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Breeding behaviour of a pair of Spotted Harriers *Circus assimilis* near Tamworth, New South Wales

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Abstract. A pair of breeding Spotted Harriers *Circus assimilis* was observed in an agricultural environment near Tamworth, New South Wales, in winter–spring 2020 for 290 hours over 68 days from pre-laying and incubation to the post-fledging period. Laying occurred at the end of June, hatching at the beginning of August and fledging in mid September. Only the female incubated and brooded, and the male supplied all prey from the incubation period to late in Week 3 of the nestling period, after which the female contributed. Two chicks fledged of three that hatched; there was some sibling competition for food. The incubation period lasted 34 ± 1 days, and the nestling period 43 days for the older (female) chick and *c.* 40 days for the younger (male) chick. Prey consisted of ground-dwelling small mammals, birds and reptiles that are typical of agricultural land. The male's prey-delivery rate to the incubating female was 0.22 item/h. Overall, the male delivered 0.31 item/h and the female 0.09 item/h to the nestlings, for a combined average of 0.4 item/h, peaking in the pre-fledging fortnight. The combined rate in the post-fledging period was 0.39 item/h (Week 1), declining to 0.16 item/h to the fledglings in Week 2 when only the male delivered prey and the adult female consumed some of his catch. Estimated biomass delivered ranged between ~20 and ~100 g/item (often 20–50 g/item). Breeding behaviour and nestling/fledgling growth and development are described. The juveniles appeared to be dependent or partly so for at least 3 weeks, and apparently roosted in the nest area in Week 4, after which they could not be located.

Introduction

The Spotted Harrier *Circus assimilis* is a medium-sized (~410–750 g), aerially foraging raptor that captures terrestrial prey in open habitats, and nests in open or remnant woodland (Marchant & Higgins 1993). It is listed as threatened (Vulnerable) in New South Wales (New South Wales *Biodiversity Conservation Act 2016*), but is little studied in that state. Marchant & Higgins (1993) reviewed the sole major study by Baker-Gabb (1982, 1984a), conducted in arid Victoria, and the otherwise anecdotal information on the Harrier's biology. Since then, there has been one study of the Harrier's breeding biology, foraging behaviour and diet in central Australia (Aumann 2001a,b,c); a description by Debus (1995) of an aerial advertisement display that has rarely been reported in this species (Marchant & Higgins 1993); a prey list for Western Australia, and several notes on incidental prey and foraging behaviour (Johnstone & Storr 1998; Christie 2004; Hassell 2004; Buij 2014; Hollands 2021). Morley (2021), in describing some aspects of breeding behaviour, provided background on the Harrier's biology and diet. Some aspects of behaviour and routines in the pre-laying period are little described.

In south-eastern Australia, the Spotted Harrier inhabits grassland, open woodland and agricultural land (e.g. pasture, dryland cropping) and its breeding diet in the agricultural belt includes quail (Phasianidae) and House Mice *Mus musculus* (Marchant & Higgins 1993). Autumn–winter breeding by the Harrier is associated with mouse plagues (Baker-Gabb 1985; Schrader 1985; Morley 2021). Although Baker-Gabb (1982) studied some behavioural aspects of the breeding cycle (territory and nest establishment and defence, courtship and mating, sex-roles, parental behaviour, nestling and fledgling behaviour), there has been no record of parental time-budgets and limited information (Morley 2021) on parental feeding rates and other behaviour during the incubation, nestling and early post-fledging stages.

Confusion between juvenile Spotted Harriers and adult Swamp Harriers *C. approximans* persists in modern publications and among birdwatchers (e.g. recent published cases noted by Debus *et al.* 2018). We note here a further example of a juvenile Spotted Harrier mislabelled as a Swamp Harrier (McCrie & Noske 2015, p. 117), such confusion potentially blurring the ecological distinction between the two harrier species. For comparison, photographs of adult Swamp Harriers appear elsewhere (Debus 2019; Seaton *et al.* 2019; Hollands 2021).

Here we describe and quantify the breeding cycle of a pair of Spotted Harriers in the New South Wales sheep–wheat belt, from the pre-laying phase until the juveniles approached independence, and list observed prey items. We also provide photographs of the juveniles in our study, highlighting their plumage characters, in order to emphasise their morphological differences from the Swamp Harrier.

Study area and methods

The Spotted Harriers' nest was located on private agricultural land (exact location withheld), ~15 km south of Tamworth (31°05'S, 150°55'E) in northern inland New South Wales. The habitat consists of a mosaic of crops,

pasture, paddock trees and remnant eucalypt woodland, with some planted shelter belts of native trees and shrubs, on gently undulating land traversed by wooded creeklines. Despite the extreme drought in 2019 and following above-average rainfall in the first half of 2020, the under-stocked subject property had abundant tall grass cover and was well populated with Stubble Quail *Coturnix pectoralis* and Brown Quail *Synoicus ypsilophorus* (SJSD pers. obs.). There were also reportedly increasing numbers of House Mice in the surrounding North-west Slopes region by August 2020 (A. Baker pers. comm.). A neighbouring property also had good grass cover at the time and, together with the study property, provided an area of contiguous suitable grassland foraging habitat of ~400 ha (landholder pers. comm.). In addition, adjoining crop paddocks of Oats *Avena sativa* were harvested during the Harriers' post-fledging period, thus potentially providing exposed and vulnerable prey.

The Harrier nest was observed from the pre-laying phase to near independence of the juveniles by means of focal-animal sampling, by a team of observers in rotation (often in pairs), using binoculars and telescopes and assisted by digital photography. Observations (total 290 hours) covered 68 days from the pre-laying period (19 June) until the juveniles could no longer be located (9 October): 6 h over three mornings late in the pre-laying period, 54.5 h over 16 days in the incubation period, 165.5 h over 33 days in the nestling period, and 64 h over 16 days in the post-fledging period. Observation sessions of usually 1–3 h (commonly 2 h) were conducted initially every few days, increasing to almost daily and several times per day (sometimes continuously) as the nestling period progressed. An attempt was made to cover most daylight hours, although the period before 0800 h was under-represented, because of observer travel time to the site. Other than the pre-laying period, for logistical reasons observation sessions were biased towards afternoons, especially during the incubation period (Table 1). In Weeks 4–6 of the nestling period, observation periods on a few days spanned 0630–1400 h or 0900–1730 h continuously. The height of the nest tree and of the nest above ground were estimated (from the viewing point) from an observer standing against the trunk, and from adjacent 2-m-high fence poles.

