Occupancy patterns of the introduced, predatory sugar glider in Tasmanian forests.

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## ABSTRACT

Introduced mammals pose serious threats to native island fauna, and understanding their distribution is fundamental to evaluating their conservation impact. Introduced sugar gliders (*Petaurus breviceps*) are the main predator of critically endangered swift parrots (*Lathamus discolor*) on mainland Tasmania. We surveyed sugar glider occurrence over ~800 km$^2$ in an important swift parrot breeding area, the Southern Forests. During repeated visits to sites we used call broadcast of predatory owls to elicit sugar glider alarm calls and surveyed 100 sites during February/March 2016. Naïve occupancy by sugar gliders was high (0.79), as was detectability (0.523± 0.03 s.e.) resulting in a cumulative detection probability of effectively 1. Occupancy modelling indicated a positive effect of the proportion of mature forest cover on occupancy. The best model, based on AIC scores, included the proportion of mature forest cover within a 500m radius with constant detectability. Our study revealed surprisingly high rates of occupancy of available forest habitat throughout the heavily logged study area, such that even when mature forest cover was < 10 %, sugar glider occupancy was > 0.5. Where forest cover approached 100% (i.e. in the best quality breeding habitat for swift parrots), occupancy by sugar gliders approached 1. Our results reveal that sugar gliders are widespread across the study area and may be indicative of occupancy rates elsewhere in the breeding range of the critically endangered swift parrot. As a result, the risk of predation for small birds may be widespread across logged Tasmanian forests. Additional work to identify whether population densities of sugar gliders vary with forest cover (and whether this may

impact predation likelihood) is critical to understanding the conservation consequences of deforestation in the breeding range of the swift parrot.

**Key words**

*Petaurus breviceps*, occupancy modelling, predation, swift parrot *Lathamus discolor*, deforestation

## Introduction

Introduced species threaten global biodiversity (Blackburn *et al.* 2004; Simberloff *et al.* 2013). Understanding and addressing the impacts of introduced species on small islands can be straightforward, however, large islands can substantially hinder management actions and knowledge of patterns of occurrence due to the logistic challenges imposed by topography and survey area (Nogales *et al.* 2004; Towns and Broome 2003). On large islands, introduced species that are cryptic or occur at low densities may be difficult to detect, which may limit efficacy of conservation management if action is targeted at suboptimal locations.

Arboreal nocturnal mammals pose particular challenges for standardised surveys because they are often difficult to detect and can occur at low densities in (often) challenging terrain (Goldingay and Sharpe 2004). Survey methods for arboreal mammals often involve long surveys at night using a range of techniques (e.g. call broadcast, spotlight searches) and imperfect detection (or false absences) is a common problem (Wintle *et al.* 2005). Occupancy modelling (utilising presence/absence data) accounting for imperfect detection is now a commonly used technique to understand species occurrence (MacKenzie *et al.* 2006).

Overcoming the problem of false absences often involves a trade-off between the time spent during a single site visit (for example by surveying for longer periods) and spatial replication of the area surveyed. For species that are rare and/or have large potential distributions maximising detectability while minimising the time required for a single site visit can allow far greater spatial replication thus increasing sampling effort and or spatial coverage (Bowler *et al.* 2016; Crates *et al.* 2017; Webb *et al.* 2017).

Here we use an occupancy modelling framework to identify the distribution of an introduced arboreal marsupial, the sugar glider (*Petaurus breviceps*). Sugar gliders were introduced to Tasmania during the 1830s (Gunn 1851) and unlike in its native range (Lindenmayer 2002), the introduced Tasmanian population is poorly studied (Heinsohn 2004). Tasmanian sugar gliders are the main predator of critically endangered swift parrots *Lathamus discolor* and other small cavity nesting birds (Stojanovic *et al.* 2014b). Sugar gliders occur across the swift parrot breeding range, excluding offshore islands, but little is known about their occurrence at finer spatial scales (Heinsohn *et al.* 2015). However, mature forest extent may impact the predatory behaviour of sugar gliders (Stojanovic *et al.* 2014b), but the mechanisms behind this relationship are unknown. We aim to advance knowledge of the occurrence of sugar gliders in the swift parrots breeding range, and examine the potential effect of mature forest cover (and other factors) on glider occurrence. We discuss our results in context of the ecological impact of sugar gliders on the conservation of Tasmanian cavity nesting birds.

