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Breeding biology and behaviour of the Pacific Baza *Aviceda subcristata* in subtropical coastal New South Wales

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Abstract. The breeding biology and behaviour of predominantly two pairs of Pacific Bazas *Aviceda subcristata* were studied in subtropical north-eastern New South Wales from 2007 to 2017, with intensive observations in 2010–2012 (442.5 h). Fifteen breeding attempts were documented: eleven from observed nest sites, and four from observations of dependent juveniles. The pre-laying period occupied late August and September, with nest building taking 6–19 days. The mean incubation period was 31 days, usually from early October to early November. Both male and female shared diurnal incubation (Pair 1: male 42%, female 58%, only the female incubated overnight; Pair 2: male 62%, female 38%, sharing overnight incubation). The mean nestling period was 37.5 days, including a brooding period of 9–14 days. Breeding productivity was 1.87–2.0 fledglings/attempt (*n* = 15) across all sites combined. Fledging generally occurred in December, but on two occasions occurred in mid–late February. The post-fledging dependence period lasted at least 22 days, with juveniles joining flocks of other broods in the area at *c.* 40 days, and leaving the study area *c.* 45–60 days after fledging. Delivered prey was predominantly insects, especially cicadas (Hemiptera: Cicadoidea) and phasmatids (Phasmatodea: Phasmatidae) by number, and tree frogs *Litoria* spp. by biomass. Bazas brought prey at a mean rate of 1.2 items/h/juvenile (nestling and post-fledging periods combined), with juvenile intake estimated at 7.6 g/h/juvenile. Various behaviours – nest building, vocalisations, inter- and intraspecific interactions and their frequencies and contexts, and changes in juvenile morphology through the post-fledging period – are described for the years 2010–2012.

Introduction

The Pacific Baza *Aviceda subcristata* was little studied until recently. Information available on its natural history, including vocalisations, was summarised by Czechura (1993) and Marchant & Higgins (1993), and further observations were provided by Sonnenburg (1998), James (2004) and Morgan & Morgan (2010), who also cited recent anecdotal fragments. These later studies, with small samples from subtropical eastern Australia, provided descriptions or estimates of the pre-laying (*c.* 16 days), incubation (*c.* 29 or >27 days), nestling (35 days), and post-fledging dependence (*c.* 22 days) periods, roles of male and female through the breeding cycle, and growth and development of nestlings. McCrie & Noske (2015) provided further anecdotal observations on behaviour, foraging, prey and breeding in tropical northern Australia. Finally, Briggs (2018), at the southern end of the tropical zone in Queensland, conducted a detailed long-term study of the Baza's breeding biology and behaviour, also covering diet and feeding rates, nest sites and construction, incubation (29–33 days) and nestling (34–37 days) periods, juvenile independence (by 30 days post-fledging), and productivity (1.67 fledglings/breeding attempt). Marchant & Higgins (1993) noted that the context of certain behaviours and vocalisations was inadequately documented.

Here we present the results of a detailed behavioural study, over 11 breeding seasons from 2007 to 2017, for two focal pairs of Bazas in subtropical New South Wales (11 and 2 pair-years, respectively), with records of one additional pair at the main site. We cover the aforementioned ecological aspects as well as nest building; intraspecific, interspecific and territorial behaviour; undulating displays; sun- and rain-basking; vocalisation rates; hunting, prey and feeding rates; and roles of the male and female. Some of our observations are novel or provide context for certain behaviours. We also compare the Baza's biology in the subtropics with that in the tropics.

Study area and methods

The study area at Stokers Siding (28°23′S, 153°26′E) (Figure 1), located in the Tweed Valley in northern coastal New South Wales, supports regenerating wet sclerophyll forest, most of which was cleared within the last 50 years. Small pockets of subtropical rainforest are present nearby. Predominant tree species are Brush Box *Lophostemon confertus* and Flooded Gum *Eucalyptus grandis*, with some Broad-leaved Apple *Angophora subvelutina*, Tallowwood *E. microcorys*, ironbark (probably Northern Grey Ironbark *E. siderophloia*), White Mahogany *E. acmenoides* and introduced Camphor Laurel *Cinnamomum camphora*. The vicinity is mostly small holdings fragmented by roads, with powerlines, driveways, creeks, dams and paddocks. Adjacent to the most frequently used nesting gully is a small clearing, with some vines, mid-storey vegetation and epiphytes around the edges; otherwise, the study zone is forested. Mooball National Park (300 m above sea level), 0.5 km to the east of the study site, is steeper, with dense forest. Rainfall was well above mean levels in the early years of the study (2008–2010) and in 2013 and 2017 (Figure 2) (Bureau of Meteorology 2018).

The three Stokers Siding pairs of Bazas were designated Pair 1 (male M1 and female F1), Pair 2 (M2, F2), and Pair 3 (nest site note found), which was known through observations of aerial displays, intraspecific activity and the arrival of extra juveniles. Another site, in the Tweed Valley Way, 2.3 km away, was a notable locus for displays and

Figure 1. Locations of Pacific Baza nests between 2008 and 2017, Stokers Siding, NSW: 1 = 2008, 2 = 2009, 3 = 2010, 4 = 2011, 5 = 2011, 6 = 2012, 7 = 2013, 8 = 2014, 9 = 2015, 10 = 2017. Locations of Nests 5 (2011) and 10 (2017) are approximate, from begging calls recorded, as these nests were not found.

intraspecific behaviour but, as a nest was not found, data from this location were limited to bolstering descriptions of behavioural aspects. In order to improve context, two breeding records were collected from two additional pairs, one at Murwillumbah, 8.0 km north, and the other at Cudgera Creek, 7.5 km east of the main study site.

Bazas were sexed and aged by plumage characteristics, as described by Cupper & Cupper (1981), Marchant & Higgins (1993) and Menkhorst *et al.* (2017), and by comparison with videos and notes of copulations. In comparison with F1, F2 was distinctively pale, and had immature remiges and rectrices (Figure 3). In 2010, M1's rectrix 6 was damaged on the left side and his undamaged rectrix 6 on the right was banded to the tip. This temporary damage lasted through the breeding season from which Pair 1's behavioural and hunting information was obtained.

