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Singing behaviour of male Rufous Scrub-birds in the New South Wales Gloucester Tops

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Monitoring programs for the endangered, cryptic Rufous Scrub-bird, *Atrichornis rufescens* are mainly based upon detecting singing males on their territories, but a problem with this approach is that little is known about singing activity variation during the year and therefore which are the optimal months for monitoring. We attempted to rectify this deficiency by documenting the year-round singing activity of five males (subspecies *ferrieri*) on well-separated territories in the same general area of the New South Wales Gloucester Tops from 2015-2019 using an automated recording unit. We analysed temporal variability in the number of characteristic territorial chipping songs of males. Parameters assessed were the number of songs emitted per day, the percentage of 20-minute periods per day in which singing occurred and the median number of songs per 20-minute period in which singing occurred, the last two being daylength-independent. Results for all parameters showed that males sang frequently from mid-September to December, with song levels dropping sharply in January and then further in February. Daily singing activity varied considerably from February to August, but was mostly much lower than in other months. Our study thus indicated that for maximum efficacy Rufous Scrub-bird population monitoring programs in the Gloucester Tops should be conducted between mid-September and December, the only period when scrub-birds sing consistently and can thus reliably be detected.

Key words: Rufous scrub-bird; chipping song; singing activity; automatic recording unit; implications for population monitoring.

INTRODUCTION

The Rufous Scrub-bird *Atrichornis rufescens* (RSB) occurs in five isolated remnant populations in New South Wales and southern Queensland (Newman *et al.* 2014). It is classified as Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and on the IUCN Red List, and as Vulnerable under the New South Wales *Biodiversity Conservation Act 2017*. The populations of both the northern (*A. r. rufescens*) and southern (*A. r. ferrieri*) subspecies are suspected to be in decline (Garnett *et al*. 2011) and there are ongoing monitoring programs for all sub-populations (Andren 2016; Stuart and O'Leary 2019).

As it is difficult to see scrub-birds, which mostly forage within and below the dense, ground level vegetation in their territories (Ferrier 1984), monitoring programs involve listening for singing males (e.g. Stuart and Newman 2018). Females make a soft call which can only be heard if the listener is very close (Ferrier 1984), but male vocalisations are often loud. Males produce a variety of calls, including mimicry (Gole and Newman 2010), but their most distinctive vocalisation is the territorial "chipping" song, comprising a series of single syllable notes delivered in rapid succession (Stuart and O'Leary 2019). The number of syllables uttered per song is variable and a bird will often cycle through a singing bout in which syllable number per song increases and decreases. In monitoring programs using teams of volunteers, only instances of the territorial chipping song are accepted as confirmed records of the species' presence (Newman *et al*. 2014; Stuart and Newman 2018) because inexperienced surveyors sometimes struggle to differentiate the other scrub-bird calls from the calls of other co-habiting bird species.

The design of effective monitoring programs for RSBs requires an understanding of how often the birds utter their chipping song and whether and how this varies throughout the year, information that is not currently available. To provide an analytical tool which would help to generate such an understanding, we developed a method involving automated recording and semi-automated data analysis that proved useful in studying the singing behaviour of a male RSB (Stuart and O'Leary 2019). In that initial study, we showed that ~97% of all instances of the bird making its characteristic chipping song could be detected by an automated scan, with some false-positive results which could easily be eliminated manually (Stuart and O'Leary 2019).

The focus of the present study was to use this analytical tool to investigate daily and seasonal variability in chipping song production by male RSBs in their territories in the Gloucester Tops. The resulting information should assist the design of future RSB monitoring programs.

METHODS

Data collection

All recordings were made at known RSB territories in the Gloucester Tops, New South Wales (Stuart 2020; Stuart and Newman 2018). After a preliminary investigation at each

territory to determine the approximate boundaries of the male's singing area, we placed an automated recording unit (ARU) in the approximate middle of that area. Rufous Scrub-bird singing areas cover about 1-1.5 ha (Stuart 2018) and thus the ARU was almost always within ~60 m of the singing bird. Most recordings were made using Wildlife Acoustics Inc. Song Meter™ model SM3 units; a small percentage of them used an SM4 recorder. Both units incorporate two omnidirectional microphones.

