All the eggs in one basket: are island refuges securing an endangered passerine?

Matthew Webb[1] , Fernanda Alves[2], Ayesha Tulloch[1], Justine Shaw[3], Sally Bryant[4], Dejan Stojanovic[1], Ross Crates[1] and Robert Heinsohn[1]

1. Fenner School of Environment and Society, Australian National University, Acton, ACT, Australia
2. Research School of Biology, Australian National University, Acton, ACT, Australia
3. Centre for Biodiversity and Conservation Science, School of Biological Science, The University of Queensland, St Lucia, Qld, Australia
4. Tasmanian Land Conservancy, Sandy Bay, Tas, Australia
5. Corresponding author: matthew.webb@anu.edu.au, +61400104088

Acknowledgements

Funding was received via crowdfunding (The parrot, the possum and the pardalote) and from the Australian Government's National Environmental Science Program through the Threatened Species Recovery Hub. Thanks to Weetapoona Aboriginal Corporation for land access. Surveys were conducted with ANU animal ethics approval A2014/26 and under a Tasmanian Government Scientific Permit (TFA14232).

Abstract

Refuges for threatened species are important to prevent species extinction. They provide protection from a range of environmental and biotic stressors, and ideally provide protection against all threatening processes. However, for some species it may not be clear why some areas are refuges and others are not. The forty-spotted pardalote (*Pardalotus quadragintus*) is an endangered, sedentary, cryptic and specialized bird endemic to the island of Tasmania, Australia. Having undergone an extreme range contraction over the past century the species is now mostly confined to a few small offshore island refuges. Key threatening processes to the species include habitat loss, wildfire, competition and predation. The ways in which these processes have molded the species' contemporary range have not been clearly evaluated. Furthermore, the security of the remnant population within refuges is uncertain. To overcome this uncertainty we assessed key threats and established the population status in known refuges by developing a robust survey protocol within an occupancy modelling framework. We discuss our results in the context of planning trial reintroductions of this endangered species in suitable habitat across its former range. We found very high occupancy rates (0.75-0.96) at two refuges and in suitable conditions, the species was highly detectable (p, 0.43-0.77). At a third location our surveys indicated a local extinction, likely due to recent wildfire. We demonstrate that all refuges are at high risk of one or more threatening processes and the current distribution across island refuges is unlikely to secure the species from extinction. We identified large areas of potential habitat across the species' former mainland range, but these are likely too distant from source populations for natural recolonization. We propose that establishing new populations of forty-spotted pardalotes via reintroduction is essential to secure the species and that this is best achieved while robust source populations still exist.

Key words

Forty-spotted pardalote *Pardalotus quadragintus*, refuges, conservation biology, threatening processes

Introduction

The identification of refuges for at risk species is increasingly important to conservation biology (Keppel and Wardell-Johnson Grant 2012). In the Australian context, refuges can generally be defined as locations or habitat within a landscape that facilitate survival of species after disturbance events (e.g. fire, drought) or protection against introduced predators (Pavey *et al.* 2017). Refuges can originate through geographic isolation (e.g. islands), topographic position and vegetation types less prone to fire, or anthropogenic activities such as predator control, fencing and fuel reduction burning (Taylor *et al.* 2005). There are numerous cases where a species' survival hinges on its persistence within refuges (Atkinson 2002; Morris 2000; Webb *et al.* 2016). Understanding the processes that form refuges is critical to conservation management. Moreover, understanding the spatial and temporal nature of these processes is important to evaluate if the protection provided by a refuge is short-term (e.g. fire refuges, invasive species), or potentially long-term security (e.g. islands) (Woinarski *et al.* 2011). This will ultimately determine what actions can be undertaken to increase their effectiveness (e.g. fire management, reservation, biosecurity) (Caughley 1994).

For small or rapidly declining populations, failure to act can quickly lead to extinction (Martin *et al.* 2012; Woinarski 2016). When a species has reached this critical stage, its distribution has often contracted to refuges (Lomolino and Channell 1995) and by default, these areas often become foci for conservation planning (Webb *et al.* 2016; Stojanovic *et al.*

2017). In such cases, conservation actions usually focus on the reservation of occupied habitat, increasing habitat area (Smith 2008) and evaluating how best to expand or protect refuges depending on spatial and temporal factors related to extinction risk (McCarthy *et al.* 2005; Schultz Courtney *et al.* 2013).

Typical approaches for threatened species in conservation are increasing population size (McCarthy *et al.* 2005); managing specific threats (Wilson *et al.* 2007), and ex situ conservation or translocations (Seddon 2015). If populations are viable but local habitat is at carrying capacity, creating 'new' populations (or restoring locally extinct populations) in suitable but unoccupied habitat may provide greatest cost-benefits rather than attempting to enlarge existing populations (McCarthy *et al.* 2005).

