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Photosensitive automated doors to exclude small nocturnal predators from nest boxes

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Abstract

Nest boxes are a crucial tool for wildlife conservation. Although boxes are often safer from predators than natural nests, if predator and prey are of similar body size survival in boxes may become unacceptably low. Protecting boxes from small predators may be critical to the aims of a project, but no available tools can be reliably deployed for long periods in the field. We trial automated light sensitive mechanical doors on nest boxes to protect birds nesting in boxes from a small nocturnal predator. At three sites we deployed arrays of nest boxes, and fitted a subset (treatment group) with automated doors, while others were left unprotected. Box occupancy by the target species, clutch size and nest fate (successful/failed) were monitored using motion activated cameras and by manual checking. Birds in nest boxes fitted with automated doors had a significantly lower risk of nest failure 0.25 ($\pm$0.11 SE) compared to 0.81 ($\pm$ 0.07 SE) in the control group. No nests in the treatment group failed due to predation, whereas all nest failures in the control group were attributable to predation. The treatment group did not differ significantly from controls in clutch size. Automated doors operated for a 3 month breeding season reliably, with minimal maintenance (but battery charge should be monitored). We provide a useful new tool for protecting nest boxes from nocturnal predators, and automated doors did not have any deleterious reproductive consequences on the nests they protected. The automated doors offer practical conservation solutions for nest box conservation programs that (1) are conducted in remote locations with limited accessibility, (2) require protection measures to be deployed for long periods, (3) minimize behavioural/physiological impacts on target species, (4) require targeted protection against nocturnal predators against which more conventional approaches are ineffective or inappropriate.

Introduction

Many species are dependent on tree cavities for nesting or shelter sites, but suitable cavities for wildlife can be rare (Gibbons & Lindenmayer, 2002). In some habitats, cavity nesters are limited by the availability of suitable cavities (Newton, 1994), and deforestation exacerbates these shortages (Lindenmayer *et al.*, 2013; Webb, Stojanovic & Heinsohn, 2018). Many cavity nesting species readily occupy artificial nest boxes deployed for research or conservation purposes (Bolton *et al.*, 2004; Flaquer, Torre & Ruiz-Jarillo, 2006; Olah *et al.*, 2014). Tree cavities passively exclude large predators, making them safe nesting sites (Martin & Pingjun, 1992). Relieving predation pressure may also be an explicit aim of the nest box projects (Smith *et al.*, 2011). By tailoring nest box design to exclude large predators, survival can be better in nest boxes than natural nests (Libois *et al.*, 2012; Bailey & Bonter, 2017). However, small predators may able to overcome the passive defence of a small nest cavity entrance hole (Miller, 2002; Stojanovic *et al.*, 2017). Small nocturnal predators of bird nests are globally widespread, and can have important consequences for breeding success (Williams, Wood & Thompson Iii, 2002; Bradley, Marzluff & Thompson Iii, 2003). In such cases, predation risk in boxes may equal or exceed predation in natural cavities (Evans *et al.*, 2002). In small populations that depend on nest boxes (Tatayah *et al.*, 2007; Stojanovic *et al.*, 2018), small predators pose unacceptable risks to conservation. However, the logistic challenges of protecting nests in field settings over a long breeding season remain a major impediment to conservation and ecology projects.

In this context, we report the results of a field trial of a new tool for protecting nest boxes. Sugar gliders *Petaurus breviceps* are introduced to Tasmania (Campbell *et al.*, 2018) where they are a major predator of small, tree cavity nesting birds (Stojanovic *et al.*, 2014). There is a urgent conservation need to protect birds in nest boxes from sugar gliders (Heinsohn *et al.*, 2015). We address this challenge by trialling an automated, solar powered door attached to nest boxes. We use tree martins *Petrochelidon nigricans* to evaluate the efficacy of our automated doors because they are an abundant occupant of nest boxes in our study system. Tree martins are obligate tree cavity nesters and suffer predation from sugar gliders (Stojanovic *et al.*, 2014). Our study aimed to: (1) trial the efficacy of automated doors at protecting bird nests from sugar gliders, and (2) investigate whether operation of the doors impacted key demographic parameters of birds.