Because the adult Harriers were habituated to routine farm activity and were confiding and approachable, observations were made from an unconcealed position on the ground in a grassy paddock ~80 m from the nest. Approach to the best viewing point involved driving on a farm track almost below the nest and past some of the Harriers' regular perches on fenceposts, yet the Harriers did not flush or appear alarmed. The male and female were identifiable by size dimorphism (female larger) when seen together, and by the female having a protruding bent feather on her right inner forewing, which persisted throughout the breeding cycle. Similarly, the two fledglings were sexed as female (the older) and male (the younger) by size relative to each other and to the adult female.

The Harriers' diet was determined by sighting delivered prey in the adults' talons as they approached the nest area and exchanged prey in flight, and by viewing enlarged digital photographs of some such deliveries. Only one pellet was found under the nest, amongst tall, dense ground vegetation; it contained feathers consistent with one of the observed prey species.

Results

History of the breeding territory

In *c.* 2014, another pair of Spotted Harriers had started nesting at this study site, but suddenly disappeared when the breeding event should have progressed. The landholder was then told by a neighbour that he (the neighbour) had shot two 'big, dark chicken hawks' over concern about lambs, which suggests that the Harriers were the shooter's victims. In 2020, the subject pair of Harriers arrived, occupied the territory and built a nest in almost exactly the same place, in the adjacent tree.

Nest site

The Harriers' nest, a rather flat stick platform, was built in the top of a mature, spreading Rough-barked Apple *Angophora floribunda*, on horizontal branches amid the outer foliage and somewhat exposed to the sky. It was estimated to be ~17 m above the ground, the nest tree being ~20 m tall and >1 m in diameter at breast height. The nest tree was located in a creekline amid other trees including Rough-barked Apple, Eastern Grey Box *Eucalyptus moluccana*, Yellow Box *E. melliodora* and Blakely's Red Gum *E. blakelyi*. During the pre-laying and early incubation phase, the male Harrier sometimes perched on a high horizontal branch in the top of what had been the previous pair's nest tree (Rough-barked Apple) ~10 m from the current nest. There were green crops (Oats) on adjoining properties within sight of the Harriers' nest, and sown pasture of tall tropical grasses Digit Grass *Digitaria eriantha* and Bambatsi Panic *Panicum coloratum* on the property, ~1 km from the nest, which appeared to be a favoured hunting ground.

Table 1. Observation schedule (hours of observation) at a Spotted Harrier nest near Tamworth, NSW, during each 2-hour interval of daylight (Eastern Standard Time), pre-laying period to post-fledging period, June–October 2020.

Stage	*<0800*	*0801–1000*	*1001–1200*	*1201–1400*	*1401–1600*	*>1600*
Pre-laying		1.5	4.5			
Incubation	2.0	4.0	7.5	5.0	25.0	11.0
Nestling	3.0	18.0	37.5	40.0	49.5	17.5
Post-fledging	0.75	11.5	14.25	16.25	19.0	2.0
Total	**5.75**	**35.0**	**63.75**	**61.25**	**93.5**	**30.5**

Breeding chronology

The landholders reported the pair of Harriers and their nest in June 2020, with one Harrier seen carrying a stick to the nest on 17 and 18 June. Building and/or lining, by the female, appeared to continue until 19 June, but was not observed to occur on 24 and 27 June. Incubation was inferred to have started on 29 June ± 1 day (female not incubating on 27 June, incubating by 1 July). Laying of at least three eggs (three hatched) thus occurred at the end of June/start of July. Pipping or hatching was inferred, from the sitting female's restless behaviour, on 2 August. The female for the first time took prey to the nest (instead of consuming it off the nest) and offered pieces into the nest cup on 3 August, with a chick's downy white head first seen on 4 August. Branching occurred on 13 September, and fledging (of two surviving chicks) on 14 and 15 September.

Reaction to disturbance

The Harriers' nest was located almost directly above a farm track, which was overhung by the opposite side of the nest tree. There was daily movement on the track by various farm vehicles (utility, quad bike and, once, a ride-on mower), the landholder(s) walking with dogs, and observers' vehicles arriving and departing. The Harriers appeared undisturbed by such routine, familiar activity, the incubating or brooding female simply looking down at such activity passing below and sometimes appeared to ignore it. The Harriers sometimes perched atop the 2-m-high poles of a deer fence, and tolerated vehicles or people passing within ~10 m without flushing. They sometimes flew low over the observation point, or landed on a deer-fence pole within ~30 m of the observers. The female also remained perched high in a tall Yellow Box (a favourite tree) over the track, ~30 m from the nest, while two people installed a passive acoustic monitor on the trunk of the nest tree (see below). The adult Harriers thus seemed habituated to benign human presence, and were not overtly alarmed by human activities. The fledged juveniles, in trees, on fenceposts or on the ground, were similarly confiding in the presence of people or vehicles.

Aerial display

The male Harrier was seen to perform an aerial undulating display on two occasions, rising and falling with continuous, languid sweeping wing-beats. On the first occasion, late in the incubation period (female incubating), he left a fencepost and flew purposefully, with some soaring and slow flapping, to ~600 m from the nest then performed the display, although no intruding Harrier could be seen. On the second, at the end of the nestling period after both adult Harriers had departed from the nest area together, he performed the display from high soaring flight ~500 m from the nest area, but again no intruder was seen.