We selected five territories for the study, all conveniently accessed by foot from the nearest road. The exact locations of the territories are confidential, but all were within a study area of approximately 5 km radius, centred at 32º04'S 151º34'E. They were well-separated, the shortest distance between any two territories being ~1 km. However, we could not determine if it was the same scrub-bird at each singing area throughout our study, so the findings represent the behaviour of at least five, but possibly more, males.

Data collection occurred from January 2015 to March 2019. On numerous occasions within that period, we placed an ARU in one territory ("Territory 1") and the same or a second ARU in either Territory 2 or Territory 3. The Territory 2 male disappeared after February 2017 (although we left the ARU in its singing area for several months to confirm the bird's absence), so from September 2017 we recorded at Territory 3 instead. From October 2018, use of an additional ARU allowed data collection at three territories simultaneously i.e. at Territories 1 and 3, and at either Territory 4 or Territory 5.

Each of the ARUs was programmed to record daily from 30 minutes before dawn until 30 minutes after dusk, providing there was sufficient battery power. Typically, we obtained 6-8 full days of recordings from each ARU deployment before battery failure. We placed each ARU ~0.3 m above the ground, sampling frequency was 24000 Hertz and the typical gain was 16 deciBels.

Data analysis

We recorded data onto SD cards and later transferred them to a computer for analysis with Raven Pro 1.5 software, using the conditions developed for rapid, semi-automated analysis of recordings of the RSB's chipping song by Stuart and O'Leary (2019). We analysed the recordings in 20-minute periods, choosing this duration because when walking at a rate of 1 km/h through a RSB territory (which is the recommended survey method e.g. see Newman *et al.* 2014), a surveyor has an approximate 20-minute window of opportunity to hear a scrub-bird, given that calls can be heard from 150 m away under favourable conditions (Ferrier 1984).

To address potential complications arising from rainfall effects on scrub-bird song output, we obtained precipitation data for the Careys Peak weather station, which is located at 1,430 m altitude in the Gloucester Tops 10-15 km from the RSB territories we investigated, which were all at altitudes of ~ 1,200-1,300 m. We used these data to exclude from further analysis any recordings from days when >2 mm of rain fell. Our preliminary study showed that light rainfall did not affect singing behaviour, but heavier falls did (Stuart and O'Leary 2019).

We only analysed recordings for which there was a full day of data. We logged each instance of the chipping song as a single singing event, regardless of how many syllables it contained. After scanning the recordings and eliminating false-positives, we noted the daily total number of singing events. This is the simplest way to evaluate a RSB's singing performance, but of course the number of daylight hours varies during the year. In summer in the Gloucester Tops there are ~40% more hours of daylight than in winter. Therefore, using the number of singing events made in every 20-minute period of recording, we also assessed daily singing performance using two daylength-independent parameters, the percentage of daily 20-minute periods that were active (i.e. in which singing occurred) and the median daily number of songs per active 20-minute period. We calculated the mean, standard error and 95% and 99% confidence intervals for each data set. Our comparisons among data sets were based upon whether the confidence intervals did/did not overlap.

In the text, we often report median values of the parameters measured, but we determined the significance of disparities in singing between various pairs of time periods using two-tailed independent *t* tests of the differences in means (assuming unequal variances and $\alpha = 0.05$). Percentages were not transformed for analysis.

RESULTS

Scope of recordings

Although the ARUs commenced recording from 30 minutes before dawn, no chipping songs were detected before dawn. Occasionally a scrub-bird called at dusk, but we never detected any chipping songs any later than that hour. Recordings were made in from 2-5 years among the various territories (Table 1a).

