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ARTICLE

Timing of breeding and wing moult in the Yellow White-eye (*Zosterops luteus*) near Broome, Western Australia

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Abstract. This study examines the timing of breeding and wing moult in Yellow White-eyes in the Broome region using data from 2,991 birds captured in banding studies. It concludes that Yellow White-eyes in this location predominately breed from December to February. The study also suggests that rainfall has an influence on the timing of breeding each year, and that the early onset of the rainy season may stimulate Yellow White-eyes to breed earlier than in years when the first rains fall later. The high proportion of actively-breeding adults also undergoing wing moult is revealed.

Keywords. Zosteropidae, banding study, breeding biology

Introduction

A bird's survival depends on its ability to meet the energetic demands placed on its body. In addition to demands caused by environmental stressors, each adult faces annual periods of high energy demand due to breeding and the need to moult. Understanding the timing of these two activities is an essential part of appreciating how a bird is adapted to its environment.

This study focuses on the Yellow White-eye (*Zosterops luteus*), a small arboreal passerine found in coastal and near-coastal habitat from Shark Bay to the Gulf of Carpentaria, Australia (Barrett *et al.* 2003). At the study sites on the west Kimberley coast near Broome flocks of Yellow White-eyes are regularly observed foraging in trees, gleaning insects from foliage and flowers and probing flowers for nectar in the mangrove forests and nearby swamps, vine thickets and woodlands (Johnstone 1990, personal observations).

Nesting behaviour has rarely been documented in this species and the timing of breeding is poorly understood (Barrett *et al.* 2003; Higgins *et al.* 2006). Published reports that do exist are conflicting. For example, Johnstone and Storr (2004) state that eggs are laid in the Kimberley from November to March, whereas other reports from northern Australia observed breeding from April to November (Barrett *et al.* 2003) or October to January (Frith and Davies 1961). A study in Darwin Harbour (Noske 1996) recorded that Yellow White-eyes showed no obvious seasonality in breeding, with nests or fledglings being reported in all months except March, August and November.

Moulting of wing feathers is a gradual process involving high energetic costs, both from the production of new feathers and from decreased flight efficiency caused by gaps in the wings as newly-grown feathers push out and replace those that are old and worn. Research on a range of finches and honeyeaters in the Kimberley region has revealed that breeding and moult are generally mutually exclusive, the prevalent tendency being for birds to undertake wing moult at the end of the breeding season (Lewis 2010; unpublished data). However, observations from Yellow White-eyes reveal a different moult strategy (J. Lewis and K. G., A. and D.I. Rogers cited in Higgins *et al.* 2006) which is further explored in this study.

To establish the timing of breeding and wing moult, and to test the relationship between these two activities in Yellow White-eyes near Broome, Western Australia, this study examined data from 2991 birds captured during banding studies. As the connection between the breeding season and rainfall or the effects of rain has been shown in a number of species in northern Australia (Frith and Davies 1961), the study also examined daily rainfall data gathered by the Bureau of Meteorology at Broome Airport to determine if a relationship

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between the timing of Yellow White-eye breeding and the onset and duration of the Wet Season could be established.

Methods

Yellow White-eyes were captured during separate studies by the authors at locations between Broome Port (18°0'26"S; 122°12'29"E) and Barred Creek (17° 39'46"S; 122°11'21"E) from 1997 to 2010. Records were also collected by the Broome Bird Observatory (BBO) in the same period at Crab Creek (17°59'14"S; 122°22'4"E).

Birds were captured using mist-nets erected on a rotational basis at 8 banding sites, seven of which are less than 250 m from the coast. Three of the sites are in, or immediately adjacent to mangrove forests; the other 5 are near or in paperbark swamps or coastal vine thickets. All sites are within a 35 km radius of Broome Airport Weather Station 003003 where rainfall data are collected according to the protocols of the Bureau of Meteorology. Records are available from the Bureau of Meteorology website http://www.bom.gov.au/climate/data/weather-data.shtml. A fall of ≥25 mm rain was chosen to identify the start of the wet season. In fact, in 6 out of the 10 years where the onset of breeding was investigated, ≥50 mm of rain occurred on the same or day following a fall 25 mm, indicating a tendency for 'the Wet' to arrive with a deluge rather than a drizzle (Bureau of Meteorology 2010).

