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Population assessment of the Endangered Forty-spotted Pardalote *Pardalotus quadragintus* on Maria Island, Tasmania

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Abstract. The Forty-spotted Pardalote *Pardalotus quadragintus* is one of the smallest birds in Australia and is endemic to Tasmania, where it occurs only in forest or woodland containing White Gum *Eucalyptus viminalis*. It is listed as Endangered under the Tasmanian *Threatened Species Protection Act 1995* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. A habitat-stratified survey of Forty-spotted Pardalotes on Maria Island, off the eastern coast of Tasmania, was undertaken in August 2023 to provide a robust estimate of the population. Initial stratification using available vegetation mapping overestimated the availability of suitable habitat based on survey-site habitat evaluations. Forty-spotted Pardalotes were detected at 14 of 74 survey sites, with all detections being at sites where White Gum was the main tree species present. Their mean density was 1.66 birds per hectare, with an estimated total population of 847 birds (CV 0.38, confidence intervals 404–1776 birds). This estimate is consistent with previous uncorrected count-based estimates, although comparisons with historical counts are highly subjective given the substantial methodological differences. Only ~5% of Maria Island supports the preferred habitat for this species and further research on the requirements for, and abundance of, suitable microhabitat is recommended to further refine population estimates and guide conservation management actions.

Introduction

The Forty-spotted Pardalote *Pardalotus quadragintus* (Gould 1838) is endemic to the island state of Tasmania. Weighing ~10 g and measuring 9–10 cm in length, it is one of the smallest birds in Australia (Woinarski & Bulman 1985; Higgins & Peter 2002). It occurs only in forest or woodland containing White Gum *Eucalyptus viminalis*, upon which it depends as a critical food resource (Bulman *et al.* 1986). Forty-spotted Pardalotes are foliage gleaners feeding on arthropods, lerps (the sugary secretion produced by the larvae of psyllids) and particularly manna, a sugary exudate produced on the foliage and young shoots of White Gum (Woinarski & Bulman 1985; Case & Edworthy 2016). They are unique among Australian birds in deliberately cutting grooves or clipping the leaf axils of White Gum with their bills, which stimulates the tree to exude manna (i.e. they cultivate or farm manna), upon which they feed, or feed to their young (Case & Edworthy 2016). As with many specialist species. they occupy a narrow niche and are vulnerable to even relatively small changes in their preferred habitat (Ye *et al.* 2013).

The distribution of the Forty-spotted Pardalote has declined greatly in the past two centuries. Historically this species was widely distributed in lowland forests of White Gum in eastern Tasmania, and also on King and Flinders Islands, although always considered uncommon or rare (Campbell 1903; Woinarski & Bulman 1985; Brown 1986; Bryant 2010; Bryant & Webb 2014). Since 1986, it has been found only on Flinders Island, Maria Island, Bruny Island, and parts of mainland Tasmania in the south-east, particularly adjacent to Bruny Island. It is listed as Endangered under both the Tasmanian *Threatened Species Protection Act 1995* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Although the close association with White Gum is a micro-scale determinant of habitat choice, the extensive areas of Tasmania where there is abundant White Gum, but from which Forty-spotted Pardalotes are absent, suggest that other factors operate to determine the distribution at a macro-scale (Brown 1986; Alves *et al.* 2022).

The total population of Forty-spotted Pardalotes is reported to have declined from an estimated 3520 individuals in 1986 (Brown 1986, 1989) and 3840 individuals in 1994–1997 (Bryant 1997) to 1486 birds in 2009 (Bryant 2010), representing ~60% decline in 14 years. However, aligning data and commentary on changes in the size of the population is complex given variation in methods used over time. Nevertheless, there are proximate indicators of population declines based on the disappearance of Forty-spotted Pardalotes from areas where they previously occurred on mainland Tasmania (Bryant 2010) as well as a decline in the frequency of encountering birds in areas where they have been historically recorded on both Bruny and Maria Islands (Bryant 2010).

