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Documenting demise? Sixteen years observing the Swift Parrot *Lathamus discolor* in suburban Hobart, Tasmania

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Abstract. The Swift Parrot *Lathamus discolor* is listed as Critically Endangered because modelling suggests that its population is declining by >80% within three generations (12–18 years) as a result of just one of many factors impacting the species: predation by introduced Sugar Gliders *Petaurus breviceps.* Unfortunately, verification of this prediction through monitoring of the entire population across its breeding range is difficult because of the amount of observer effort required to count all individuals within the often dense canopies of *Eucalyptus* trees, where it forages predominantly from flowers. This study entails 16 years of opportunistic observations at a single location within this species' breeding range. Regression models indicated that over 16 breeding seasons the mean size of the largest flock per month declined by ~90%, and grand mean size of all flocks per month by ~70%. This was not the result of decreasing local flowering intensity in the Swift Parrot's favoured food plants, as adjusting the two measures of abundance for local inter-annual variation in flowering had little effect on the rates of decline. This concordance between observations at the local scale and modelling of the entire population supports the findings of the modelling, suggesting that urgent action is required to prevent extinction of this species.

Introduction

Concerns have recently been expressed regarding the conservation of parrots (Psittaciformes) across the world. Reviews on this subject have found that Australia is among the countries of highest priority for parrot conservation (Olah *et al.* 2016), with Tasmania being of particular importance (Geyle *et al.* 2018; Olah *et al.* 2018). Another recent review concluded that levels of population monitoring of parrots globally are broadly inadequate relative to the threats posed to parrots by environmental change (Marsden & Royle 2015).

The Swift Parrot *Lathamus discolor* is a threatened species with a single panmictic population (Stojanovic *et al.* 2018a) that migrates from the south-eastern Australian mainland to breed each spring in Tasmania (Brown 1989; Brereton 1996a). In recent decades, it has been transferred into higher threat categories under national legislation (*Environment Protection and Biodiversity Conservation Act 1999* and preceding legislation). When the first recovery plan was produced for this species, it was classed as Vulnerable (Brereton 1996b) but it was soon uplisted to Endangered (Brereton 1999). It was upgraded to Critically Endangered in 2016 because modelling predicted a decline in population size of >80% within three generations (12–18 years) as a consequence of just one of the many factors impacting the species: predation of nesting females and eggs by the Sugar Glider *Petaurus breviceps* (Heinsohn *et al.* 2015), an introduced species in Tasmania (Campbell *et al.* 2018). In addition to predation, frequent direct mortality of Swift Parrots also results from collisions with windows and fences (Pfennigwerth 2008). Hence, a recent assessment of Australia's threatened birds concluded that there is a 31% chance of the Swift Parrot becoming extinct in the next 20 years, making it the seventh most likely species in Australia to do so (Geyle *et al.* 2018).

In any population modelling there are inherent uncertainties (Rueda-Cediel *et al.* 2018), and verification of any projected decline requires monitoring of the population. It is important to note that the population decline forecast by Heinsohn *et al.* (2015) was based on predation rates from 2010 to 2013. Thus, if the modelling is accurate, the population size should have been decreasing for at least the last 5 years. However, monitoring the population of Swift Parrots is challenging because they are nomadic, can breed across an area of ~10,000 km^2 (Heinsohn *et al.* 2015; Webb *et al.* 2017), and are difficult to count because they are small, green, and tend to forage high in the often dense canopies of *Eucalyptus* trees (Hingston & Potts 2005). Hence, no data to confirm a decreasing population size have been published. However, if the predicted declines in population size (Heinsohn *et al.* 2015; Geyle *et al.* 2018) are accurate, they are so large that it might be possible to detect them at a small spatial scale over the length of time on which those predicted reductions are based. In this study, I test the hypothesis that the numbers of Swift Parrots inhabiting a small area declined over approximately three generations (2002–2017) at a similar rate to the decrease forecast over similar lengths of time by the models of Heinsohn *et al.* (2015). A second hypothesis tested, which is also consistent with a declining population because of high rates of nest-depredation, is that few fledglings would be observed. A third hypothesis tested was that frequent mortality of Swift Parrots would also result from collisions with windows and fences in the urban section of the study site.

Methods

Study site

This study was done in an area of 8 km^2 that encompassed the suburb and surrounding bushland at Mount Nelson on the southern edge of Hobart, the same area in which a feral population of Rainbow Lorikeets *Trichoglossus haematodus moluccanus* was monitored between 2007 and 2018 (Hingston 2019). Vegetation in the bushland comprised mostly dry sclerophyll forest dominated by White Peppermint *Eucalyptus pulchella*, Tasmanian Blue Gum *E. globulus*, Swamp Gum *E. ovata*, Manna Gum *E. viminalis* and Silver Peppermint *E. tenuiramis*. This graded into wet sclerophyll Tasmanian Blue Gum and Messmate *E. obliqua* forest within gullies, and Drooping She-oak *Allocasuarina verticillata* dominated the drier hill-slopes. Scattered individuals of these trees occurred in the suburb, which covered ~30% of the study site.

Collection of data

Swift Parrots were recorded opportunistically whenever they were encountered from July 2002 until June 2018, a period during which I consistently spent large amounts of time at the study site. Data collected included the number of birds observed, the date and time, any evidence of breeding or mortality, and any foraging activities. Opportunistic data collection allowed me to move to the best position and spend as long as needed to obtain an accurate count of the number of birds present. Because it was often not possible to see every bird while a flock foraged in a tree-canopy, the numbers of birds were determined by waiting indefinitely and counting them as they flew from the canopy until no birds could be seen or heard within the canopy. The entire flock within any canopy was assumed to be foraging in the same way as any birds that could be seen. In the few cases where a bird was seen foraging on more than one food source, the main source was recorded. If individuals were present for periods >30 minutes, repeated observations of such birds were separated by at least 30 minutes.

Because the numbers of Swift Parrots present within the study site each year might have been influenced by local food availability, the main food items used by Swift Parrots during their breeding season (flowers of Tasmanian Blue Gum and Swamp Gum: Brown 1989; Brereton 1996a) were documented. The flowering intensities of these trees were scored in the study site each year from 2002 to 2017, with the term 'year' referring to the period from 1 July until 30 June of the following calendar year. Flowering was scored on a scale of 0–4 relative to the maximum possible flowering for each species, and so is broadly similar to the scale used by Webb *et al.* (2014, 2017). Flowering scores were: 0 = very light (<1% of maximum possible flowering), 1 = light (1–10%), 2 = moderate (11–25%), 3 = heavy (26–50%) and 4 = very heavy (>50%).