Materials and methods

We developed and field-tested photosensitive doors for nest boxes (referred to as 'Possum-keeper-outterers' during fundraising activities, hereafter PKOs). Sixty nest boxes were erected at three locations in south-eastern Tasmania in December 2017 – Feb 2018 (20 boxes per site). The three sites (Southport Lagoon: S43°28′, E146°56′; Meehan Range: S42°49′, E147°24′, Tooms Lake: S42°13′, E147°47′) were characterized by dry forests and selected based on high sugar glider predation risk (Heinsohn *et al.*, 2015) and presence of swift parrots *Lathamus discolor* (which are critically endangered by sugar glider predation, Heinsohn *et al.*, 2015), tree martins and sugar gliders at the time of the study. Other potential nocturnal nest predators (e.g. brush-tailed possums *Trichosurus vulpecula*, Tasmanian boobooks *Ninox leucopsis*) and other diurnal nest predators were all present at the time of the study at all sites. Nest boxes occupied by tree martins were randomly assigned to either treatment (up to five nest boxes per site) or control groups (all other nest boxes at the site). Nests were monitored with motion activated cameras (Reconyx^{TM}) attached within 20 cm of the nest box entrance hole. PKOs and cameras were deployed on nest boxes after tree martin nest construction began but before the first egg was laid.

Possum-keeper-outterers incorporate a photosensitive trigger mechanism that causes the door to open/close when ambient light exceeds/falls below 20 lumens (effectively first and last light of each day). This light level was chosen based on a trial of PKOs before the experiment was implemented and using data on first/last nest visitation by swift parrots from motion activated cameras (Stojanovic, D. unpublished data). We opted for a light sensor rather than a clock with fixed open/close schedules because at our high latitude field site, day length varies by ~ 4 h/day over the course of a breeding season. PKOs were powered in the field deployments by a 12V28A car battery, recharged continuously by a 12V4A solar panel. Trees with dense canopies that shaded the solar panels were assigned a second panel to compensate. Panels and batteries were deployed in the tree below the nest boxes using 5 cm external wood screws on straight, unobstructed sections of trunk to protect equipment and cables. PKOs were attached to nest boxes using screws, leaving a gap of ~5 mm between the door and the box face (to prevent snagging). Nest boxes were randomly oriented, so PKOs experienced a range of prevailing weather and light conditions depending on the orientation of the nest box, and which side of the tree the nest box was situated on. Components and assembly instructions for PKOs are provided in Data S1.

To test the efficacy of PKOs at protecting bird nests from sugar glider predation (aim one), we recorded nest fate as successful (at least one nestling surviving to fledge) or unsuccessful (no surviving nestlings). Nest fate and confirmation of predation by sugar gliders were determined by reviewing images from the cameras and inspecting nests manually to look for egg fragments and carcases. We fitted four generalized linear models using nest success as the response variable, with binomial error distributions, and four fixed effects: (1) null, (2) study site, (3) treatment type and (4) study site + treatment type.

To investigate whether PKOs impacted key demographic parameters of birds (aim two), we recorded clutch size of each tree martin nest (as an index of nest productivity and was known for all but one nest). We fitted four generalized linear models using clutch size as the response variable, with Poisson error distributions and the same four fixed effects as above.

Competing models were compared using ΔAIC <2, and all analyses were undertaken in R (R Development Core Team, 2017).

Results

We recorded 47 tree martin nesting attempts, and 17 of these were successful. Of the 30 nests that failed, four were in the treatment group and 26 in the control group (Table 1).