From 2007 to 2009, breeding was noted in the main Stokers Siding study area by FH during morning walks and opportunistically from her home. Between September 2010 and October 2012, 442.5 hours of observations (by KF & FH) in sessions averaging 2.0 h were undertaken, with 84% (372 h) comprising nest observations and the remainder (observer walking nearby) within hearing distance of the study site. These observations covered the full breeding season of Pair 1 from September 2010 to March 2011, the non-breeding period of 2011, the breeding season of Pair 2 from nest discovery in November to breeding failure in early December 2011, encounters with Pair 1 and their juveniles early in 2012, and the pre-laying period in 2012 of Pairs 1, 2 and 3 (Table 1). Some sessions went all day during key periods, such as when

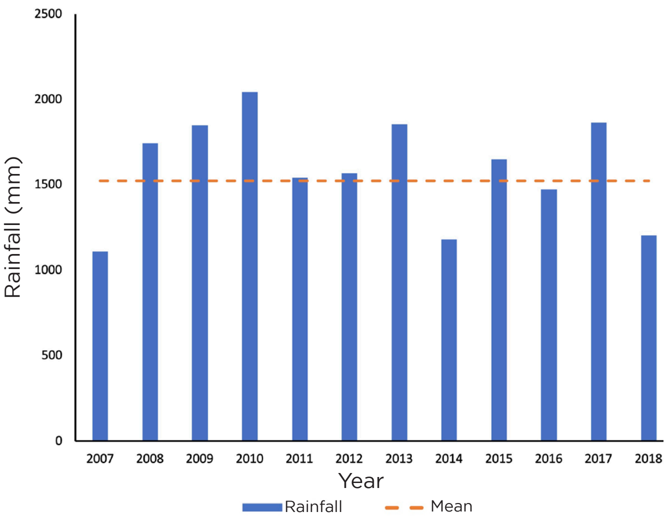

Figure 2. Tweed Valley annual rainfall (mm), 2007–2018.

Figure 3. Differences between female Pacific Bazas: Top row, Pair 1 female (F1), December 2012. Bottom row, Pair 2 female (F2), October 2011. Photos: Keith David Fisher

we were determining the sex of the incubating/brooding Bazas or the time of hatching or fledging. The nest sites, timing and fledging success of Pair 1 were monitored by FH until 2017. Equipment used included voice recorders, binoculars, telescopes with videoscope arrangements and a digital SLR camera.

For the purpose of this study, the non-breeding period was from early April through a period of limited or no activity until late August, when pre-laying began. All behaviours from the first sightings of the new season (including calls and displays, copulations and nest building) until laying, were counted as part of the pre-laying period. If, during the pre-laying period, the Bazas built on a nest that had been used in the previous season, ceased, and then built a new nest before laying, this was counted as just one breeding attempt.

The weight of observed prey items was estimated from various sources (Appendix 1). The estimate used a proposed upper limit of 30 g (Czechura 1993), and ~8.7 g for medium-sized frogs. The crude estimate of biomass delivered per hour was made by comparing notes on relative prey size.

Vocal terminology follows Marchant & Higgins (1993) (e.g. *wee-choo* disyllabic call). Bouts of the calls of the two main types, *wee-choo* and *ticking* (*toc* of Hollands 1984 and *clucking* of Briggs 2018), are analysed in three ways: their context, variation and rate. Because of the variability in the way that Bazas call, a simplifying rule was used to define a bout as any amount of calling (irrespective of number of phrases), separated from the next calling by ≥5 minutes of silence.

The context of calling bouts in relation to behaviours was determined by allocating the observation schedule into 10-minute blocks and comparing the timing of calling bouts with those of copulations, undulating displays, intra- and interspecific events, and prey deliveries to the nest.

Secondly, variation in calling was noted by counting the number of disyllabic *wee-choo* phrases made during bouts of calling. An additional detail is that during a calling bout, these phrases were often clustered together into groups in which phrases came *c.* 1 second apart. In our results, the word 'group' defines a cluster of phrases before a long pause. Variation was also considered in context and included the observer's perception of volume and tone.

Table 1. Observation schedule at Pacific Baza nests, Stokers Siding, NSW, in 2010–2012. Figures represent hours. # = Pair 1, ^ = Pair 2, * = Pair 3.

Period and year	*Sunrise–0830 h*	*0831–1100 h*	*1101–1330 h*	*1331–1600 h*	*1601 h–sunset*	*Total hours*
Pre-laying 2010 #	19.0	0	0	0	0	19.0
Incubation 2010 #	14.0	14.5	7.5	5.5	6.0	47.5
Brooding 2010 #	17.5	11.5	6.0	9.5	19.5	64.0
Nestling (after brooding) 2010 #	15.0	24.5	11.0	15.0	25.0	90.5
Post-fledging 2010–2011 #	26.5	9.0	3.5	2.5	5.5	47.0
Non-breeding 2011 #	11.5	14.0	6.5	2.5	0	34.5
Pre-laying 2011 ^	5.0	0	0	0	0	5.0
Incubation 2011 ^	7.0	7.0	6.5	6.5	4.5	31.5
Brooding 2011 ^	1.5	0	0	2.0	3.5	7.0
Post-fledging 2011–2012 # *	15.5	8.0	0	0	0	23.5
Non-breeding 2012 # *	9.5	5.0	0	0	0	14.5
Pre-laying 2012 # ^ *	21.0	28.5	7.0	2.0	0	58.5
Total	**163**	**122**	**48.0**	**45.5**	**64.0**	**442.5**

The calling rate was the number of calling bouts divided by the number of hours of observation in that period of breeding. It was used to analyse the varying intensity of calling between different breeding periods, from pre-laying to incubation, to brooding and nestling post-brooding, to post-fledging and then to the non-breeding period.

The rate per hour of intraspecific events, and undulating displays, was calculated in a similar way to call rates: a single bout was a cluster of interacting or deliberate stalling separated from the next cluster by ≥5 minutes of inactivity.

Results

Timing of breeding

For Pair 1 (10 attempts), the most frequent timing of breeding (eight attempts) consisted of a pre-laying period from late August through to early October, including nest building in late September into early October, laying by 9 October, and fledging in mid December (Appendix 2). In 2012, Pair 1's timing initially appeared the same; however, the young fledged 2 weeks later. In 2018, the young fledged in February and were last seen in March. Pair 2 (two attempts) built from mid October and laid in early November.

Pair 3 and a pair in Murwillumbah had young that fledged in December, and at Cudgera Creek a pair had fledged young in February.