Vocalisations

The adult Spotted Harriers used three main vocalisations, as described by Marchant & Higgins (1993): the shrill, monosyllabic *seep* solicitation call, often uttered in series, and used mainly by the female; the soft chittering call *kitter-kitter…* used by both male and female when arriving at the nest; and a louder chatter sometimes used during agonistic encounters with other species, e.g. in flight when evading aggressive mobbing or harassment. Advanced nestlings and fledged juveniles food-begged with the *seep* call, and a nestling occasionally used the chatter when defending a food item against a sibling. Additional information on vocalisations recorded near the nest will be provided in a later comparison (C. Larkin unpubl. data).

In the pre-laying period, the female was highly vocal from the nest or a fencepost perch, or in the airspace around the nest, *seep*-calling frequently while the male was foraging in view, or when they interacted aerially. When he arrived in the nest tree, she called increasingly frequently and shrilly, until he apparently departed and was later seen hunting.

Similarly, in the first week of the incubation period, the female was highly vocal, *seep*-calling from the nest or its vicinity. She frequently called at the male while he was in the nest area without prey or foraging within sight, and even displaced him from a perch, whereupon he went foraging after they had aerially interacted briefly. Thereafter, when noted, the female called only or mostly during aerial prey exchanges. The male occasionally *seep*-called softly and intermittently from a fencepost while the female incubated after a food exchange; she did not respond.

During the nestling period, the female sometimes *seep*-called during aerial food exchanges, or from the nest in the male's presence (or apparent absence), or after feeding the chicks or when flying. The male occasionally appeared to utter a food-call when bringing prey: once chattering while approaching the nest tree for an aerial exchange; or *seep*-calling with the female as prey was transferred aerially; or at fledging time *seep*-calling as he approached, circling, before dropping prey on the nest in the adult female's absence.

Pre-laying period

Over three non-consecutive mornings in the last week or so preceding the inferred laying dates, the female mostly stood on the nest (42% of the observation time of 6 h), perched in the nest tree (6%) or perched on a fencepost across the grassy paddock ~300 m from and in view of the nest (35%). For the balance (18%), she made two forays (0.3/h) to collect nesting material, was in flight over the nest area (once interacting with the male), or absent/out of view. The male once stood on the nest for 2 minutes, while the female was on a fencepost, and he once perched in the nest tree, for an undetermined time (possibly <1 min.; departure unobserved) while the female was standing on the nest. He was otherwise hunting over the paddocks, in flight in the nest area, or absent/out of view. Courtship (supplementary) feeding was not observed during the limited observation time (6 h) close to the laying dates.

On some occasions, the female performed apparent advertisement or vigilance activities as well as seeking food from the male, e.g. on 19 June she made two circling flights over the treetops around the nest patch, sometimes calling. On 27 June, she soared, with slow flapping and legs partly lowered, over the nest area before soaring more distantly. When the male appeared low over the nest

area, she rose, they converged in soaring flight, the male's legs lowered (but without prey), and he then descended to hunt low over distant paddocks. She then flew to the nest, collected nesting material, and placed it in the nest, before perching higher in the tree.

Incubation period

Only the female incubated, in timed stints of 2–104 minutes (mean 37 min., *n* = 22). The shorter stints were interrupted either by a prey delivery by the male soon after she had resettled after other breaks (e.g. standing up, collecting foliage), or towards pipping or hatching by frequent restlessness (standing up and resettling). There were 16 other stints of at least 1 h when she was incubating beyond the start and/or finish of observation sessions, including five stints of >90 minutes, four of >2 h and one of >3 h. She spent 89% of observation time (54.5 h) incubating, 5% absent (e.g. flying, feeding on delivered prey), 2% standing on the nest, 1% each perched in the nest tree or in surrounding trees, and 2% perched on fenceposts within view of the nest. Her individual absences from the nest or nest tree ranged from 1 to 16 minutes (mean 7.5 min., *n* = 30), but there were five watches of 2–3.5 h when she did not leave the nest during the entire session [standing up briefly during three watches, and on two watches incubating for the entire watches (of 2 and 3.5 h)]. She made four observed forays to collect foliage for the nest (0.1/h), in the morning and afternoon.

The male stood on the nest briefly (*c*. 1 min.) on one morning, in the female's absence (collecting foliage), in the first few days of the incubation period, and again briefly (*c*. 1 min.) at initial pipping/hatching when the female was incubating. He perched in the nest tree (<1% of observation time, on three occasions early in the incubation period and once at pipping/hatching), in surrounding trees (2%), or on fenceposts within sight of the nest (9%). Otherwise, he was flying or foraging in sight of the nest, or was absent or undetected.

The male's prey transfers to the female (*n* = 14) took place aerially, by dropping the prey as the female rolled to catch it (Figure 1), except on one occasion when the exchange took place after both descended to the ground together. The female always consumed the prey on the ground, sometimes landing on a fencepost first, and the male appeared to guard her by perching on a nearby

Figure 1. Aerial prey exchange from male to female Spotted Harrier, Tamworth, NSW, incubation period. Photos: Denise Kane

fencepost or on the ground with her while she fed. On Day 1, when the prey was lost to piracy (see later), the female called at the male and he returned within 50 minutes with another item (successfully transferred). Following a later exchange on that day, the female mantled the prey on a fencepost while the male was on a nearby post.

Interaction at the nest, at pipping/hatching, followed a prey transfer and the female returning to incubate. The male flew, chittering, to an adjacent tree then flew to the nest, where both adults chittered. Later, he flew in to the nest tree, chittered, then both left together, although he had no prey and the female quickly returned to incubate.

Incubation was inferred, from the behavioural cues described above, to have taken 34 ± 1 days.