Predation by sugar gliders was the sole cause of nest failure in the control group, determined by detection of carcases or egg fragments in nest boxes, and confirmed by cameras (Fig. 1). At six treatment nests, where sugar gliders were detected (Fig. 1), cameras recorded mean 5.3 unsuccessful predation attempts over the nesting period (median: 3, range: 1 to 14), whereas all control nests failed after a single predation attempt (Data S1, Video S1). The best model of nest success included only the treatment type. Nests protected by PKOs had a 0.25 ($\pm$0.11 SE) probability of failing compared to 0.81 ($\pm$0.07 SE) in the control group. Three of the four nests that did not survive in the treatment group failed for unknown reasons (these nests failed during inclement weather, which may have impacted on nestling survival). The fourth was attributable to a PKO failing to open due to battery failure following several days of cloudy weather and shading of the solar panel. A replacement nesting attempt in that nest box was successful after a second solar panel was

Table 1 Sample size of tree martin nests per site and treatment group, presented as number of failed nests/total number of nests

Site	Control	Treatment	Total
Southport Lagoon	7/8	0/5	13
Meehan Range	12/15	3/6[a]	21
Tooms Lake	7/8	1/5	13

[a]Two successive nesting attempts occurred in the same nest box.

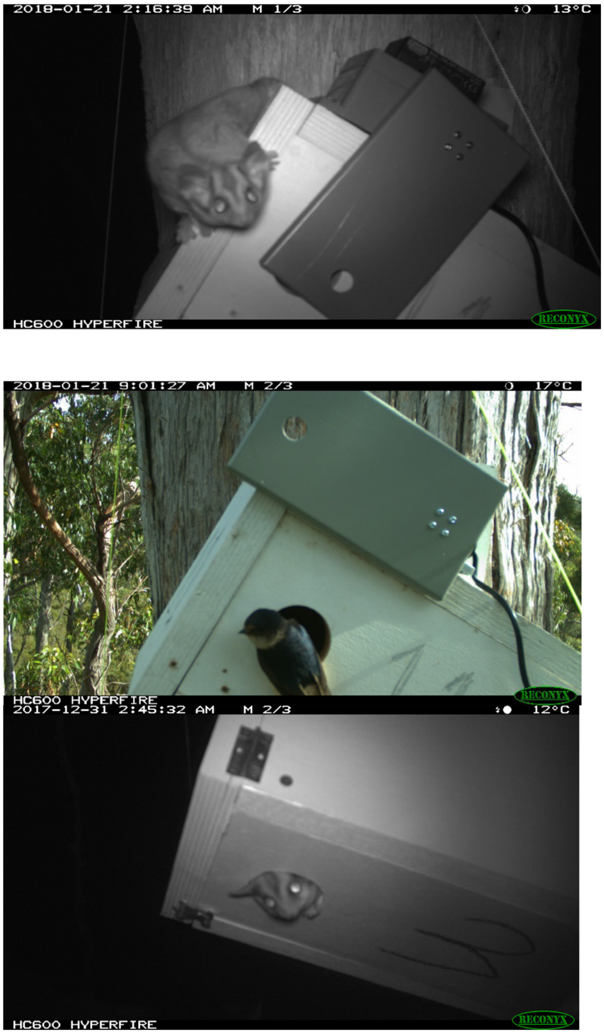

Figure 1 Automated doors successfully excluded sugar gliders from nest boxes containing tree martin nests despite repeated predation attempts (top). Tree martins had a higher probability of nest success in boxes equipped with PKOs. Sugar gliders could enter nest boxes not fitted with automated doors (bottom).

added to the system. The other PKOs worked correctly (confirmed with camera images) for the duration of the 3 month study. PKOs required minimal maintenance (intermittent checks of battery voltage) after initial checking and repositioning of solar panels away from shade to ensure battery charge was being maintained. We also observed brush-tailed possums visiting two nest boxes, and PKOs prevented them from reaching into boxes with their forelimbs or snouts. Black currawongs *Strepera fuliginosa* were also detected at 16 nest boxes during the day, but these predation attempts failed because the box entrances were too small.