Despite islands being disproportionally represented in species extinctions (Blackburn *et al.* 2004; Tershy *et al.* 2015), conversely they can also provide critical refuges if threatening processes are absent (Heinsohn *et al.* 2015; Lentini *et al.* 2018; Taylor *et al.* 2005). Here we examine the benefits of focusing management actions on the protection of refuges compared to actions that target threats, both historic, current and future. We use the case study of an endangered bird that now only occurs in refuges, primarily on islands (Threatened Species Section 2006). The forty-spotted pardalote (*Pardalotus quadragintus*) is a small, cavity nesting, leaf gleaning passerine dependent on white gums (*Eucalyptus viminalis*) for food, and primarily nests in tree cavities of eucalyptus species (Woinarski and Bulman 1985). Historically the species was widely distributed across Tasmania (Fig 1) and it is now presumed extinct across most of its former range (Brown 1986; Rounsevell and Woinarski 1983). This range contraction has been occurring at least since the early last century and has continued over recent decades (Bryant 2010; Rounsevell and Woinarski 1983; Threatened Species Section 2006). Three decades ago the species' area of occupancy was estimated to be <50 km^2, mostly on Bruny, Maria and Flinders Islands off the Tasmanian coast and a mainland location, Tinderbox Peninsula. Tinderbox Peninsula is < 1.5 km from Bruny Island (Fig. 1; Figs. S1 & S2), and based on genetic evidence is likely supported by birds dispersing from Bruny Island (Edworthy 2017) . These locations are foci for the species' conservation, and 77% of refuge habitat has some level of statutory protection (Bryant 2010). Importantly, an implicit assumption of this approach is that the species can be secured from extinction at these locations.

The probable causes of the species' range contraction are diverse (Table 1). Likewise, it is not known whether forty-spotted pardalotes are now restricted to island refuges, or if they are capable of recolonizing parts of their historical range on mainland Tasmania either naturally or through translocation (Threatened Species Section 2006). Here, we aim to: (1) quantify current threats to refuges and their security, and (2) provide baseline population data. We use our results to examine management options to prevent further range contraction and evaluate potential for range expansion through reintroductions.

Methods

Aim 1: quantifying the historical and future impact of threats and updating conservation assessments of refuge habitat

We focus on widespread threatening processes with strong evidence of direct impacts: (i) deforestation, (ii) wildfire, (iii) noisy miner *Manorina melanocephala* competition, and climate change (see Table 1), but also consider threats where impacts are more uncertain such as a newly discovered parasitic fly that can cause high nestling mortality (Edworthy 2018). For each threat, we evaluated the potential risk of it impacting refuges.

To assess the impact of recent deforestation, we quantified the area of core forty-spotted pardalote refuge habitat using two data sources: (i) a 30-year-old spatial layer of core refuge habitat (Brown 1986; habitat (Natural Values Atlas www.naturalvaluesatlas.tas.gov.au, accessed 1 September 2015) and (ii) a recent map of vegetation types TASVEG 3.0 (Department of Primary Industries, Parks Water and Environment 2013) to identify key forest habitats. We assessed contemporary habitat loss/disturbance using a spatial layer of forest loss derived from Landsat imagery at 30 x 30 m resolution (Hansen *et al.* 2013). Hansen *et al.* (2013) classifies 'forest loss' as the result of land clearing, timber harvesting and wildfire. Here, we defined the cumulative area of impact of these processes as deforestation area. Using ArcMap 10.2, we estimated the total area of potential habitat of the forty-spotted pardalote and the total area of habitat affected by recent deforestation.

The forty-spotted pardalote's current and historical distribution is highly fire-prone (Fig S3 and S4). To assess the potential historical impacts of fire on refuges, we used a spatial layer of fires in Tasmania (1969 – 2016) (Tasmanian Fire Service 2017) to estimate the area of forty-spotted pardalote habitat affected by wildfire during this period. We also assessed the future risk of fires occurring in refuges using the Tasmanian Bushfire Risk Assessment Model (Parks and Wildlife Service, unpublished) by quantifying the area of each refuge and its respective 'fire ignition potential'. Ignition potential in this model is based on the number of historical fires, lightning probability and Bureau of Meteorology observations.

Noisy miners do not currently occur in forty-spotted pardalote refuges. However, they are widespread on the Tasmanian mainland, having expanded with land clearance (MacDonald and Kirkpatrick 2003). To examine possible historical impacts of noisy miners on pardalote populations and assess the future risk of noisy miner colonization of refuge habitat, we compared noisy miner environmental suitability of forty-spotted pardalote refuges and their historical range. We modeled environmental suitability for noisy miners across Tasmania using MaxEnt (Phillips *et al.* 2006). We used verified occurrence data with a location accuracy < 500 m downloaded from the Atlas of Living Australia (ALA, http://www.ala.org.au, downloaded 4/9/2016). We also included unpublished data collected by the authors, resulting in a total of 1550 noisy miner records for modeling. Predictor variables were total rainfall during the driest quarter, mean temperature of the warmest quarter, minimum temperature of the coldest period, temperature seasonality, vegetation cover (cleared or not), and ecosystem type (11 categories, reclassified from the Major Vegetation subgroups from the National Vegetation Information System v4.1, Australian Government 2012); these variables are known to relate to noisy miner prevalence and abundance (Maron *et al.* 2013; Thomson *et al.* 2015). Based on model outputs, we assessed the environmental suitability of forty-spotted pardalote refuges for noisy miners. We reclassified the Maxent logistic output into predictions of noisy miner presence or absence using equal sensitivity and specificity threshold values for each year (Liu *et al.* 2013). This resulted in a map of predicted suitable or unsuitable environments. This map aimed to represent current suitability and did not account for potential expansion of the species resulting from future disturbance or a changing climate. The potential impacts of climate change were considered in the context of the species' highly restricted distribution and likely exacerbation of other known threats (e.g. fire).