Nestling period: parental behaviour

Only the female brooded, fed and guarded the nestlings. Her nest-attendance routine changed through the nestling period, from mostly brooding in the first 2 weeks, standing on the nest or perching in the nest tree in the middle weeks, and perching in the surrounding trees in later weeks, to being increasingly absent or unaccounted for in the final weeks (Table 2). These changes matched the growing and feathering chicks' development and ability to thermoregulate and feed themselves on delivered prey. The female roosted at the nest until at least Day 20, but on Day 22 she roosted at dusk in a favourite tree ~30 m from the nest tree. On Day 38, she performed possible enticement behaviour: for 30 minutes, she soared low over the nest area in a strong breeze, carrying prey and briefly landing in a nearby tree while the chicks watched her or jumped and flapped. She then consumed some of the prey on the ground and on a fencepost before eventually going to the nest and feeding the chicks.

In Week 1, the female's timed brooding stints lasted 5–139 minutes (mean 40 min., *n* = 6; mostly 20–45 min.), but there were six other occasions when she brooded beyond the start or finish of the watch (including once >80 min., once >2.5 h). In Week 2, she brooded for one timed stint of 9 minutes, with five other occasions when she brooded beyond the start or finish of the watch (>20 min., >40 min., >90 min., >2 h, >3 h). At the start of Week 3 (Day 15), on a cold and overcast day, she brooded for two observed stints (of >68 min. and >11 min.) but was not observed to brood in daytime thereafter. Her shorter brooding stints were typically interrupted by prey deliveries by the male.

The female fed the chicks bill to bill until their 'branching' day, though from Day 22 she sometimes dropped prey on the nest for the chicks to feed themselves. Parental feeding sessions lasted 7 and 11 minutes in Week 1 (Days 1 and 2), 12–25 minutes (mean 18 min., *n* = 3) in Week 2 (Days 10–12), 1–20 minutes (mean 9 min., *n* = 10) in Week 3, 1–13 minutes (mean 6 min., *n* = 11) in Week 4, 2–10 minutes (mean 8 min., *n* = 13) in Week 5, and 2–19 minutes (mean 7 min., *n* = 15) in Week 6. These feeding sessions partly reflected brood size, the chicks' ability to feed themselves on prey in the nest, and later the female dropping prey in the nest, and the nestlings' vigorous feeding in their final week when they exercised their wings strongly.

Table 2. Parental time-budget of female Spotted Harrier near Tamworth, NSW, in the nestling period (August–September 2020) by week: % observation time (rounded, total 165.5 h) spent in each activity. Stand = female standing on nest (including feeding herself); nest tree = perching in the nest tree; trees = perching in surrounding trees in the nest patch; post = perching on fencepost(s) within view of the nest; absent = away from nest tree and nest patch (e.g. flying, out of sight). Numbers in parentheses = numbers of hours of observation in each week. Week 1 = first week after hatching, etc.

Activity	*Week*					
	1	*2*	*3*	*4*	*5*	*6*
	(12)	*(14)*	*(23)*	*(38.5)*	*(35)*	*(43)*
Brood	87	57	6	–	–	–
Stand	9	10	17	5	1	4
Nest tree	–	6	2	7	–	–
Trees	–	3	26	30	27	21
Post	–	4	7	6	9	8
Absent	2	13	35	50	59	62
Feed chicks	2	7	7	3	4	5

In Week 1, Days 1 and 2 when there was probably one chick, the female fed it at a rate of one morsel per 3 seconds except when she consumed larger pieces. In Week 2, 35 morsels were provided over 2 minutes (~1 morsel/2 sec.) with a brief pause while the adult fed. On Day 12, the largest (oldest) chick received most of the food, but the female appeared to feed the smallest chick first; then all three chicks, with each apparently receiving similar attention. In Week 3, Day 19, over 8 minutes the female fed the oldest chick (of three) 45 morsels (~5 morsels/min.), interrupted by feeding herself. In Week 6, Day 37, the female fed mainly the smaller chick (of two survivors) one morsel per second, slowing to one morsel per 2–3 seconds. On Day 41, during parental feeding of mainly the larger chick, the smaller chick (begging) managed to obtain a morsel every few seconds (not timed precisely).

In Week 1, the female was absent from the nest for three observed stints of 5–6 minutes. In Week 2, she was absent from the nest, nest tree and surrounding guard-trees on four observed occasions of 4–106 minutes (mean 35 min.). She started perching in guard-trees, rather than on the nest or nest tree, from late in Week 2 (Day 11), coinciding also with her longest absence on a fine morning (106 min., 31 min. of which she was perched on a fencepost away from the nest patch). In Week 3, she was absent from the nest patch for 1–58 minutes (mean 21 min., *n* = 22), with one other absence of >90 minutes. Thereafter, her absences increased in duration (Week 4: 2–129 min., mean 33 min., *n* = 25, with another >2 h; Week 5: 2–140 min., mean 29 min., *n* = 24, two others >1 h, two >100 min., one >2 h, one >2.5 h; Week 6: 5–170 min., mean 42 min., *n* = 30, three >1 h, one >100 min.). Her shorter absences were typically associated with receiving prey from the male and dealing with it before taking it to the nest, or occasionally consuming it herself. Her longer absences were often associated with foraging, or were occasionally punctuated by brief flyovers of the nest patch or soaring over the nest area. She was first seen foraging early in Week 3 (Day 17), and to bring self-captured prey to the nest on Day 19. On a few occasions, food was retrieved from within the nest to feed the chicks.

The female brought green foliage to the nest throughout the nestling period until Week 6 (and one stick in Week 6), in the morning and afternoon: a rate of 0.03 item/h (n = 5). There were other occasions when she collected foliage but dropped it. The male collected a stick among trees >300 m north of the nest in Week 6 (Day 38), but did not bring it to the nest.

The male's main role was to provide food in aerial exchanges, after which he often (until Week 6) perched on a fencepost or on the ground near the female while she fed on the ground before taking the prey to the nest. He may then have been guarding her, e.g. against harassment or potential robbery (see below). He occasionally also accompanied her part-way back to the nest as she carried the food. During one aerial exchange, the prey was dropped but a Pied Butcherbird *Cracticus nigrogularis* watching the proceedings found the prey on the ground and the female Harrier then reclaimed the prey.