Table 1

a) Rufous Scrub-bird recordings used in this study and **b)** the number of full-day recordings made in each month on five male Rufous Scrub-bird territories during 2015-2019.

a)

Territory	1	2	3	4	5
Recording period (years)	2015-19	2015-17	2017-19	2018-19	2018-19
No. of days with recordings	191	49	122	28	42

b)

Month	No. of days	No. of territories
January	23	3
February	40	3
March	42	3
April	39	4
May	36	4
June	14	2
July	21	3
August	27	2
September	77	3
October	23	3
November	45	4
December	45	3

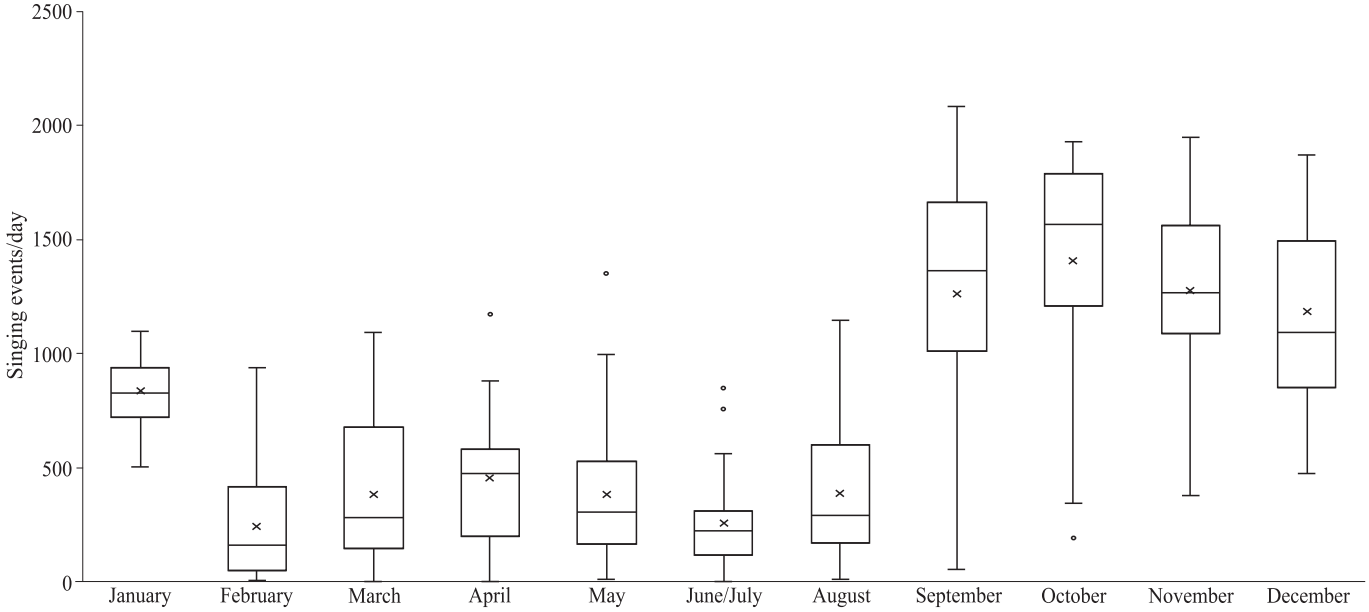

Figure 1. *Monthly summary of the combined number of chipping song events per day emitted by five male scrub-birds. June/July data combined to give a more robust winter sample. The medians are represented as horizontal lines between the interquartile ranges (boxes) and 1.5 x interquartile ranges by whiskers. Means are shown by the symbol* x *and outlier values are presented individually. This presentation protocol also applies to Figures 2 and 3.*