Most recently, Bryant *et al.* (2021) estimated the total population to be 1800 mature individuals (range 1400–11,200) and noted that recent population estimates were lacking from three of the four main breeding areas, including Maria Island which is estimated to hold 52% of the total population. Maria Island lies ~8 km off the eastern coast of Tasmania and is managed as a national park. Although some low-lying areas were cleared for livestock pasture in the 19th and early 20th centuries, most (>90%) of the island remains covered in sclerophyll forest

dominated by Stringybark *E. obliqua*, Tasmanian Blue Gum *E. globulus* and White Gum (Parks and Wildlife Service 1998). In this paper we aim to provide a robust estimate of the total size of the population of Forty-spotted Pardalotes on Maria Island, as part of a multi-year program to assess the population size of the species across its entire range.

Methods

To implement a robust survey design and optimise fieldwork, the assumed suitability of habitat for Forty-spotted Pardalotes on Maria Island was allocated to one of four strata based on areas where there have been sightings of this species in the past and the mapping of likely suitable habitat based on Tasmanian vegetation types in TASVEG 4.0. TASVEG is a Tasmania-wide vegetation map produced by the Tasmanian Vegetation Monitoring and Mapping Program and comprises 157 mapping units captured at a nominal scale of 1:25,000. TASVEG is continually revised and updated and version 4.0 is the fourth major release of the TASVEG layer since 2004 (Department of Primary Industries, Parks, Water & Environment 2020). Common names for all plant species follow Wapstra *et al*. (2005).

The four strata were:

1. a core area of White Gum communities identified during Forty-spotted Pardalote surveys conducted by Brown (1989) and continued by Bryant (2010), and S. Bryant (unpubl. data);
2. a primary area that contained one of the following vegetation communities (the three-letter TASVEG codes are given in parentheses): White Gum–Tasmanian Blue Gum coastal forest and woodland (DVC), White Gum grassy forest and woodland (DVG), Tasmanian Blue Gum dry forest and woodland (DGL), White Gum wet forest (WVI), and White Peppermint *E. pulchella* forest and woodland (DPU);
3. a secondary area that contained one of the following vegetation communities: Stringybark dry forest (DOB), Black Gum *E. ovata* forest and woodland (DOV), and Gum-topped Stringybark *E. delegatensis* dry forest and woodland (DDE); and
4. Other areas (unsuitable habitat).

Based on these habitat strata, the position of point-sampling locations was selected using the *R* package 'Distance sampling survey design' (Dssd: Marshall 2021) with 60% of the overall survey effort allocated in Stratum (i), 30% in Stratum (ii), and 10% in Stratum (iii). No survey effort was allocated to unsuitable habitat. Following review of the original survey design, three sites in Stratum (iii) were removed because of unsafe terrain, leaving 98 potential survey sites. Of these, 74 (76%) were surveyed (Figure 1), covering 50 of 62 sites in Stratum (i), 21 of 29 sites in Stratum (ii) and three of 7 sites in Stratum (iii). The minimum separation distance between sites was 300 m.

During the survey, a habitat description was recorded for each site, including a description of the dominant tree species and a count of the number of Tasmanian White Gum trees within 25 m of the survey point, with each site classified into one of the following four habitat categories:

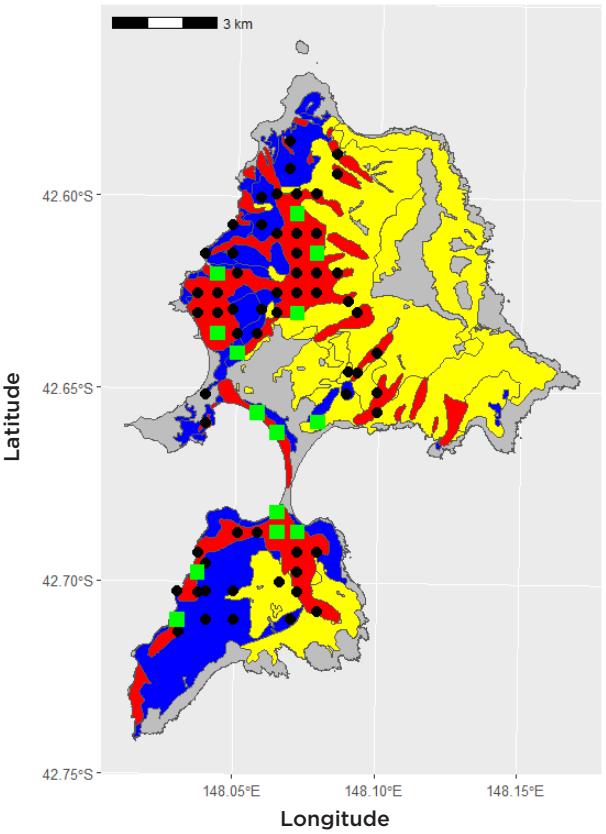

Figure 1. Maria Island location of points that were surveyed (black dots) and those where Forty-spotted Pardalotes were recorded (green squares) in Stratum (i) (red), Stratum (ii) (blue) and Stratum (iii) (yellow). Remaining parts of the island (grey) all have unsuitable habitat [Stratum (iv)].

A. White Gum dominated,

B. White Gum abundant (but not the dominant tree species),

C. White Gum sparse, and

D. White Gum absent

The survey followed a point-count distance-sampling survey technique (Bibby *et al.* 2000; Buckland *et al.* 2001) in which the 'point-to-object linear distance' (the horizontal distance to the base of the tree in which a bird is located, not the oblique distance from the observer to the bird) was measured using a laser range finder for each Forty-spotted Pardalote encountered in a 5-minute survey period. The census survey did not involve call playback and was undertaken during still, clement weather by ornithologists with experience of Forty-spotted Pardalotes. Surveys were conducted by three two-person teams (a safety requirement given the remote locations) over 4 days in August 2023 when birds were likely to be calling most frequently before egg-laying.

Results

In total, 74 of the 98 sites (76%) were surveyed (Figure 1), 50 of 62 sites in Stratum (i), 21 of 29 sites in Stratum (ii) and three of 7 sites in Stratum (iii). The unsurveyed sites were typically in more remote and inaccessible areas in the south and east of the island. Forty-spotted Pardalotes were observed at 14 sites [12 in Stratum (i) and two in Stratum (ii)] (Figure 1) involving

Table 1. Number of Forty-spotted Pardalotes detected (with percentages in parentheses) in each stratum and habitat category (see Methods).

Stratum	*Habitat category of survey sites*			
	A	*B*	*C*	*D*
i	10 (45)	7 (32)	0	0
ii	4 (18)	1 (5)	0	0
iii	0	0	0	0

Table 2. Number of sites surveyed for Forty-spotted Pardalotes in each survey stratum and in each habitat category (see Methods). *One site in Stratum (i) was not assigned to a habitat category.

Stratum	*Habitat category of survey sites*			
	A	*B*	*C*	*D*
i: 49*	8	17	15	9
ii: 21	2	3	7	9
iii: 3	0	1	1	1

22 birds. Three of the four sites with more than one bird detected were in Stratum (i). All detections were in sites where White Gum was either dominant (Habitat category A; 14 of the 22 detections) or abundant (Habitat category B; eight of the 22 detections) (Table 1).

Initial stratification using available vegetation mapping overestimated the availability of suitable habitat based on survey-site habitat evaluations. Survey Stratum (i) was assigned based on the expectation that White Gum was either dominant or abundant throughout this stratum. However, White Gum was only dominant at eight sites and abundant at 17, so that it was either sparse or absent at almost 50% of sites assigned to Stratum (i) (Table 2). Similarly, in Stratum (ii) White Gum was either dominant or abundant at only five (24%) sites but either sparse or absent at 76% of sites (Table 2). Within Stratum (i) and Stratum (ii) there were 40 sites with sparse or no White Gum (Table 2) and there were no detections at these sites. This suggests that almost half of the sites in Strata (i) and (ii) were in sub-optimal/unsuitable habitat (Categories C and D) for Forty-spotted Pardalotes based on the site-specific habitat characterisations.

Based on the observed relationship between habitat type and the detection of Forty-spotted Pardalotes, a post-survey stratification was implemented to better reflect the habitat and survey area. This used the detection data from only those sites in habitat Categories A and B (regardless of the survey strata); the use of the combined data from these two categories is because of the limitations of sample size of detections and mapping of habitat at finer spatial scales. The total area of the combined polygons of vegetation communities in TASVEG 4.0 that comprise predominantly White Gum is 509.8 ha [these are White Gum–Tasmanian Blue Gum coastal forest and woodland (417.4 ha), White Gum grassy forest and woodland (58.9 ha) and White Gum wet forest (33.5 ha)]. This more appropriately represents the actual extent of suitable habitat (pale-blue area in Figure 2).