Investigations into mortality resulting from Swift Parrots colliding with man-made structures were focused on a chain-link fence around the Mount Nelson Primary School tennis court with which numerous Parrots had collided during the 1980s and 1990s (Brown 1989; Pfennigwerth 2008), and other chain-link fences within the school grounds. The perimeters of these fences were walked at the earliest opportunity after Swift Parrots were observed flying in the school grounds. Additional evidence of collisions was obtained opportunistically from other locations. To gain insight into the factors that made certain fences collision hazards for the Parrots, I measured specifications of three chain-link fences with which collisions occurred and of another chain-link fence which they did not strike. The length and height of each fence was measured with a tape measure, and the gauge (thickness) of the wire and the minimum aperture size (internal and parallel to wire) were determined with digital callipers. Ten measurements of gauge and aperture were made at random points on each fence.

Analysis of data

Testing of the hypothesis of declining abundance of Swift Parrots involved three steps. The first was to identify the time of year that the Parrots used the study site consistently over the 16 years, to avoid masking any variation among years with variation within years resulting from irregular seasonal movements in this nomadic species. The second step involved determining which food sources were most important to the Parrots during that time of year, so that values for Parrot abundance could be adjusted to take account of any local inter-annual fluctuations in the production of these food sources. The final step entailed establishing whether the abundance of the Parrots within that time of year showed any directional change over the years from 2002 until 2017, both for raw data and after adjusting for inter-annual variation in food production.

Step 1. Seasonal activity patterns

Identifying the time of year that Swift Parrots consistently used the study site involved exploring for each year: the dates of the first observation, the last observation, and when the largest flock was seen. If the largest flock in any year was recorded on more than one date, the mean date of those observations was used. To investigate whether seasonal activity patterns of the species changed over the 16 years, regressions were done between sequential year of survey and each of these dates over the years. Both linear and exponential regressions were carried out for each of these analyses, and the model with the higher r^2 (proportion of variation of the dependent variable that is explained by the independent or predictive variable: Kasuya 2019) was presented.

Step 2. Foraging activities

Determining which food sources were most important to Swift Parrots entailed comparing the proportions of Parrots seen foraging on a range of sources over the entire study, and averaging these for each month across the 16 years. Because I found that most foraging was from flowers of Swamp Gum and Tasmanian Blue Gum, particularly during the time of consistent use of the study site, patterns of production of these resources were explored. The middle of the range of percentages for each flowering score for these species was used as the measure of flowering intensity during data analyses (score 0 = 0.5%, score 1 = 5.5%, score 2 = 18%, score 3 = 38% and score 4 = 75.5%), rather than the non-linear flowering scores, because the sum of the flowering intensities of the two species was sometimes used as a predictive variable. To determine if the flowering intensities of the two species varied independently of each other, a correlation between these was done with years as replicates. To test whether their flowering intensities showed a directional change over the 16 years, regressions were done between year of survey and the flowering intensities of each species and also the sum of the flowering intensities of the two species. Both linear and exponential regressions were carried out for each of these analyses, and the exponential regressions always yielded higher r^2.

Before adjusting the values for abundance of Swift Parrots to take account of local inter-annual variation in the flowering intensities of Swamp Gum and Tasmanian Blue Gum, I ascertained whether these needed to be weighted because they favoured the flowers of one of these species over the other. Regression models were constructed between the flowering intensities of each species and the percentages of foraging Parrots seen on flowers of each species, with years as replicates. For ease of presentation, similar regressions were done based on the differences in flowering intensity of the two species (intensity of Swamp Gum minus that of Tasmanian Blue Gum). These analyses were based on foraging behaviour between Swift Parrots arriving at the study site and the end of their breeding season (July–December) because flowering intensities were scored for the period from 1 July onwards each year, and because the Parrots foraged almost exclusively on flowers of these species at this time of year and used the study site most consistently during the breeding season. Because no Parrots were seen foraging from flowers in 2017, these analyses were restricted to the years 2002–2016. Both linear and exponential regressions were carried out for each of these analyses, and the linear models always resulted in higher r^2.

Step 3. Numbers of Swift Parrots observed in each breeding season

Analysis of changes in the numbers of Swift Parrots inhabiting Mount Nelson over the 16 years were restricted to observations made during the breeding season (September–December: Gartrell 2002a,b; Webb *et al.* 2012) because Steps 1 and 2 revealed that the Parrots used the site regularly, and foraged in relatively constant ways, at that time of year. Because Step 2 showed that the major food sources during the breeding season were flowers of Swamp Gum and Tasmanian Blue Gum, with no clear preference between these sources, the sum of the flowering intensities of these two species was used in analyses. Regressions were done between Parrot abundance and both sequential year of survey and the summed flowering intensities of Swamp Gum and Tasmanian Blue Gum. Because any overall trend in abundance across the 16 breeding seasons might have been masked by local inter-annual fluctuations in flowering, regressions were also done on abundance divided by the sum of the flowering intensities of Swamp Gum and Tasmanian Blue Gum at the study site in that year. Both linear and exponential regressions were carried out for each of these three analyses, and the model with the higher r^2 was presented.

Two measures of abundance during the breeding season were used as response variables in the above analyses. These were the mean size of the largest flock, and the grand mean size of all flocks, observed per month from September to December. Both the size of the largest flock and the mean flock size in each of the 4 months of the breeding season were summed before dividing by four, to differentiate breeding seasons when flocks were observed for only a brief period from those when flocks of similar sizes were observed at the study site throughout the breeding season. For months that included no observations of Swift Parrots, the mean flock size was set to zero. The mean size of the largest flock per month provided an estimate of the numbers of birds that occurred in the study site during that breeding season, but is potentially biased by any differences in observation time among years in a study such as this without a systematic sampling regime. That is, if I spent more time observing Swift Parrot habitat in some years I would have greater opportunity to encounter large flocks. To guard against this potential bias, the grand mean size of all flocks seen during the breeding season was also used as a measure of abundance. Flock sizes were the numbers of birds observed at any point in time.

Collisions

Differences among the four chain-link fences in gauge of the wire and diameter of the aperture were tested using One-way Analysis of Variance. *Post-hoc* pairwise tests were done with two-tailed *t*-tests with Bonferroni corrections.

