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TECHNICAL REPORT

Do nest boxes breed the target species or its competitors? A case study of a critically endangered bird

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Nest boxes are widely used for habitat restoration. Unfortunately, competitors of the target species may exploit nest boxes, creating perverse outcomes. Avoiding habitats preferred by nontarget species, while favoring those of the target species, requires an adaptive management approach if limited information about species preferences is available when deploying boxes. Using nest boxes intended for Swift Parrots *Lathamus discolor*, we identify factors associated with nontarget species occupancy (Common Starling *Sturnus vulgaris* and Tree Martin *Petrochelidon nigricans*) in newly deployed boxes in 2016, and then again after 3 years had elapsed in 2019. Box occupancy by different species depended on the interaction between distance of individual boxes to the forest edge and year. Although the target species exploited similar numbers of nest boxes in both years, competitors were the main beneficiaries of established boxes. A subordinate native nest competitor increased box occupancy likelihood at greater distances from forest edges in both years, but the relationship was stronger in 2019. Introduced Common Starlings *S. vulgaris* were most likely to occupy boxes close to forest edges, but the magnitude of this relationship was much greater for established than newly deployed boxes. We suggest that permanent box deployments for Swift Parrots may produce perverse outcomes by increasing nesting habitat for Common Starlings. We suggest that for species that only use cavities for part of their life cycle, managers should limit access to boxes outside of critical times to reduce the likelihood that pest populations can exploit restoration efforts and create new problems.

Key words: cavity nesting animals, Common Starling *Sturnus vulgaris*, conservation management, natural resource management, Swift Parrot *Lathamus discolor*, threatened species, Tree Martin *Petrochelidon nigricans*

Implications for Practice

- Time since deployment, as well as habitat characteristics, must be considered when evaluating the success of nest boxes at providing habitat for the target species (and its competitors).
- Time interacts with habitat features to make some nest boxes more likely to be occupied by nontarget species than others.
- Nest box projects should be adaptive, and consider removing or sealing nest boxes at times/locations where pests may benefit from restoration efforts at the expense of the target species.

Introduction

Nest boxes are a globally important resource for wildlife and are widely deployed in forests to restore habitats where tree cavities are rare (Poysa & Poysa 2002; Tatayah et al. 2007; Goldingay & Stevens 2009; Olah et al. 2014). However, although it is possible to achieve good restoration outcomes with nest boxes (Bolton et al. 2004; Olah et al. 2014), there is debate about whether they are a universally viable habitat restoration tool. This is because they require specialist skills to deploy, require long-term maintenance, and sometimes do not benefit target species (Lindenmayer et al. 2016; Lindenmayer et al. 2017). Furthermore, nest boxes are often exploited by nontarget and introduced species (Goldingay & Stevens 2009; Le Roux et al. 2016; Goldingay et al. 2020). Providing more habitat for competitors of the target species could lead to perverse outcomes (e.g. increased competition at nest boxes and natural tree cavities), which can be very challenging to correct (Stojanovic et al. 2019*c*). High occupancy rates of nontarget species reduces the availability of vacant boxes, canceling out the intended benefits for the target species (Goldingay & Stevens 2009). Reducing nontarget occupancy of boxes can be at least partly achieved

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by designing boxes according to the preference of the target species. Planning nest box projects should also avoid habitat features preferred by nontarget species, while favoring those of the target species. This requires an adaptive management approach if limited information about species preferences is available at the inception of a project (Robinson et al. 2018). Part of adaptive management requires evaluation of how nest box occupancy changes over time (Durant et al. 2009; Goldingay et al. 2015), because different species may learn to exploit nest boxes at different rates. Given that nest box projects are very resource intensive, failure to adequately address challenges as they arise can waste effort, funding, and opportunities to support threatened species (Lindenmayer et al. 2017).

