AUSTRALIAN FIELD ORNITHOLOGY 2008, **25**, 165–193

Biology and Diet of the White-bellied Sea-Eagle *Haliaeetus leucogaster* Breeding in Northern Inland New South Wales

S.J.S. DEBUS

Zoology, University of New England, Armidale, New South Wales 2351
(Email: sdebus@une.edu.au)

Summary

The breeding biology, behaviour and diet of the White-bellied Sea-Eagle *Haliaeetus leucogaster* were studied throughout 69 hours of observation from nest-renovation to the post-fledging period, and by analysis of prey remains and pellets, at two nests in northern inland New South Wales in 2007. Supplementary observations and collections of food remains were made at two other nests. Egg-laying occurred in July (three clutches) and August (one clutch). At two nests, incubation (by both male and female) lasted an average of ~41 days (39 ± 2 days; 42 ± 1 days). At one nest, the nestling period lasted 78–84 days; the post-fledging dependence period lasted at least 2 months, and a juvenile still roosted in the nest area 5 months after fledging. Parental time-budgets in each phase are described and quantified, and juvenile growth and development are described. Fledgling productivity was 0.8 young per attempt over 5 pair-years. The breeding diet consisted of waterbirds, freshwater turtles and fish: mostly waterbirds and turtles in remains (n = 15 prey items), and mostly fish (82%) by observations (n = 17 items). Hunting and attack behaviour are described; seven of 18 attacks were successful (39%: all attacks on fish successful, none of 11 on birds successful).

Introduction

For its size, appearance, and abundance on the densely human-populated coasts of south-eastern Australia, the White-bellied Sea-Eagle *Haliaeetus leucogaster* is remarkably little studied. Aspects of its basic biology are poorly known, and there has been no quantified account of a complete breeding cycle from nest-building to independence of the young.

The Sea-Eagle's breeding behaviour is little known; the incubation period has been estimated as 'probably 35–40 days (Fleay 1948)' and 'c. 6 weeks (Bilney & Emison 1983)', as quoted by Marchant & Higgins (1993), but the latter estimate was only inferred from peak laying and hatching dates given by Bilney & Emison. It has also been given as 40–41 days (Olsen 1995, without source data) and '7 weeks' (Olsen 1999), apparently an error for 6 weeks. Similarly, the 'fledging period' has been given as '65–70 days' (Brown & Amadon 1968, quoted by Marchant & Higgins 1993), but this estimate (repeated by Ferguson-Lees & Christie 2001) could refer to the time until nestlings are fully feathered, rather than the completed nestling period (i.e. the time to first true flight from the nest). Breeden & Slater (1968) found that one juvenile had fledged at 72 days, Cupper & Cupper (1981) and Hollands (1984) reported juveniles still in the nest at 10 and 11 weeks old, respectively; Olsen *et al*. (1993a) gave the nestling period as 70–80 days; and Olsen (1999) variously gave the nestling period as 'about 9 weeks' and '10 weeks'. The post-fledging dependence period has been stated as up to 3 months, with juveniles said to be driven from the natal territory at ~4 months (Hollands 1984; Marchant & Higgins 1993), although Ferguson-Lees & Christie (2001) stated that juveniles may remain with adults for 3–6 months after fledging. Implicit in the various accounts

of White-bellied Sea-Eagle breeding behaviour is the observers' assumption of a strong division of labour, with the female said to perform most of the nest-based parental behaviour and the male most of the hunting (Cupper & Cupper 1981; Hollands 1984; Marchant & Higgins 1993; Olsen 1995, 1999).

The White-bellied Sea-Eagle's diet has been quantified at a few locations, notably on inland waters. Anecdotal reports (Cupper & Cupper 1981; Woodall 1982) and quantified studies (Olsen *et al*. 2006a,b) found that inland-breeding Sea-Eagles take mostly fish, freshwater turtles and waterbirds. There is little evidence of the introduced Rabbit *Oryctolagus cuniculus* as important prey, and therefore little likelihood that the Rabbit influences the inland population of Sea-Eagles (Olsen *et al*. 2006a; *contra* Shephard *et al*. 2005a). Rabbit remains attributed to Sea-Eagles may have resulted from Wedge-tailed Eagles *Aquila audax* previously using the nest concerned (see Debus 2005).

Otherwise, since the summary by Marchant & Higgins (1993), there have been Australian studies of the White-bellied Sea-Eagle's habitat use and foraging ecology in relation to human activities (Spencer & Lynch 2005; Wiersma in press); its morphology, conservation genetics and trends in continental distribution and abundance (Shephard *et al*. 2004, 2005a,b); its distribution, status and possible threats (Olsen *et al*. 1993b; Dennis & Lashmar 1996; Stokes 1996; Dennis 2004; Spencer 2005; Dennis & Baxter 2006; Thurstans in press a); and its breeding-habitat characteristics (Thurstans in press b). There have also been anecdotal reports of its interactions with Wedge-tailed Eagles (reviewed by Debus 2005), and of its foraging behaviour in Australia and Melanesia, including the form now classified as subspecies *Haliaeetus leucogaster sanfordi* (Leonard 1995; Gosper & Baker 1997; Olsen 1997; Heinsohn 2000; Fitzsimons 2002; Reid & Reid 2002; James 2004; Debus 2006; Dennis & Brittain 2006; Davis 2007; Seale 2008). The New South Wales annual bird reports, published in *Australian Birds* since 1993, contain many opportunistic prey records, most of which were waterbirds and seabirds (an observer bias).

The White-bellied Sea-Eagle is now of conservation concern in the heavily settled parts of south-eastern Australia with development pressure on the coast, particularly on the nesting sites of this shy and easily disturbed species (Emison & Bilney 1982; Marchant & Higgins 1993; Dennis & Lashmar 1996; Dennis 2004; Threatened Species Unit 2005; Wieneke 2005; Dennis & Baxter 2006; Thurstans in press a). Understanding its breeding biology is one step towards a knowledge base for its conservation and management.