Using the information outlined above and the combined expert knowledge of the authors we used a standard threat risk assessment process (Hart *et al.* 2005) to identify the relative future risk posed by each threat to each refuge (and habitat in the historical range) over a 30-year period. Each threat was assessed for the consequence to the species and the likelihood of that consequence happening (Supplementary Material). Consequence was defined by the expected magnitude of the impact of a threat and the overall threat footprint. For example, habitat clearance in reserved refuges would be major but only small areas (i.e. threat footprint) are likely to be affected. Overall risk posed by each threat was then assessed using the consequence and likelihood ratings in a standard risk matrix (Supplementary Material).

Aim 2: develop a monitoring protocol to provide baseline population data for refuges

There is currently no systematic monitoring program for the forty-spotted pardalote. To account for false absences (i.e. imperfect detection) we adopted a standard occupancy modelling approach (MacKenzie et al. 2002). We undertook baseline surveys on known pardalote refuges Maria Island, North Bruny Island and Flinders Island (Figs. S1, S2 & S3), which combined supports ~79 % of the species contemporary area of occupancy, with the remainder occurring on South Bruny Island and Tinderbox Peninsula (calculated in ArcMap 10.2 using the spatial layer of habitat outlined above (Natural Values Atlas 2015). The number of sites and site visits is summarized in Table 5. As our objective was to estimate occupancy in critical habitat (i.e. forest containing white gum, *E. viminalis*), we used the spatial layer of refuge habitat outlined above as a guide for site selection. All sites had at least one white gum present, and were selected as follows: from a random starting point the nearest white gum was located which became the first sampling site. Subsequent sites were established by following a random compass bearing to the nearest white gum ≥200m from the previous site. For logistical reasons the locations of sites on North Bruny Island were influenced by access and on Maria Island sites were restricted to within ~100m of existing walking tracks (Fig. S1). We used repeated five-minute visits to record the presence/absence of birds within 100m of the site (based on calls and observation). Monitoring was conducted intermittently between 2010 and 2016. Other locations in the historical range were surveyed opportunistically.

The forty-spotted pardalote is extremely cryptic owing to its soft call, small size, and two other sympatric pardalote species (*P. striatus and P. punctatus*) (Rounsevell and Woinarski 1983). During the species' breeding season (i.e. spring/summer), several avian migrants and other resident species, can form noisy aggregations that can drown out the soft vocalizations of the forty-spotted pardalote. To increase and control for variation in detectability, we restricted our surveys to still, clement weather in the non-breeding season (i.e. autumn/winter, when migratory species had left the study area) to maximize the likelihood of detecting the soft calls of the target species. We used occupancy modelling to estimate overall occupancy (Ψ) in critical habitat for each refuge. We fitted simple constant occupancy models using the package *unmarked* in R (Fiske and Chandler 2011; R Development Core Team 2011). We used estimates of detectability (p) to assess the reliability of absences at other locations where data were too sparse.

Results

Aim 1: quantifying the historical and future impact of threats and updating conservation assessments of refuge habitat

The species' area of occupancy based on mapped habitat (Natural Values Atlas www.naturalvaluesatlas.tas.gov.au, accessed 1 September 2015) was estimated as ~ 42 km^2, but only 35.5 km^2 of this area is currently eucalypt forest and woodland. According to our overall risk assessment, all refuges face high, very high, or extreme risks from multiple threats (Table 2). Consequence and likelihood ratings for each threat in each refuge are provided in Appendix A.

Only 0.82 km^2 (< 2 %) of refuge habitat has been affected by deforestation since ~1996. Overall, deforestation through habitat clearance is likely to be relatively low risk to refuge populations, as 77% (Bryant 2010) of refuges has some level of statutory reservation and risk level was identified to vary depending on the location (Table 2). Furthermore, fire is likely the cause for ~75% of the disturbance classified as deforestation (Hansen *et al.* 2013).

Historical fire mapping indicates that of all refuge habitat has burned since 1969 (17 %, 7.1 km^2), with most of this (62 %, 4.1 km^2) attributable to the 2003 fire on Flinders Island (Fig. S3). Other fires in refuge habitat were smaller (mean 0.12 km^2; range 0.0002 – 1.2 km^2) and 83% of extant habitat has not burned for > 45 years. The Tasmanian Bushfire Risk Assessment Model identifies 83% of refuge habitat as having a moderate to very high ignition potential (Table 3).