Results

Seasonal activity patterns

During the 16 years from 2002 to 2017, I made a total of 20,155 observations of Swift Parrots at Mount Nelson. Swift Parrots were observed more consistently during the breeding season (September–December: Figure 1); 16,105 observations were made at that time of year. However, observations spanned all 12 months of the year, with three birds overwintering in 2010 (Figure 1). In all years, my first observation of a Swift Parrot occurred by 23 September (mean ± standard error = 10 August ± 6 days), and the date of this did not show a significant

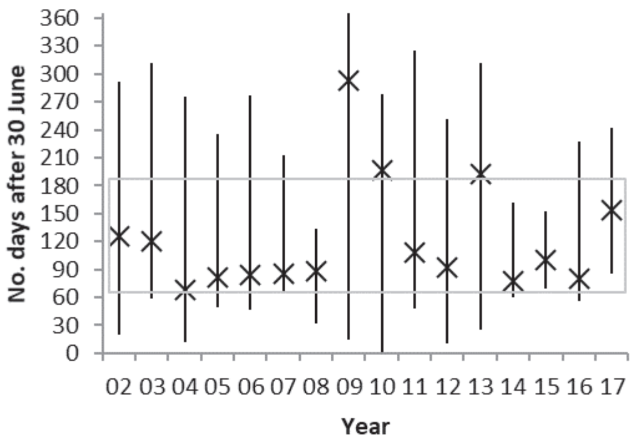

Figure 1. Durations of seasonal observations of Swift Parrots at Mount Nelson in each year from 2002 to 2017. Years are from 1 July in the calendar year shown until 30 June the following calendar year. Bars span the time between the first observation (lower) and last observation (upper) in that year. Crosses show the dates when the largest flocks were seen in each year, with these being means for 2007 and 2015 because the largest flocks were seen on 2 days in each of those years. The breeding season of September–December is within the box spanning days 63–184.

directional change over the study (linear, $r^2 = 0.13$, $P = 0.17$: Figure 1). My observation of the largest flock each year usually occurred during the breeding season (median = 4 October), and this also showed no evidence of directional change over the 16 years (exponential, $r^2 = 0.018$, $P = 0.62$; Figure 1). Observations of the year's largest flocks in January 2011 and 2014 and April 2010 (Figure 1) probably reflect post-breeding influxes from elsewhere, because the flock sizes involved (75, 45, and 100, respectively) were far greater than the largest flocks seen during the preceding breeding seasons (21, 10, and 14, respectively). Hence, the months post-breeding were characterised by influxes of large flocks in some years, but also absence of the species over varying amounts of time in most years (Figure 1). The date on which I last observed a Swift Parrot varied widely among years, from 10 November to 30 June (mean = 10 March ± 16 days), but did not exhibit a significant directional change through the study (linear, $r^2 = 0.10$, $P = 0.23$; Figure 1).

Foraging activities

I observed 10,208 instances of Swift Parrots foraging over the 16 years (Table 1). Over 99% of foraging observations occurred in three species of trees—Swamp, Tasmanian Blue and Manna Gums—and their hybrids (Table 1). Foraging from the flowers of these species accounted for 91.2% of foraging observations, and gleaning leaves or bark of these species made up 8.6% of foraging observations (Table 1). Flowers of Swamp Gum and Tasmanian Blue Gum accounted for 89.1% of all foraging activities (Table 1). Although these were the major food sources between the Parrots arriving at the study site and the end of the breeding season (July–December), the diet was supplemented in the latter part of the breeding season by gleaning leaves of Manna Gum (Figure 2). Episodes of leaf gleaning on Manna Gum tended to be associated with outbreaks of the psyllid *Cardiaspina* sp. and its associated lerp. Foraging activities changed greatly after the end of the breeding season, when the Parrots made use of a wider array of sources (Figure 2).

The flowering intensities of Swamp Gum and Tasmanian Blue Gum varied among years (Figure 3), but were not significantly correlated with each other ($r = –0.41$, $P = 0.11$). Although there were 5 years during which one of these species failed to flower, one species always flowered to at least a moderate level (Figure 3). There were no significant directional changes in flowering intensities across the 16 years for Swamp Gum (exponential, $r^2 = 0.059$, $P = 0.37$), Tasmanian Blue Gum (exponential, $r^2 = 0.083$, $P = 0.28$), or the sum of the intensities of the two species (exponential, $r^2 = 0.0090$, $P = 0.73$: Figure 3).

During the months between Swift Parrots arriving at the study site and the end of the breeding season (July–December), the inter-annual patterns of foraging on flowers of Swamp Gum and Tasmanian Blue Gum largely followed an ideal free distribution relative to the flowering intensities of these two species. The percentage of foraging individuals that used flowers of Swamp Gum showed a significant positive linear relationship with flowering

Table 1. Food sources used by Swift Parrots at Mount Nelson between July 2002 and June 2018: number of observations (and % of total in parentheses).

Food source	*No. of observations*
Flowers of Swamp Gum	7103 (69.6)
Flowers of Tasmanian Blue Gum	1991 (19.5)
Gleaning leaves of Manna Gum	478 (4.7)
Gleaning leaves/bark of Tasmanian Blue Gum	297 (2.9)
Flowers of Manna Gum	132 (1.3)
Gleaning leaves/bark of Swamp Gum	97 (0.95)
Flowers of Tasmanian Blue Gum x Swamp Gum hybrids	81 (0.79)
Gleaning leaves of White Peppermint	12 (0.12)
Flowers of Lemon Bottlebrush *Melaleuca pallida*	6 (0.06)
Gleaning leaves/bark of Tasmanian Blue Gum x Swamp Gum hybrids	5 (0.05)
Seeds of Silver Birch *Betula pendula*	5 (0.05)
Flowers of Silver Banksia *Banksia marginata*	1 (0.01)

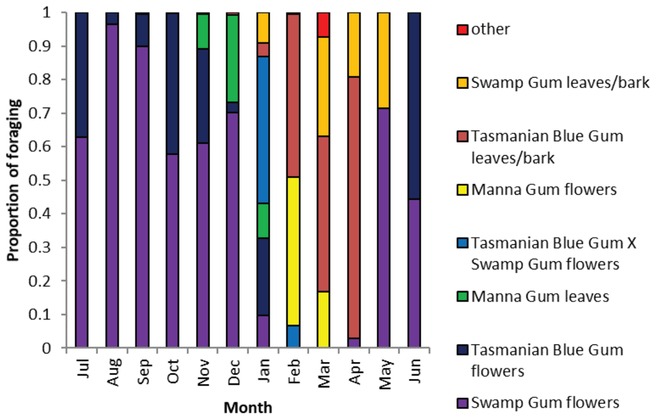

Figure 2. Mean proportions of Swift Parrots seen foraging on a range of sources through the months of the year from July 2002 until June 2018 at Mount Nelson.