Each individual caught was banded on the right tarsus with a numbered metal band from the Australian Bird and Bat Banding Scheme (ABBBS) and examined to identify their age. As juvenile Yellow White-eyes are very similar to adults (Higgins *et al.* 2006), the characteristics used to distinguish juveniles from adults were developed from published data (Higgins *et al.* 2006) and the combined experience of local ornithologists. Juvenile birds were identified by the presence of several of the following characteristics: duller plumage; incomplete, very narrow or slightly buff-coloured eye ring; bare underwing; all new wing feathers; very loose or fluffy body feathers and/or under-tail coverts. The presence of a synchronous tail bar was not used as a distinguishing indicator as this characteristic was also regularly observed on captured individuals known to be adults.

Primary moult was scored according to the ABBBS conventions in Lowe (1989). Birds were considered to be actively moulting if one or more of the primary feathers was less than fully grown. The breeding status of each captured adult was established by visually examining the brood patch and cloaca. Brood patches were scored on a scale of 0 to 3 (Lowe 1989) where:

0. No active brood patch;
1. Loss of feathers from thorax to cloaca; inflamed and shiny skin;
2. Well developed brood patch with heavy vascularisation and inflamed skin;
3. Fully developed brood patch with heavy blister-like swelling and a whitish 'waterbed' appearance

The presence of an active brood patch was accepted as evidence that a bird was breeding.

The authors' individual banding data from 1997 to 2010 were combined to produce monthly totals. Where pooled data for a particular month was less than a 100 birds, it was supplemented with data supplied by Broome Bird Observatory.

Results and Discussion

Between 1997 and 2010, 82 banding sessions resulted in the capture of 2,991 Yellow White-eyes (Table 1). Of these, 2,873 individuals were determined to be adults and 118 (3.95%) to be juveniles.

Presence of brood patches

A total of 258 individuals (8.9% of captured adults) were considered to have an active brood patch based on the characteristics described in the ABBBS bander's manual (Lowe 1989).

Although studies report that both sexes incubate eggs (Noske cited in Higgins *et al.* 2006), no specific descriptions of Yellow White-eye brood patches or cloacal protuberances have been published (Higgins *et al.* 2006). Our field observations revealed that, at times when some birds had swollen brood patches, other adult individuals without swollen brood patches had swellings around the vent area that pushed their cloacae upwards or forward. As male and female Yellow White-eyes are identical in plumage and size, and can not therefore be separated on appearance, it was not possible to identify the sex of individuals with this characteristic. Considerable unresolved debate amongst local researchers resulted, both over the implications of this observation and the particular characteristics that could or should be used to denote active breeding in adult males. This may have led to an undercount of actively breeding males, impacting on the results in Figure 1.

In addition, we observed that while some individuals, identified as female from the shape of their backward-pointing cloacae, had very swollen abdomens, few attained a stage 3 brood patch with the blister-like swelling described in Lowe (1989). The greatest swelling seemed to occur when eggs were about to be laid, but the skin remained pink or red rather than whitish. It is possible that, once birds started brooding a clutch, they did not forage over a wide enough area to be captured in our mist nets, thereby biasing the sample. An-

Table 1. Number of Yellow White-eyes captured on a monthly basis between 1997 and 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
No. adult birds	200	173	279	250	202	201	425	544	209	118	137	135	2873
No. juveniles	13	48	18	14	4	2	9	1	2	4	2	1	118
No. of years sampled	8	6	6	7	5	7	7	8	8	7	5	8	

other possibility worthy of further investigation is whether the need for efficient heat-exchange mechanisms is less urgent in tropical climates, obviating the need for the hugely-swollen brood patch described by Lowe.

Onset of breeding

Analysis of months when birds with an active brood patch were present indicates that Yellow White-eyes in the Broome region predominately breed in the period between December and February (Figure 1). These months, when over 30% of adults captured had an active brood patch, equate to the start of the wet season (Fig. 1). This supports Frith and Davies (1961) findings in the Adelaide River District of the Northern Territory that insectivorous birds, such as Yellow White-eye, commenced breeding as soon as wet season storms began.