The male dropped one food item to the nestlings in the female's absence (Day 26), but he did not feed them bill to bill. He also sometimes flew or soared over the nest area or nest tree, possibly guarding the nest.

On Day 40, after a prey exchange as the female held the prey on a fencepost, the male landed on her back (i.e. attempted mating). That incident, and subsequent behaviour on Days 41 and 42 (e.g. brief aerial interaction and vocalisations, stick collection), suggested a possible resumption of nesting behaviour.

Nestling period: development of young

Age/stage here refers to the oldest and largest chick (a female). The youngest and smallest did not survive the downy white stage, and was last seen on Day 19 (at ~12 days old). It appeared to lag behind in development, e.g. on Day 12 it appeared less than half the size of the oldest chick, and less advanced than the middle chick on Day 10. The chicks were downy white for their first 2 weeks, becoming downy grey with a white face early in their third week. From observations through telescopes, remiges and rectrices (as burst pin-feathers) had visibly emerged on Day 19; remiges were estimated as ~5 cm long on Day 22, and ~15 cm long on Day 29. On Day 24, upperwing feathers had emerged; on Day 28, chicks were well-feathered dorsally, and on Day 29, dorsally and ventrally; at 5 weeks, they were fully feathered though with traces of down on the head. At 6 weeks, they were fully feathered, with short wings and tail (Table 3). The younger (smaller) surviving chick, a male, never caught up in size, but rapidly caught up in feather development in his final week in the nest. The chicks made audible (from ~80 m away) food-begging *seep* calls, when being fed, from Day 22. They also called (in the adults' absence, on Day 28) as a White-faced Heron *Egretta novaehollandiae* flew past the nest.

The chicks could stand, move about the nest and interact on Day 12; stretch their wings, nibble at sticks, peck at food in the female's foot and defaecate over the rim by Day 15; flap their wings on Day 16; feed themselves by picking pieces from prey in the nest on Day 19 (though unsteady on the nest); walk about the nest by Day 23; flap their wings strongly, almost lifting off on Day 32; and jump and flap on the nest on Day 34 (though still clumsy on the nest on Day 37) (Table 3). On Day 11, the downy chicks were panting on a warm morning in the female's absence, while the sun shone on the exposed nest. Both 'branched' on Day 42, returning to the nest for food, and the younger had sun-basked, standing with spread wings, on Day 37. Advanced chicks performed object play by nibbling at sticks in the nest, pecking at foliage of the nest tree, or manipulating foliage that the female had placed on the nest.

Overall, relations between the chicks appeared amicable while there were three, although the oldest sometimes received the most morsels of food and sometimes pecked the middle chick. For instance, on Day 16, the oldest obtained more than twice the food (in apparent quantity and feeding time) than the second and third chicks did. Through the middle weeks, the two surviving chicks sometimes took turns to be fed or to feed themselves from prey, and occasionally pecked at each other. Competition for food intensified in the final week. On Day 41, when the female brought prey, the older chick took it, chattering, and its sibling turned away on the nest rim. As the adult fed the older chick the younger obtained some morsels, begging with fluttering wings and a squeaky chatter. On Day 42, when the female delivered prey, the older chick seized and mantled the prey, chattering. Its sibling turned away, but then tried to acquire the food, begging, and then managed to tear and eat some prey while chattering.

The nestling period, from inferred hatching and first evidence of a chick, was 43 days for the older (female) chick and, assuming a 2-day laying and hatching interval, *c.* 40 days for the younger (male) chick, which fledged a day earlier.

Fledging

Both fledglings could fly well on their respective fledging day. After 'branching' for only a day, next morning at 0900 h the male fledgling (hereafter J2) was on the ground near the nest tree, then flew adeptly to a tree ~30 m from the nest, landing clumsily. Eight minutes later, he flew to the nest tree, jumping and flapping from branch to branch until reaching the nest within 7 minutes, where he later fed on prey dropped therein by the female. He remained there for the rest of the day, sometimes jumping and flapping and feeding on further prey items dropped by the female.

Next morning, on the observers' arrival at 0815 h, neither fledgling was on the nest. The female fledgling (hereafter J1) suddenly flew up from long grass near the nest tree and landed unsteadily on the outer foliage of a nearby tree. The adult female flew past, calling. After 20 minutes, J1 flew back to the ground, landing in long grass ~30 m from the observers. After almost an hour, just after the adult female had flown past the nest tree with prey, J1 flushed up (as the landholder walked past within ~10 m) and flew competently to a limb in the nest tree ~1 m below the nest. J2 was then located on a branch in the nest tree. Later, J1 clambered back to the nest, and after the adult female dropped prey (amid much calling by the adult and J1), J2 flew out and dropped onto the nest. For the rest of the day, the juveniles occasionally jumped and flapped on the nest, independently flew to branches in the nest tree and back to the nest (J2 twice), once perching in the tree together,

Table 3. Growth and development of Spotted Harrier nestlings, Tamworth, NSW, August–September 2020. Week and day refer to age of the oldest of initially three chicks; a difference in age of c. 2 days is assumed where comments apply to the younger chick(s).