This paper describes and quantifies behavioural aspects of the breeding cycle of two pairs of Sea-Eagles from courtship and nest-refurbishment to independence of the juveniles of one of these pairs; supplementary observations were conducted at two other nests. The eagles' breeding diet was also quantified at these four nests. Data on these four pairs, in northern inland New South Wales, are supplemented by casual observations on coastally breeding pairs at Jervis Bay, southern New South Wales (obtained during the survey reported by Debus 1997). The White-bellied Sea-Eagle clusters genetically in a 'southern' group of fish-eagles (African *H. vocifer*, Madagascar *H. vociferoides*, Sanford's *H. [l.] sanfordi*, and fishing-eagles '*Ichthyophaga*' which are grouped within *Haliaeetus*), rather than with the 'northern' cluster of White-tailed *H. albicilla*, Bald *H. leucocephalus*, Pallas's *H. leucoryphus* and Steller's *H. pelagicus* (Lerner & Mindell 2005). Therefore, comparison is made particularly with the best-studied of the southern group: the ecologically equivalent African Fish-Eagle and Madagascar Fish-Eagle (cf. Brown 1980;

Ferguson-Lees & Christie 2001). These two groups (northern, vs southern) may even warrant generic separation (Lerner & Mindell 2005); the southern genus would be *Cuncuma* Hodgson 1837.

Study area and methods

The four Sea-Eagle nests studied in 2007 were located at Malpas Dam (30°17′S, 151°44′E; ~2 km^2) near Guyra (Pair 1), Quipolly Dam (31°25′S, 150°42′E; ~1.5 km^2) between Werris Creek and Quirindi (Pair 2), Lake Inverell (29°47′S, 151°09′E; ~0.5 km^2 + McIntyre River) at Inverell (Pair 3), and Little Llangothlin Lagoon (30°05′S, 151°46′E; ~1.5 km^2) north of Guyra (Pair 4). That is, they were separated by tens of kilometres to >100 km. All four nests were located within 1 km of a water body, in a pastoral landscape with remnant woodland. Those at Malpas Dam (~1230 m above sea level) and Little Llangothlin Lagoon (~1350 m asl) were at high elevation in Black Sallee *Eucalyptus stellulata*–Manna Gum *E. viminalis* grassy woodland; that at Quipolly Dam was at low elevation (~420 m asl) in open woodland of scattered Yellow Box *E. melliodora* and Rough-barked Apple *Angophora floribunda* paddock trees, with a wooded ridge (eucalypts and cypress-pine *Callitris*) nearby; and that at Lake Inverell was at intermediate elevation (~600 m asl) in riparian Manna Gum woodland adjoining extensive White Box *E. albens* grassy woodland, though with cleared paddocks on the opposite side of the river.

The primary pairs (Nests 1 and 2, of Pairs 1 and 2 respectively) were observed opportunistically, and Nests 3 and 4 (of Pairs 3 and 4 respectively) were visited occasionally; Nest 1 refers to Pair 1, Nest 2 to Pair 2, etc. Observations were conducted with 10 × 40 binoculars and a 25× telescope, from unconcealed positions (i.e. no hide was used) at distances that did not disturb the Sea-Eagles, as judged by their ignoring observer presence: Pair 1 from ~600 m and downhill, and Pair 2 from ~800 m across the lake on the opposite shore. Nest 1 was observed for 5 h over 6 days in the prelaying phase, 4.5 h over 5 days in the incubation period, and 29.5 h over 23 days in the nestling period until fledging (total 39 h), and nest 2 was observed for 9 h over 8 days in the prelaying phase and 21 h over 11 days in the incubation period until failure at the hatchling stage (total 30 h). Total observation time (69 h) was distributed unevenly through the day (Table 1). Most nest-watches were for 1–2 h (rarely 0.5 h), with one all-day watch of 7 h at Nest 2 during the incubation period. Observation sessions at Nest 1 occasionally extended until dusk and resumed at dawn. Nests 1 and 2 were visited daily around anticipated hatching times, to pinpoint hatching dates, since laying dates were determined within 1–2 days. The post-fledging period was

Table 1

Hours of observation at White-bellied Sea-Eagle nests in nest-building, incubation and nestling periods (June–November 2007), northern inland New South Wales (two nests; see text), during each 2-h interval of daylight. Upper row = Nest 1, lower row = Nest 2, subtotals for each stage in bold (for nestling period, Nest 1 only).

<0800	*0801–1000*	*1001–1200*	*1201–1400*	*1401–1600*	*>1600*
Nest-building:					
–	–	0.25	4.0	0.25	0.5
–	1.0	–	4.25	3.25	0.5
–	**1.0**	**0.25**	**8.25**	**3.5**	**1.0**
Incubation:					
–	–	–	3.25	0.75	0.5
2.0	6.5	2.5	2.0	4.75	3.25
2.0	**6.5**	**2.5**	**5.25**	**5.5**	**3.75**
Nestling period:					
6.0	5.5	7.5	1.0	5.5	4.0

monitored twice in week 1 (including at sunset for roosting behaviour on day 3), then opportunistically for ~1 h each, in the mornings, in weeks 4 (day 28), 7 (day 49), 10 (day 64), 12 (day 78), 13 (day 85), and 15 (day 105). Observations then lapsed until week 23, when the nesting territory was checked at sunset for roosting individuals.

Data on the incubation period were obtained mostly for Pair/Nest 2, and all data on the nestling period and post-fledging period were obtained for Pair/Nest 1. Most observations of the nestling period at Nest 1 were conducted in the first 6 weeks, with a lapse in weeks 7–9 and only 2 h in each of weeks 10–12. Nest 1 was also partly obscured by foliage, so that at the observation distance it was sometimes difficult to see fine detail (e.g. chicks being fed).