Aerial displays

Pre-laying (September) displays, frequently observed, included:

1. A 'chasing display', which was level and direct in nature, with 'following' by two or three Bazas, ~25 m apart, with or without calls, sometimes with the leading bird making undulating movements that centred around the same path.
2. Mature males undulating intensely (Figure 4) after intruding Bazas undulated in their territories, and
3. Mutual soaring of three to six Bazas, usually with one or two birds undulating, both with and without calling, followed by separating into assumed respective pairs, or movement of an immature away from a pair.

In the incubation period, intraspecific mutual soaring continued, and the incubating bird sometimes left the nest for up to 5 minutes to join its mate and one to three additional Bazas (assumed to be from one of the neighbouring pairs or immatures).

Figure 4. Pacific Baza Pair 1 male (M1) at the apex when undulating over the nesting area, 23 October 2012. Photo: Keith David Fisher

Table 2. Pacific Baza behaviour observed at Stokers Siding, NSW: number of bouts of each behaviour (number of bouts/hour in parentheses) in years 2010–2012 See text for details on bouts of *wee-choo* and *ticking* vocalisations. # = Pair 1 in 2010–2011, ^ = Pair 2 in 2011, #^* = Pairs 1, 2 and 3 in 2012.

Period and year	*Intraspecific interactions*	*Undulating displays*	*Copulations*	Wee-choo *calls*	Ticking *calls*
Pre-laying 2010 #	1 (0.05)	2 (0.10)	2 (0.10)	17 (0.90)	5 (0.25)
Incubation 2010 #	7 (0.15)	3 (0.05)	0 (0)	22 (0.50)	28 (0.60)
Brooding 2010 #	4 (0.05)	1 (0.05)	0 (0)	15 (0.25)	50 (0.80)
Nestling (after brooding) 2010 #	2 (0.05)	4 (0.05)	11 (0.10)	79 (0.90)	70 (0.80)
Post-fledging Dec. 2010–Mar. 2011 #	6 (0.15)	2 (0.05)	3 (0.05)	47 (1.00)	23 (0.50)
Non-breeding 2011 #	28 (0.80)	26 (0.75)	8 (0.25)	91 (2.65)	25 (0.75)
Pre-laying 2011 #	1 (0.20)	3 (0.60)	0 (0)	5 (1.0)	5 (1.00)
Incubation 2011 ^	2 (0.05)	2 (0.05)	0 (0)	21 (0.65)	10 (0.30)
Brooding 2011 ^	1 (0.15)	1 (0.15)	1 (0.15)	8 (1.10)	2 (0.30)
Post-fledging 2011–2012 # ^ *	2 (0.10)	0 (0)	0 (0)	5 (0.20)	0 (0)
Non-breeding 2012 # ^ *	0 (0.05)	0 (0)	0 (0)	3 (0.20)	0 (0)
Pre-laying 2012 # ^ *	21 (0.35)	39 (0.65)	55 (0.95)	102 (1.75)	58 (1.00)

Displays in the post-fledging and non-breeding periods (February–June) included:

1. Repeated linear undulating, and a level, deliberate, very slow glide with no dip before alighting, by M1 en route to Nest 2, on which he then landed and made *ticking* and loud disyllabic calls.
2. Frequent linear flights, of three to five Bazas, with one or two Bazas calling and undulating briefly.
3. M1 (presumed) calling and displaying for *c*. 10 minutes over the gullies towards knolls and along spurs (i.e. following topographic features), returning to the nest gully or continuing on.

The highest rates of undulating displays were in March and April 2011 in the period before the winter absence, and in the pre-laying phase of 2012 (0.75 bout/h and 0.65/h, respectively). When incubating in October 2010 (Pair 1) and November 2011 (Pair 2), both pairs performed undulating displays at a lower rate (0.05 bout/h). In the brooding period of 2010, Pair 1 displayed at the same rate as in the incubation period (0.05 bout/h), whereas displays were seen at a higher rate (0.15 bout/h) in the short brooding period before the breeding attempt of Pair 2 failed in 2011 (Table 2).

Vocalisations

Wee-choo

Wee-choo calling was associated with intraspecific activity, arrivals and departures from the patch when bringing prey to the chicks, incubation and brooding changeovers, sun-basking, copulations, interspecific activity, and undulating displays.

The highest *wee-choo* call rates occurred when groups of two or three pairs of Bazas were active in the non-breeding (2.65 bouts/h) and pre-laying (1.7 bouts/h) periods of 2012 (Table 2). Generally, higher calling rates were related to higher numbers of phrases: i.e. when calling bouts happened more often, they also contained more phrases, but this was not always the case. Low rates (Pair 1, 0.5 bout/h; Pair 2, 0.65/h) were recorded for both pairs when they were incubating, yet groups of calls from Pair 2 contained many phrases. Later, Pair 1's arrival calls given after catching prey typically consisted of only one group of one or two phrases. Towards the end of the nestling period, Pair 1 often called again after delivering prey.

In the post-fledging period, *wee-choo* bouts were more intense, with groups of calls often consisting of three or more phrases, as Pair 1 fed their young, particularly when predators or harassers (Spangled Drongos *Dicrurus bracteaus* or Torresian Crows *Corvus orru*) were nearby. At other times, yet also early in the juvenile dependence period, M1 called in many groups while making circuitous flights away from and back to the family. During the period from late April until the end of May 2011, when Nest 2 was refurbished, the rate of bouts of *wee-choo* calling were the highest recorded in our study. At this time, such bouts sometimes lasted for >1 hour, and consisted of many groups of loud phrases; sometimes a single group contained well over 10 disyllabic phrases.

Ticking

Ticking was associated with nest building and maintenance, changeovers during incubation and brooding, copulations, pair-related exchanges before taking prey to the nestlings, intraspecific events, and interspecific events. Twice, *ticking* was heard during courtship flights, once involving Pair 1 in the nestling phase, and once between M1 and an immature female while F1 incubated. *Ticking* was also noted around the time of sun-basking, and when the Bazas were harassed. Infrequently, there were short fragments

Figure 5. Nest 2, of Pacific Baza Pair 1, pictured during post-fledging rebuild, 22 December 2010. Photo: Keith David Fisher

of *ticking* in foraging groups. *Ticking* could be fast or slow, loud or soft. When *ticking* during the incubation or brooding periods, the Baza's body could be seen oscillating. Sometimes, when this body movement continued, *ticking* became very hard to hear, or could not be heard at all by the observer. Rapid harsher *ticking* seemed agonistic and was loud enough to be heard throughout the nesting areas during intraspecific and territorial activity.