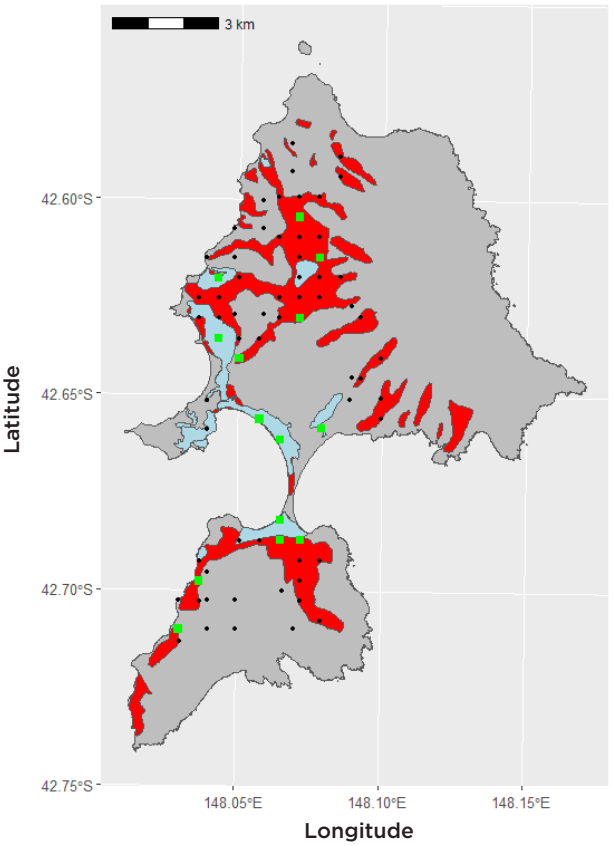

Figure 2. Maria Island location of points that were surveyed (black dots) and those where Forty-spotted Pardalotes were recorded (green squares). Our original Stratum (i) is shown in red and the revised extent of suitable habitat used in the analysis is overlaid in pale blue.

Detection probabilities were modelled, and densities were estimated, using the Distance package in *R* (Miller *et al.* 2019; R core Team 2023). The small number of detections is well below the number suggested by Buckland *et al.* (2001) to model a detection function. However, based on the form of the probability density of sightings, a half-normal detection with a truncation at 5% and no adjustments was used (Figure 3). The result of the goodness-of-fit test for this model [Cramer–von Mises test (unweighted) = 0.060, P = 0.81] indicates a good fit of the model detection function to the data. The estimated probability of detection within the 60.95-m truncated distance was 0.33. The mean density of Forty-spotted Pardalotes in the habitat Category A and B sites was 1.66 birds per hectare, yielding a total population for the 509.8 ha of White Gum dominant habitat of 847 birds (CV 0.38, confidence intervals 404–1776 birds).

Discussion

The population size estimate for Forty-spotted Pardalotes on Maria Island from this study is consistent with the estimate of 950 mature birds by Bryant *et al.* (2021), albeit the latter used a different method to estimate the extent of suitable habitat and did not use a correction for detection probability during a survey. The density of 1.6 birds ha^{-1} is also consistent with the lower 95% confidence interval of Alves *et al.* (2019) in White Gum forest on North Bruny Island from surveys conducted in the post-breeding season when the population density would