Incubation, hatching and brooding/feeding of new chicks were inferred from adult behaviour (see descriptions of behaviour in the relevant Results sections). Parental time-budgets were quantified by continuous focal-animal sampling as in previous related studies (e.g. Debus *et al*. 2007). The adults were difficult to sex unless seen together, when females were seen to be noticeably larger than males (cf. Marchant & Higgins 1993; Shephard *et al*. 2004). Their honking calls also differed in pitch and tempo (male higher and faster). Early in the breeding cycle, members of a pair were separable by moult pattern when in flight, but as the season progressed the moult patterns of male and female converged. When seen side by side on their lookout perch, and as confirmed when they copulated, the female of Pair 2 was taller than the male and also had more tail projecting below the perch, compared with the more compact male; later she also developed a more nest-stained, scruffy belly. By the nestling period, the female of Pair 1 also developed a slightly scruffy belly. Nevertheless, sexing was at times tentative, and for Pair 1 is qualified by 'presumed' female or male. Distances, heights of nests above ground, and tree sizes were measured as previously (Debus *et al*. 2007), or from 1:25 000 topographic maps.

The few pellets and prey remains (orts) were collected from the ground below the four nests and associated perching trees. Those from Pair 1 were collected at the fledging stage; from Pair 2 early in the prelaying phase, with a further collecting visit after the nest had failed at the hatching stage (although no new items were found); from Pair 3 at the incubation stage and again after the nest had failed (the earlier visit did not cause the failure); and Pair 4 at the fledging stage. The initial (single) collections at Nests 2 and 3 were opportunistic, and further visits were not attempted until the anticipated advanced nestling stage; collections at Nests 1 and 4 were delayed until the young had fledged, in order to minimise disturbance. Prey items were identified by reference to Cogger (2000) for turtles, or by A.B. Rose for birds, reptiles and fish as described previously (Debus *et al*. 2007). For a given pair, there was no overlap in prey types between pellets, orts and items observed brought to nests, and thus no risk of double-counting of items.

Results

Sea-Eagle population

As well as one breeding pair on each of the four study lakes (Inverell, Little Llangothlin, Malpas and Quipolly), Sea-Eagle pairs were observed or reported in the study region at Copeton Dam, near Inverell; upper Sara River gorge north-east of Guyra (active nest: SD pers. obs); Mother of Ducks Lagoon (Guyra) and the Moredun Dams area west of Guyra (W. Ball pers. comm.); the upper Macleay River gorge near Armidale (active nest: S. Trémont pers. comm.); 'Tullimba' near Kingstown, and Dangars Lagoon at Uralla (H. Ford pers. comm.); the Peel River near Tamworth (E. Fair pers. comm.); Lake Keepit between Tamworth and Gunnedah (active nest: SD pers. obs); and the trout hatchery at Ebor, where a duetting pair may have had a nest in forest above the ponds in a past year (SD pers. obs.), but by 2007 only one eagle remained (P. Sheather pers. comm.). In addition, an adult was at the Gara Dam, Armidale, in spring 2006, and an immature lived on a large farm dam near Gara Dam for part of 2005. Thus, the species is sparsely distributed on major water bodies throughout the region, with at least 13 pairs in the study area (Figure 1) and perhaps twice that, or ~30 pairs, on the Northern

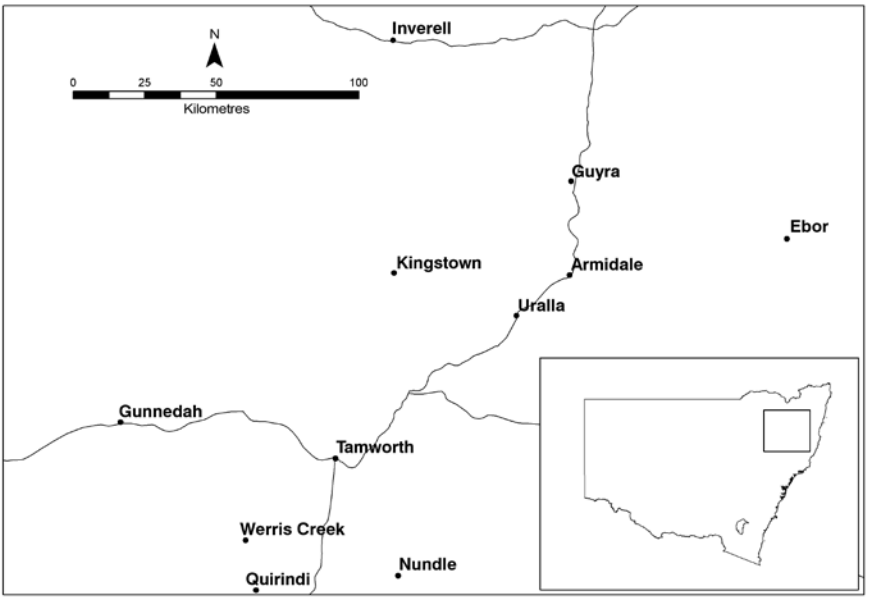

Figure 1. Study region in northern inland New South Wales, showing locations mentioned in the text.

Tablelands and North-west Slopes of New South Wales. However, Chaffey Dam (between Tamworth and Nundle) was found not to support Sea-Eagles; the water level was low in 2007, but when levels are higher the prevalence of water-skiing or boating may discourage the eagles.

Nest-sites

The nests of all four pairs in this study were in living trees in woodland within 1 km of water, in positions varying from near a lake or river margin, to on a ridge overlooking a river or lake (Table 2). Active nests were sheltered by the tree-canopy, but one old (disused) nest was in a leafless, almost dead tree. Near the nests there were also prominent, live or dead perching trees. The territory of Pair 1 had a dead tree and a large live tree on the exposed hilltop between the nest (~400 m away) and the lake, from which the adults could see the nest and their foraging grounds. That of Pair 2 had a large live tree (Yellow Box, hereafter called 'lookout tree'), with a dead horizontal branch near the top, 140 m towards the lake shore from the nest-tree, and a dead tree 220 m from the nest-tree. That of Pair 3 had several dead or dead-topped trees surrounding the current nest-tree, and that of Pair 4 had a dead tree as well as the bare-topped old nest-tree in the vicinity of the current nest.