Copulation squeal

A specific call was given only during copulation, and was audible from up to 50 m away, depending on wind direction and other ambient sounds. At times, copulations were recorded solely on the basis of the observer hearing this copulation squeal. This call was similar in tone to a soft cockatoo-type call but was prolonged, lasting 0.5–2.5 seconds.

Nest sites

Of 10 nests that were detected, six different species of nest tree were identified (Appendix 2). Nest position was most frequently high (mean 12.7 m, range 10–16 m) above the ground, sometimes immediately below the canopy crown of a senescent tree. In 2007 and 2008, Pair 1 nested in a Camphor Laurel (Nest 1) in gully 1 (Figure 1), then, in 2009, after initially rebuilding there again, moved to the adjacent gully, building in a roadside ironbark (Nest 2) and breeding successfully.

In 2010, Pair 1 initially rebuilt Nest 2 (Figure 5) before moving to the centre of the gully and breeding at Nest 3, built in a White Mahogany and then (between 20 and 23 December and between bouts of feeding juveniles) M1 rebuilt Nest 2. The juveniles, with another from Pair 3, 'played' at this nest on Day 40 post-fledging, and it was the site of intraspecific, territorial and pair-related behaviour from March to May 2011, with M1 refurbishing it until then. The nest soon deteriorated and was not used again. Pair 1's assumed Nest 5 was not found in 2011 but breeding was confirmed after juvenile begging calls were later recorded.

In 2011, Pair 2 built, and in 2012 refurbished, Nest 4 in a large Box Mistletoe *Amyema miquelii* in a Flooded Gum, close to the saddle between the two gullies, ~100 m from Pair 1's nests (Nests 5 and 6). In 2011, Pair 2's breeding progressed through to hatching but failed early in the brooding period. In 2012, this pair rebuilt this nest sporadically for 17 days, but the next day, after an intense 2 h of *ticking*, undulating displays, swooping, loud calling and copulations involving six Bazas, all activity at the site ceased and breeding did not progress to incubation.

From 2012 to 2014, Pair 1 bred successfully in gully 2 in Nests 6–8, which were in separate trees, <10 m apart, beside a dam and close to Nest 3. Like Nest 3, these nests were mostly under the crown of senescent Brush Boxes. In 2015, Nest 9 was in a large eucalypt (species not identified) ~100 m to the south. No breeding was detected in 2016 and, in 2017, Nest 10 was located back towards the centre of the gully, as were Nests 5–8.

At Cudgera Creek, two young fledged, and one died in February 2013, from a nest built in an unidentified eucalypt adjacent to a house.

Nest-building behaviour

Throughout the study, nest building took between 6 and 19 days (n = 6) to complete. In the pre-laying period for Pair 1, M1 collected all nesting material, which was twigs (some with green leaves attached), often picked with the feet from Brush Box. F1 was not observed to collect material, but sometimes positioned twigs and trampled on the nesting material, or was otherwise apparently not attending the nest. Pair 2 did not arrange sprays with leaves projecting outwards, and hanging over the side of the nest, as did Pair 1 (Figure 5). Males frequently *ticked* rapidly and continuously while building.

M1 and M2 (in 2008 and 2012) repeatedly bobbed the head when giving *ticking* calls on the nest, with the body held horizontally. At full depth of the bob, the male touched his bill on the nesting material. Sometimes the female watched closely and moved onto the nest to bob with the male, but at a slower and less regular pace. On one occasion in 2012, M1 bobbed 38 times in 126 seconds (0.3/sec.), and F1 bobbed eight times. Minutes later, after both had left the nest and returned, M1 bobbed rapidly at the edge of the nest (0.5/sec., *n* = 21), gradually moving further into the centre while bobbing, sometimes touching or pulling at twigs or shaking his head, followed closely onto the nest by F1. When she was beside him, M1 faced her, bobbing with larger oscillations. Both bobbed with heads close together, F1 more slowly. Later again, M1 bobbed (0.7/sec., *n* = 17), and the following day (0.3/ sec., *n* = 10), while F1 bobbed slowly or not at all. M1 briefly head-bobbed from a perch close to the nest, during a *ticking* exchange with F1, halfway through the nestling period in 2010. Head-bobbing, similar to (though not as pronounced as) that observed in the pre-laying period, was also observed in April and May 2011 on the rebuilt 2009 nest (Nest 2).

In between bouts of hunting for their young, from 0730 to 0900 h on 22 December, and from 1100 to 1140 h on 23 December 2010, M1 rebuilt the nest of the previous year (14.5 trips to the nest/h, arranging for c. 2–3 min./ trip). M1 also brought extra prey to F1 during this period. This activity ceased within a few days without resulting in a second clutch.

Copulation

Copulations were recorded between 2010 and 2012, most frequently in September (during the pre-laying period), but in 2010 they were also recorded in the nestling period (post-brooding), into juvenile dependence and then later that season, into the non-breeding period, which was from mid March to early June 2011.

In the pre-laying period of 2010, when only Pair 1 was observed breeding, copulations (0.1/h) were infrequent (Table 2). In the incubation and brooding periods in that year, no copulations were recorded. Then in the nestling period, Pair 1 resumed copulating (0.1/h), being recorded on Days 23 and 24 (29 and 30 November), and Days 35 and 37 (11 and 13 December). Three copulations were recorded on Day 40 (16 December). A few days later, during the post-fledging period, the rate (0.05/h) reduced, and M1 stopped refurbishing Nest 2. One copulation at this time was in the presence of an immature, during agonistic activity that involved loud calls and a non-contact parry in flight with this bird, which was then chased away by the pair.

In March 2011, during the non-breeding period, M1 (presumed) made *ticking* calls on Nest 2, and copulated twice with (presumed) F1, which had been close by, apparently prompted by the arrival of two juveniles and a mature male.

During the non-breeding period from March to early June 2011, the copulation rate increased (0.25/h) and, within that period, copulations were recorded near Pair 1's Nest 2, and in the adjacent gully near where Pair 2 later (October 2011) built the only nest (Nest 4) known to be built by them.

After the winter absence of 2011, no copulations of either Pair 1 or Pair 2 were recorded in the pre-laying period of that year, although calls and displays were now frequent in the vicinity of Nest 4 (used by Pair 2). Pair 2 copulated (0.15/h) during the early brooding period (after 3 December) before observations ceased when this breeding attempt failed on 6 December.