Our MaxEnt model of noisy miner distribution indicates that an area of 10,587 km^2 across Tasmania is climatically suitable for the generalist noisy miner (see Supplementary Material for model details). Environmental suitability for noisy miners is high across most of the former and present distribution of the forty-spotted pardalote and they are well established < 4km from all refuges except Flinders Island (Fig 2). The percentage area above the threshold value of noisy miner environmental suitability for each pardalote refuge varied from 0 – 81% (Table 4).

Aim 2: develop a monitoring protocol to provide baseline population data for refuges

On North Bruny Island and Maria Island estimates of pardalote Ψ were high in all years (range 0.75-0.96, Table 5). Detectability for a single site visit was also high but more variable (0.43-0.77). Over the entire study period the species was recorded at 59 of 67 sites (88 %) on Maria Island, 55 of 61 sites (90 %) on Bruny Island, and only 7 of 115 of sites (6 %) on Flinders Island. The mean number of birds counted at a site (given presence) was 2.2 (range 1-6).

No birds were detected at any previously known forty-spotted pardalote sites on Flinders Island despite visiting these sites more often than other areas (up to 5 site visits in each year). A 'new' location was discovered on Flinders Island but is separated from the previously known refuge by >20 km of primarily agricultural land (Fig. S3). The species was also found in small patch of habitat (~10 ha) near Southport, on the Tasmanian mainland (Fig. 1). The last record of the species in the vicinity of Southport was > 120 years ago. Too few data (and birds) were available to model Ψ or p at these locations (Table 5).

Discussion

The forty-spotted pardalote is now predominantly confined to island refuges. The species is at risk from multiple threats across this highly restricted range . We have established baseline population data and quantified the historical impacts and future potential risks of threats to refuge populations. We demonstrate that occupancy rates are very high at two refuges (Maria and Bruny Islands) and that the Flinders Island population is almost extinct. This provides the first standardized quantitative assessment of refuge populations providing a baseline for assessing change in population size using Ψ as a surrogate for abundance (MacKenzie and Nichols 2004). Deforestation in refuges has abated in recent decades and these areas appear to currently support viable populations. However, our threat risk assessment (Table 2) found all refuges are extremely vulnerable to multiple threats including wildfire, colonization by the hyper-aggressive noisy miner and climate change. Islands have clearly provided critical refuges from threatening processes; however, our results indicate that these refuges are not secure from these threats despite being extensively reserved.

Fire frequency, intensity, and extent are expected to increase with climate change in this ecosystem (Fox-Hughes *et al.* 2014; Grose *et al.* 2014). In this case, the islands have clearly provided protection from fire; however, most refuge habitat has not burnt for a long time(and therefore currently support high fuel loads) and has a high ignition potential suggesting severe fire(s) are likely under suitable weather conditions (Table 3 & Fig. S4). Hence, refuges have only provided temporary protection at different spatial scales, but not security. The impact of fire will depend on fire severity, frequency and the spatial configuration and extent of burned and unburned habitat (Prowse *et al.* 2017). For example, a single severe fire on Flinders Island in 2003 (Fig. S3) that burned an entire patch of refuge habitat has likely resulted in another local extinction. Despite some forest recovery, the location remains unoccupied by forty-spotted pardalotes over a decade later. In contrast, several decades ago a fire burned all of south Maria Island (Fig. S1), but was recolonized two years later likely due to immigration from nearby refuge habitat (< 1 km) on the north of the island (Rounsevell and Woinarski 1983). Importantly, when compared to the size of many large fires the small size of refuges means they are all at risk of being totally destroyed with little chance of recolonisation.

The value of a refuge for forty-spotted pardalotes post fire will also depend on interactions with other biota including competition, predation, and parasitism (Kirkpatrick *et al.* 2011; Lindenmayer *et al.* 2006). Under post-fire conditions introduced herbivores may suppress regrowth and structural complexity of forest (Driscoll *et al.* 2010; Kirkpatrick *et al.* 2011), thus increasing environmental suitability for noisy miners (MacDonald and Kirkpatrick 2003; Maron and Kennedy 2007; Maron *et al.* 2011) or result in increased predator abundance (Hradsky *et al.* 2017). While high nestling mortality is caused by the newly discovered native parasitic fly (Edworthy 2018) it is unknown what the overall potential threat this poses. However, its effect likely varies in time and space depending on environmental conditions (e.g. Antoniazzi *et al.* 2010) and may be exacerbated under post fire conditions and climate change (Møller *et al.* 2014). Longitudinal (and larger scale) studies are required to determine the role of the parasitic fly on population dynamics for the forty-spotted pardalote..