Here, we use nest boxes intended for critically endangered Swift Parrots *Lathamus discolor* to identify factors associated with nontarget species occupancy in new and established boxes. Swift Parrots are at imminent risk of extinction due to a combination of deforestation (Webb et al. 2019) and an introduced predator (Stojanovic et al. 2014; Heinsohn et al. 2015). Although the species has specialized preferences for the dimensions of nest cavities (Stojanovic et al. 2012; Stojanovic et al. 2017), they utilize nest boxes (Stojanovic et al. 2019*a*) and there have been extensive efforts to improve breeding success at artificial nests (Stojanovic et al. 2019*b*; Owens et al. 2020). In 2016 we deployed nest boxes at a Swift Parrot breeding site where a mast tree flowering event in breeding habitat triggered nesting of these nomadic birds (Stojanovic et al. 2019*a*). Although there is still much to be learned about how best to protect this species, we argued that using nest boxes to help Swift Parrots could involve either (i) repeated deployments at different locations each year depending on where breeding might occur, or (ii) permanent deployment at known nesting sites, knowing that only few boxes will be used each year (Stojanovic et al. 2019*a*). Since that study, we left the nest boxes in situ, and in 2019 another mast tree flowering event triggered a second Swift Parrot breeding event at the study site. This provided an opportunity to test the efficacy of our second proposed management option, i.e. permanent boxes. Although specifically designed for Swift Parrots, nontarget birds also extensively exploit our nest boxes (Stojanovic et al. 2019*b*). Swift Parrots rarely breed in the same location in successive years (Webb et al. 2014; Webb et al. 2017), leaving permanently deployed boxes available for nontarget species to learn to identify them as a resource. There is no available information on the extent of nest box competition between Swift Parrots and other nontarget species, but this is a known problem for other small threatened parrots (Stojanovic et al. 2019*c*). We test whether the best predictors of Swift Parrot box occupancy (Stojanovic et al. 2019*a*) and time since box deployment are important for nontarget species. We discuss whether permanent deployment of nest box infrastructure for Swift Parrots is a viable management approach.

Methods

Swift Parrots (approximately 70 g) are very selective about where they nest, and suitable cavities comprise as little as 5% of the standing cavity resource (Stojanovic et al. 2012; Stojanovic et al. 2017). In 2016 we deployed boxes matching the mean internal depth, floor diameter, and entrance size of preferred nest cavities (Stojanovic et al. 2019*a*) on Bruny Island, Tasmania, Australia. The dimensions of boxes were 45 × 15 × 15 cm with a 5 cm diameter entrance hole, and were deployed haphazardly within an area of forest used by parrots for nesting, from the forest edge inward to the center of the forest block (Stojanovic et al. 2019*a*). Boxes were deployed in the winter of 2016 before Swift Parrots arrived to breed in September. Our study presents data from the summer breeding seasons of 2016 and 2019 when parrots bred at the study area (during the interval, parrots were absent from the site). Details of the study site are reported by Stojanovic et al. (2019*a*). We focus on 104 nest boxes deployed at Roberts Hill, an area of grassy, dry, blue gum *Eucalyptus globulus* and white peppermint *E. pulchella* forest.

Only two nest box competitors of Swift Parrots (approximately 70 g) occur on Bruny Island: Tree Martins *Petrochelidon nigricans* and Common Starlings *Sturnus vulgaris*. Tree Martins (approximately 18 g) are native, and readily exploit nest boxes in this and other areas (Stojanovic et al. 2019*c*). Common Starlings (approximately 85 g) are introduced and abundant at the study area and can usurp nest boxes intended for other species (Pell & Tidemann 1997). Tree Martins are subordinate nest competitors to both Swift Parrots and Common Starlings (D. Stojanovic unpublished data). There is no information about whether Swift Parrots are subordinate, equal, or dominant competitors to Common Starlings. However, the authors have observed Common Starlings destroying Swift Parrot eggs and, conversely, successful nest defense by Swift Parrots against starlings. These anecdotal observations suggest Swift Parrots and Common Starlings may (sometimes) be equal competitors.

Boxes were checked in November and December in each year of the study, which was during the nestling/fledging period for Common Starlings, mid incubation/mid nestling period for Swift Parrots, and nest building/incubation for Tree Martins. We recorded which species nested in each box either by directly observing adults, eggs, or nestlings, or by identifying their nests. In the case of boxes from which starlings were recently fledged, we distinguished between old and recent nesting attempts based on freshness of nest material and presence of recent droppings in nest boxes (for established boxes, we ignored nests built before 2019). Tree Martins use different nesting materials for nest construction to Common Starlings in the study area, making their nests straightforward to differentiate. Most boxes were only checked once, but at a subset of boxes where the occupant was uncertain, we undertook a later second climb to confirm. We used the distance of each nest box to the nearest forest edge (measured using geographic information systems) because this predicted Swift Parrot occupancy of boxes in 2016 (Stojanovic et al. 2019*a*). Year is confounded with “new” and “established” boxes in this study, so we used year in all analyses.

We used R program for all analyses (R Development Core Team 2020), and compared competing models using ΔAIC (Akaike information criterion) <2 (Burnham & Anderson 2002), and visualized the data with ggplot2 (Wickham 2016). We implemented generalized linear models for each species separately, and included occupancy of nest boxes (0/1) by each species as response variables with a binomial error distribution. For each species, we fitted a null model and models with the following fixed effects: distance to forest edge, year, distance to forest edge × year, and distance to forest edge + year. We predicted occupancy probabilities from the preferred model using the package *emmeans* (Lenth 2018).

Results

Swift Parrots used 20 nest boxes in 2019/2020 compared to 29 in 2016/2017 (Table 1) with only five nest boxes reused in 2019/2020. We recorded 14 instances of nest box serial use by two species in the same year, comprising Common Starlings then Swift Parrots ($n = 7$), Common Starlings then Tree Martins ($n = 5$), or Swift Parrots then Tree Martins ($n = 2$).