Then no copulations were recorded from either Pair 1 or 2 until the pre-laying period of 2012 when 55 copulations (0.9/h) were recorded between 24 September and 29 October. Thirty-two (58%) of these were between 24 and 30 September. Most were attributable to Pair 1 and some to Pair 2 but, during a few observation sessions, the related squeal was heard coming from another, unknown, pair nearby. On 1 and 2 October, no copulations were recorded, but there were five in total on 3–4 October. From 5 to 21 October, one or two copulations were noted on 4 days. Between 22 and 29 October, when breeding of Pair 2 failed, 12 were recorded in the vicinity of Nest 4. Three more were noted, one each on 5, 7 and 8 November, of Pair 2 near their nest before their breeding activity ceased.

Intraspecific interactions

Intraspecific activity, including displays, copulations, *wee-choo* and *ticking* calling, and mutual foraging at Stokers Siding (Pairs 1, 2 and 3 and immatures), were recorded throughout the breeding seasons in 2010–2012 until the last sightings before the winter absence. This activity appeared to reflect the presence of immatures and a new pair (Pair 2 in 2011 and 2012) in close proximity, because of favourable conditions. During the non-breeding period of 2011, intraspecific activity (0.8 event/h) was at the highest rate we recorded (Table 2).

In the pre-laying period of 2010, the rate of intraspecific activity (0.05/h: Table 2), was low: there were almost no observations of more than two Bazas at a time. Then, in 2011 (0.2/h) and 2012 (0.35/h), the intraspecific rates during the pre-laying periods were higher than in all of the other periods from incubation to post-fledging combined (Table 2).

At the Tweed Valley Way site from 2013 to 2014, frequently recorded activity showed a similar pattern to that at Stokers Siding, including intense and frequent *wee-choo* calls and an aerial clash between two males in the non-breeding period.

Incubation regime

Incubation behaviour of Pair 1 was studied in 2010, and of Pair 2 in 2011. During 46.9 hours of observation, Pair 1's incubation sessions showed that F1 contributed a

Table 3. Parental feeding rates of Pacific Bazas through the breeding cycle (nestling period: Days 1–14, 15–27 and 28–40; post-fledging period: Days 1–22) for Pair 1 in 2010, Stokers Siding, NSW, by number (*n* = 427) and by estimated biomass.

Prey delivery rate	*Nestling period (days)*			*Post-fledging (days)*
	1–14	*15–27*	*28–40*	*1–22*
No. items/h/chick	0.53	1.45	1.38	0.62
Biomass (g/h/chick)	3.73	11.00	9.50	–

higher percentage of diurnal time incubating than did M1 (42% male vs 58% female) and was the only one seen to incubate overnight, which was recorded on Days 15, 19, 22 and 30 of the incubation period.

F1 was never observed completing a full incubation session from arrival to departure, but usually incubated from late evening until early morning, before being replaced by M1. Because of the bias towards early-morning observations, F1 was observed incubating more than M1. However, several long watches through the day showed M1 completing two sessions (Day 20: 1005–1456 h; Day 30: 0815–1403 h). From this combination of mid-morning to mid-afternoon incubation by M1 (up to *c*. 6.0 h per session), and late afternoon, overnight, and early morning incubation (*c*. 18.0 h) by F1, the actual total contributions of the mated pair (diurnal and nocturnal hours combined) is inferred to be much higher from F1 (25% male vs 75% female) than revealed by our direct daytime observations.

In 2011, M2 contributed a higher percentage of diurnal incubation time than immature F2 (male 62% male vs 38% female) and also one (probably two, based on observed plumage details) of four overnight incubation shifts that were monitored.

Pair 1 was observed changing over slightly less frequently than Pair 2 (Pair 1: 0.31 changeover/h, *n* = 13; Pair 2: 0.39/h, *n* = 12) and left the nest unattended at changeovers for less time (Pair 1: mean *c*. 65 sec., range 0–180 sec.; Pair 2: mean *c*. 150 sec., range 90–360 sec.).

For Pair 1, there were *ticking* bouts before 70% of changeovers during incubation, usually started by the incubating bird. The incoming Baza often perched nearby for *c*. 30 seconds before alighting on the nest. The regime of Pair 2 was similar.

The mean incubation period was 31 days (*n* = 4) (Appendix 2).

Brooding regime

Brooding bouts by the male and female of Pair 1 in 2010 were regular (from 34.5 h of observations, mean length of brooding bout for M1 = 1.0 h, range 0.2–2.5 h; F1 = 1.2 h, range 0.3–2.6 h; overall time male 45% male vs 55% female, *n* = 31) and both male and female brooded overnight (M1 on 5 nights, F1 on 7 nights). During changeovers, the Bazas were typically off the nest for 20–30 seconds, although on three occasions they were on the nest together for <1 minute. The mean brooding period was 13 days (range 9–14; *n* = 3).

Foraging and prey-delivery behaviour

In the brooding period in 2010, M1's hunting contribution of prey deliveries to the nestlings was higher (72% male vs 28% female, *n* = 76). Prey was brought to the nestlings during the brooding period in two ways. In the first, the incoming adult brought prey to brooding changeovers, and then fed it to the nestlings, before settling to brood. From this activity, the contribution of M1 and F1 was equal (50% male vs 50% female, *n* = 41). The second method consisted of mostly M1 delivering prey to F1 and then departing (99% male vs 1% female, *n* = 35), leaving her to feed the items to the nestlings.

Combining all prey delivered to the nestlings during the nestling period (including brooding period) and delivered to the juveniles during the post-fledging period in 2010, there was a total of 427 prey deliveries. From a sample in which the sex of the delivering Baza was identified, the male captured prey more often than the female (60% male vs 40% female, *n* = 230).

During hunting bouts, adult Bazas interspersed long-distance with short-range foraging forays. Most hunts were attacks from above and below, and within ~10–15 m of the Bazas' perched positions. During the nestling period, the adults often hunted close to the nest, delivering again quickly after having delivered prey obtained from a more distant location. They hunted in the lower mid-storey near the nest late in the nestling period and took small moths and larvae (Lepidoptera) from vines and mid-storey vegetation near the nest. On three occasions, a female fed nestlings unidentified prey attached to foliage that she brought to the nest. Once, in the nestling phase, M1 was observed undulating (flying) strongly en route to the nest with prey in his bill while F1 and an intruding immature female were nearby. Larger prey items were often half-eaten before delivery. Deliveries were usually bill to bill, with the adult sometimes departing in <1 second.