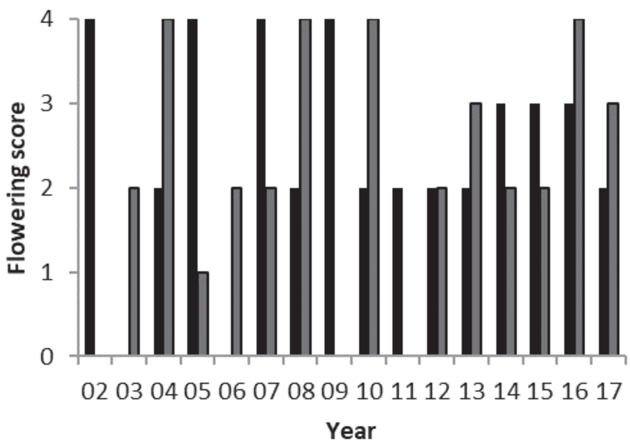

Figure 3. Flowering scores for Swamp Gum (black) and Tasmanian Blue Gum (grey) at Mount Nelson each year from 2002 to 2017. Years are from 1 July in the calendar year shown until 30 June in the following calendar year. Scores are: 0 = very light (<1% of maximum possible flowering), 1 = light (1–10%), 2 = moderate (11–25%), 3 = heavy (26–50%) and 4 = very heavy (>50%).

intensities of Swamp Gum (r^2 = 0.31, P = 0.032) and the opposite relationship with those of Tasmanian Blue Gum (r^2 = 0.31, P = 0.030) across the years of the study. Similarly, the percentage of individuals that foraged from flowers of Tasmanian Blue Gum showed a significant positive linear relationship with flowering intensities of this eucalypt (r^2 = 0.33, P = 0.026) and the opposite relationship with those of Swamp Gum (r^2 = 0.36, P = 0.019). Hence, the flowering intensities of Swamp Gum minus those of Tasmanian Blue Gum showed a significant positive linear relationship with the percentage of foraging Parrots that used flowers of Swamp Gum (r^2 = 0.44, P = 0.0070: Figure 4a) and the opposite relationship with the percentage that used flowers of Tasmanian Blue Gum (r^2 = 0.48, P = 0.0041: Figure 4b). The y-intercept in both of the latter regressions was near 50% (Figure 4), suggesting that the Parrots would forage in equal frequencies on the two eucalypt species when they flowered at the same intensity.

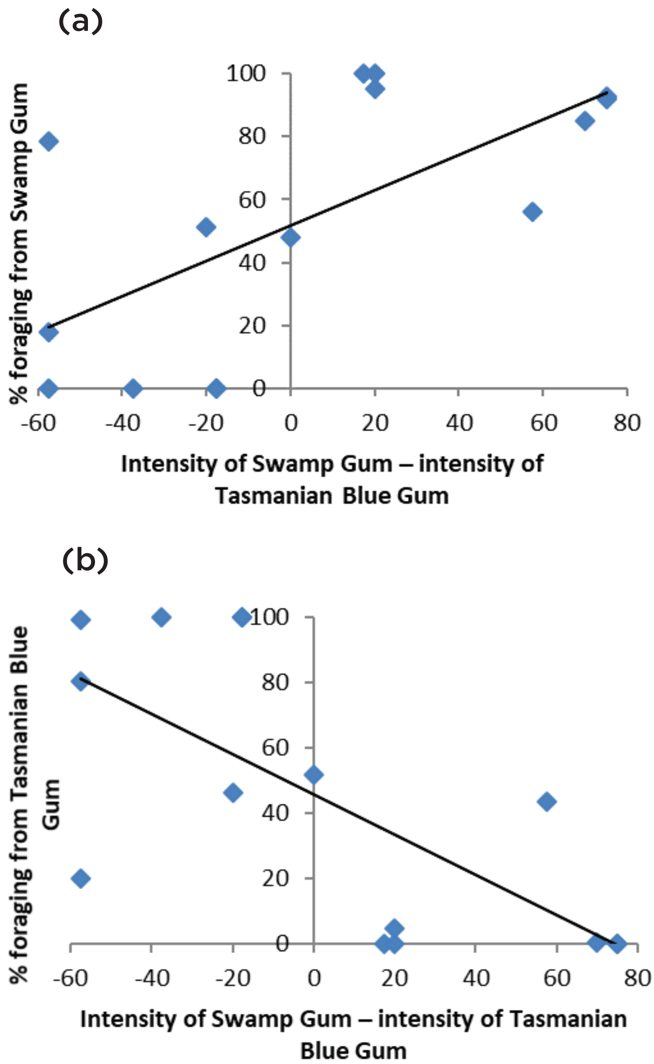

Figure 4. The percentage of foraging individual Swift Parrots that used (a) flowers of Swamp Gum and (b) flowers of Tasmanian Blue Gum, relative to the flowering intensities of Swamp Gum minus those of Tasmanian Blue Gum from 2002 to 2016 at Mount Nelson. The lines of best fit for linear regressions are: (a) $y = 0.5632x + 51.795$, (b) $y = -0.6152x + 46.016$. There are two points at each of (-17.5, 0) and (75, 92) in (a), and two points at each of (-17.5, 100) and (75, 0) in (b).

Numbers of Swift Parrots observed in each breeding season

Swift Parrots were observed at Mount Nelson in all 16 breeding seasons. However, the mean sizes of the largest flocks per month varied greatly among breeding seasons (Figure 5a), with this showing a stronger relationship with the sequential year of survey than with concomitant eucalypt flowering intensity. The mean size of the largest flocks per month in the 2002 breeding season was 93 birds (Figure 5a), and flocks of this size were also observed in at least 1 month during the 2004, 2005, and 2014 breeding seasons when mean largest flocks per month were 27–45 birds (Figure 5a). For all other breeding seasons, the largest flocks never exceeded 30 and mean largest flocks per month were <15 birds (Figure 5a). Consequently, the largest values for the latter variable occurred in three of the first four breeding seasons (Figure 5a). In addition, Swift Parrots were observed in all 4 months of all breeding seasons from 2002 to 2014, but only 3 months in each of 2015 and 2016 and 2 months in 2017. As a result, there was a significant negative exponential relationship between year and mean largest flock per month in the