There were two models of Swift Parrot nest box occupancy with equivalent support (i.e. the interactive and additive models, Table 2). We preferred the simpler additive model (because the estimates from the interactive model were similar to the additive one). Based on this model (estimates and confidence intervals shown in Fig. 1), there was a negative relationship between distance to forest edge and Swift Parrots box occupancy in both years. The overall likelihood of Swift Parrots using a nest box within 500 m of a forest edge was 0.44 in 2016 and 0.19 in 2019. The likelihood of Swift Parrots using a nest box more than 500 m from a forest edge was 0.09 in 2016 and 0.12 in 2019. There were two models of Common Starling nest box occupancy with equivalent support (i.e. the interactive and additive models; Table 2). We preferred the simpler additive model (because the estimates from the interactive model were similar to the additive one). Based on this model, Common Starlings were most likely to occupy boxes close to forest edges, but this relationship differed between years (estimates and confidence intervals shown in Fig. 1). The likelihood of Common Starlings using a nest box within 500 m of a forest edge was 0.12 in 2016 and 0.74 in 2019. The likelihood of Common Starlings using a nest box more than 500 m from a forest edge was 0 in 2016 and 0.12 in 2019.

The best-supported model of Tree Martin nest box occupancy contained the interaction between distance to the forest edge and year (Table 2). Based on this model Tree Martins increased their box occupancy likelihood at greater distances from forest edges in both years, but the relationship was stronger in 2019 (estimates and confidence intervals shown in Fig. 1). The likelihood of Tree Martins using a nest box within 500 m of a forest edge was 0.44 in 2016 and 0.07 in 2019. The likelihood of Tree Martins using a nest box more than 500 m from a forest edge was 0.68 in 2016 and 0.75 in 2019.

Table 1. Sample sizes for the number of nests of each species found in nest boxes per year. Some boxes were used repeatedly; hence, the totals differ even though the number of boxes is the same between years. Nest boxes were deployed to target Swift Parrots on Bruny Island, Tasmania, Australia.

Box Occupant	*2016/2017*	*2019/2020*
Tree Martin	57	43
Common Starling	7	59
Swift Parrots	29	20
Empty	11	1
Total	104	123

Discussion

Our results show the interaction between time and habitat is important for nest box utilization, and suggest that permanent box deployments in Swift Parrot breeding habitat may produce perverse outcomes (i.e. more breeding by introduced Common Starlings). Although Swift Parrots exploited similar numbers of nest boxes in both years, nontarget species were the main beneficiaries of permanent boxes. Tree Martins occupied the most boxes in the study, and they had the highest likelihood of using established boxes far from forest edges. The likelihood of Common Starlings occupying new nest boxes was low, but increased by more than six times for established boxes near forest edges. Newly deployed boxes may be difficult to find for species like

Table 2. List of models fitted to each species ranked by AIC. Asterisks indicate the preferred model.

Response Variable	*Fixed Effect*	df	*AIC*	*Δ*
Swift Parrot	Distance to forest edge + year*	3	226.21	0.00
	Distance to forest edge × year	4	226.85	0.65
	Distance to forest edge	2	229.62	3.41
	Year	2	236.32	10.12
	Null	1	238.81	12.61
Common Starling	Distance to forest edge + year*	3	169.41	0.00
	Distance to forest edge × year	4	170.55	1.14
	Year	2	225.61	56.20
	Distance to forest edge	2	228.70	59.29
	Null	1	275.68	106.27
Tree Martin	Distance to forest edge × year*	4	232.94	0.00
	Distance to forest edge + year	3	251.23	18.29
	Distance to forest edge	2	258.70	25.76
	Year	2	306.42	73.48
	Null	1	313.47	80.53