At Jervis Bay, the nests of four pairs were all in large living Blackbutts *Eucalyptus pilularis* in open forest: variously 150 m, 400 m, 800 m and 900 m from the nearest major water body (lagoon, estuary or sea); three were in or on the flank of a minor gully. At least one of these nests had a lookout perch, in the form of an emergent dead tree nearby, used by the adults.

Table 2

Nest-site characteristics of White-bellied Sea-Eagle nests in northern inland New South Wales, 2007: characteristics of nest-tree and position of nest. For tree species, 1 = Manna Gum *Eucalyptus viminalis*, 2 = Rough-barked Apple *Angophora floribunda*, 3 = White Box *E. albens*; dbh = diameter at breast height; nest height = height of nest above ground.

Pair/nest	*Tree species*	*Tree height (m)*	*Tree dbh (cm)*	*Nest height (m)*	*Position*
1	1	18	69	13	Ridge (flank of saddle) overlooking river ~400 m away and lake ~900 m away
2	2	27	155	12	Flat, open woodland ~250 m from lake shore
3a (current)	1	28	67	14	Bluff overlooking river ~150 m away; lake ~1 km away
3b (old)	3	25	57	20	~75 m farther into woodland than current nest
4a (current)	1	24	107	20	Woodland on slight rise ~400 m from lake shore
4b (old)	1[a]	25	113	13	25 m from current nest, towards shore

[a]Nearly dead

Breeding chronology

Pair 2 had fresh green foliage in the large, long-established nest when first inspected on 2 June, and Pair 1 was adding material to a small, fairly new nest when first found on 14 June. Pair 3 was already incubating on 18 July when found. Pairs 1 and 2 started incubation at the end of July, hatched chicks in early September and fledged young (Pair 1) in late November. Pair 4 was at the prelaying stage on 19 July, incubating or brooding on 8 October, and had a juvenile at fledging age, standing on the nest, on 30 December (therefore, laying must have been around the end of August). Thus, in northern inland New South Wales laying extended from early or mid July to late August. In 2008, the female of Pair 1 was incubating by 16 August, when the nest appeared larger than in 2007.

At Jervis Bay in the first week of August, one pair appeared to be in the prelaying phase, and in early September, another pair appeared to be in the prelaying phase and two pairs were incubating.

Nest-building and prelaying phase

Pairs 1 and 2 were observed intermittently over 6 weeks (from mid June) leading up to egg-laying, with observation times strongly biased towards afternoon (Table 1); activity rates may have been higher in the mornings. Pair 1 (sex of bird unknown) brought two items of nest-material (one green spray, one stick) to the nest in 5 h (0.4 item/h), and the adult(s) attended the nest, sometimes arranging material, for 6% of observation time (5 h). In addition, the male brought a long strip of bark but this disintegrated while he was still soaring over the nest-site, and he dropped the remnants. Greenery was added in the final days before egg-laying. The pair's lookout tree was not visible from the observation point, and copulation was not observed.

The male of Pair 2 brought two sticks and one other item of nest-material in 9 h (0.3 item/h), and attended the nest, arranging material, for 3% of observation time (9 h); he was not seen bringing or arranging material in the final 3 weeks before egg-laying. In the final week before egg-laying, the female attended the nest, apparently arranging material, for <1% of total observation time; she was not seen to bring material.

All nest-material was collected and carried in the feet. In the prelaying phase, and also the incubation period, the male of Pair 2 collected material by gliding steeply from a high perch to the neighbouring tree-canopy, and using his weight and momentum to either snap off a dead stick and continue flying with it, or to wrench off a bunch of foliage as he twisted sideways then flew on.

In the prelaying phase a courtship flight by Pair 1 was seen once: as the pair soared together over the nest area, the male passed low over the female with his feet lowered. Courtship flights by Pair 2 were seen twice: after duetting on a lakeside tree ~600 m from the nest, the pair flew in tandem towards the lookout tree and duetted side by side on arrival; after perching in a horizontal (soliciting?) posture on a dead tree near the nest-tree, the female soared and duetted with the higher-soaring male, then he descended with his feet lowered as she called with single resonant yelps, then both spiralled together over the nest-site. No talon-grappling or cartwheeling was seen, but observations were few at this stage.

Pair 2 copulated twice in one afternoon observation period (2 h) in mid June, ~6 weeks before egg-laying: after the male took a stick to the nest and arranged it, he perched beside the female on the lookout tree; after 22 minutes of resting and preening they copulated, the male with his wings spread, for ~7 seconds then continued to perch side by side. Over the ensuing 40 minutes they duetted again twice (once as a Whistling Kite *Haliastur sphenurus* flew over), then duetted and mated again for ~5 seconds while the female (?) called with slow honking notes; they continued to perch for 8 minutes before the male left.

Circumstantial evidence was obtained once of courtship (supplementary) feeding by Pair 4, but the moment of suspected food transfer was not observed. In the prelaying phase, the presumed male (non-moulting) carried a prey item towards the nest; both adults were then found standing on the nest but flew off, and the presumed female (moulting) carried the prey item on which she had apparently been feeding.

At Jervis Bay, in mid May, a pair of Sea-Eagles performed a courtship flight: mutual gliding and duetting, one bird (female?) with its feet lowered, followed by more duetting then soaring together. In early August and early September, respectively, behaviour suggestive of the prelaying phase was observed in two pairs. One female was on her lookout perch for an hour, calling occasionally, while the soaring male departed towards the coastline (presumed hunting grounds). The female of another pair was on the nest, calling, as her mate arrived (behaviour not subsequently observed during the incubation period).

