet occurrence and may be important for supporting the establishment of new subpopulations.

Eradication of the rainbow lorikeet from Tasmania appears unlikely if low-intensity, intermittent removal

is the only management approach employed. Systematic and regular removal of birds should be implemented in context of both abundance and area-based monitoring programmes to facilitate adaptive management if eradication is to be achieved. Based on the negative impacts of this species in other places it has been introduced, if eradication is to be attempted, it should happen before their population grows so much that it becomes impossible. Their limited distribution to urban areas allows for a targeted management strategy, which will limit resource wastage and direct best practice of future control attempts. Further study is necessary to better evaluate whether eradication is feasible in Tasmania and to identify how much effort (and expense) is necessary to achieve this aim.

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AUTHOR CONTRIBUTION

McLean Cobden: Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Visualization (equal); Writing-original draft (equal). **Fernanda Alves:** Formal analysis (equal); Writing-review & editing (equal). **Sue Robinson:** Writing-review & editing (equal). **Robert Heinsohn:** Supervision (equal); Writing-review & editing (equal). **Dejan Stojanovic:** Conceptualization (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Supervision (equal); Writing-review & editing (equal).

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information may/can be found online in the supporting information tab for this article.

Appendix S1. LorikeetScript_submission.R.