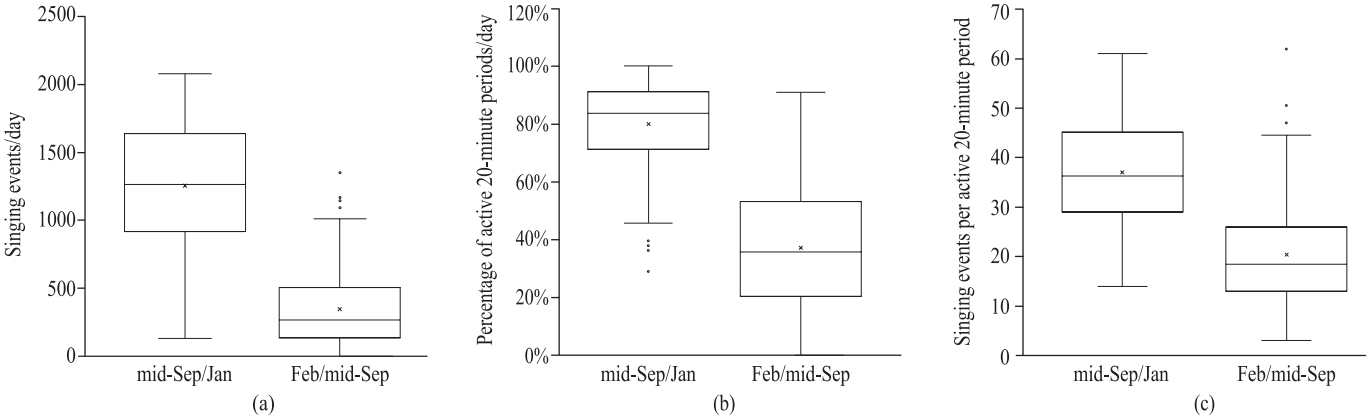

Figure 2. *Seasonal comparison of the combined singing activity of five male Rufous Scrub-birds on their territories: (a) the number of chipping song events per day; (b) the percentage of active (i.e. song containing) 20-minute periods per day; (c) the median number of singing events per active 20-minute period per day.*

For the five territories combined, there were 432 days with a full day of recordings; 44% of those days involved recordings at Territory 1 and 28% were at Territory 3 (Table 1a). There were 77 days of recordings in September (including 43 days at Territory 1), but only 14 full days for June. All other months had at least 20 full days of recordings and many had 35-45 days (Table 1b).

Seasonal variation in daily song output for all males combined

Ignoring the differences in day length, for September to December the median number of singing events per day for all five territories combined was 1,100-1,600, whereas for February to August monthly medians were all below 500 events per day, and usually well below that level (Fig. 1). Close inspection of the September data revealed that several of the days with low numbers of singing events were recorded from Territory 1 in early September (2-8 September 2017); on average, this bird only sang 167 times per day in those eight days (maximum = 350 chipping songs on 4 September 2017). The September data for all males combined showed that singing activity increased noticeably from around the middle of the month. The mean for mid-September to January (1,219 singing events per day, n = 213 days of data) was greater than that for February to mid-September (351 singing events per day, n = 219 days of data) ($t_{349} = 23.475$, $P < 0.001$) (Fig. 2a).

Variation in daily singing activity determined from day length-independent parameters

Analysis of singing performance on a monthly basis for all males combined using the two daylight-independent parameters (percentage of 20-minute periods per day in which the bird was singing and median number of singing events per active 20-minute period each day) indicated that the general seasonal