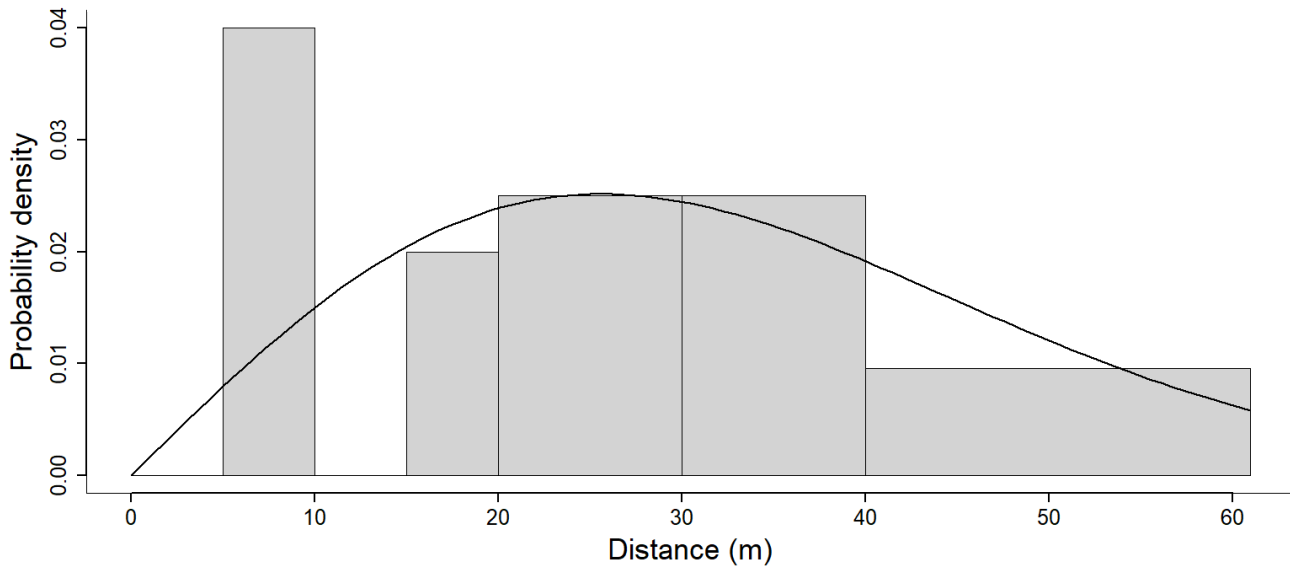

Figure 3. Half-normal detection function (fitted line) of detection data combined into distance bins to improve model fitting.

be expected to be higher, reflecting the presence of both adult and juvenile birds.

The population estimate of 950 mature individuals for Maria Island in Bryant *et al.* (2021) was based on an area of functional habitat on Maria Island of 20.3 km^2 [using the same area as Stratum (i) in this study] to which they then assumed an average coverage of 50% White Gum. Within this habitat area, Bryant *et al.* (2021) assumed a mean territory size of 1.6 ha (Woinarski & Bulman 1985) and mean occupancy rate estimates for Maria Island of 0.75 following Webb *et al.* (2019), based on data from 5-minute point surveys conducted intermittently along walking tracks on the island from 2010 to 2016.

The estimate of 950 in Bryant *et al.* (2021) is consistent with the uncorrected count-based estimate of 974 in Bryant (2010) and the current estimate. However, given the substantial methodological differences, both in terms of survey sites, density estimation methods, and the area of suitable habitat used, such comparisons are highly subjective. In essence, Bryant (2010) applied an uncorrected (lower) density value over a larger area of suitable habitat, but we have applied a corrected (higher) density value over a smaller area of suitable habitat.

The Distance sampling approach assumes that objects are distributed evenly within the survey strata and that they are available to be detected at all sites. Thus, the differences in whether they are recorded at a site or not is a function of the detectability. However, the assumption that Forty-spotted Pardalotes are evenly distributed across all sites within each of the original survey strata was not supported by the survey-site-specific habitat categorisation. In this situation, using the survey data as originally assigned by survey strata to estimate the number of Forty-spotted Pardalotes would likely lead to a considerable overestimate of population size in those strata. However, including a habitat characterisation for each survey site allowed the re-stratification of the survey to provide a more credible extent of habitat over which to extrapolate the observed density of birds.