We identify a large area of climatically suitable habitat for noisy miners across Tasmania (Fig. 2). The high bioclimatic suitability of most forty-spotted pardalote refuges for noisy miners, and their proximity to refuges (< 4 km) suggests there is a very high likelihood of colonization. Given that noisy miners favor fragmented environments (MacDonald and Kirkpatrick 2003; Maron *et al.* 2013), the impacts of colonization of refuges may vary depending on local forest fragmentation (Fig. S1 & S2). Since most occupied habitat on Bruny Island is adjacent to fragmented agricultural land, noisy miners could penetrate most pardalote refuges. By contrast, forest on Maria Island is more intact providing less opportunities for miner expansion, but historically cleared areas maybe ideal for noisy miners. Furthermore, intense grazing by introduced herbivores across large parts of Maria Island severely suppresses understory vegetation, reducing (or eliminating) cover which may advantage noisy miners (Maron and Kennedy 2007; Maron *et al.* 2011). Thus, our use of vegetation mapping likely provides an optimistic view of the area of 'intact' forest.

Historical range contraction

Failure to account for historical processes that have resulted in a species' current range can lead to misleading inferences about a species' ecological niche (Warren *et al.* 2014). Since European settlement, waves of local extinctions caused by large scale land clearance, subsequent habitat fragmentation and stochastic events (e.g. wildfire) and habitat fragmentation most likely resulted in no refuge populations to recolonize recovering habitat. We argue these processes probably disrupted pre-existing extinction-colonization dynamics, causing the species' range contraction. Some potential habitat in the species' historical range appears to be suitable forty-spotted pardalote habitat (M.H.W personal observations). However, the threatening processes (outlined above) allowed the concomitant expansion of noisy miners (and other aggressive birds with a similar niche), thus preventing dispersal through the agricultural matrix and recolonization of suitable habitat. Considering the spatial and temporal nature of the processes that caused the species range contraction, We suggest that suitable habitat may be available, but natural recolonisation is no longer possible.

Translocations in the species historical range

We call for immediate action to identify and prioritize potential reintroduction sites for the forty-spotted pardalote and attempt to establish new populations while apparently viable source populations exist within refuges. Moreover, reintroducing individuals from wild sources can be more effective since even small amounts of genetic adaptation in captive-bred individuals may negatively impact long-term wild population size and genetic diversity (Willoughby & Christie 2018). We propose that any attempt would undertake a structured decision-making process to identify an optimal source population (as per Wauchope et al. *in press*). There are well established protocols to inform conservation reintroducitons (IUCN/SSC 2013) and many precedents to inform a pardalote program (e.g. Taylor et al. 2005; Ortiz-Catedral & Brunton 2010; Collen et al. 2014).

Revegetation programs usually result in small areas of the landscape being revegetated (Thomson *et al.* 2015), require large investments (Atyeo and Thackway 2009; Menz *et al.* 2013) and take many years to achieve their objectives. Targeted revegetation programs (Understorey Network 2011) at refuges may eventually increase the area of occupancy, but this will not address the immediate threats to these refuges.

The creation of new populations via translocation may provide substantial opportunities to secure the species, particularly we are proposing reintroductions into the species former range. There is currently >1100 km^2 of white gum forest across the species former range, 610 km^2 of which occurs in patches >1 km^2 in area (mean, 3.1 km^2; S.D. 4.4 km^2) and often form part of larger forest remnants (Harris and Kitchener 2005) (Fig. S5). Despite the high climatic suitability of much of the former range for noisy miners, they rarely occur in the intact interior of larger forest patches (Maron *et al.* 2013); these areas may be ideal for creating new populations. In this context, a common failure in conservation planning is that locations designated as critical habitat rarely include suitable but unoccupied locations (Camaclang *et al.* 2014) and currently unoccupied potential habitat within the species' former range is afforded no legislative protection.

While reintroductions may be perceived as a 'risky' strategy (Ricciardi and Simberloff 2009) and the outcomes uncertain in some instances (e.g. persistence, population growth rate), they may be essential for the species' long-term survival and knowledge gained from undertaking such actions may be extremely valuable (Rout *et al.* 2009). Because of the current threats to refuges we believe any risks associated with translocations far outweigh the risks of not acting. Moreover, our assessments show this opportunity could rapidly be lost due to collapse of refuge populations (e.g. Flinders Island), or clearance of potential reintroduction sites and action must be undertaken promptly.

Conclusion

Our study highlights the need to consider the processes that create refuges for endangered species, and if they provide long-term security or merely represent the final locations to be affected by threatening processes. Diagnosing the processes that have led to a species current distribution is extremely valuable because previous local extinctions does not necessarily mean these sites remain permanently unsuitable, and vice-versa.

Literature Cited

Antoniazzi L. R., Manzoli D. E., Rohrmann D., Saravia M. J., Silvestri L. & Beldomenico P. M. (2010) Climate variability affects the impact of parasitic flies on Argentinean forest birds. *Journal of Zoology* **283**, 126-34.