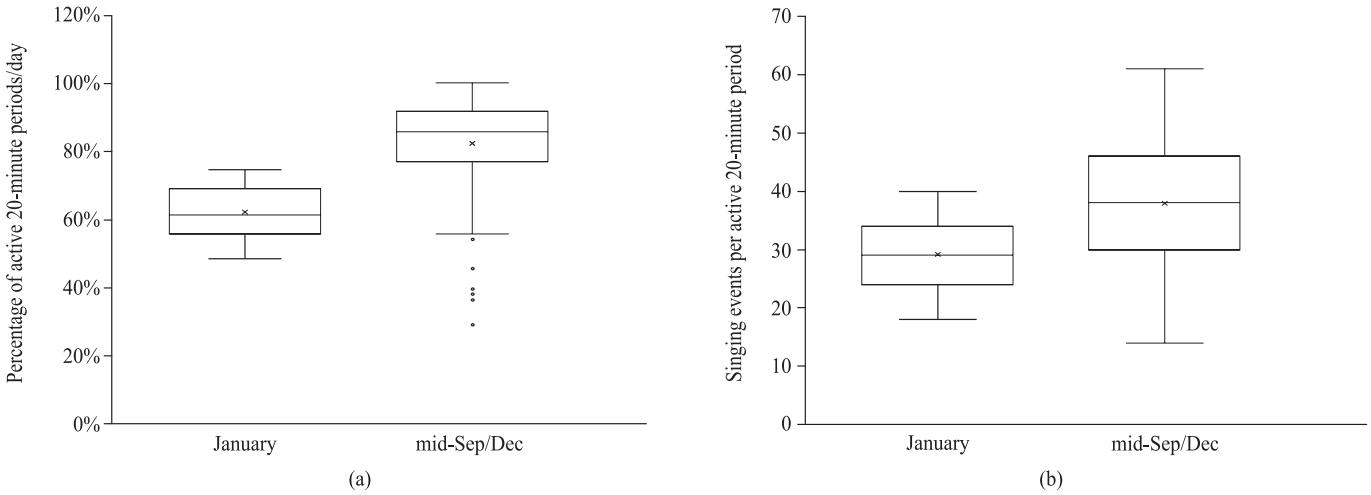

Figure 3. *Comparison of Rufous Scrub-bird singing activity for January and the period mid-September to December: a) percentage of active (i.e. with singing) 20-minute periods per day, and b) median number of singing events per active 20-minute period per day.*