Week	*Day*	*Comments*
1	2	Downy, white.
2	10	Two older chicks downy, soft grey/white; stood and moved wings.
	11	When fed, oldest (largest) chick received most food and pecked at smaller (middle) chick.
	12	Three chicks visible: all interacting, standing, moving about, pecking at one another's bills (not overtly aggressive). All three were fed, apparently amicably.
3	15	Stretched wings, nibbled at nest sticks, pecked at prey in female's foot (not eating any), defaecated over nest rim. Oldest and middle chick fed, youngest missed out.
	16	Three chicks, fed in turn apparently amicably (no obvious bullying), though largest received most food. Two smallest stretched wings (i.e. at ~13 and ~11 days old). Oldest downy grey, flapped wings. Older two pecked at each other.
	17	Still downy, no feathers visible. All three chicks fed.
	19	Last sighting of three chicks: older two downy grey with white face, youngest downy white (at ~12 days old). Oldest had emerging remiges and rectrices (pin-feathers); unsteady on nest. Older two fed themselves by picking bits off prey in nest; no squabbling.
4	22	Only two chicks: older had emerging remiges ~5 cm long; younger (middle chick) now had emerging remiges.
	23	Walked around nest.
	24	Upperwing feathers emerged. Appetites appeared to have increased.
	28	Well-feathered dorsally.
5	29	Well-feathered dorsally and ventrally; remiges ~15 cm long. Brief pecking of younger chick by older chick during feeding session.
	32	Flapped wings strongly, almost lifted off nest.
	34	Jumped and flapped on nest.
6	36	Younger chick noticeably feathered up over last few days.
	37	Chicks still clumsy on nest; younger still slightly downy on head, adopted sun-spreading posture.
	41	Older chick defended food against sibling by chattering.
	42	Older chick defended food against sibling by mantling over food and chattering. Both nestlings 'branched'. Fully feathered, wings and tail short, younger still had down above bill.
7	43	Younger (male) nestling fledged.
	44	Older (female) nestling fledged.

and fed on two prey items dropped on the nest by the adult male.

Post-fledging period

Events on Days 1 and 2 were as described above (see Fledging). For the balance of Week 1 (to Day 5), the fledglings were either on the ground within 70 m of the nest, in the nest tree (often hidden amongst foliage), or on the nest, sometimes begging or resting prone (until Day 5, as in pre-fledging days), where they were given prey and where they jumped and flapped (until Day 4). J2 seemed the more competent at flying and landing, whereas J1 was clumsy on landing in a tree and on the nest. On Day 5, J2 was first seen soaring briefly, en route to the Yellow Box 30 m from the nest tree. On Day 3, competition between the two fledglings at the nest for delivered prey was intense, with tussling, flapping and vigorous calling; J1 was dominant and prevailed, with J2 consuming the leftovers. It appeared that J1 seized the adult male's foot with prey as he delivered it, both flapping as he struggled free.

In Week 2, the juveniles were often on the ground (Figure 2) or in the Yellow Box, and still went to the

Figure 2. Juvenile Spotted Harrier in grassy paddock, Day 11 post-fledging, Tamworth, September 2020. Note extensive rufous forewings and dorsal scalloping. Photo: Jan Hosking

Figure 3. Juvenile female Spotted Harrier on deer fence, Day 16 post-fledging, Tamworth, September 2020. Photo: Jan Hosking

Figure 4. Both juvenile Spotted Harriers (male on left, female on right), Day 18 post-fledging, Tamworth, October 2020. Note overall rufous plumage of new fledglings. Photo: Jan Hosking

nest (Day 8, though no prey was seen delivered there). On Day 8, the juvenile(s) fed on the ground, where the adult male had arrived with prey. On Day 11, one juvenile attempted an aerial prey exchange from the adult male unsuccessfully (prey dropped), though the juvenile located and claimed the prey by repelling a Pied Butcherbird that had found it on the ground. Landings on the outer foliage of trees were still clumsy.

In Week 3 (Day 16), the juveniles were variously perched on fenceposts (Figure 3), on the ground, or in the Yellow Box where they sometimes perched together (either or both sometimes calling from all such sites). Both soared in circles over the nest area (J2 more so). Both had been roosting nightly in the Yellow Box (landholder pers. comm.). On Day 18, both juveniles were again variously on fenceposts, on the ground or in the Yellow Box (Figure 4), sometimes calling. They soared in circles high over the nest area to ~500 m from the nest, and performed an aerial manoeuvre like that of a prey exchange. J2 also appeared to perform incipient hunting behaviour when flying low over paddocks. On Day 20, both were initially absent (towards the adults' favoured hunting area) and returned to the nest area: J1 to the nest, calling, and J2 to a fencepost, also eventually calling from the post. Both performed foraging behaviour, dropping into the grass from low flight (J2) and from fenceposts (both), possibly hunting insects. J2 displaced a Black-shouldered Kite *Elanus axillaris* from a tree in the nest area; both juveniles then flew, calling, to the nest area, interacted in the air and displaced each other from tree perches before perching together, *seep*-calling. They were still giving begging calls, though there were no observed food deliveries in Week 3 and the adults were seldom seen in the nest area. On Day 21, J1 was on the nest, calling to the adult female, which circled and departed. By Days 16–18, the juveniles appeared almost adult in bodily proportions (Figures 3–4).

In Week 1, parental prey deliveries were to the nest: by the female (via aerial exchange from the male, Day 1) or by the male (Day 2), and the adult sometimes perched in a tree in the nest area after a delivery. Thereafter, all observed prey deliveries were by the male to the nest (Days 3 and 4), then to the ground in a nearby paddock (Days 5 and 8), then by attempted aerial exchange to a juvenile (Day 11). No prey deliveries were observed in Week 3. In Week 4, over three mornings (Days 22, 25 and 26), no Harriers were observed, although they were reportedly heard in trees in the nest area in the evenings (landholder pers. comm.).

Interspecific interactions

During the incubation period, a Black Falcon *Falco subniger* suddenly appeared and tried to steal the prey during an aerial prey exchange by the Harriers. The prey was lost and the Harriers could not find it by searching (from low over and on the ground) where it fell. Otherwise, the Harriers usually did not interact with or respond to other medium-sized or large raptor species in their territory. A Square-tailed Kite *Lophoictinia isura* flew past, drifting directly over the nest area, but the incubating female Harrier only uttered several *seep* calls. During the nestling period, a pair of Wedge-tailed Eagles *Aquila audax* soaring ~500 m away, a Brown Falcon *F. berigora* flying past the nest area, and a pair of Brown Goshawks *Accipiter fasciatus* courting and nesting >300 m away drew no response. In the post-fledging period (Day 5), a Brown Goshawk gliding and circling high over the nest area drew no response from the adult Harriers.