Prey types, provisioning rates and biomass of prey

The feeding rate peaked towards Day 30 of the nestling period and then slowly decreased (Table 3). The weight of most individual prey items delivered to nestlings was estimated at <10 g. Very large prey (20–30 g) was brought to the chicks more frequently during the 12–14-day brooding period (the first third of the nestling period); otherwise, prey of a range of sizes (small ≤5 g, medium 6–9 g and large 10–20 g) was generally consistent across the nestling period (Table 4). In 2010, from 115 prey items, prey consisted of 65% insects and

Table 4. Percentages of Pacific Baza prey items of different sizes and total number of prey items through the nestling period (Days 1–14, 15–27 and 28–40; *n* = 115), Stokers Siding, NSW. Approximate prey sizes: small (≤5 g), medium (6–9 g), large (10–20 g) and very large (21–30 g).

Prey size	*Nestling phase (days)*		
	1–14	*15–27*	*28–40*
Small	52	47	50
Medium	28	21	19
Large	12	28	26
Very large	8	4	5
Total no. of prey items	59	32	24
No. of observation hours	60	45.5	49

35% vertebrates (mostly frogs). In terms of estimated biomass, the most important items included frogs (53%), phasmatids (Figure 6) (16.5%) and insect larvae (12.5%) (Table 5). In 2010–2014, a few items were identified to species level: Graceful Tree Frog *Litoria gracilenta*, Goliath Stick Insect *Eurycnema goliath* (Figure 6), Pink-winged Phasma *Podacanthus typhon*, Giant Stick Insect *Acrophylla enceladus* and Spiny Leaf Insect *Extatosoma tiaratum*.

The mean prey delivery rate overall to chicks was 1.2 items/h/chick, and average prey biomass was estimated at 7.6 g/h/chick (during the nestling period, including brooding, and post-fledging dependence period, *n* = 427). Peak hunting was at 0830–1100 h in the morning and 1330–1600 h in the afternoon, when prey biomass of 30–45 g/h/chick was delivered in rapid bouts of up to 10 deliveries/h.

Feeding of nestlings

Adults partly consumed much of the prey before delivering it to the chicks, and early in the brooding period the adults consumed most of each of the large prey items (>10 g). For the first few days, the adults held prey in their talons and tore off tiny pieces that they fed to the chicks, and thereafter the chicks were fed small and large pieces. From Day 8, F1 offered cicadas (Hemiptera) and frogs (Anura), which the chicks swallowed whole. On Day 12, a chick also swallowed whole the cylindrical body of a large phasmatid. After the brooding period, prey was mostly transferred intact (not torn into pieces) directly from bill to bill and swallowed quickly but some was held underfoot and consumed more slowly. Feeding durations were timed from when the adult first presented food to the chick until the chick had finished swallowing the food and averaged 2.8 minutes (range 0.17–11.00 min., *n* = 59) in the brooding period and 0.54 minutes (range 0.01–20.00 min., *n* = 252) in the rest of the nestling period.

Figure 6. Adult male Pacific Baza with female Goliath Stick Insect, Pottsville, NSW, August 2012. Photo: Keith David Fisher

Table 5. Prey items delivered to Pacific Baza nestlings by Pair 1 (*n* = 115), Stokers Siding, NSW, 7 November–16 December 2010, as percentage by number and by biomass (estimated).

Prey item	*Order*	*% items by number*	*% biomass*
Invertebrates			
Beetle	Coleoptera	1.6	1.0
Cicada	Hemiptera	24.2	7.0
Dragonfly	Odonata	1.6	0.5
Grasshopper	Orthoptera	1.6	0.5
Unidentified insect	Insecta	8.9	4.0
Caterpillar	Lepidoptera	8.0	12.5
Mantid	Mantodea	1.6	1.0
Phasmatid	Phasmatodea	15.3	16.5
Vertebrates			
Frog (*Litoria* spp.)	Anura	34.7	53.0
Lizard	Squamata	0.8	1.0
Mouse	Rodentia	0.8	1.0
Total		**100**	**100**

Development of nestlings

The yellow cere and gape and grey pin-feathers of the nestlings developed as the brooding period ended (*c*. Day 14). The crest then began to develop, and the nestlings' general appearance became darker. From *c.* Day 22, chest barring developed from the sides and the dorsal appearance was brown. By Day 35, chicks had full juvenile plumage, with complete barring on the breast, dark-brown crown stripe, rufous neck, white supraciliary stripe, bright-yellow cere, and yellow tarsi.

From *c*. Day 20, the chicks grabbed at prey with their talons and began flapping their wings and were curious and alert towards nearby passerines. They nibbled at and repositioned twigs on the nest. By *c.* Day 28, they were calling (rapid high-pitched *chip* calls) and begged with quivering wings. They began tearing prey held in their talons. At no time was sibling aggression observed, and competition between nestlings for food was minimal. From Days 20 to 35, when entering the maximum growth phase until they were advanced and branching, the chicks seemed confident during stormy weather, flapping and exercising in strong wind and rain. Branching began on Day 34.

Fledging behaviour

In 2010, the fledging of both nestlings of Pair 1 occurred, with both adults within close proximity of the nest and when nestlings were aged 38 days. From an exposed perch on the northern side of the gully, F1 flew towards where M1 was calling, and almost immediately one (female) nestling fledged in that direction while, simultaneously, the remaining nestling (male) appeared to startle, dropping from the southern edge of the nest and coming to rest 1 m lower in a fork on the trunk. F1 arrived and departed soon after, returning in minutes with a large female Goliath Stick Insect for this nestling, which had clambered back to the nest. It fledged the following morning, entangling itself in foliage on landing, extricating itself and continuing to fly ~30 m along a driveway, then landing with wings spread, on thick mid-storey vines. Giving rapid disyllabic calls while under severe harassment from Spangled Drongos, it freed itself and flew back to perch adjacent to the nest tree.

Length of nestling period and breeding success

The mean length of the nestling period (including brooding) was 37.5 days (*n* = 5). For one occasion, it was exactly 38 days, and for four occasions it was estimated, ranging from a minimum possible of 36 days to a maximum of 39 days (Appendix 2).