There was a marked peak in the number of birds identifiable as juveniles captured in February and, to a lesser extent, in March, confirming that breeding had occurred in the preceding months (Fig. 1). After March, a rapid decline in the number of identifiable juveniles was evident. Observations from recaptured individuals confirmed that there is only a short period when juvenile birds can be distinguished from adults (Higgins *et al.* 2006). For example, 2 individuals identified as juveniles on 22 February 2003 when 45% of birds captured were juveniles showed no juvenile characteristics when recaptured 2 months later, on 25 April.

Timing of breeding in relation to the onset of rain

Although amalgamating monthly data over a 13 year period produces a clear trend of the timing of breeding, there were limitations that restricted detailed analysis for single years. Firstly, banding did not occur at sites where Yellow White-eyes are prevalent every month and was subject to the vagaries of weather, road conditions and tides which influenced the ability to catch birds, even if they were present. Small samples may not represent the actual breeding activity of birds, rather the challenges of mist-netting at that time of the year. The lack of December data for some years is a particular limitation. Secondly, the authors' experience indicates that rainfall is not uniform across the study sites. It is not uncommon for rainfall at Broome Airport to be twice or half that occurring up the coast or across Roebuck Bay. Therefore, Bureau of Meteorology rainfall data can only give an indication of the rain that may have occurred at a capture site.

Nevertheless, analysis of data for the years 2000-2010 suggests a correlation between the onset of breed-

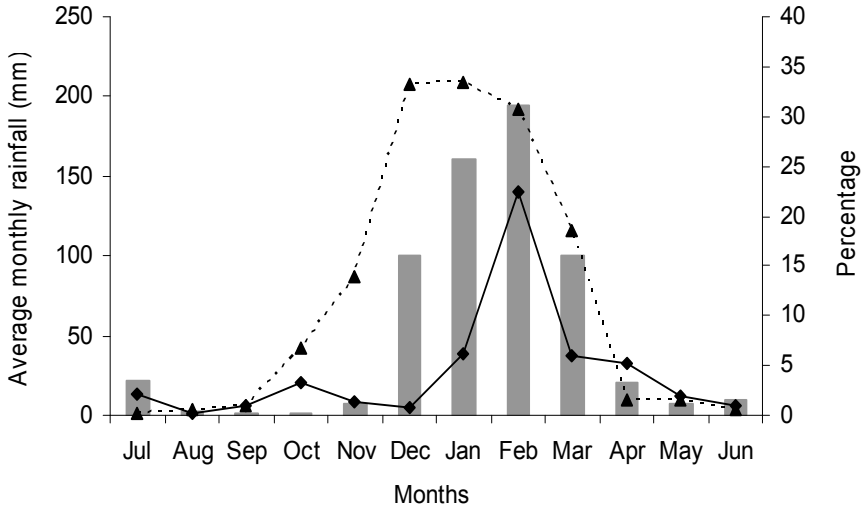

Figure 1. The percentage of adult Yellow White-eyes with active brood patches (triangle), and juveniles (diamonds) captured on a monthly basis in the Broome region from 1997 to 2010 compared to average annual rainfall for 2000-2010 (solid bars).

Table 2. The relationship between rainfall stimuli and the capture of Yellow White-eyes with active brood patches (BPs).

	2000-1	2002-3	2003-4	2004-5	2007-8	2009-10
% adults with active BPs in December	68.8	0	unknown	unknown	0	30.8
% adults with active BPs in January and sample size (*n*)	52.4 (*n* = 42)	25 (*n* = 8)	25.8 (*n* = 31)	0 (*n* = 4)	23.4 (*n* = 47)	46.9 (*n* = 49)
Date of first fall of ≥25 mm rain	8/12/00	19/1/03	1/1/04	31/12/04	29/12/07	6/11/09
1st banding date of birds with active BPs after ≥25mm rain	27/12/00	14/1/03	17/1/04	17/2/05	18/1/08	29/12/09
No. days between ≥25 mm rain and birds with active BPs	19	-5	16	48	19	No Nov. banding

ing and the arrival of rain (Fig. 2). In years when the first rain fell relatively early, breeding also began earlier than in other years (Table 2). For example, in December 2000 the first fall of ≥25 mm was on 8 December. By 27 December 68% of adults had active brood patches. Similarly, in 2009 the first fall of ≥25 mm was on 6 November, with November having a total of 46.2 mm. On 30 December 2009 30.8% of adults captured had active brood patches.