Atkinson I. (2002) Recovery of wildlife and restoration of habitats New Zealand. *Pacific Conservation Biology* **8**, 27-35.

Atyeo C. & Thackway R. (2009) Mapping and monitoring revegetation activities in Australia – towards national core attributes. *Australasian Journal of Environmental Management* **16**, 140-8.

Blackburn T. M., Cassey P., Duncan R. P., Evans K. L. & Gaston K. J. (2004) Avian extinction and mammalian introductions on oceanic islands. *Science* **305**, 1955-8.

Brown P. (1986) The forty-spotted pardalote in Tasmania. Technical Report 86/4. National Parks and Wildlife Service,, Hobart, Tasmania.

Bryant S. (2010) Conservation assessment of the endangered forty-spotted pardalote 2009-2010. In: *Report to Treatened Species Section, DPIPWE and NRM South*, Hobart, Tasmania.

Camaclang A., Maron M., Martin T. & Possingham H. (2014) Current practices in the identification of critical habitat for threatened species. *Conservation Biology* **29**, 482-92.

Caughley G. (1994) Directions in conservation biology. *Journal of Animal Ecology* **63**, 215–44.

Collen, R., B. Cash, L. Adams, L. Oritz-Catedral, M. Booth, R. Gray, D. Fastier, K. Nagakawa and T. Ward-Smith. (2014). Best practice techniques for the translocation of red-crowned parakeet (kakariki), Cyanoramphus novaezelandiae novaezelandiae and yellow-crowned parakeet (kakariki, Cyanoramphus auriceps). Department of Conservation, Wellington, New Zealand.Department of Primary Industries P., Water and Environment, . (2013) TASVEG 3.0. Tasmanian Vegetation Monitoring and Mapping Program. (ed T. Government), Hobart.

Driscoll D. A., Lindenmayer D. B., Bennett A. F., Bode M., Bradstock R. A., Cary G. J., Clarke M. F., Dexter N., Fensham R., Friend G., Gill M., James S., Kay G., Keith D. A., MacGregor C., Russell-Smith J., Salt D., Watson J. E. M., Williams R. J. & York A. (2010) Fire management for biodiversity conservation: Key research questions and our capacity to answer them. *Biological Conservation* **143**, 1928-39.

Edworthy A. B. (2016) Avian hosts, prevalence and larval life history of the ectoparasitic fly Passeromyia longicornis (Diptera : Muscidae) in south-eastern Tasmania. *Australian Journal of Zoology* **64**, 100-6.

Edworthy A. B. (2016). Native fly parasites are the principal cause of nestling mortality in endangered Tasmanian pardalotes. Animal Conservation. doi:10.1111/acv.12444

Edworthy A. (2017). Ecology and conservation of the endangered forty-spotted Pardalote. PhD thesis, Australian National University.

Fiske I. & Chandler R. (2011) unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. *Journal of Statistical Software* **043**.

Fox-Hughes P., Harris R., Lee G., Grose M. & Bindoff N. (2014) Future fire danger climatology for Tasmania, Australia, using a dynamically downscaled regional climate model. *International Journal of Wildland Fire* **23**, 309-21.

Grose M. R., Fox-Hughes P., Harris R. M. B. & Bindoff N. L. (2014) Changes to the drivers of fire weather with a warming climate – a case study of southeast Tasmania. *Climatic Change* **124**, 255-69.

Hansen M. C., Potapov P. V., Moore R., Hancher M., Turubanova S. A., Tyukavina A., Thau D., Stehman S. V., Goetz S. J., Loveland T. R., Kommareddy A., Egorov A., Chini L., Justice C. O. & Townshend J. R. G. (2013) High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**, 850-3.

Harris S. & Kitchener A. (2005) From Forest to Fjaeldmark: Descriptions of Tasmania'sVegetation. . (ed D. o. P. I. a. Water), Hobart.

Hart B., Burgman M., Webb A., Allison G., Chapman M., Duivenvoorden L., Feehan P., Grace M., Lund M., Pollino C., Carey J. & McCrea A. (2005) Ecological Risk Management Framework for the Irrigation Industry, Report to National Program for Sustainable Irrigation (NPSI) Water Studies Centre, Monash University.

Heinsohn R., Webb M. H., Lacy R., Terauds A., Alderman R. & Stojanovic D. (2015) A severe predator-induced decline predicted for endangered, migratory swift parrots (*Lathamus discolor*). *Biological Conservation* **186**, 75-82.

Hradsky B. A., Robley A., Alexander R., Ritchie E. G., York A. & Di Stefano J. (2017) Human-modified habitats facilitate forest-dwelling populations of an invasive predator, Vulpes vulpes. *Scientific Reports* **7**, 12291.

IUCN/SSC. (2013). Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland

Keppel G. & Wardell-Johnson Grant W. (2012) Refugia: keys to climate change management. *Global Change Biology* **18**, 2389-91.

Kirkpatrick J. B., Marsden-Smedley J. B. & Leonard S. W. J. (2011) Influence of grazing and vegetation type on post-fire flammability. *Journal of Applied Ecology* **48**, 642-9.