On Day 19 of the nestling period, an Australian Hobby *Falco longipennis* swooped at the nest, possibly in an attempt to dislodge a chick, but the female Harrier promptly arrived and soared over the nest as the Hobby retreated. Early in the incubation period, the male Harrier briefly chased an Australian Magpie *Gymnorhina tibicen* in the nest area. Several times through the nestling period, one or more possibly scavenging Pied Butcherbirds approached the nest to within 1 m while the female Harrier was on the

Figure 5. Adult female Spotted Harrier being harassed by Australian Magpies, nestling period, Tamworth, NSW, September 2020. Photo: Denise Kane

nest, but she ignored them. On Day 23, in her absence, two Pied Butcherbirds approached the nest, one peering in, but after a Noisy Miner *Manorina melanocephala* chased them the female Harrier arrived promptly and perched in the top of the nest tree. Just after an aerial prey exchange while the female was feeding, an Australian Raven *Corvus coronoides* attacked the male Harrier on a nearby fencepost, and he retaliated in aerial skirmish, presumably in defence of the female.

Otherwise, the Harriers were subject to harassment or mobbing by Masked Lapwings *Vanellus miles*, Noisy Miners, Australian Magpies (Figure 5), Pied Butcherbirds, Magpie-larks *Grallina cyanoleuca* and Australian Ravens, or groups of Galahs *Eolophus roseicapilla* or Little Corellas *Cacatua sanguinea*. Usually, the Harriers simply took evasive action, sometimes by rolling and parrying with the feet. The female uttered shrill notes and a chatter when attacked by a Magpie. In the post-fledging period, the juveniles were harassed by Miners, Magpies and Butcherbirds, and by a Nankeen Kestrel *Falco cenchroides* and an Australian Hobby.

Hunting behaviour and prey

As well as the usual low, slow aerial foraging behaviour (e.g. Marchant & Higgins 1993), the adult Harriers sometimes appeared to be perch-hunting: standing on fenceposts, scanning about, then dropping into the grass near the post. The female was also seen running about on the ground with her wings raised, as if chasing prey in the grass. The low-flying male flushed a quail then dropped into the grass from which it had flown, and he also flushed from grass a small bird, which he caught in flight.

Observed prey items brought to the nest were all vertebrates. Items were often unidentifiable, but identified items included a mouse (3) or probable mouse (2) (only possible species in the area is the House Mouse); probable juvenile Black Rat *Rattus rattus* (1); quail/rear half of quail (5); quail chick (1) (Figure 6); probable quail (3); quail or Australasian Pipit *Anthus novaeseelandiae* (1); probable Brown Songlark *Cincloramphus cruralis* (1); unidentified bird (7) (often plucked or part of body); dragon lizard (1) (probable immature Eastern Bearded Dragon *Pogona barbata*); small snake (or legless lizard?) (1); and a rodent or lizard (1). A few unidentifiable items were judged to be the size of a quail or European Rabbit kitten *Oryctolagus cuniculus*, but Rabbit could not be confirmed in the diet. Thus, the prey consisted of ground-

Figure 6. Adult female Spotted Harrier delivering prey (a quail chick), nestling period, Tamworth, NSW, August 2020. Photo: Denise Kane

Table 4. Prey-delivery rates to the female by the male, and to the nest or young by the adult Spotted Harriers during each stage of the breeding cycle, Tamworth, NSW, July–September 2020: number of items delivered per hour by the male and female. Prey sample sizes are given in parentheses; number of hours of observation is given for each stage. Combined = resulting delivery to the incubating female and to the young after the incidents noted in footnotes; M = male, F = female.

Stage	*M*	*F*	*Combined*
Incubation (54.5 h)	0.26 (14)[a]		0.22 (12)
Nestling period:			
Week 1 (12 h)	0.33 (4)[b]		0.25 (3)
Week 2 (14 h)	0.29 (4)[c]		0.21 (3)
Week 3 (23 h)	0.22 (5)[c]	0.04 (1)	0.22 (5)
Week 4 (38.5 h)	0.42 (16)[d]	0.08 (3)	0.42 (16)
Week 5 (35 h)	0.34 (12)	0.17 (6)	0.51 (18)
Week 6 (43 h)	0.44 (19)[d]	0.14 (6)[c]	0.49 (21)
Total nestling period (165.5 h)	0.31 (51)[e]	0.09 (15)	0.40 (66)
Post-fledging period			
Week 1 (30.75 h)	0.33 (10)[c]	0.10 (3)	0.39 (12)
Week 2 (18.25 h)	0.27 (5)[f]		0.16 (3)

[a]1 prey item lost to piracy, 1 lost during attempted exchange.
[b]F did not collect item, M consumed it.
[c]F consumed 1 prey item.
[d]F consumed 3 prey items.
[e]Actually delivered to F or young.
[f]F consumed 2 prey items.

dwelling small mammals (introduced species), birds and reptiles of pasture and crops.

Feeding rates

The male's effective prey-delivery rate to the incubating female was 0.22 item/h. His rate increased during the first half of the nestling period, when the nest-attending female entirely consumed a few of his delivered items. The combined parental prey-delivery rate to the nest doubled in the second half of the nestling period, after the female started hunting late in Week 3. Nevertheless, the male brought the bulk of the nestlings' food throughout (average combined rate 0.40 item/h over the nestling period: Table 4). The female continued to consume a few of his delivered items, though taking her own captures to the nest for the chicks (except for one mouse, which she consumed). It appeared from the occasional slowness of the female or chicks to respond to the food-bearing male or to maternal feeding visits, and prey stored in the nest at some maternal feeds, that there was sometimes a surplus of food in the first half of the nestling period. There were rare occasions when the male brought prey while the female was still dealing with his previous item or her self-caught item. Notably short intervals between the male's deliveries were 16, 24 and 27 minutes; otherwise, prey deliveries were often approximately hourly. Conversely, he was sometimes absent for 2–3 hours.