## Methods

### *Study area*

We surveyed ~800 $km^2$ across a key swift parrot breeding area in southern Tasmania, Australia. The Southern Forests are characterized by wet *Eucalyptus globulus, E. delegatensis, E. regnans, E. nitida* and *E. obliqua* dominated forests severely fragmented by industrial scale logging. The forests comprise a patchwork of cleared land, regenerating and old-growth native forest and plantation (Hickey 1994). Across much of the study area, the understory is dominated by temperate rainforest and other mesic vegetation. Mean minimum and maximum temperatures in the region range from 10 - 22°C in February to 2 - 12°C in July and average annual rainfall is 877mm (BOM 2016). Elevation of the survey sites ranged from 12 to 687 m.

*Study Design*

We selected 100 survey sites over the study area (Figure 1) including existing swift parrot monitoring sites (Webb *et al.* 2017; Webb *et al.* 2014) and additional sites selected using the following criteria. All sites contained at least one mature, cavity-bearing *Eucalyptus* within 100 m of the centroid (i.e. potential sugar glider/swift parrot habitat) and were at least 500 m away from other sites. Sites were defined as a 200 m radius around the centroid. Repeated five minute site visits (4 - 5 visits/site) were undertaken during February/March of 2016. Based on the results of a pilot study (Allen, M. unpublished data) we improved sugar glider detectability using southern boobook *Ninox novaeseelandiae* call broadcast to elicit alarm calls from sugar gliders. Surveys consisted of two minutes of listening, followed by three minutes of intermittent call broadcast from a portable speaker.

To reduce the potential effects of weather on sugar glider detectability (sugar gliders become torpid during inclement weather (Lindenmayer 2002)), surveys were only conducted between 21:00-02:00 h, within a temperature range of 10 – $20^{o}$ C and when wind speeds were

< 20 km/h (i.e. clement weather). A fifth survey was undertaken at sites where the gliders were not detected in the first four surveys. During surveys we recorded: (i) sugar glider detection/non-detection ; (ii) wind speed; (iii) temperature, scored as: 1 = 9 - 12 $^{o}$C, 2 = 13 - 16 $^{o}$C, 3 = 17 - 20 $^{o}$C; (iv) moon brightness, scored as: 0= new moon, 1 = small crescent moon, 2 = large crescent moon, 3 = full moon, and; (v) southern boobook detection/non-detection (based on calls). Temperature and wind speed were measured with a Kestrel 3000 RH/Wind Meter (Nielson-Kellerman, Boothwyn, PA, USA).

We used ArcMap 10.3 to derive site-level variables: (i) elevation and (ii) mature forest cover within the following radii from the site: 200 m, 500 m, 1000 m, 1500 m and 2000 m. Mature forest cover was estimated using the aerial forest inventories that quantify the spatial extent of mature, cavity-bearing forest (FPA 2011), and are a good indication of potential habitat for tree cavity dependent animals (Stojanovic *et al.* 2014a). We followed (Stojanovic *et al.* 2014b) and pooled data for three categories (low, medium and high) of mature forest cover because all constitute potential sugar glider habitat because of the occurrence of mature trees in each.

*Statistical analysis*

To quantify patterns of sugar glider occurrence across the study area we followed an occupancy modelling approach (MacKenzie *et al.* 2006), using single-season models implemented in R (R Core Team 2017) using the package *unmarked* (Fiske and Chandler 2011). We modelled sugar glider occupancy and detectability and included site-level (forest covers, elevation) covariates that could impact occupancy, and observation-level (temperature, moon phase, owl occurrence) covariates that could impact detection. We selected the best model using the Akiake Information Criterion and we tested goodness of fit using the parametric bootstrap method with 1000 simulations.

## Results

Naïve occupancy (i.e. the proportion of sites sugar gliders were detected) was 0.79, almost equivalent to the modelled occupancy estimate of 0.81 assuming constant occupancy and detection. Twenty four sites were visited a fifth time because gliders had not been detected in the first four visits (total 424 surveys). Because we controlled for the potential effect of wind, 83 % of site visits had wind speeds < 5 km/h and all were < 10 km/h. Due to this small variation, we excluded wind speed from further analysis.  The best model, based on AIC scores (Table 1) included a significant included a significant positive effect of mature forest within 500 m of the site on likelihood of sugar glider occupancy (estimate: 5.51 ± 2.54, z: 2.17, p: 0.03) and a non-significant effect of temperature in the detectability component (p: 0.1). The second best model based on AIC also included a positive effect of mature forest within 500 m of the site on likelihood of sugar glider occupancy (estimate: 5.58 ± 2.48, z: 2.25, p: 0.02) and assumed constant detectability. We selected the simpler (constant detectability) model as our preferred (Figure 2). Given estimated detectability for the best model was 0.523 (± 0.03 SE), the cumulative probability of detecting sugar gliders if they were present at a site, was 95 % by the fourth site visit (Figure 3).