Conversely, in years when the first fall of rain was delayed, breeding also commenced later (Table 2). In 2007 the first fall of ≥25 mm did not occur until 29 December. No birds caught in December had an active brood patch, however, on 18 January 2008, 23.4% of birds caught had active brood patches. A similar pattern was recorded in 2003-4 with the first rain falling on 1 January 2004 and 25.8% of birds caught having active brood patches on 17 January.

Table 2 lists the length of time between the first fall of ≥25 mm rain and the first subsequent banding date when birds with active brood patches were captured. Sixteen days is the shortest duration recorded, revealing that, if a single fall of rain is the trigger that stimulates breeding, some birds have the capacity to respond very rapidly. However, data from January 2003 may indicate another pattern. On 14 January 2003 birds had commenced breeding even though only 15.4 mm of rain had fallen in that month and 8.6 mm the month before, suggesting that a cumulative amount of, for example 25 mm may be the trigger, rather than the volume of an individual fall.

The end of the breeding season

Analysis of the correlation between the end of the breeding season and the cessation of rain is hampered by lack of data. In the years when good volumes of rain fell in March and April, in 2007 and 2006 for example, catches were not made in the following months. Data for 2002 suggests that the late start of the rains, (first fall of ≥25 mm being on 17 January) and huge falls of rain in February (396 mm) resulted in some breeding continuing into April, 1 out of 11 adults captured having an active brood patch on 13 April. In 2003 the first fall of ≥25 mm did not occur until 19 January and rain again fell heavily in February (356 mm). In this instance a bird with an active brood patch was found in May. Conversely, in the 2009-2010 wet season, although breeding started early due to November rains, the absence of rain in February may have impacted on the season's continuation. While 31% of

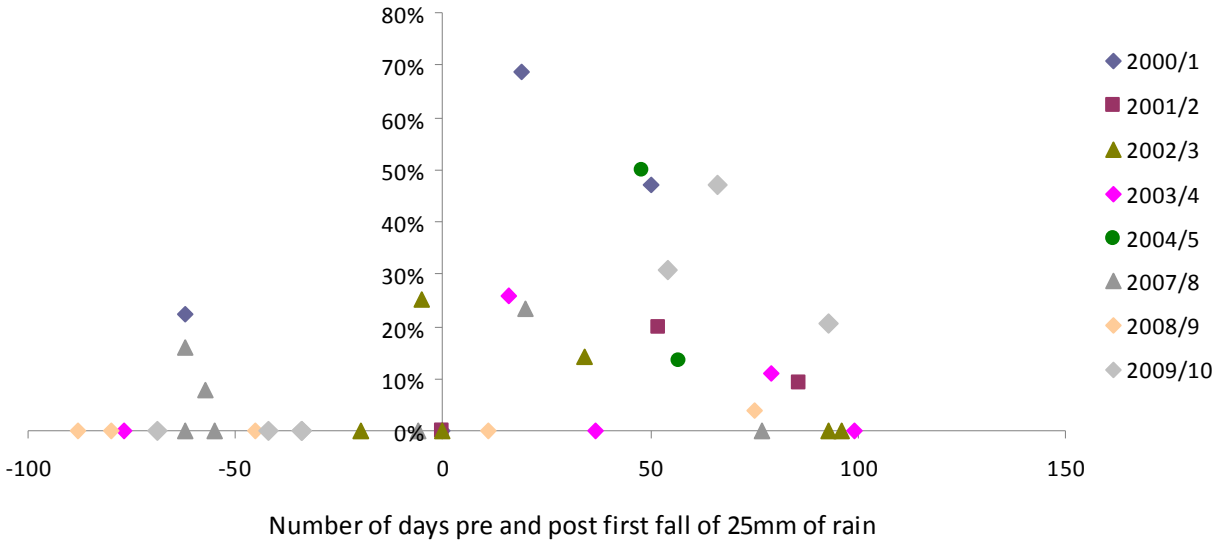

Figure 2. Percentage of Yellow White-eyes with an active brood patch pre and post the first fall of 25 mm of rain each wet season.