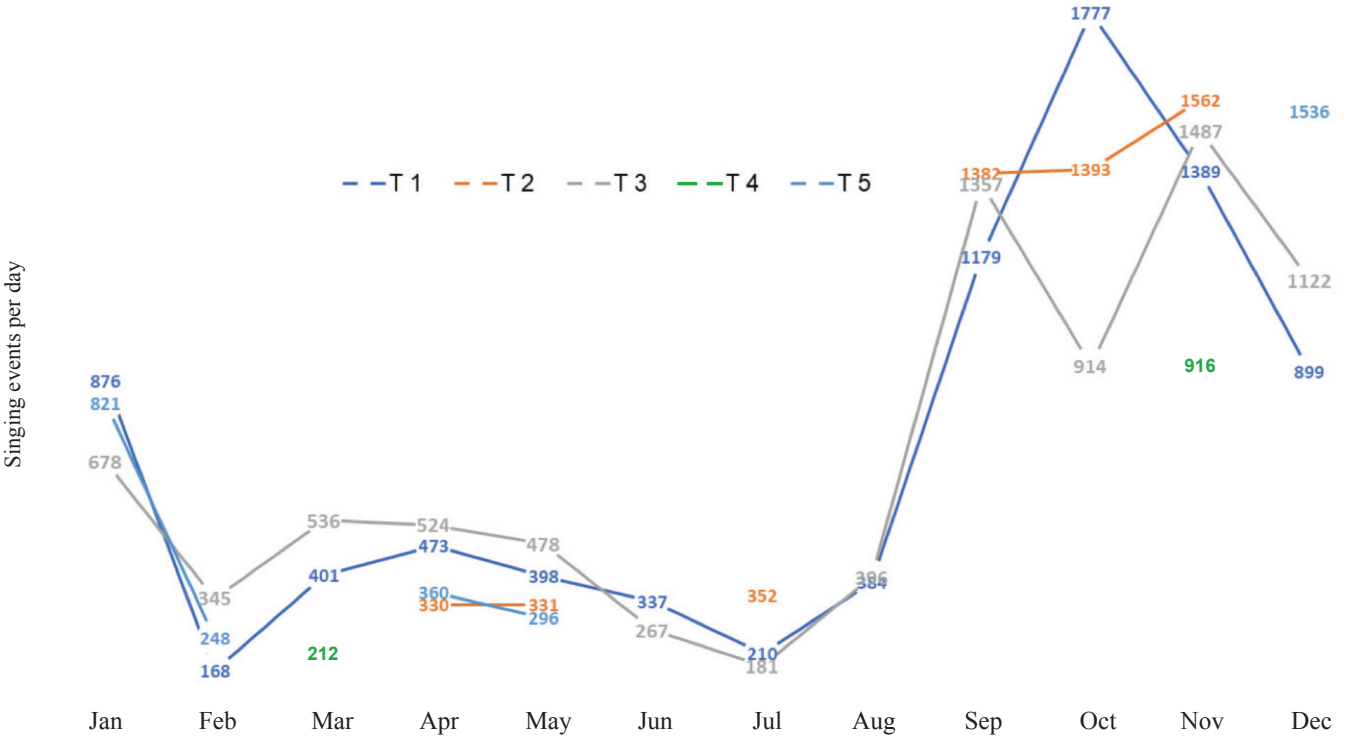

Figure 4. *Comparison of Rufous Scrub-bird singing activity (average number of territorial singing events per day) at five male territories (T1 to T5) in the Gloucester Tops. The numbers shown are the median number of songs recorded on a territory per day in that month. Territories 2, 4 and 5 did not have data for every month.*

pattern was similar to that for total song output per day described above. The mean percentage of active 20-minute periods per day from mid-September to January (79%, n = 213 days) was greater than that for February to mid-September (37%, n = 219 days) (t_{403} = 22.391, P<0.001) (Fig. 2b). For the same two time periods, the mean numbers of singing events per active 20-minute period per day were 36 (n = 213 days) and 21 (n = 216 days), respectively (t_{420} = 14.486, P<0.001) (Fig. 2c).

We did not formally analyse how scrub-bird singing performance varied diurnally. However, from inspection of daily recordings there did not appear to be any clear pattern. On days when a scrub-bird sang often, there were occasional but apparently random intervals with no singing. On days when a scrub-bird sang infrequently, it seemed to be about as likely to sing in the middle of the day as to sing in the early morning or late afternoon.

Singing activity in January

The pattern in Figure 1 suggests that song output in January was intermediate between that in mid-September-December and that in February and analysis supported this interpretation. The

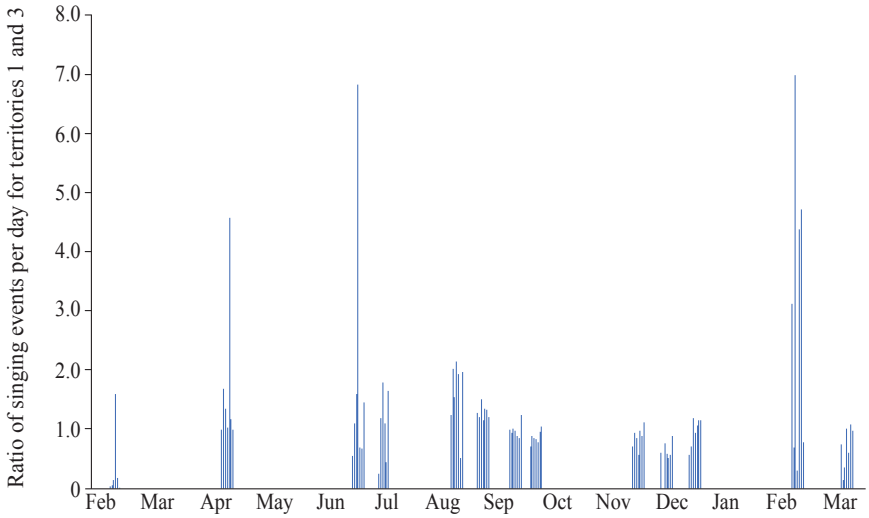

Figure 5. *Ratio of the number of singing events per day for the Rufous Scrub-bird male on Territory 1 to the number for the male on Territory 3 for the period February 2018 to March 2019. Only days when there were data for both territories included in calculation.*

mean percentages of active 20-minute periods per day were 82% (n = 183 days) and 62% (n = 23) for mid-September-December and January, respectively (t_{37} = 10.174), and the mean numbers of songs per active 20-minute period per day were 38 (n = 183 days) and 29 (n = 23) for these two seasonal time periods, respectively (t_{40} = 5.742) (P<0.001 in both cases) (Fig. 3a, b). The scrub-birds sang in 62% (n = 23 days) of the 20-minute periods per day in January compared with 28% (n = 40 days) in February (t_{55} = 8.794) and the mean number of songs per active 20-minute time-period daily was greater in January (29) (n = 23 days) than in February (17) (n = 40 days) (t_{53} = 7.084) (P<0.001 in both cases).