In Week 1 of the post-fledging period, the combined parental feeding rate was somewhat lower than in the final pre-fledging weeks, especially for the adult male, though the female's rate remained similar. She delivered some self-caught items to the nest, but she consumed one of the male's delivered items herself. In Week 2, the male's overall delivery rate declined little from Week 1, but his effective delivery rate to the young almost halved, as the female consumed a few of his delivered items and she was not seen to provision the juveniles (Table 4). No deliveries were observed in the limited observation time (9.5 h) in the nest area in Week 3, and in Week 4 (in 5.25 h) the adults and juveniles could not be located in the nest area by day.

It was not possible to estimate biomass consumed, as many prey items brought to the nest area were either difficult to see, were not identifiable, or were often plucked and partly consumed before delivery. The largest items brought were quail or part thereof (likely 50–100 g) or a headless lizard (dragon species, ~100 g), but some were small (mouse size, ~20 g). Most prey items appeared to be in the range of 20–50 g.

2021 season

In mid May 2021, a pair of Harriers was reported carrying sticks to the nest used in 2020 (landholder pers. comm.). In late May, an adult male was perched in the adjacent eucalypt, *seep*-calling, while a female (a new bird, in second-year plumage) circled low around the nearby source of nesting material used in 2020 before both departed together, foraging (SJSD; G. Clark pers. obs.). In mid June and mid July, the Harriers were not observed, and a pair of Australian Ravens had built a nest in a neighbouring tree. The male Harrier's perch-tree had died (from lightning strike) and Black-shouldered Kites had adopted the nest, one Kite incubating in mid July.

Discussion

Breeding parameters (season, brood size, incubation and nestling periods) of the Spotted Harrier pair at Tamworth were within values previously recorded, and parental sex-roles were as previously described, with the present study adding much detail and quantification (cf. Baker-Gabb 1982, 1984a; Marchant & Higgins 1993; Aumann 2001a; Morley 2021). Aspects of the late pre-laying period and the nest structure were also consistent with previous information, although annual reuse of nests is reportedly infrequent (Marchant & Higgins 1993). The aerial undulating display may be more common than has been reported, as it has also been observed by D. Whelan (pers. comm.). Aspects of nestling and fledgling behaviour, growth and development were consistent with, and enlarge upon, previous information (Baker-Gabb 1982; Marchant & Higgins 1993; Morley 2021).

The observed rate of adding greenery to the nest during the nestling period was lower than has been reported (by Baker-Gabb 1982), but early-morning peaks in such activity would have been largely missed at Tamworth. Similarly, parental time-budgets and feeding rates might have been affected by our observations being conducted mostly after 1000 h (Table 1), thus potentially missing peaks in activity before 1000 h. It seemed likely that the breeding female communicated her and the brood's food needs to the male via begging calls (*seep* call), and that he foraged accordingly. Further observation could establish whether the male regularly food-calls when approaching the nest with prey, as indicated by Marchant & Higgins (1993) and the observations of Morley (2021).

Siblicide was not observed, although known in the Spotted Harrier (Marchant & Higgins 1993). There was some sibling rivalry between the two older chicks at feeding times. It seems likely that the youngest chick could not compete effectively for food, lagged in development and starved (and possibly suffered exposure during the female's increasing absences). After fledging, the two juveniles spent much time back on the nest, continuing pre-fledging behaviour (e.g. jumping and flapping, resting prone) for at least 5 days. The nestling period could therefore be over-estimated, unless true first flights were witnessed. Fledglings also spent much time on the ground, as noted by Baker-Gabb (1982, 1984b).

The two juveniles were still dependent or partly so, and sometimes visited the nest, at up to 3 weeks post-fledging. Inability to locate them thereafter meant that we could not determine the post-fledging dependence period, previously reported to be 6 weeks (Marchant & Higgins 1993; Morley 2021). Meanwhile, from just before fledging time and thereafter the adults showed signs of resuming mating behaviour, courtship (supplementary) feeding and incipient nest building by the male, although we could not investigate the possibility of a second breeding event within the year.

Hunting behaviour of the Harriers at Tamworth was consistent with previous information, with the addition of previously unreported perch-hunting in an environment with abundant low perches in tall grassland (cf. Marchant & Higgins 1993; Aumann 2001b; Buij 2014). The Harriers' dietary profile at Tamworth (vertebrate classes captured), albeit from a limited sample of observations without orts or many pellets, is also consistent with collective previous information (Marchant & Higgins 1993; Johnstone & Storr 1998; Aumann 2001c; Hassell 2004; Buij 2014; Morley 2021). It remains to quantify the diet and prey biomasses in temperate south-eastern Australia, as well as in other parts of the Harrier's range such as south-western Australia, Queensland and the tropics. Feeding rates during the incubation, nestling and early post-fledging periods at Tamworth were lower than those reported by Morley (2021) for a nest with four hatchlings and three surviving fledglings during a mouse plague. This difference may have been related to brood size, prey abundance and possibly prey size, all permitting or necessitating more frequent prey deliveries (mostly smaller items, i.e. mice/rodents, recorded by Morley 2021).

Our study presents a reasonably comprehensive and supplementary behavioural account of the Spotted Harrier's breeding cycle, albeit 'snapshot' in nature and for a single successful pair. There is scope for a more complete time-budget study covering all daylight hours, and greater coverage of the post-fledging dependence period. It remains to conduct population studies of the Spotted Harrier in the New South Wales sheep–wheat belt and elsewhere (e.g. long-term territory occupancy, breeding density and productivity in sample areas). Nest-site and breeding-habitat characteristics at the Tamworth nest (i.e. mature Rough-barked Apple in eucalypt woodland on drainage lines amid pasture and crops) suggest the types of sites where other nests might be found in the wider region and elsewhere in temperate inland New South Wales. It also remains to conduct, by radio- or satellite-telemetry, studies on home range and habitat use, juvenile ranging behaviour through the post-fledging period, natal dispersal and potential for migratory movements. Such knowledge would contribute to understanding of a species that is listed as threatened in New South Wales, and thus suggest appropriate management strategies.

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