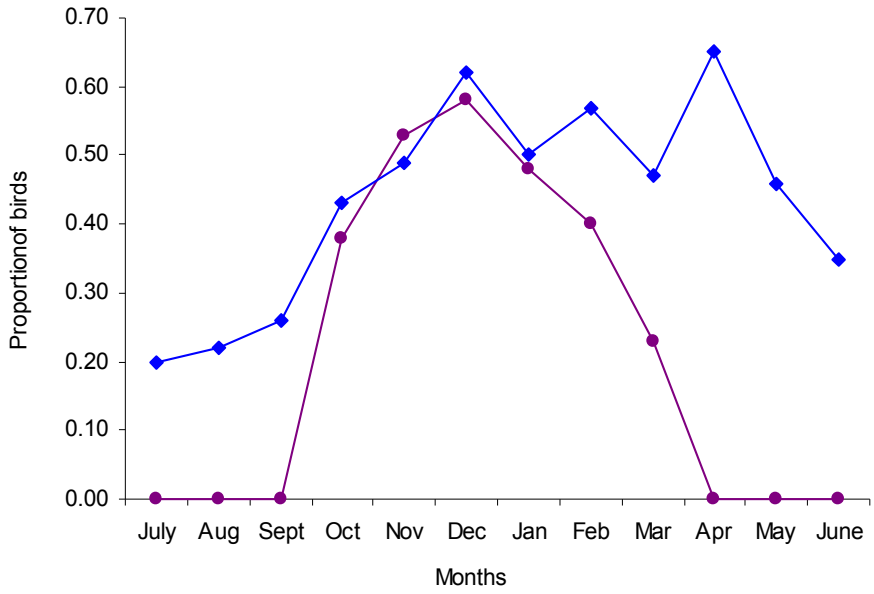

Figure 3. Proportion of adult (blue) and actively-breeding adult (purple) Yellow White-eyes with active wing moult.

adults still had brood patches on 25 March, this had fallen to 4.8% by 22 April.

Unseasonal breeding events

Not surprisingly, given studies on other species (Zann *et al.* 1995), unseasonal rain appears, in some cases, to provide an explanation for the existence of a few birds with active brood patches outside the main breeding season. For example, in 2004, 35.6 mm of rain fell in the last week of May and one out of eleven birds caught on 17 June had an active brood patch. Similarly, 11 mm fell on 25 August 2005 and a bird was captured with an active brood patch on 11 September. However, there are other times when birds with active brood patches have been caught despite no rainfall being recorded at Broome Airport, September 2000 (n = 1), and October 2001 (n = 3) and 2007 (n = 3) being examples. As these birds were all caught as part of BBO's cooperative banding program, the possibility of active brood patches being mistakenly identified can not be discounted. Alternatively, although rain may not have fallen at the Bureau of Meteorology data collection site, localised rain may have fallen at Crab Creek.

Timing of the moult of primary wing feathers

Examination of the wing moult of 2063 adults in this study revealed that Yellow White-eyes have quite a different strategy from those Kimberley species which moult their wing feathers after the breeding season is over (Fig. 3). Breeding and moult are not mutually exclusive. Primary wing moult occurred in all months of the year, peaking in the breeding season from December to February, and reducing slightly in the colder months of the year in July and August when the energetic costs of loss of insulation at night are higher. Actively breeding birds also exhibited active wing moult (Fig. 3). 58% of birds with active brood patches captured in December and 48% captured in January also had active wing moult. This suggests either that the energetic demands of breeding and moulting can be met by the food resources available during the early wet season, or that birds have the capacity to suspend wing moult while breeding occurs.

Rainfall per se or an associated influence?

Yellow White-eyes are known to eat mosquitoes (Johnstone 1990). Our field notes indicate that Yellow White-eyes are more abundant both when mangroves are flowering and when mosquitoes and sand flies are numerous, for example, when high spring tides and unseasonal rain lead to an explosion in numbers of the common saltmarsh mosquito, *Aedes vigilax* (Shire of Broome 2010). As rainfall is known to influence both the presence of insects in mangrove forests and the flowering of mangrove plants, (Noske 1996), further work is required to establish if it is, in fact, the onset of the rainy season per se that stimulates Yellow White-eye breeding or a related aspect, important to Yellow White-eye biology, that has also been triggered by the onset of rain.

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