Comparison of singing activity on different territories

Although we did not compare singing levels among territories statistically, it is evident from Figure 4 that the activity level on all territories decreased from January to February, was relatively stable from February-August, and then increased in September-December. Moreover, singing activity level was clearly broadly similar in magnitude on all five territories.

We also calculated the ratio of singing activity on Territory 1 to that on Territory 3 from February 2018 to March 2019, a period when both ARUs were working reliably and we obtained 89 full days of simultaneous recordings on both territories (Fig. 5). There were many days in this period when the Territory 1 male sang far more often than the bird on Territory 3, including two days when it sang almost seven times more often and three other days when it sang more than four times as often (i.e. ratios of singing events in the range 4-7). Conversely, but less apparent in Figure 5 because of the scale, there were also many days when the Territory 3 male sang more often than the Territory 1 bird (ratios of < 0.5). Overall, for the period under consideration when there were song output data for both males on the same day, the Territory 1 male sang 11% more frequently than the Territory 3 bird; however, from September-December 2018, when both birds were singing most actively, the difference was only 5%.

DISCUSSION

Seasonal distribution of singing activity

There was considerable daily variability in the singing activity of the scrub-birds in all months. On any given day in any month, a scrub-bird might sing often, but the next day it might be much less vocal. Nevertheless, there was an overriding significant seasonal pattern to the birds' singing activity. From around the middle of September (early spring), singing activity increased markedly and remained high from October to December (early summer). In January, singing activity decreased substantially and there was a further decline in February, which on average was the month with the least singing activity. Singing activity remained low from February (late summer) to mid-September, albeit with apparently unpredictable daily variations. The significant September increase in singing was apparent in all three parameters measured and, taking into account the increasing day length at this time of year, the total daily number of singing events increased about five-fold.

Individual variation in scrub-bird singing activity

The singing activity of all five, monitored scrub-birds followed the same general seasonal pattern, as shown by comparison of the mean number of singing events performed daily by each male in each month (Fig. 4). After January, when the averages were 678-876 songs per day, the singing activity of all birds dropped by about 50% and remained at around that level throughout February to August. The singing activity of all males then increased substantially and remained high (899-1,777 songs per day) for the remainder of the year.

One notable exception to this trend of similarity was that the mean number of songs per day emitted by the Territory 3 male decreased from 1,357 in September to 914 in October. This bird's average song output was affected by a three-day period in late October 2017 when it only produced 916 songs in three days. The lower activity level during this period may have been rainfall-related. On the previous day, precipitation at the nearby weather station was 58 mm and light rain continued

to fall during the three days on which the male was relatively less vocal. As noted above, in our preliminary study (Stuart and O'Leary 2019) we observed that singing activity decreased on days with moderate to heavy rain, so this rainfall event may have depressed the singing activity of the Territory 3 male. Unfortunately, an equipment malfunction meant that we did not obtain comparative data from Territory 1 at that time which might have substantiated this interpretation.

The similarity in the seasonal singing activity patterns of the five males raises the question of whether they were independently responding to common environmental cues or affecting one another's singing activity (or both). Territories 1 and 3 were *c* 1.3 km apart, and there were no intervening territories, so it seems rather unlikely in this case that one male's singing activity would have affected the other bird's behaviour. If both birds displayed exactly the same behaviour, the ratio of their song outputs per day would be 1.0. From September-December 2018, when both birds were in their most active singing phase, the ratio was indeed mostly quite close to parity (0.8-1.2). However, in the other months of the year, the ratio was sometimes much higher (3.0-7.0) or much lower (below 0.3). Thus, one of the two territorial scrub-birds never *consistently* sang far more often than the other individual over a long period of time; rather, on one day a particular bird would sing frequently and on another it would not and vice versa, particularly from February to mid-September. These variations in the ratio of the number of songs produced per day on the two territories highlight the unpredictability of RSB singing behaviour, particularly from February-August. It thus seems likely that underlying environmental cues dominate in determining the temporal singing activity patterns of RSBs, although if territorial males are sometimes in close proximity there may be some social effects.