Across all sites, productivity was 28–30 fledglings from 15 breeding attempts (1.87–2.0 fledglings/breeding attempt.) This was based on 10 observations from Pair 1 (2007–2017), two observations of Pair 2 (2011–2012), and one each from Pair 3 (Stokers Siding), and pairs at Murwillumbah and Cudgera Creek (Appendix 2).

Post-fledging period

In 2010, the two juveniles at Stokers Siding roosted together from Day 1 post-fledging. They regularly begged with chipping calls, sometimes slightly harsh like a squeaky toy and at other times softer, while quivering their wings. They soon made circuitous flights out over the clearing. The juveniles followed the hunting adults and, during intense periods, continued to beg between swallowing prey, sometimes receiving items while still feeding on the previous one.

Young juveniles sometimes hawked for insects in the first week post-fledging and, in December 2013, three juveniles, 2 weeks after fledging, hunted for insects along with Blue-faced Honeyeaters *Entomyzon cyanotis* and Noisy Friarbirds *Philemon corniculatus*. Direct attacks into foliage for prey were seen by Day 6. Such attacks were more frequent by Day 11, although success was not witnessed until Day 18. From Day 15, juveniles prepared prey after receiving it and flew to perches that were easily visible to the hunting adults. Several female Goliath Stick Insects were noted amongst prey. The last adult prey delivery observed in 2010 was on Day 22 post-fledging; nevertheless, begging continued thereafter. Between Day 22 post-fledging and loss of contact on Day 53, of 31 observed hunting attempts by the juveniles, at least 16 were successful. No competition for food was witnessed in 2010, but in 2014 on Day 60 post-fledging, one juvenile snatched prey that an adult was taking to a different begging juvenile.

When juveniles became separated for periods of time, they usually called and regrouped. Call variations were noted from Day 12 and included a higher-pitched version of adult disyllabic calls.

The post-fledging dependence period (when juveniles were fed by the adults) was at least 22 days in 2010 and 60 days in 2014. Intermixing of juveniles from different broods was not seen earlier than Day 40 post-fledging.

Development of juveniles

In 2010, the juveniles fledged with short tails, which appeared nearly full length by Day 8 post-fledging. Around Day 16 post-fledging, the cere appeared yellow-green or yellow-grey. By Days 40–50, at least two juveniles had a grey rather than yellow cere, and new grey feathers among their brown feathers. The undertail-coverts were pale (female) and darker (male), as for adults.

Large congregations

In late January and February 2011 and 2014 (*c*. Day 60 post-fledging), groups of eight Bazas containing adults and juveniles soared over the study area. Juveniles in one such group in 2014 were catching prey for themselves but still taking prey from adults in the group. They foraged, then all took flight together almost simultaneously, soaring for a few minutes before dropping to forage again.

Sun-basking and rain-bathing

Sun-basking was witnessed most frequently in the post-fledging period of 2010 (0.3 bask/h, *n* = 14). Six basking events were recorded in 1.5 hours on Day 4. When basking, primary feathers were placed either in front of, or behind the rectrices. The Bazas also ‘half-basked’ with wings drooped. In 2010, F1 used a full basking posture in rain for several minutes.

Winter absence: main study site

Bazas appeared to vacate the immediate breeding area for the winter, although some (not necessarily the described pairs) were occasionally recorded flying over and calling in the study zone from June to August, and Bazas were sometimes encountered in the Tweed region during these months.

Discussion

The findings of our study generally support, confirm or extend those of earlier studies, and provide additional detail, context and quantification for behavioural and vocal aspects. We recorded variations on previous descriptions of aerial displays: the ‘chasing’ display is restricted to the pre-laying phase (apparently associated with courtship). Undulating flight was used in various contexts, including prey delivery, and in territorial and intraspecific pair-related activity. The copulation call and head-bobbing nest display were previously undescribed, as was breeding by an immature (presumed yearling) Baza (F2), albeit unsuccessful. Males appear to be more involved in advertising and displays, and nest building and maintenance, than are females. Our observations support the view (Czechura 1993) that in calling and displaying along ridges and over knolls, Bazas may be using these topographic features to define territory.

Our study provides local variations on recorded nest trees, with novel detail of nest-building rates and nest refurbishment post-breeding. Breeding density at Stokers Siding was exceptional (100 m between nests, vs 3–5 km elsewhere: Marchant & Higgins 1993), although Pair 2 failed and ultimately abandoned the site. The rate of intraspecific intrusions also suggests a high local density and presence of ‘floating’ immatures.

Breeding chronology was similar to that in the tropics (Briggs 2018), showing that even in the subtropics late broods can fledge in autumn (March or April: Cooper *et al.* 2014). Breeding parameters were generally similar to those recorded in previous studies, e.g. duration of nest construction; incubation period (close to the average of Briggs 2018); nestling period (in 2010, 1–2 days longer than found by Briggs 2018); post-fledging dependence period, independence and time to joining local flocks; and productivity (1.67 fledged/attempt in the tropics: Briggs 2018). The most frequent brood size (three) matched that found by Briggs (2018), and we recorded two losses from nest falls: one after strong wind soon after brooding finished in 2010 and another from near Cudgera Creek, where a chick fell and died at ~60% adult size (wingspan 650 mm, mass 213 g: specimen BF4035, Australian Museum).

Breeding productivity of Pair 1’s observed nests was 2.5 fledglings/year from eight attempts and, if Nests 5 and 10 (not found) are included, 2.2–2.4/year from ten attempts. Pair 1’s productivity was therefore slightly higher than for all pairs combined (1.87–2.0 fledglings/year).

The following factors seem most likely when considering Pair 1’s productivity: crypsis in nest construction and location (as discussed also by Briggs 2018), and perhaps behavioural factors relating to maturity and experience. Pair 1 did not cease brooding completely until Day 14 of the nestling period, nearly twice as long in the tropics (6–7 days: Briggs 2018), a factor perhaps related to ambient temperatures or differing defence needs. Both pairs (Pair 1 and Pair 2) had encounters with Grey Goshawks *Accipiter novaehollandiae* and Brown Goshawks *A. fasciatus* but, from this small sample, Pair 1 appeared more aggressive in response. Pair 1's changeovers in incubating and brooding were fast. High rainfall in the early years of the study may explain high pair and prey densities and increased breeding activity; however, Pair 1 was just as productive in years of lower rainfall from 2012 to 2016. Antagonism between the pairs may explain Pair 2's breeding failure in 2012, as one instance of contact aggression (assumed to be between one Baza from Pair 1 and one from Pair 2) on a perch adjacent to Pair 2's nest (Nest 4 of this study) was observed.