Lentini P. E., Stirnemann I. A., Stojanovic D., Worthy T. H. & Stein J. A. (2018) Using fossil records to inform reintroduction of the kakapo as a refugee species. *Biological Conservation* **217**, 157-65.

Lindenmayer D. B., Franklin J. F. & Fischer J. (2006) General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biol Cons* **131**, 433-45.

Liu C., White M. & Newell G. (2013) Selecting thresholds for the prediction of species occurrence with presence-only data. *Journal of Biogeography* **40**, 778-89.

Lomolino M. V. & Channell R. (1995) Splendid Isolation: Patterns of Geographic Range Collapse in Endangered Mammals. *Journal of Mammalogy* **76**, 335-47.

MacDonald M. A. & Kirkpatrick J. B. (2003) Explaining bird species composition and richness in eucalypt-dominated remnants in subhumid Tasmania. *Journal of Biogeography* **30**, 1415-26.

MacKenzie, D., Nichols, J., Lachman, G., Droege, S., Royle, J., and Langtimm, C. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology* **83**, 2248-2255.

MacKenzie D. & Nichols J. (2004) Occupancy as a surrogate for abundance estimation. *Animal Biodiversity and Conservation* **27**, 461-7.

Maron M., Grey Merilyn J., Catterall Carla P., Major Richard E., Oliver Damon L., Clarke Michael F., Loyn Richard H., Mac Nally R., Davidson I. & Thomson James R. (2013) Avifaunal disarray due to a single despotic species. *Diversity and Distributions* **19**, 1468-79.

Maron M. & Kennedy S. (2007) Roads, fire and aggressive competitors: Determinants of bird distribution in subtropical production forests. *Forest Ecology and Management* **240**, 24-31.

Maron M., Main A., Bowen M., Howes A., Kath J., Pillette C. & McAlpine C. A. (2011) Relative influence of habitat modification and interspecific competition on woodland bird assemblages in eastern Australia. *Emu* **111**, 40-51.

Martin T. G., Nally S., Burbidge A. A., Arnall S., Garnett S. T., Hayward M. W., Lumsden L. F., Menkhorst P., McDonald-Madden E. & Possingham H. P. (2012) Acting fast helps avoid extinction. *Conservation Letters* **5**, 274-80.

McCarthy Michael A., Thompson Colin J. & Possingham Hugh P. (2005) Theory for Designing Nature Reserves for Single Species. *The American Naturalist* **165**, 250-7.

Menz M. H. M., Dixon K. W. & Hobbs R. J. (2013) Hurdles and Opportunities for Landscape-Scale Restoration. *Science* **339**, 526.

Møller A. P., Merino S., Soler J. J., Antonov A., Badás E. P., Calero-Torralbo M. A., de Lope F., Eeva T., Figuerola J., Flensted-Jensen E., Garamszegi L. Z., González-Braojos S., Gwinner H., Hanssen S. A., Heylen D., Ilmonen P., Klarborg K., Korpimäki E., Martínez J., Martínez-de la Puente J., Marzal A., Matthysen E., Matyjasiak P., Molina-Morales M., Moreno J., Mousseau T. A., Nielsen J. T., Pap P. L., Rivero-de Aguilar J., Shurulinkov P., Slagsvold T., Szép T., Szöllősi E., Török J., Vaclav R., Valera F. & Ziane N. (2014) Assessing the Effects of Climate on Host-Parasite Interactions: A Comparative Study of European Birds and Their Parasites. *PLOS ONE* **8**, e82886.

Morris K. D. (2000) The status and conservation of native rodents in Western Australia. *Wildlife Research* **27**, 405-19.

Ortiz-Catedral, L., S and D. H. Brunton. 2010. Success of translocations of red-fronted parakeets Cyanoramphus novaezelandiae novaezelandiae from Little Barrier Island (Hauturu) to Motuihe Island, Auckland, New Zealand. Conservation Evidence **7,** 21-26.

Pavey, C. R., Addison, J., Brandle, R., Dickman, C. R., McDonald, P. J., Moseby, K.E., Young, L. I., 2017. The role of refuges in the persistence of Australian dryland mammals. *Biological Reviews* 92, 647-664.

Phillips S. J., Anderson R. & Schapire R. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190**, 231-59.

Prowse T. A. A., Collard S. J., Blackwood A., O'Connor P. J., Delean S., Barnes M., Cassey P. & Possingham H. P. (2017) Prescribed burning impacts avian diversity and disadvantages woodland-specialist birds unless long-unburnt habitat is retained. *Biological Conservation* **215**, 268-76.

R Development Core Team. (2008) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reside A., Welbergen J., Phillips B., Wardell-Johnson G., Keppel G., Ferrier S., Williams S. & VanDerWal J. (2014) Characteristics of climate change refugia for Australian biodiversity. *Austral Ecology* **39**, 887-97.