## Discussion

We used an occupancy framework to undertake a rapid, landscape scale survey of sugar gliders within a key breeding area for swift parrots. Our results reveal high rates of sugar glider occupancy across the study area, and a positive correlation with the proportion of mature forest cover within 500 m radius. Even when mature forest cover was low (< 10 %), sugar glider site occupancy of survey sites was still greater than 0.5. This finding underscores the widespread predation risk for small cavity nesting birds in this landscape even in small habitat fragments. Sugar glider predation on birds may be correlated with forest disturbance, such that areas of low forest cover suffer the worst predation rates (Stojanovic *et al.* 2014b). In their native range, sugar gliders are common in fragmented landscapes (Suckling 1984) and are known to tolerate logging  (Kavanagh and Bamkin 1995).

We demonstrate the efficacy of short surveys incorporating predatory owl call broadcast for surveying sugar gliders. Sugar gliders can be challenging to detect using spotlighting searches because they commonly turn away from lights, and have relatively dull retinal reflectance compared to other nocturnal mammals (Wintle *et al.* 2005). We had a 77 % likelihood of detecting sugar gliders with only two five minute site visits, and this likelihood increased to 89 % and 95 % for three and four visits respectively (Figure 3). The method we used is fast and low cost, facilitating increased spatial replication across our large study area. Controlling for survey conditions (i.e. good weather) improved survey efficacy even in challenging terrain because sugar gliders may be heard calling over hundreds of meters on calm nights. This approach was particularly valuable in our study area, where access to off-road study sites can be challenging even in daylight hours.

Our results have serious implications for swift parrots and other cavity nesting birds because sugar gliders are resident in their territories, and occupy most of the potential swift parrot habitat in the study area. Areas with greater abundance of mature forest may be attractive for the group-nesting swift parrot, but  depending on fine scale habitat configuration, nests may suffer severe predation (Heinsohn *et al.* 2015). More data on abundance and behavior of sugar gliders both at large (swift parrot breeding range) and fine scales (sugar glider home ranges) is necessary to identify the mechanisms that underpin the relationship between forest cover and nest predation. Fine scale variation in population densities of sugar gliders may have important ramifications for bird nesting success, and given the high conservation threat sugar gliders pose to Tasmanian birds, this warrants urgent attention.

We demonstrate the conservation value of identifying efficient survey approaches for invasive species to overcome the challenges of monitoring large areas of rugged terrain. Given the vulnerability of island species to introduced predators, overcoming data limitations about where predators occur is a critical first step to conserving vulnerable native species. Our study demonstrates an effective approach to detecting potential predation risk that, in combination with information about where swift parrots are likely to nest, provides a useful management tool for prioritising areas for nest protection.


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## Tables and Figures

**Table 1.** Candidate models of sugar glider occupancy ($\Psi$) and detectability ($p$). nPars = number of parameters.

| Model | nPars | AIC |
|---|---|---|
| $\Psi$(500m) . $p$(temperature) | 4 | 534.32 |
| $\Psi$(500m) . $p$(.) | 3 | 534.99 |
| $\Psi$(500m) . $p$(moon) | 4 | 536.38 |
| $\Psi$(500m) . $p$(owl) | 4 | 536.99 |
| $\Psi$(200m) . $p$(temperature) | 4 | 538.74 |
| $\Psi$(200m) . $p$(.) | 3 | 539.39 |
| $\Psi$(1000m) . $p$(temperature) | 4 | 539.77 |
| $\Psi$(1000m) . $p$(.) | 3 | 540.6 |
| $\Psi$(200m) . $p$(moon) | 4 | 540.9 |
| $\Psi$(200m) . $p$(owl) | 4 | 541.38 |
| $\Psi$(1000m) . $p$(moon) | 4 | 542.01 |
| $\Psi$(.) . $p$(temperature) | 3 | 542.42 |
| $\Psi$(1000m) . $p$(owl) | 4 | 542.58 |
| $\Psi$(1500m) . $p$(temperature) | 4 | 543.03 |
| $\Psi$(.) . $p$(.) | 2 | 543.25 |
| $\Psi$(1500m) . $p$(.) | 3 | 543.82 |
| $\Psi$(2000m) . $p$(temperature) | 4 | 544.13 |
| $\Psi$(elevation) . $p$(temperature) | 4 | 544.35 |
| $\Psi$(.) . $p$(moon) | 3 | 544.75 |
| $\Psi$(2000m) . $p$(.) | 3 | 544.95 |
| $\Psi$(elevation) . $p$(.) | 3 | 545.16 |
| $\Psi$(elevation) . $p$(moon) | 3 | 545.23 |
| $\Psi$(.) . $p$(owl) | 3 | 545.23 |
| $\Psi$(1500m) . $p$(moon) | 4 | 545.27 |
| $\Psi$(1500m) . $p$(owl) | 4 | 545.8 |