Territorial advertisement and defence

Both male and female soared over the nest area, singly or together, and performed bouts of duetting on perches or in flight, in the prelaying phase. They also soared singly, sometimes calling (usually when harassed by other birds), throughout the breeding cycle. In the prelaying phase the soaring female of

Pair 1, after a courtship flight with the male, made a series of passes over the nest-tree, then a low flight past the nest, as if advertising its location. Females also sometimes gave bouts of honking calls from their lookout trees. In the case of Pair 2, calling by the female sometimes appeared to be stimulated by aircraft (including low-flying light aircraft), other raptors such as Whistling Kites, or Australian Pelicans *Pelecanus conspicillatus* flying or soaring overhead. Apart from a juvenile Sea-Eagle flying (unchallenged) through the territory of Pair 1 in mid June, no intraspecific intrusions were observed, as there was only one pair of Sea-Eagles per isolated water body studied, and hence no potential for foraging ranges to overlap.

Breeding Sea-Eagles strongly defended their immediate nesting territory against incursions by low-flying Wedge-tailed Eagles. During the incubation period of Pair 1, the male took off and soared as an immature Wedge-tailed Eagle came soaring low over the nest area; he repeatedly stooped at the Wedge-tailed Eagle and drove it out of the territory to ~600 m from the nest, and the Wedge-tailed Eagle rolled and parried at each stoop. In week 6 of the nestling period, one of the adult Sea-Eagles made one swoop at an adult Wedge-tailed Eagle soaring over the dam ~1 km from the nest; the Wedge-tailed Eagle rolled and parried, and glided away. High-soaring and/or distant adult Wedge-tailed Eagles, alone or in pairs, were usually not attacked, and it appeared that resident eagles respected one another's boundaries. For instance, in the prelaying period, Pair 2 spiralled with a Wedge-tailed Eagle over the Sea-Eagles' nest area, but took no further action; in the incubation period, a Wedge-tailed Eagle flying directly past the area, within 500 m of the nest, went unchallenged. Similarly, Pair 1 usually ignored high-soaring Wedge-tailed Eagles; for example, in the prelaying period the female soared with a pair of Wedge-tailed Eagles >500 m from her nest, but took no further action, even though one Wedge-tailed Eagle performed undulating dives. The soaring male of Pair 1, in the nestling period, once glided in the direction of a soaring Little Eagle *Hieraaetus morphnoides* ~500 m from the nest, then circled as the Little Eagle apparently retreated.

After the nest of Pair 3 had failed, an immature Wedge-tailed Eagle was flushed from the Sea-Eagles' old nest, on which it had been standing (~75 m from the current nest), but the Sea-Eagles did not appear or defend the area. The site and structure of the old nest suggested that it may have been built originally by Wedge-tailed Eagles, although the many turtle carapaces beneath it indicated that it had been used in recent years by the Sea-Eagles.

In the nestling period, the male of Pair 1 was frequently attacked by one or both of a pair of nesting Forest Ravens *Corvus tasmanicus* as he soared in their mutual nest area; he often returned the attack by turning, stooping and chasing a Raven. Also at this stage, one of the adult eagles flew to the nest-tree, perching above the nest, after a Brown Goshawk *Accipiter fasciatus* flew past the nest.

Reaction to disturbance

Pair 1 was not seen to be subject to human disturbance during the breeding cycle, and the nest area was not approached within the eagles' alert distance (defined as when the adults appeared to notice the observer) before the fledging stage. The pair's foraging grounds were subject to weekend recreational activities (sailboating) on the lake, and to occasional powerboat incursions during official maintenance activities, and the nesting territory was subject to occasional motor-vehicle movements during maintenance of water-management facilities around

the dam wall, or during livestock management by the landowner. The eagles appeared unaffected by these activities, which did not approach within 500 m of the nest. In the post-fledging period, in a lakeside area where they were used to seeing humans, an adult and a juvenile appeared to tolerate the approach of people on foot to ~100 m. [On a similar reservoir (Burrinjuck Dam) in southern New South Wales, Sea-Eagles ignore water-skiers but are disturbed by slower boats, e.g. fishermen: J. Olsen pers. comm.].

Being on private land, the nest area of Pair 2 was subject only to routine livestock management by the landowner. The incubating female sat tight but alert as a farm vehicle was driven past and stopped for a person to open and close a gate near the lookout tree (~150 m from the nest), but the male flushed from the lookout tree as the vehicle approached it within 50 m. On another occasion, the incubating female sat tight as a vehicle went through the open gate and later returned. Otherwise, the nest was not approached during the breeding cycle, and was observed from well outside the pair's alert distance. However, at the hatching stage (male sitting?), the female left the lookout tree and soared low over the observer (800 m from the nest) then perched in a nearby tree, watching, as if concerned by human presence even at that distance.

The nest of Pair 3 was in an area remote from human activity, although the pair frequently foraged on a lake used by recreationists. The incubating male (invisible from below) sat tight as people unknowingly approached from downhill and stood beneath him; he flushed when the people had retreated ~50 m uphill and he could see them over the nest-rim, but he returned to incubate (for at least the ensuing hour) as soon as the people had promptly retreated to ~180 m and partly concealed themselves behind an embankment. Thus, the nest was still active after this inadvertent, short disturbance.

The nest of Pair 4 was remote (~200 m) from a picnic area and walking track, but the eagles would have been used to foraging near human presence on the lake shore. In the prelaying phase the pair flushed from the nest at inadvertent human approach within ~100 m, but the incubating or brooding adult later sat tight when checked once briefly at ~150 m, and a juvenile subsequently fledged.

Incubation

At Nests 1, 2 and 3, and at Jervis Bay, both male and female shared daytime incubation, though females took the greater share. On one day at Nest 3 the male arrived at the nest with a full crop, and the larger, moulting female left and soared upriver, apparently hunting; he incubated for the ensuing hour in her absence. On one day at Jervis Bay, the male arrived soaring over the nest area, the larger female rose from the nest and soared, departing on a long glide for hunting grounds, and the male descended to the nest and incubated.

At Nest 1, in 4 h over different days, the eggs were uncovered for <1% of observation time during a changeover; the presumed female incubated for 83% of time, and the presumed male for 17%. The female incubated for three stints of >60 minutes (i.e. beyond the start and finish of observation sessions), and the male for one stint of >41 minutes. During a changeover he brought greenery to the nest and stood on the rim, the female remained sitting while he repeatedly lowered his head towards the nest-cup in apparent intention-signalling movements, then she left and he stepped into the cup and settled to incubate. On one other occasion he brought greenery to the nest but she remained sitting, and he left; and on two

occasions he visited the nest (without prey or greenery) but she remained sitting, and he left. No prey was seen to be brought to the nest during this stage.