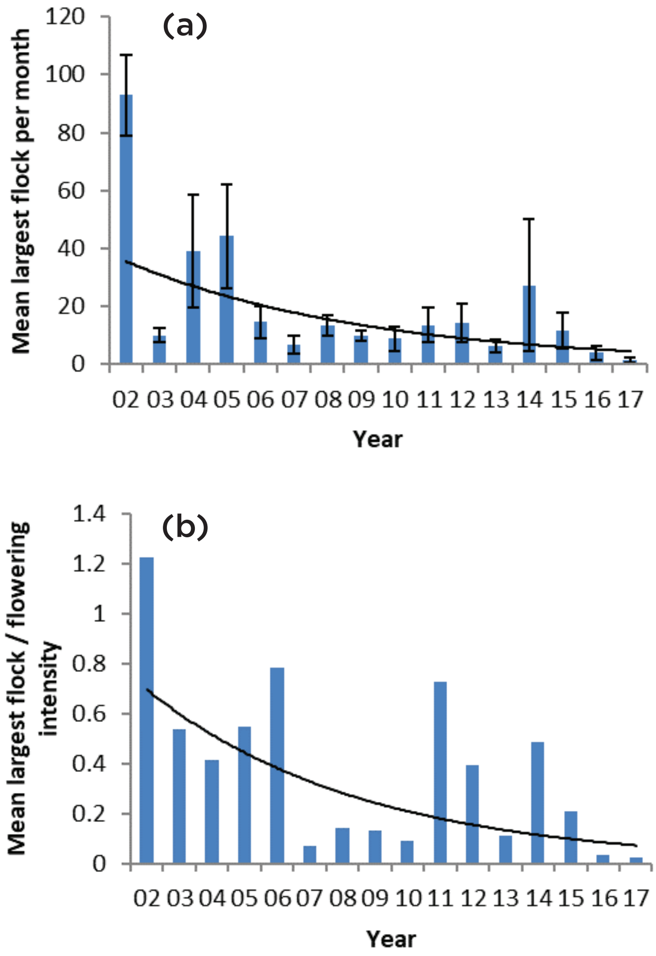

Figure 5. The mean size of the largest flocks of Swift Parrots observed in each of the 4 months of the breeding season (September–December) from 2002 to 2017 at Mount Nelson: (a) raw means ± standard error; (b) raw means divided by the concomitant summed flowering intensity of Tasmanian Blue Gum and Swamp Gum. The lines of best fit for regressions are: (a) $y = 40.78 \times 0.87^x$, (b) $y = 0.81 \times 0.86^x$.

breeding season ($r^2 = 0.45$, $P = 0.0047$) that was equivalent to an 87.3% decline over 15 years (Figure 5a). Although this regression was heavily influenced by the particularly large flocks in 2002 (Figure 5a), this relationship remained significant from 2003 to 2017 (78.6% exponential decline, $r^2 = 0.33$, $P = 0.024$). Significant exponential declines were also apparent after dividing mean largest flock sizes by the summed local flowering intensities of Tasmanian Blue Gum and Swamp Gum from 2002 to 2017 (decline = 89.5%; $r^2 = 0.39$, $P = 0.0098$: Figure 5b) and from 2003 to 2017 (decline = 84.7%; $r^2 = 0.30$, $P = 0.034$). In contrast, across the 16 breeding seasons the better fitting model between mean largest flock and the sum of the flowering intensities of the two eucalypts was not significant (linear, $r^2 = 0.020$, $P = 0.61$).

The average flock sizes of Swift Parrots during the breeding season were also more strongly related to sequential year of survey than to concomitant eucalypt flowering intensity. The grand mean of the size of all flocks observed in each of the 4 months of the breeding season showed no evidence of a relationship with the sum of the flowering intensities for Swamp Gum and Tasmanian Blue Gum (linear, $r^2 = 0.0076$, $P = 0.75$). In contrast, there was a significant negative exponential relationship between sequential year of survey and the grand mean of the size of all flocks observed in each of the 4 months of the breeding season (decline = 65.5%, $r^2 = 0.34$, $P = 0.018$), although this was heavily influenced by the particularly large flocks in 2002 (Figure 6a). However, when data for 2002 were removed, this relationship still approached significance (decline = 43.4%, $r^2 = 0.20$, $P = 0.097$). When this measure of Parrot abundance was divided by the summed flowering intensities of the two eucalypts in that spring, the exponential declines approached significance over the breeding seasons from 2002 to 2017 (decline = 71.3%, $r^2 = 0.23$, $P = 0.062$: Figure 6b) but were not significant across 2003–2017 (decline = 59.4%, $r^2 = 0.13$, $P = 0.18$).

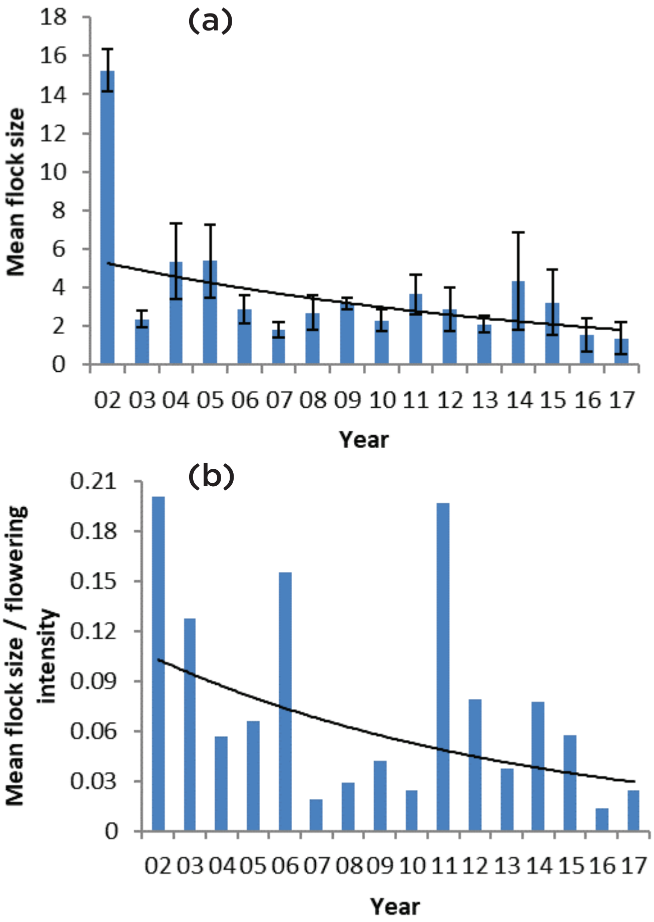

Figure 6. The grand mean of the size of all flocks of Swift Parrots observed in each of the 4 months of the breeding season (September–December) from 2002 to 2017 at Mount Nelson: (a) raw grand means ± standard error, (b) raw grand means divided by the concomitant summed flowering intensities of Tasmanian Blue Gum and Swamp Gum. The lines of best fit for regressions are shown: (a) $y = 5.64 \times 0.93^x$, (b) $y = 0.11 \times 0.92^x$.

Breeding

Evidence of Swift Parrots breeding was observed, but fledglings rarely accounted for >10% of observations in any month (Table 2). Pairs of Parrots were seen copulating on 23 October 2006, 5 November 2008, and 9 October 2015, and two adults were seen engaging in stomodeal trophallaxis on 28 November 2010. Fledglings were observed during only eight of the 16 years, and none were encountered in the years when copulation was observed (Table 2). The very high proportion of Parrots that were fledglings in February following the 2016 breeding season

Table 2. Numbers of observations of Swift Parrot fledglings (with the largest number of fledglings observed at any one time in parentheses) and the percentages of all Swift Parrot observations that were of fledglings, per month, across 16 years at Mount Nelson. No fledglings were observed in months outside November–February.