| | | |
|---|---|---|
| Ψ(2000m) . *p*(moon) | 4 | 546.43 |
| Ψ(2000m) . *p*(owl) | 4 | 546.93 |
| Ψ(elevation) . *p*(owl) | 4 | 547.12 |

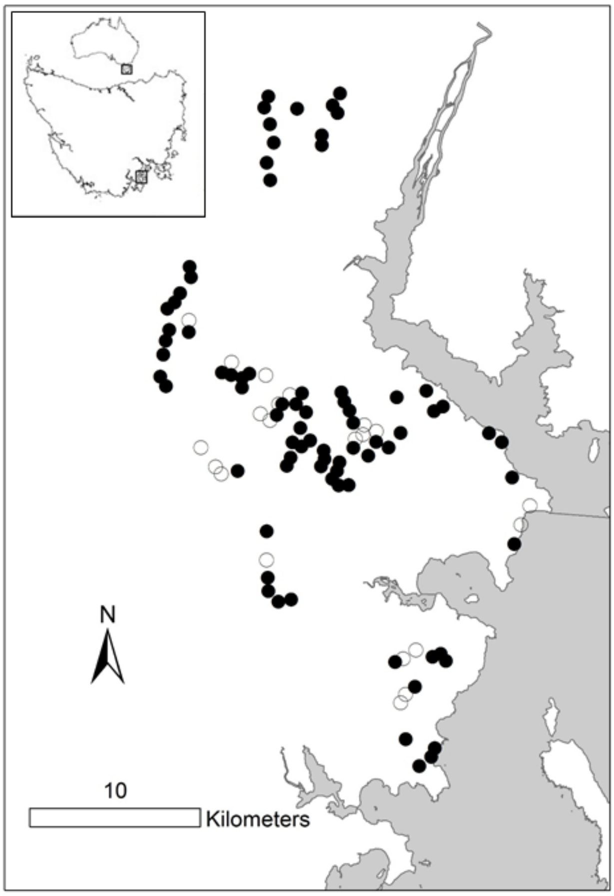


**Figure 1.** Study area showing the location of the survey sites where sugar gliders were present (black) and absent (white).