At Nest 2, the female incubated for 55% of time overall (21 h), and the male for 40%; the eggs were uncovered for usually 1–2 minutes (4% of observation time) during changeovers, while the adult(s) stood on the nest. The nest was unattended for periods of 2–4 minutes (<1% of observation time), during which the male was in the nest-tree for ~1 minute and either adult was on the lookout perch for the remainder. During the all-day watch, the female incubated for 73% of time (7 h) and the male for 16%. The female's timed stints averaged 40 minutes (range 6–87 min., n = 9), but she also incubated for three stints of >60, >60 and >66 minutes (i.e. beyond the start or finish of observation sessions). Apart from one abortive stint of 1 minute when the female immediately relieved him, the male's timed stints averaged 48 minutes (35–67 min., n = 3), but on other days he also incubated for three stints of >60 minutes, and others of >40, >30 and >23 minutes (i.e. beyond the start and/or finish of watches).

During changeovers at Nest 2, when the male relieved the female, typically he brought greenery, placed it and stood on the rim until the female rose, stepped to the rim and left, then he settled; once both birds arranged greenery before she left. When he brought a stick, she stepped to the nest-branch as he placed it. The male also sometimes arrived without greenery, and stood on the rim until the female rose and left, before he settled. On one occasion the female spontaneously rose and flew to the lookout perch, and the male then arrived at the nest and settled. When the female relieved the male, usually she arrived at the nest and stood while the male rose, stepped to the rim and left, then she settled. On two occasions she stepped into the cup (once trying to settle) before he rose and left. On another occasion the sitting male spontaneously rose and went to the lookout tree, perching beside the female, where they duetted before she went to the nest and settled. Only the male brought material to the nest (six green sprays and one stick in 21 h, or 0.3 item/h). Typically, the relieved bird went foraging and sometimes caught prey, or remained perched on the lookout tree or another tree. Prey was generally not brought to the nest, and the male did not provision the female, although early on the all-day watch there was food on the nest and both birds fed from it periodically during the day; later that day the female caught a small prey item, took it to the nest and ate (while the incubating male stood and left). On the all-day watch, and on a 3-h watch on another day, there were four changeovers of incubation duty, and the relieved female did not always depart to forage, but sometimes remained perching nearby. Nest 2 was built up with sticks during the incubation period, making the rim higher; the incubating male, in particular, became less visible towards the hatching day.

The estimated laying date of 31 July ± 2 days at Nest 1 to pipping or hatching on 8 September gives an incubation period of 39 ± 2 days. The estimated laying date of 31 July ± 1 day to pipping or hatching on 11 September at Nest 2 gives an incubation period of 42 ± 1 days. The mean interval, or overlap in these estimates, gives an incubation period of ~41 days. For both pairs, pipping or hatching was signalled by the sitting adult being restless, frequently rising and peering beneath its breast, or standing and peering into or nibbling in the nest-cup, and resettling (slightly higher on the nest than during incubation) with much rocking. At Nest 1 on the pipping/hatching day, after being relieved by the male, the female left the nest and returned with prey (contrasting with the pattern during incubation). She tore

at the prey and fed herself, then brooded higher on the nest, with dorsal plumage fluffed, but the watch then ceased; on day 4 (next watch day) she fed a chick.

From their behaviour, Pair 2 hatched a chick but it must have died within a day or two, as the pair then reverted to incubation routines, apparently continuing to sit on a second egg that failed to hatch. Incubation behaviour continued for at least another 2 weeks, well beyond the normal incubation period, and the nest was abandoned by 3 weeks after the hatching date. The landowner, who saw the nest almost daily, also noticed that the breeding event came to a premature end, with no young fledged (J. Stent pers. comm.).

Nestling period: parental behaviour (Nest 1)

At Nest 1 the male and female shared parental duties, with the female performing most of the care of the chick in the early weeks, though the male also took a significant share. The parents' nest-attendance routines changed from mostly brooding in the first 2 weeks, to standing on the nest or perching in the nest-tree (guarding) in the middle stages, to being mostly absent in the final weeks (Table 3). They were not seen to day-brood after week 2, but the female settled to brood at dusk, in preparation for night-brooding on day 39 (week 6). Both parents were on the nest together for a small and declining proportion of time, and both parents tore prey and fed the chicks bill to bill, until at least week 6 (Tables 3 and 4). These trends in parental attention parallelled the growing chicks' ability to thermoregulate and feed themselves on prey left on the nest (cf. Table 5).

The female brooded for stints of >31, >37, >42, >55, >57 and >63 minutes, and the male's stints averaged 21 minutes (8–56 min., n = 4). Even in week 1, the female's absences ranged from 8 to 86 minutes, but the male was usually at the nest in her absence. In weeks 1–2 the nest was unattended for periods of 1–12 minutes (commonly 3–9 min.), but an adult was usually in the nest-tree, soaring over the nest area, or probably on the lookout tree (as suggested by calling from that direction, although the tree was not visible from the observation point). During changeovers of brooding or nest-attendance, the male or female arrived at the nest with or without prey, and the other adult usually then left; the incoming bird stood, or sometimes tore at prey, until the other had left before starting to feed the chicks. Once (week 1), the male delivered prey and left, and the female (on the nest) ate some of it, then left; he returned, ate some scraps, then brooded. Occasionally, the nest-attending bird left and soared, and the other then arrived at the nest. Once (week 4), the male brought prey and started eating, and the female (standing on the nest) reached for it with her bill, but he kept eating and she left, then he fed the chicks. Once (week 5), the male brought prey to the unattended nest, and the female arrived and claimed it; he left, then she fed the chicks. In week 4 the female deposited prey on the unattended nest, then left and soared.