The best model of clutch size was the null model, and we found no effect of study site or treatment group (Table 2).

Cameras recorded occasional repeated opening/closing of PKOs during overcast mornings and evenings. This was corrected by addressing voltage drop in the cables by shortening

Table 2 Mean ± SD of clutch size of tree martin nests among the three study sites and two treatment groups

Site	Control	Treatment
Southport Lagoon	2.7 ± 1.2	3.3 ± 0.8
Meehan Range	2.9 ± 1.8	3.6 ± 0.5
Tooms Lake	3.4 ± 0.8	3.4 ± 0.9

the length of the wiring between the battery and boxes. PKOs cost ~ $340 USD per unit (including materials and assembly, batteries, solar panels and tree climbing time).

Discussion

Protecting animals in nest boxes against predators is a fundamental element of projects that require high survival of the target species. Until now, effective tools to protect nest boxes from small predators have been unavailable despite urgent need. Sugar gliders were unsuccessful despite repeated attempts to prey on nests fitted with PKOs, which improved nest success by 56% relative to the control group. Predation accounted for all nest failures in boxes without PKOs, and predation events involved the death of adult tree martins and their eggs/nestlings. Our results demonstrate the efficacy of the PKO at eliminating predation even where background predation risk was high and predators persistent. Our results are also encouraging for species vulnerable to larger-bodied predators (Beggs & Wilson, 1991), because PKOs prevented brush-tailed possums from reaching into nest boxes, and the design we use could be scaled to suit predators of different sizes. Based on these results, PKOs may be a useful new conservation tool for targeted nest protection against both small and large nocturnal mammals.

Clutch size did not differ between the treatment and control groups. Observations of PKOs in operation did not suggest tree martins were distressed by the movement of the door, which was relatively quiet during operation. We did not explicitly test for behavioural change by nest building tree martins after PKOs were deployed on their nests, and this may warrant investigation for species more sensitive to disturbance. We observed no obvious behaviours indicative of distress, and tree martins typically resumed bringing nesting material to boxes within 15 min of PKO deployment. Species that may be more sensitive to disturbance could be managed either by (1) preemptively deploying PKOs on all nest boxes, or (2) deploying ‘dummy’ PKOs on all nest boxes available, before switching to an operational unit when the target species occupies a nest box. This may overcome potential phobia of newly fitted PKOs, leaving animals to tolerate only the opening/closing of the door at first and last light. Replication of this experiment in a predator-free habitat may be necessary to detect subtle behavioural/physiological impacts of PKOs, which may have gone undetected in this study because of the high predation rates we recorded. For swift parrots, which are critically endangered by sugar glider predation (Heinsohn *et al.*, 2015), potential behavioural/physiological impacts of PKO function should be identified and weighed against the risk of severe predation mortality (Stojanovic *et al.*, 2014).

Possum-keeper-outterers represent a new approach for protecting animals in boxes for the duration of (at least) 3 months breeding season. Low maintenance tools are a key in field programs in remote locations for threatened species and PKOs performed well in this regard. Shading of the solar panels and overcast conditions caused failure of one PKO. Given the unacceptable mortality risk posed by this scenario, we suggest that in shaded habitats or where maintenance checks of PKOs will be infrequent, additional solar panels or backup batteries may be required. Alternatively, where access to field sites is straightforward, regular swapping of batteries may allow solar panels to be dispensed with altogether. However, batteries are heavy, and impractical to carry for long distances in the field, which may limit the range of conditions where this approach is viable.

Possum-keeper-outterers may also be set to open at night and close during the day, to protect nocturnal species from diurnal predators, or to allow nest boxes to be used as a trap for researching nocturnal mammals. Given the effectiveness, simplicity of manufacture, long-term reliability and the ease of deployment on most standard nest box faces, the PKO is a useful new tool that will enable conservation biologists to overcome the substantial risk posed by predators that can breach traditional passive nest box protection measures.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. PKO construction.
Video S1. First known footage of sugar glider predation on a bird.