Year	*Nov.*	*Dec.*	*Jan.*	*Feb.*
2002–2003		2 (1), 0.12%		
2003–2004			2 (1), 20.0%	
2004–2005	4 (1), 1.11%	11 (4), 9.09%	32 (2), 16.4%	27 (3), 14.2%
2005–2006		2 (1), 4.08%	1 (1), 5.0%	
2006–2007				
2007–2008				
2008–2009				
2009–2010			3 (1), 5.9%	
2010–2011			7 (2), 1.2%	
2011–2012				
2012–2013				
2013–2014			8 (3), 6.1%	
2014–2015				
2015–2016				
2016–2017				5 (2), 83.3%
2017–2018				

Table 3. Dates and locations of Swift Parrots that were unable to fly, mostly as a consequence of collisions with man-made structures. Details of chain-link fences are given in Table 4.

Date	*Observation*	*Location*
13 Sep. 2002	Carcass	Beside chain-link fence A
15 Sep. 2002	Pile of feathers, including flight-feathers	Beside chain-link fence A
17 Sep. 2002	Carcass	Beside chain-link fence B
28 Sep. 2002	Carcass	Beside chain-link fence B
11 Oct. 2002	Live bird picked up and carried away by a Forest Raven *Corvus tasmanicus*	Beside chain-link fence B
23 Nov. 2002	Carcass	Beside chain-link fence B
29 Nov. 2002	Bird on ground at 2000 h flew into a tree and perched 6 m high. Still there 0900 h next day but had disappeared by 1100 h.	Beside chain-link fence B
16 Dec. 2002	Carcass	Beside chain-link fence C
16 Dec. 2002	Bird perched 0.5 m high near carcass at 1030 h. Still there at 1200 h, but had disappeared by 1400 h.	Beside chain-link fence C
19 Dec. 2002	Two piles of feathers	Beside chain-link fence B
28 Dec. 2002	Carcass	Below window
29 Dec. 2002	Pile of feathers	Beside chain-link fence B
30 Dec. 2002	One fledgling on ground, too weak to fly or perch. Taken into care.	Mount Nelson Primary School
7 Feb. 2005	Fledgling on ground with feathers missing from top of its head. Placed on branch of nearby tree at 0830 h. Still there at 2000 h. Taken into care.	Beside chain-link fence B
11 Oct. 2005	Bird on ground. Taken into care.	Below window
c. 1 Mar. 2010	Carcass (J. de Jonge pers. comm.)	Below window
10 Sep. 2011	Pile of feathers, including flight-feathers (T. Hingston pers. comm.)	Below window
18 Sep. 2011	Pile of feathers, including flight-feathers	Below window
14 Oct. 2011	Two birds on ground. Taken to vet and then released (T. Hingston pers. comm.)	Beside chain-link fence B
12 Jan. 2014	Carcass	Below window

was almost certainly the result of an influx of birds that had not bred at Mount Nelson because no Swift Parrots had been observed within the study site for almost 3 months before that.

Collisions

There were many observations of Swift Parrots colliding with chain-link fences or windows, often with fatal consequences (Table 3). Of the probable 21 collisions with man-made structures, 13 occurred between September and December 2002 (Table 3). This represents 11.1% of the up to 117 birds inhabiting the study site in 2002. All but one of these 13 collisions involved chain-link fences around tennis courts (fences A and B) or a soccer field (fence C). However, I did not observe any Swift Parrot collisions with chain-link fence D around a netball court that was 10 m from the tennis court where most collisions were observed (fence B), despite both fences being approximately the same length (Table 4). I cannot say whether there was something about the location or alignment of fence D that prevented Parrots from striking it. However, fence D differed from fences A, B, and C in having a green PVC coating over the wire that resulted in its being significantly thicker than the uncoated wire on the other fences (P <0.0001 for

Table 4. Specifications of chain-link fences, and the number of Swift Parrot collisions observed with each fence (A = Hobart College tennis court, B = Primary School tennis court, C = Primary School soccer field, D = Primary School netball court). Aperture (internal and parallel to wire) and gauge (means ± standard error) were each determined from 10 measurements. Significant differences between fences for aperture and gauge, as determined by *post-hoc* two-tailed *t*-tests with Bonferroni corrections ($P < 0.0083$) following 1-way ANOVA, are designated with different superscript letters within each of the relevant columns, i.e. values within columns with the same superscript letter are not significantly different whereas those with different superscript letters are significantly different.

Fence	*Length (m)*	*Height (m)*	*Aperture (cm)*	*Gauge (mm)*	*No. collisions*
A	216.4	3.3	5.31 ± 0.02^{a}	2.51 ± 0.01^{a}	2
B	104.3	3.8	5.31 ± 0.02^{a}	2.71 ± 0.03^{b}	11
C	136.9	1.7	5.17 ± 0.02^{b}	3.30 ± 0.02^{c}	2
D	110.2	2.3	5.09 ± 0.02^{c}	4.30 ± 0.04^{d}	0

Figure 7. The Mount Nelson Primary School tennis court (fence B) in (a) March 2003 and (b) December 2018. Photos: (a) Pakinee Hingston, (b) Andrew B. Hingston

all pairwise comparisons; Table 4), and the aperture width significantly smaller than on the other fences (P <0.001 for all pairwise comparisons; Table 4). Fence D was also 1.5 m lower than fence B (Table 4), and this factor might have also contributed to Parrots not colliding with fence D. However, two Swift Parrots collided with fence C nearby which was 0.6 m lower than fence D (Table 4), indicating that fence D was not too low for the Parrots to strike.

As many as eight Swift Parrots collided with fence B (Figure 7), around the Mount Nelson Primary School tennis court, between September and December 2002 (Table 3). Remedial action was attempted on 23 December 2002 in the form of tying streamers in the fence (Figure 7a), but this did not prevent another collision occurring the following week (Table 3). Bushes were also planted alongside the fence, and these have now grown thickly to the height of the fence to force most Parrots to fly above the fence (Figure 7b). Fewer collisions with this fence were observed in subsequent years, none of which were fatal (Table 3).

Discussion

Eighty percent of observations of Swift Parrots at Mount Nelson were made during the breeding season (September–December: Gartrell 2002a,b; Webb *et al.* 2012), with post-breeding observations occurring more irregularly. The major food sources used during the breeding season were flowers of Swamp Gum and Tasmanian Blue Gum. Hence, assessments of changes in the abundance of the Parrots through the study period were based on those observed during the breeding season, and were adjusted to take account of the variation in local flowering intensities of both of these eucalypts.