Implications for the timing of breeding

Rufous Scrub-birds are considered to be resident in the Gloucester Tops; however, to date there has never been a confirmed breeding record for the area (Williams 2020) and so the timing of the breeding season remains uncertain.

For songbirds in general, there is known to be a broad correlation between the seasonal production of male song, occupation of a territory and attraction of a mate for breeding, with singing activity decreasing post-breeding as the male's hormone levels return to non-breeding levels (Catchpole and Slater 2008). This suggests that the significant increase in male Rufous Scrub-bird singing activity from mid-September was linked with the onset of the breeding season and that males began then to advertise and defend their territory and to mate-guard females. Similarly, the decrease in male singing activity in January suggests that the breeding season was then coming to an end. Therefore, it seems quite probable that the Gloucester Tops *ferrieri* scrub-birds breed in spring. This accords with studies of the northern subspecies *rufescens* in the early 20th Century, which found that northern scrub-birds had nests with young in the period October-December (Jackson 1911, 1921).

One important focus for future studies of RSBs should be a better understanding of their breeding biology. There is no information available for the southern subspecies and very little for the northern subspecies. Ideally, some active nests should be found and observed. From the findings of the present study, the optimal time to search for active nests in the Gloucester Tops would seem to be October-November, several weeks after the singing activities of male birds have escalated dramatically.

Implications for population monitoring programs

We found that there is rarely any day in the year when a Gloucester Tops RSB male does not sing at least a few times, provided it has not been raining too heavily. Therefore, a sure way to ascertain if a known or suspected scrub-bird territory is occupied would be to set up an ARU near the bird's singing area, leave it there for two dry days and then analyse the recordings using our semi-automated procedure. Within that time at least a few songs should have been recorded if a male was present. The role of ARUs in detecting other cryptic species is well documented (e.g. Bluff 2016; Leseberg *et al*. 2020).

Most RSB monitoring programs involve walking through areas of likely habitat and listening for singing birds. That procedure allows newly-established territories to be identified, as well as confirming the continued occupancy of previously-occupied territories. Our analyses here suggest that at any time of year the presence of a male RSB could potentially be detected by walking through its territory and listening for the territorial chipping song. However, the probability of detecting the bird would be much higher in the mid-September-December period, the putative breeding season. Even so, in that period it may be necessary to make several passages through the territory before the bird is detected. This is so because although the median behaviour trend was for scrub-birds to sing in more than 80% of each day's 20-minute periods after mid-September, and therefore very likely be detected within 1-2 surveys, there were often days when males sang for less than 50% of the time. At such times, after two passages through the territory there would still be more than a 25% probability of not detecting a resident bird.

In January, scrub-bird singing activity decreased to a median of ~60% of the day's 20-minute periods. After six passages through the territory by a surveyor in this month there would therefore still be a 6% probability of not detecting the male. The probability of detecting territorial scrub-birds in surveys between February and mid-September would be even lower. Monitoring at these times of year would therefore not be effective.

The RSB monitoring program in the Gloucester Tops has focussed on the September-October period (Stuart and Newman 2018). It seems that systematic surveying could continue through November and December, and this is an important finding because it would allow additional areas of apparently suitable habitat to be surveyed using available resources.

In a single population of *ferrieri* RSBs in the Gloucester Tops, clear seasonal patterns of singing activity were identified, with a marked increase in activity in spring. However, the behaviour of *ferrieri* scrub-birds in other populations in New South Wales might be different and requires investigation, as does the behaviour of the northern subspecies *rufescens*.

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