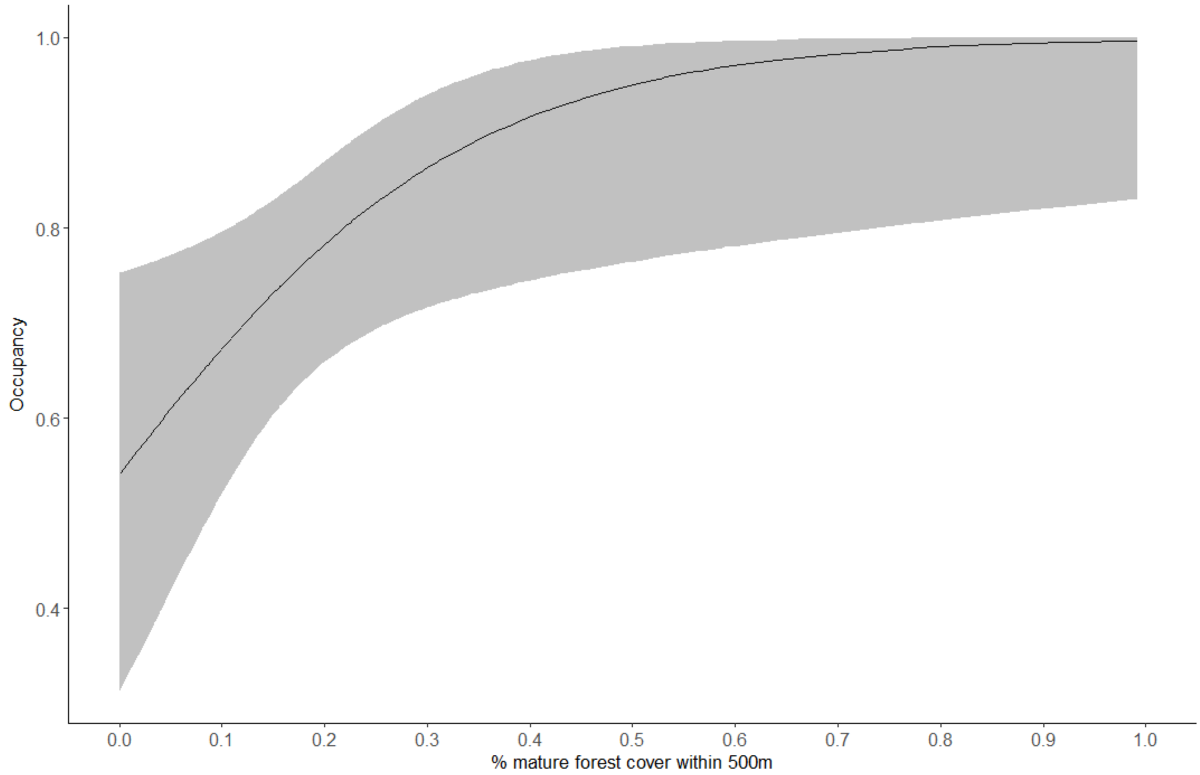


**Figure 2.** Modelled probability of sugar glider site occupancy relative to cover of mature forest within 500 m of the survey site centroid. Line is the occupancy predicted and grey area represents 95% confidence interval.

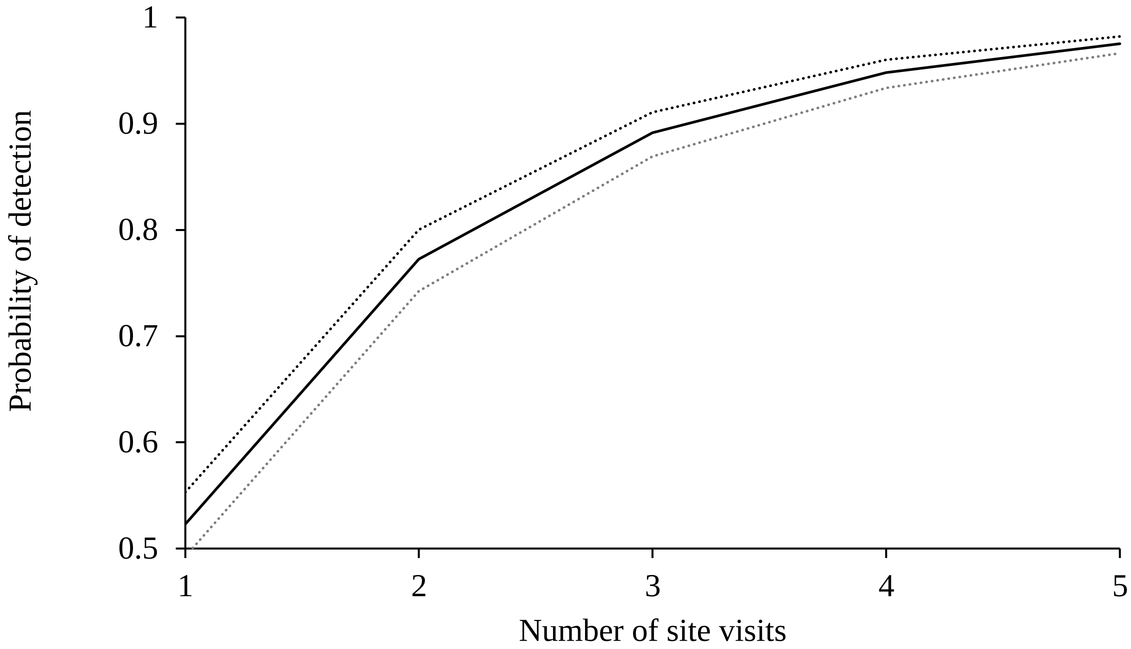


**Figure 3**. Cumulative detection probability of sugar gliders. The black line represents a detection probability of 0.523 (± 0.03 s.e.) for a single site visit, derived from the best model.