Our findings on roles of the male and female in the breeding cycle generally accord with previous studies, showing that both the male and female share incubation and brooding almost equally, and for the first time recording male overnight shifts. Male overnight incubation and brooding may be under-recorded in raptors, although it has been recorded in the Square-tailed Kite *Lophoictinia isura* (Lutter *et al.* 2004).

Foraging and prey were similar to previously descriptions (e.g. Czechura 1993; Marchant & Higgins 1993; James 2004; Briggs 2018). Foraging times were similar to other studies, though foraging often occurred later in the morning (Czechura 1993; James 2004).

Sonnenburg (1998), at Kalinga Park in suburban Brisbane, Queensland, observed two juveniles foraging on the ground, which we did not observe; perhaps more plentiful resources made it unnecessary, or dense vegetation obscured the view to potential threats at Stokers Siding.

Our observations support the view (Marchant & Higgins 1993) that agonistic interactions appear to be related to territorial activity against intruding conspecifics, including clashes between males in the non-breeding and pre-laying periods. Although *ticking* calls appear most strongly related to copulation and other pair-related breeding behaviours (including between mates off the nest while the male undulates), strident or harsher versions (as for *wee-choo* calls) are also associated with agonistic or territorial encounters. Our data show that both call types are associated with various activities across all stages of the annual cycle.

Our observations suggest, and atlas data show (Cooper *et al.* 2014), some winter dispersal or migration, particularly away from cold upland areas in New South Wales, although Bazas remain year-round on the subtropical New South Wales coast and may make only local movements away from breeding territories. Our observation of pairs of adults foraging in the Tweed region in April and August suggest that in far northern, subtropical New South Wales, pairs may be resident, and may hold their territories by staying active at nest sites in the non-breeding season. The Tweed region (where there are numerous sheltered gullies on the leeward side of ranges in a high-rainfall zone) appears to be a population stronghold for the species in New South Wales.

Now that the behaviour of the Pacific Baza is well known from several post-2000 studies (James 2004; Morgan & Morgan 2010; Briggs 2018), and its recent range expansion in New South Wales is one of the few positive raptor trends (Cooper *et al.* 2014), future work might usefully concentrate on population aspects (e.g. nest dispersion and breeding density), movements and long-term productivity.

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Appendix 1. Estimated weights of prey items of Pacific Bazas, Stokers Siding, NSW. * = very large individuals or gravid.

Prey item	*Mass (g)*			
	Small	*Medium*	*Max.*	*Source*
Female Goliath Stick Insect *Eurycnema goliath*			24–28*	Czechura (1993); J. Hasenpusch pers. comm.
		11–14		J. Sinclair pers. comm.; M. Gleeson pers. comm.
Frog			30	Czechura (1993)
		8.7		P. Couper pers. comm.
Cicada	1.6			Lin (1979); P. Couper pers. comm.
Large larva		8–10		Robin Kruse pers. comm.

Appendix 2. Breeding of Pacific Bazas at the Stokers Siding study site and at Murwillumbah and Cudgera Creek, NSW. Timing at Murwillumbah is assumed from heavily dependent juveniles. * = inferred from behaviour and other observations.

Nest no.	*Pair no.*	*Years nest used*	*No. young fledged*	*First sighting*	*Nest building*	*Lay*	*First hatch*	*End of brooding*	*Fledging*	*Last sighting*	*Nest details*		*Length of period*			
											Nest tree	*Approx. height above ground (m)*	*Pre-laying (days)*	*Nest building (days)*	*Incubation (days)*	*Nestling (days)*
1	1	2007	2						7–14 Feb.	29 Mar. 2008	Camphor Laurel	10				
1	1	2008	3	16 Sep.					16 Dec.	15 Mar. 2009	Camphor Laurel	10				
1	1	2009	0	25 Aug.	31 Aug.–6 Sep.						Camphor Laurel	10		7		
2	1	2009	3		15 Sep.–3 Oct.	4 Oct.	4 Nov. ± 1day	14 Nov.	10–13 Dec.	21 Mar. 2010	Ironbark	12	39	19	30–32	36–39
2	1	2010	0	6 Sep.	7–14 Sep.							12		8		
3	1	2010	2		30 Sep.–7 Oct.	8 Oct.	7 Nov.	18–20 Nov.	15–16 Dec.	29 May 2011	White Mahogany	16	32	8	30	38
2	1	2010	0		18/19–23 Dec.						Ironbark	12		6		
Unknown	3	2010	2						Dec.		Not found					
5	1	2011	1–3	7 Oct.					Mid Dec.	1 Feb. 2012	Not found					
4	2	2011	0			30 Oct.–2 Nov.	3 Dec.				Box Mistletoe in Flooded Gum	16	21–25		30–34	
6	1	2012	2	1 Sep.	*c.* late Sep.	24–26 Oct.	23–26 Nov.	3–7 Dec.	30–31 Dec.	24 May 2013	Brush Box	12	53–55		29–32	37 ± 1
4	2	2012	0		14 Oct–1 Nov.									19		
7	1	2013	3	20 Aug.	In progress 30 Sep.		3 or 4 Nov.	12–14 Nov.	10–13 Dec.	25 Feb. 2014	Brush Box	16	43		Max. 33	37–38
8	1	2014	2	7 Aug.					Mid Dec.	17 Jan. 2015			56			

Appendix 2 continued

Nest no.	*Pair no.*	*Years nest used*	*No. young fledged*	*First sighting*	*Nest building*	*Lay*	*First hatch*	*End of brooding*	*Fledging*	*Last sighting*	*Nest details*		*Length of period*			
											Nest tree	*Approx. height above ground (m)*	*Pre-laying (days)*	*Nest building (days)*	*Incubation (days)*	*Nestling (days)*
9	1	2015	3	23 Aug.			5 Nov. ± 1 day	16 Nov.	12 & 13 Dec.	24 Mar. 2016	Eucalypt		40			36–39
10	1	2017	1					21–23 Nov.	Dec.	7 Mar. 2018	Not found					
Murwillumbah		2013	2						Late Dec.		Not found					
Cudgera Creek		2013	2						Late Feb.		Eucalypt					