Both the male and female brought prey to the nest from week 1; on day 1, while the male took a brooding shift, the female left and returned with prey. There was no indication that the female collected prey from the male away from the nest. Rather, she brought fresh prey (fish) from the direction of the lake while the male was at the nest or otherwise visible. In week 2, after feeding sessions, the female twice took a fish tail from the nest towards the lookout tree; and in week 5, after respective feeding sessions, the male removed a fish tail from the nest, the female took the rear half of a fish towards the lookout tree, and the male removed a fish remnant from the nest and dropped it in flight.

Table 3

Parental time-budget of White-bellied Sea-Eagle pair at Malpas Dam, Guyra, NSW (Nest 1: see text), in the nestling period, September–November 2007: % observation time (total 29.5 h) spent in each activity. Stand = adult standing on nest (including adult feeding itself), in tree = adult perched elsewhere in nest-tree, unattended = neither adult at nest. Number in parentheses = no. of hours observation in each week. Week 1 = first week after hatching.

Sex/activity	*Weeks*			
	1–2 (9.5)	*3–4 (6.5)*	*5–6 (7.5)*	*10–12 (6.0)*
Female:				
Brood	59		2[a]	
Stand	8	11	14[b]	?[d]
Feed chicks	2	2	5[c]	
In tree	<1	1	14	?[e]
Male:				
Brood	15			
Stand	5	35	15[b]	?[d]
Feed chicks	2	9	2[c]	
In tree	4			?[e]
Unattended	7	25	44	65
Both at nest	12	2	<1	

[a]At dusk, before night-brooding, on day 39

[b]Plus adult of unknown sex standing on nest for a further 5% of time

[c]Plus adult of unknown sex feeding chicks for a further 3% of time

[d]Adult of unknown sex standing on nest for 8% of time

[e]Adult of unknown sex in nest-tree for 27% of time

In week 3 (day 19) and 4 (day 28), in mid morning, the male and female, respectively, stood on the northern rim of the nest, back to sun and casting their shadows on the chicks, though without spreading their wings. In week 5 (day 29), during a feeding session, the satiated chick moved into the male's shadow while he fed the other chick.

Data were incomplete, but it appeared that the duration of feeding sessions, and the amount of food taken by the chicks, tended to increase as the chicks grew (Table 4). The female also appeared more efficient than the male at feeding the chicks, and she sometimes fed both chicks alternately, whereas if the male fed both chicks in a session, it was sequentially after the older chick was satiated. The male sometimes reached awkwardly between or beside his legs to feed a chick behind him.

Table 4

Parental feeding of White-bellied Sea-Eagle nestlings, Malpas Dam, Guyra, NSW, September–November 2007 (Nest 1: see text): chicks' meal sizes and morsel consumption rate. F = female, M = male parent. No data after week 5.

Week/day	*Length of parental feeding bout*	*No. morsels taken by chick(s)*
1/4	F: >5 min.	6 pieces in 5 min. (= 1.2 pieces/min.)
1/7	M: 9 min., 3 min.	16+ pieces in 6 min. (= 2.7 pieces/min.)
2/9	F: 6+ min.	~12 pieces in 6 min. (= 2.0 pieces/min.)
3/19	M: 11 min.	~18 pieces in 3 min. (= 6.0 pieces/min.), then 4 pieces in 1 min. after pause
3/20	M: 17 min.	17 pieces in 6 min. to larger chick (= 2.8 pieces/min.), then 7 pieces in 2 min. to smaller chick (= 3.5 pieces/min.)
	F: 9 min.	35 pieces in 5 min. (= 7 pieces/min.), then 10 pieces in 3 min. (= 3.3 pieces/min.) after pause
4/28	M: 15 min.	38 pieces in 10 min. (= 3.8 pieces/min.), then 6 pieces in 2 min. (= 3.0 pieces/min.) after pause
5/29	M: 3 min.	14 pieces in 3 min. (= 4.7 pieces/min.)
	F: 16 min.	101 pieces in 6 min. (= 16.8 pieces/min.), to both chicks alternately
5/31	F: >5 min.	33 pieces in 5 min. (= 6.6 pieces/min.)
	M: 9 min.	28 pieces in 4 min. (= 7.0 pieces/min.), then 7 pieces in 1 min. after pause
5/32	M: 3 min.	15 pieces in 3 min. (= 5 pieces/min.)

In week 4 (day 27) the female brought a stick to the nest; in week 4 (day 28) the male brought two green sprays to the nest within 30 minutes in mid morning; on the afternoon of day 29 there was fresh greenery on the nest; and on day 40 (week 6) the male brought greenery in the early morning. Thus, one stick and three green sprays were brought in 29.5 h (= 0.1 item/h). Thereafter there were no data, but there was no fresh greenery on the nest in week 12 (day 84, the day before the younger nestling fledged).

In week 6 (day 39) the female roosted (brooding) on the nest, and the male perched at dusk in a live eucalypt next to the nest-tree. In week 10 (day 70), from before sunset until dusk, the adults were not seen on or in the vicinity of the nest.

Nestling period: development of young (Nest 1)

At Nest 1, two juveniles fledged. They were downy for their first 4 weeks, with remiges burst by week 5; from week 6 feathers gradually appeared, dorsally at first then finally on the head, until by week 10 the juveniles were mostly feathered with downy underwings, and had short wings and tail beyond week 11 (Table 5). By day 20 they could defaecate over the nest-rim, and by day 27 they could move around the nest. One flapped its wings on

Table 5

Growth and development of nestling White-bellied Sea-Eagles, Malpas Dam, Guyra, NSW, September–November 2007 (Nest 1: see text). Chicks not sufficiently visible in weeks 1–4 to ascertain plumage details; observations lapsed in weeks 7–9.