We recognise that the survey design implemented reflects a balance of observer effort and coverage of potential habitat and that the large confidence intervals around our population estimate reflects the low number of detections. However, the initial survey design provides the basis for refinements for future surveys to apportion greater survey effort into what are now identified as the areas of suitable habitat. Increasing the number of detections would allow an improved estimate of the detection function and provide an increase in the precision of results to ensure that population estimates from different locations can be modelled consistently and the power to detect trends can be evaluated. The refinements in future survey design would also allow examination of the influence of covariates such as small-scale habitat quality metrics (see e.g. Alves *et al.* 2019). Suitable habitat for Forty-spotted Pardalotes depends on the spatial congruence of White Gum with healthy canopy, where manna can be farmed, and suitable nest cavities. Hence, their distribution is often aggregated around old-growth White Gum trees, as these provide both of those habitat requirements (Bryant 2010; Alves *et al.* 2019). As this suitable 'microhabitat' represents only a proportion of the overall White Gum dominant vegetation strata, it is important to recognise that the area of suitable habitat over which the observed density of birds should be extrapolated, and the resulting population estimate of Forty-spotted Pardalotes, on Maria Island may be overestimates. Further research on the requirements for, and abundance of, the required microhabitat suitable for the species is recommended to further refine population estimates.

Interpreting population estimates derived using different methods, particularly where there is a prevailing narrative of an ongoing change, is a persistent challenge in conservation ecology (see Thomas 1996). The challenge of assessing the population size of threatened species is well exemplified by the situation with the Swift Parrot *Lathamus discolor*, an endemic parrot breeding in Tasmania, for which Heinsohn *et al.* (2015, p. 77) described estimates of the total population as "at best approximate" and the confidence intervals associated with individual methods do not overlap with those using other methods (Olah *et al.* 2021).

There is often a strong inference drawn from changes in the occurrence of a species in surveys and changes in the total population given the, not unreasonable, assumption of a positive correlation between the total population size of a species and the frequency with which it is present (occupancy). However, there is a range of circumstances that result in departures from this relationship. For example, where the population density of a species increases within its existing range, changes in the size of the total population may not be reflected in changes of a binary measure of occupancy. Alternatively, where the range of a species increases because of dispersal (rather than an actual population increase) there could be an increase in occupancy that does not reflect an increase in the population (Mackenzie *et al.* 2006).

Comparison with previous population estimates is confounded by the differences in the methods used to estimate the density of birds (i.e. the estimation of detection probability) and the apparent differences in the area of suitable habitat over which the density estimates were extrapolated. Bryant (2010, p. 17) noted the "white gum [*E. viminalis*] appeared sparse, stunted, and in many locations were dying" and suggested that the extent of suitable White Gum habitat was unlikely to be the same as that present when Brown (1989) undertook the initial habitat mapping. In comparison with the area defined by Brown (1989) as primary and secondary habitat [the original Stratum (i) in the present study], the area of suitable habitat now appears smaller and also appears to be in different areas of the island. At a macro scale Prior *et al.* (2013) described land clearing for agriculture as a major source of tree loss in Tasmania. However, changes in the 'quality' of White Gum as a habitat for Forty-spotted Pardalotes may be related to the phenomenon referred to as 'dieback', which is a general term used to describe a non-specific deterioration in crown health of *Eucalyptus* trees. The factors driving 'dieback' in White Gum in Tasmania may include changes in temperature or rainfall regimes although the determination of the actual causes remains elusive (see e.g. Ross & Brack 2017).

Forty-spotted Pardalotes are listed as Endangered under the *EPBC Act 1999* and the Tasmanian *Threatened Species Protection Act 1995,* and are also assessed as Endangered in the *Action Plan for Australian Birds 2020* (Bryant *et al.* 2021), the latter based strictly on IUCN criteria on the limited extent and area of occupancy and the small (≤5) number of locations with a population of 250–2500 mature individuals. The focus in the present study has been to obtain a robust estimate of the total population at the largest, wholly protected breeding site for Forty-spotted Pardalotes. The other sites that support the main populations of this species, on Bruny Island (and adjacent mainland locations), have experienced considerable changes in land use and are extensively modified habitats, especially compared with the relatively undisturbed habitat on Maria Island. This means that the conservation importance of Maria Island for Forty-spotted Pardalotes is particularly high. Furthermore, with only ~500 ha (5%) of the 10,136 ha of Maria Island supporting preferred habitat, the risk to the species from a single catastrophic event is very high. Isolated, small populations of birds have some of the highest risks to their viability from extreme events and/or disproportionate impacts of stochastic processes. Given the potentially adverse conservation outlook facing Forty-spotted Pardalotes, there is a pressing need to produce a contemporary review of their status, based on robust estimates of population size and trajectory, to provide a basis for ongoing monitoring and conservation actions.

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