Although Swift Parrots were observed in every breeding season from 2002 to 2017, there were general declines over the years in the mean size of the largest flock, and grand mean size of all flocks, observed per month. These decreases were apparent for the raw data, and also when adjusted to take account of concomitant local flowering intensity of Swamp Gum and Tasmanian Blue Gum. Both of these measures of abundance fell over the 16 breeding seasons by an amount approximating that predicted for similar numbers of years for the entire wild population based on known rates of nest-depredation by Sugar Gliders (Heinsohn *et al.* 2015). Thus, this study provides the first field-based data in support of the predictions of a plummeting population size (Heinsohn *et al.* 2015; Geyle *et al.* 2018). The low numbers of fledglings observed were also consistent with high rates of predation by Sugar Gliders (Stojanovic *et al.* 2014, 2017; Heinsohn *et al.* 2015), and the frequent collisions with man-made structures clearly add an additional source of mortality that is capable of exacerbating population decline. In addition to predation and collisions, ongoing loss of both nesting and foraging habitat through industrial forestry, harvesting of firewood, and inappropriate fire regimes, as well as agricultural, residential and other developments, is thought to adversely affect the Parrot (Hingston & Piech 2011a; Saunders & Tzaros 2011; Allchin *et al.* 2013; Saunders & Russell 2016; Stojanovic *et al.* 2016; Webb *et al.* 2019). Indeed, there is evidence that habitat loss is exacerbating the problem of predation by Sugar Gliders (Stojanovic *et al.* 2014).

Seasonal activity patterns

Swift Parrots were observed at Mount Nelson in all 16 years and all 12 months, but not all months in all years of this study. They consistently arrived at the study site in late winter or early spring, and in most years they were most abundant during the breeding season. The date on which they were last observed each year varied greatly, and in winter 2010 three birds did not leave, in accordance with their nomadic post-breeding foraging patterns (Brown 1989; Brereton 1996a). Swift Parrots also over-wintered around Hobart in 1985 and 1986 (Brown 1989), indicating that the species does not have an obligate annual migration from Tasmania to the Australian mainland. There were no long-term trends in the dates when numbers of the Parrots reached their peak for a year or when they were first or last detected. Together with the absence of long-term trends in the mean date of 13 August for the first detection each year in Hobart from 1974 to 2002 (Beaumont *et al.* 2006), the lack of long-term trends in the mean date of 10 August for the first observation during this study suggests that this variable is not undergoing any directional change. However, because the spatial distribution of the Parrots varies among years, and I sampled only a fraction of their potential range, it is possible that the absence of long-term changes in seasonal activity patterns at my study site were not reflective of other parts of Tasmania (Saunders & Russell 2016).

Foraging activities

Almost all observations of Swift Parrot foraging were from three species of trees—Swamp, Tasmanian Blue and Manna Gums. Flowers of the former two species comprised 89.1% of all foraging, and gleaning leaves of Manna Gum made up 4.7%. Other studies also found that the Parrot forages primarily from flowers of Tasmanian Blue Gum and Swamp Gum during the breeding season, supplemented with occasional gleaning of leaves of eucalypts (Brown 1989; Brereton 1996a). Because insect remains have regularly been found within the alimentary tracts of Swift Parrots, foraging from flowers might have included some insectivory as well as foraging for nectar and pollen (Gartrell *et al.* 2000).

Opportunities to forage from the flowers of one or both of Tasmanian Blue Gum and Swamp Gum existed in all 16 breeding seasons, with neither eucalypt species showing a directional change in flowering intensity across the years. Although the flowering intensities of both species varied among years, in accordance with other studies (Brown 1989; Brereton 1996a; Webb *et al.* 2014, 2017), these variations were independent of each other, resulting in one species flowering whenever the other failed to do so. Across this variation in flowering of the two eucalypts, Swift Parrots largely followed an ideal free distribution rather than favouring one species over the other. This is not expected based on the amounts of nectar produced per flower per day in these species, because that of Tasmanian Blue Gum is more than ten times as great as in Swamp Gum (Hingston & Wotherspoon 2017). However, there are other factors that contribute to foraging choices, such as nectar consumption and aggression from other species as well as the numbers and sizes of trees of the two species. Pollen availability may also influence foraging choices because Swift Parrots actively forage for eucalypt pollen (Gartrell *et al.* 2000; Hingston *et al.* 2004), ~40% of which is emptied of its protoplasm along the alimentary tract (Gartrell & Jones 2001).

Numbers of Swift Parrots observed in each breeding season

Swift Parrots were observed at Mount Nelson during all breeding seasons from 2002 to 2017, but the numbers of observations declined across this period consistent with predictions of a receding total population size (Heinsohn *et al.* 2015; Geyle *et al.* 2018). Over the 16 breeding seasons, the mean size of the largest flock, and grand mean size of all flocks, fell by rates similar to the predicted decrease in total population size of 78.8–94.7% over 12–18 years obtained from models based on known rates of nest-depredation by Sugar Gliders (Heinsohn *et al.* 2015). Hence, the observations of fewer Parrots over the course of this study may be indicative of a reduction in the total population in the wild.

There are, however, other factors that may explain the dwindling numbers of observations during this study. One such possible cause of decline is decreasing local habitat quality. Around 30% of the large Tasmanian Blue Gums and Swamp Gums in the suburb of Mount Nelson were removed during the first half of this study (Hingston & Piech 2011a), and it is these trees that flower more prolifically than those in the surrounding bushland (Hingston & Piech 2011b). In addition, Musk Lorikeets *Glossopsitta concinna,* Rainbow Lorikeets, and hybrids between these two species, along with Little Wattlebirds *Anthochaera chrysoptera,* have become more common at the study site over the past 20 years (Hird 1998; Hingston 2019; ABH pers. obs.), which might have increased competition for food with Swift Parrots. However, falling numbers of Swift Parrots at the study site cannot be attributed to decreasing local flowering intensity of Tasmanian Blue Gums and Swamp Gums, which showed no directional change over the years, and because adjusting measures of abundance of Swift Parrots according to flowering intensity had little effect on the magnitude of the calculated declines in abundance. Nor can the decrease be attributed to changes in the seasonal activity patterns of Swift Parrots at the site, as dates of observing the largest flock, and of the first and last observations each year, showed no directional change over the study. However, in the absence of relevant data, it is possible that the dates of peak flowering might have changed over the course of the study because of climate change, reducing overlap with the seasonal activity patterns of Swift Parrots (Porfirio *et al.* 2016).

Alternatively, Swift Parrots might have become less common at Mount Nelson because of increasing habitat quality elsewhere within their breeding range. The numbers of Parrots observed at Mount Nelson each breeding season would be influenced by flowering intensity at other locations, because the Parrots select areas with the greatest flowering from across the entire potential breeding range (Webb *et al.* 2012, 2014, 2017; Stojanovic *et al.* 2014, 2015, 2019; Heinsohn *et al.* 2015). Thus, a general increase in flowering intensities across other parts of the ranges of these two tree species could have caused the Parrots to abandon Mount Nelson to breed elsewhere. However, the extent of destruction of breeding habitat across other parts of Tasmania over the course of this study (Saunders & Tzaros 2011; Allchin *et al.* 2013; Stojanovic *et al.* 2016; Webb *et al.* 2019) lowers the likelihood of this occurring. For example, 33% of the Southern Forests Swift Parrot Important Breeding Area, 25–75 km south-west of Hobart, was logged between 1997 and 2016 (Webb *et al.* 2019). It is possible that changes in flowering intensities elsewhere negated the observed decline in numbers at Mount Nelson, because this decrease might have been more pronounced if it were not for the large numbers of birds present in 2014. That season was one of generally poor flowering across the breeding range, causing Swift Parrots to congregate in unusually high numbers where flowering occurred (Webb *et al.* 2017) such as at Mount Nelson. A long-term study of the population size from across the entire breeding range, or at least several more long-term studies from other locations where Tasmanian Blue and Swamp Gums both occur, may be needed to clarify this issue.