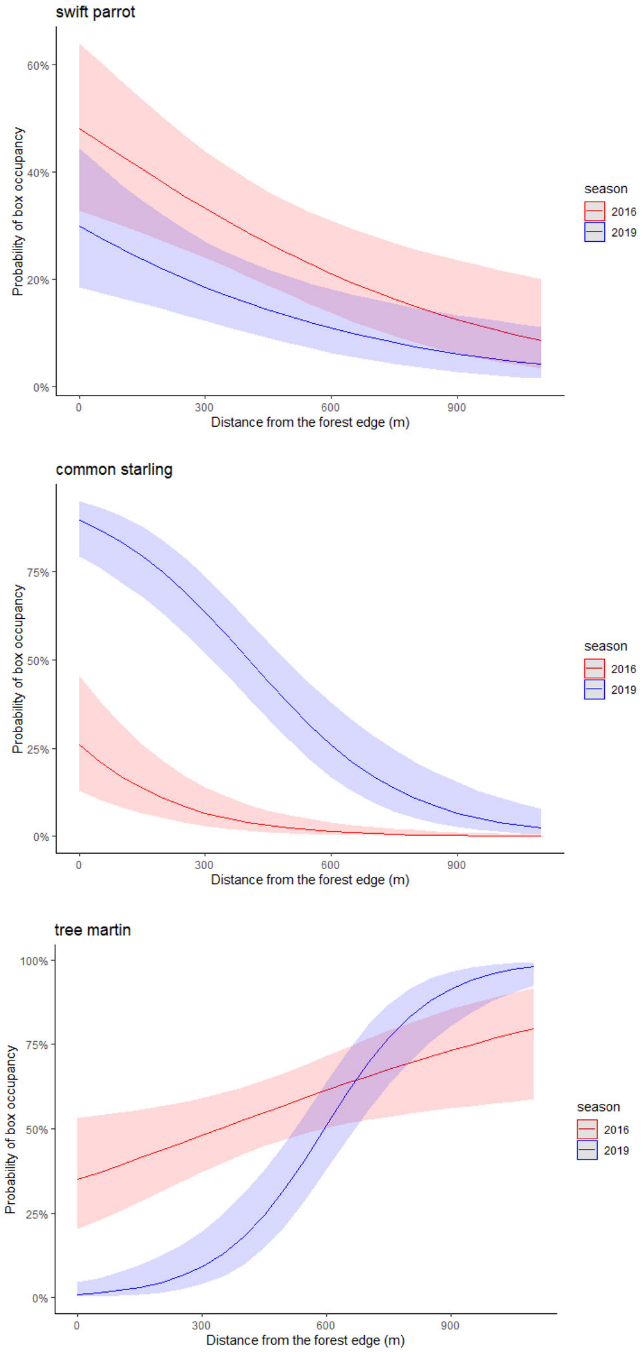

Figure 1. Predictions and CI from the best models of occupancy of nest boxes by Swift Parrots (the target species of the restoration effort), introduced Common Starlings, and Tree Martins. The lines show the predicted likelihood of nest box occupancy over distances from the edges of the forest. The models included either additive (Swift Parrot, Common Starling) or interactive (Tree Martin) effects of the distance to edges and the year of the study (when nest boxes were either newly deployed—2016, or had been in place for 3 years—2019).

Common Starlings that avoid the forest interior (Rega-Brodsky & Nilon 2017). It is perhaps unsurprising that Swift Parrots and Tree Martins utilized nest boxes more consistently each year than Common Starlings because the boxes were intentionally deployed where parrots nest naturally (Stojanovic et al. 2019*a*).

Our results provide important information for future work involving nest boxes. Land managers might utilize pre-emptive, targeted deployments of new nest boxes before the Swift Parrot breeding season, because our results suggest these are more likely to be used by breeding Swift Parrots (or at least their native subordinate competitors) than Common Starlings. Alternatively, if permanent nest box arrays are preferred, we recommend sealing boxes to exclude starlings when Swift Parrots are locally absent. This might reduce learning opportunities for Common Starlings between Swift Parrot breeding events, and reduce box saturation by nontarget species. Another alternative may be to deploy boxes at intermediate distances from forest edges. This may simultaneously improve the likelihood that Swift Parrots can find boxes, and lower the odds of Common Starlings usurping them. This is important because more Common Starlings may equate to worse competition not only for nest boxes, but also nearby natural nesting sites of Swift Parrots. These alternative approaches should be tested in future experimental deployments of nest boxes to improve the efficacy of restoration efforts in forests where Common Starlings are a problem.

Our study is a reminder of the need to be vigilant for potentially perverse outcomes in restoration projects. Introduced Common Starlings are major competitors for cavity nesting birds globally (Aitken & Martin 2008; Goldingay & Stevens 2009), so identifying and correcting their impacts is critical for nest box projects. We show such problems may not always be apparent in the immediate term, but develop over time. We hope our study encourages mindfulness about factoring both time and habitat preferences of pests (as well as the target species) into planning of nest box projects, because failure to do so may create future problems. Although our target species is a nomad (Webb et al. 2014), our results are broadly relevant because many restoration projects establish permanent arrays of nest boxes that can ultimately benefit common or pest species more than the actual target species of the effort (Lindenmayer et al. 2016; Lindenmayer et al. 2017; but see Goldingay et al. 2020). We suggest that for species that only use cavities for part of their life cycle, managers could consider limiting access to boxes outside of critical times to limit pest populations. Given the importance of nest boxes for some habitat restoration projects, our study adds to a growing body of evidence that this approach requires long-term and frequent maintenance (Goldingay et al. 2018), monitoring, and an adaptive management to ensure that new problems are not created by restoration efforts.

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