Ricciardi A. & Simberloff D. (2009) Assisted colonization: good intentions and dubious risk assessment. *Trends in Ecology & Evolution* **24**, 476-7.

Rounsevell D. E. & Woinarski J. C. Z. (1983) Status and conservation of the 40 spotted pardalote, *Pardalotus quadragintus* (Aves, Pardalotidae). *Australian Wildlife Research* **10**, 343-9.

Rout T., Hauser C. & Possingham H. (2009) Optimal adaptive management for the translocation of a threatened species. *Ecological Applications* **19**, 515-26.

Schultz Courtney A., Sisk Thomas D., Noon Barry R. & Nie Martin A. (2013) Wildlife conservation planning under the United States Forest Service's 2012 planning rule. *The Journal of Wildlife Management* **77**, 428-44.

Seddon P. J. (2015). Using the IUCN critirea to assess reintroduction success. Animal Conservation 18, 407-408

Smith F. P. (2008) Who's planting what, where and why – and who's paying?: An analysis of farmland revegetation in the central wheatbelt of Western Australia. *Landscape and Urban Planning* **86**, 66-78.

Stojanovic D., Webb nee Voogdt J., Webb M., Cook H. & Heinsohn R. (2016) Loss of habitat for a secondary cavity nesting bird after wildfire. *Forest Ecology and Management* **360**, 235-41.

Stojanovic D., Alves A., Cook H., Crates R., Heinsohn R., Peters A., Rayner L., Troy S. N., & Webb M. H. (2017). Further knowledge and urgent action required to save Orange-bellied Parrots from extinction. Emu **118**, 126-34.

Tasmanian Fire Service. (2017) State Fire History. (ed T. F. Service), https://www.thelist.tas.gov.au.

Taylor S. S., Jamieson I. G. & Armstrong D. P. (2005) Successful island reintroductions of New Zealand robins and saddlebacks with small numbers of founders. *Animal Conservation* **8**, 415-20.

Tershy B. R., Shen K.-W., Newton K. M., Holmes N. D. & Croll D. A. (2015) The Importance of Islands for the Protection of Biological and Linguistic Diversity. *BioScience* **65**, 592-7.

Thomson J., Maron M., Grey M., Catterall C., Major R., Oliver D., Clarke M., Loyn R., Davidson I., Ingwersen D., Robinson D., Kutt A., MacDonald M. & Mac Nally R. (2015) Avifaunal disarray: quantifying models of the occurrence and ecological effects of a despotic bird species. *Diversity and Distributions* **21**, 451-64.

Threatened Species Scientific Committee. (2014) Advice to the Minister for Sustainability, Environment, Water, Population & Communities from the Threatened Species Scientific

Committee (the Committee) on Amendments to the List of Key Threatening Processes under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). (ed T. S. S. Committee), http://www.environment.gov.au/biodiversity/threatened/key-threatening-processes/overabundant-noisy-miners.

Threatened Species Section. (2006) Fauna recovery plan: forty-spotted pardalote 2006-2010.

Understorey Network. (2011) Habitat Plan for the Endangered Forty-Spotted Pardalote Pardalotus quadragintus, Caring For Our Country Program. Understorey Network, Tasmania.

Warren D. L., Cardillo M., Rosauer D. F. & Bolnick D. I. (2014) Mistaking geography for biology: inferring processes from species distributions. *Trends in Ecology & Evolution* **29**, 572-80.

Wauchope H., Fuller R.A., Shanahan D.F. & Shaw J.D. (*in press*) Restoring Islands and identifying source populations for species introductions. *Conservation Biology*

Webb M. H., Holdsworth M., Stojanovic D., Terauds A., Bell P. & Heinsohn R. (2016) Immediate action required to prevent another Australian avian extinction: the King Island Scrubtit. *Emu* **116**, 223-9.

Willoughby J. R. & Christie M. R. (2018). Long-term demographic and genetic effects of releasing captive-born individuals into the wild. Conservation Biology, https://doi.org/10.1111/cobi.13217

Wilson K. A., Underwood E. C., Morrison S. A., Klausmeyer K. R., Murdoch W. W., Reyers B., Wardell-Johnson G., Marquet P. A., Rundel P. W., McBride M. F., Pressey R. L., Bode M., Hoekstra J. M., Andelman S., Looker M., Rondinini C., Kareiva P., Shaw M. R. & Possingham H. P. (2007) Conserving Biodiversity Efficiently: What to Do, Where, and When. *PLOS Biology* **5**, e223.

Woinarski J. C. Z. (2011) The mammal fauna of the Sir Edward island group, Northern Territory, Australia: refuge and death trap. *Wildlife Research* **38**, 307-322

Woinarski J. C. Z. (2016) A very preventable mammal extinction. *Nature* **535**, 493.

Woinarski J. C. Z. & Bulman C. (1985) Ecology and breeding biology of the 40-spotted pardalote and other pardalotes on North Bruny Island. *Emu* **85**, 106-20.