The dwindling numbers of observations through the course of this study could also have occurred because I might have spent less time at the study site following an increase in work commitments that often took me elsewhere for several days at a time from spring 2008 onwards. Such an explanation could account for the declining size in the largest flocks seen because of decreasing probability of my being at the study site when birds congregated in large flocks. However, this is unlikely to account for the observed significant decrease in mean flock size, as such data should be independent of observer effort. Such an explanation is also inconsistent with observations of large flocks of Swift Parrots at the study site in 2014 and increasing numbers of lorikeets and Little Wattlebirds over the course of the survey period (Hird 1998; Hingston 2019; ABH pers. obs.).

Another possible explanation is that much of this decline was driven statistically by the particularly large numbers of Swift Parrots in the first year of the study (2002). However, the mean size of the largest flock per month continued to fall significantly from 2003 to 2017, while the decline in mean flock size also approached significance. Furthermore, there are several lines of evidence suggesting that the large numbers of the Parrots observed in 2002 were probably not exceptional relative to the two previous decades. Firstly, the eight collisions of Swift Parrots with fence B in the 2002 breeding season were not unprecedented, as this number occurred in some years during the 1980s (Brown 1989), and five birds died in this way in 1 day in 1998 (Pfennigwerth 2008). In addition, in spring 1997, an estimated 488 Swift Parrots inhabited the Hobart area (Swift Parrot Recovery Team 2001). Swift Parrots were also common at Mount Nelson in 1999, when they accounted for 23–87% of the total foraging time spent by flower-feeding birds on five out of 10 Tasmanian Blue Gums (Hingston 2002) and were frequently captured in mist-nets in another study (Gartrell 2002a).

Breeding

Few fledgling Swift Parrots were observed during this study, suggesting little reproductive success in the area. Fledglings were observed in only half of the 16 years, and in one of those years (2016) these appeared to be birds that had fledged elsewhere and subsequently travelled to Mount Nelson. In that year, large numbers of the Swift Parrots nested on North Bruny Island (Stojanovic *et al.* 2019) 25 km south of Mount Nelson where, in the absence of predation by Sugar Gliders (Stojanovic *et al.* 2014, 2017; Heinsohn *et al.* 2015), many chicks fledged (Stojanovic *et al.* 2019; ABH pers. obs.). Although it is not known how many of the birds observed at Mount Nelson during the breeding seasons attempted to breed, in 3 years a pair was observed mating but no fledglings were subsequently encountered. The apparently low reproductive success at Mount Nelson could be attributed to predation by Sugar Gliders (Stojanovic *et al.* 2014, 2017; Heinsohn *et al.* 2015), which occur in the study area (Campbell *et al.* 2018; ABH pers. obs.), compounded by aggressive neglect from paired male Swift Parrots that attempt to defend their mates from unpaired male interlopers in the male-biased population (Heinsohn *et al.* 2019), death of breeding adults as a result of collisions with fences and windows (Pfennigwerth 2008), and possibly food shortages as a consequence of most nectar being consumed by introduced social bees (Honey Bees *Apis mellifera* and Bumble Bees *Bombus terrestris*: Hingston & Wotherspoon 2017). These latter two factors were both observed at the study site in 2002 (Hingston & Wotherspoon 2017; this study) and might have contributed to the particularly low reproductive output in that year when only two observations of fledglings were made (one of which was of a fledgling too weak to perch), despite flocks of up to 110, 55, 117, and 90 birds being seen in each of the months during the breeding season.

Collisions

Many Swift Parrots collided with chain-link fences and windows, as reported previously for these and other locations (Brown 1989; Gartrell 2002a,b; Pfennigwerth 2008). Over 10% of the Parrots inhabiting Mount Nelson during the 2002 breeding season were involved in such collisions. Because it was not possible to monitor all of these fences and windows continuously, and many other fences and windows at Mount Nelson were not monitored, it is highly likely that the number of Parrots involved in collisions was even higher. The frequency with which the Parrot forages in hazardous urban environments such as this is likely to be increased by loss of habitat through removal of mature trees (Allchin *et al.* 2013; Webb *et al.* 2019) and loss of food resources through competition (Hingston & Wotherspoon 2017) in non-urban environments, as well as the more prolific flowering of Swamp Gum and Tasmanian Blue Gum in urban areas than in peri-urban bushland (Hingston & Piech 2011b).

The greatest number of the documented collisions was with chain-link fence B around the Mount Nelson Primary School tennis court, a structure that has taken many Swift Parrot lives previously (Brown 1989; Pfennigwerth 2008). Following previous observations of Parrots being killed by this fence, the wire was covered with shade cloth which was not completely successful (Brown 1989). The shade cloth was no longer present at the start of this study in 2002, when at least eight collisions occurred. Fewer collisions have been observed since 2002, and none of these have been fatal, although how much of this change is because of hanging streamers in the fence and planting bushes beside the fence, and how much is a reflection of fewer Swift Parrots being present in the area, is open to conjecture.

No Swift Parrot collisions were observed with another chain-link fence made of wire coated in green PVC that resulted in the wire being 60% thicker and, hence, potentially more visible to the Parrots than fences with which they collided. However, Pfennigwerth (2008) stated that such coatings of green or black do not increase the visibility of fences to Swift Parrots. Coatings of yellow, blue or purple PVC are thought to be more effective at increasing visibility (Pfennigwerth 2008).

Conclusions

This study found rapid rates of decline in the abundance of Swift Parrots at the local scale, consistent with predictions obtained from modelling of the entire population based on known rates of nest-depredation by feral Sugar Gliders (Heinsohn *et al.* 2015). Hence, this study provides the first measurements of abundance to support the notion that the population size of the Swift Parrot is plummeting (Heinsohn *et al.* 2015) and that the species is at risk of extinction (Geyle *et al.* 2018). Thus, it seems prudent to allocate resources in an attempt to arrest its decline before it reaches the extremely challenging situation facing attempts to recover Tasmania's other Critically Endangered migratory parrot, the Orange-bellied Parrot *Neophema chrysogaster* (Stojanovic *et al.* 2018b).

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