Week	*Day*	*Comments*
3	19	Small and downy; one slightly larger than sibling.
	20	Chick defaecated over nest-rim.
4	27	Downy; active, moving, tottering on nest.
5	29	Downy with dark hind-edge to wings, scapular pins. Older/larger chick had slightly more advanced pin-feathers.
	32	Remiges burst, scapulars burst.
6	39	Chicks large; head downy, scapulars and remiges feathering, tail sprouted.
	40	Chick flapping its wings.
	41	Older chick more feathered on upperwings/scapulars than its younger sibling.
10	66	Adult size; appeared fully feathered, including brown head.
	70	Wings and tail short, underwings downy; appeared not ready to fledge. One chick more active than other: jumped across nest with wings open, picked at food remains, flapped wings unsteadily, clumsy; played with prey remains, plucked feathers from prey (eating?); several bouts of sustained jumping and flapping, barely lifting off.
11	77	Fully feathered, wings and tail short. Picked at prey on the nest; appeared too clumsy to fledge.
12	84	Older juvenile already fledged; younger sibling's last day in nest.

day 40 (week 6), and by the end of week 10 both juveniles were jumping and flapping on the nest, and feeding themselves on prey left in the nest. (No data were obtained for weeks 7–9). No sibling rivalry was observed, e.g. when they were being fed, but the younger chick often waited its turn while the older chick was fed by the male, although the female fed them more equally (cf. Table 4). One juvenile (the older and more advanced, suspected male) appeared darker than the other, and also more active towards the fledging date; it fledged earlier than its paler and less active sibling (the younger, suspected female).

The older juvenile of Pair 1 hatched on 8 September and fledged on 26 November ± 3 days, giving a nestling period of 81 ± 3 days. The younger juvenile fledged on 30 November; assuming a laying and therefore hatching interval of 2–3 days, its nestling period was 83–84 days. Thus, the nestling period was between 78 and 84 days, but likely to have been at the higher end of the range (i.e. 81–84 days), as the older juvenile appeared not ready to fledge when last seen as a nestling on 22 November (day 77).

Fledging

On day 84, after the older juvenile had fledged, the younger remained resting in the nest. Next morning the younger juvenile was on a branch of a live eucalypt on the hilltop ~300 m from the nest, towards the adults' lookout tree overlooking the lake. One adult was on a dead tree on the lake side of the hill.

Juvenile White-bellied Sea-Eagle, Newcastle, NSW

Plate 24 Photo: Ian Ladyman

Post-fledging period (Nest 1)

On day 3, around sunset, one juvenile from Nest 1 was perched at the extremity of the nest-branch, above nest-height; its wing-tips were about level with its tail-tip, and its feet were creamy yellow. The second juvenile then arrived lower in the adjacent tree. An adult perched beside it, but at dusk the adult left in the direction of the lookout tree. When it was too dark to see much detail, it appeared that both juveniles were continuing to roost on branches near the nest.

In week 4 (day 28), both juveniles were perching between the lookout tree and the dam, on dead trees on the hillside. One had a full crop, and the other flew and soared low in spirals competently; both appeared to be still dependent and waiting on parental food provision.

Juvenile White-bellied Sea-Eagle, Newcastle, NSW

Plate 25 Photo: Ian Ladyman

In week 7 (day 49) both adults were on the lake shore >1 km from the nest. One juvenile was ~1 km from the nest, along the lake shore, and followed an adult back to the dead trees on the hillside below the lookout tree. The other juvenile was also on a dead tree on the hillside, in the area where they had previously waited for parental food provision.

In week 10 (day 64) one juvenile was alone over the lake >1 km from the nest; it flew a low flap-glide hunting transect down the lake shore, intently watching waterbirds on the shoreline fleeing into the water at its approach, then it perched. Later it was flushed by two stockmen on quad-bikes, making much noise and driving cattle, when they approached within ~200 m; it soared in spirals very high over the nest-area, in an adult-like competent manner. No juveniles were detected

Juvenile White-bellied Sea-Eagle, Newcastle, NSW

Plate 26 Photo: Ian Ladyman

in the territory in weeks 12–15, when an adult was seen on each occasion, but checks were infrequent and the juveniles could have been out of sight in remote parts of the lake. In week 23 (day 158) a juvenile flew in to the adults' hillside lookout area to roost at sunset, giving 'begging' type calls (slow wailing yelps) as it approached. The juvenile(s) thus remained in or returned to the natal territory for over 5 months after fledging.

In mid June 2007, the day before Pair 1 was found nest-building (6 weeks before egg-laying), a juvenile Sea-Eagle flew past the nest area to the lake, but went unchallenged by the adults although the male had flown the same course a few minutes earlier and was perched in view of the juvenile's flight-path, in a position to intercept if he were so inclined. This incident suggests that the previous year's offspring was tolerated in the nesting territory until the start of the next breeding season, or at least 6 months after fledging.

At Jervis Bay in mid May, the pair observed in courtship flight was accompanied by two juveniles from the previous year. Two other pairs also had one and two juveniles, respectively, with them in May. Aggression was not shown towards these juveniles, although it was towards an older immature Sea-Eagle intruding in a territory. Assuming a fledging date of around December, these pairs tolerated

juveniles in the natal territory for ~5 months after fledging, and into the courtship season, though still 3–4 months before local egg-laying.

Breeding productivity

Pair 1 fledged two young, Pair 4 fledged one young, and Pairs 2 and 3 failed (for unknown reasons, though both had laid eggs) in 2007. Including data for Quipolly Dam in 2006, when Pair 2 fledged one young but a second, partly developed chick was found dead under the nest (J. Stent pers. comm.), four young fledged in 5 pair-years, or 0.8 young per attempt. In a previous year, either 2004 or 2005, Pair 2 raised two young (J. Stent pers. comm.).

The breeding failures at climatically milder sites (Inverell and Quipolly) and the successes at high elevation (Llangothlin and Malpas) in 2007 seem paradoxical, but the local highland waters are stocked with introduced fish (including trout), which may provide artificially high food abundance for the eagles. Furthermore, during the recent drought Malpas Dam remained at >90% capacity, whereas water levels were low elsewhere in the study region.

Feeding rates

No prey deliveries to the nest or female were observed in the prelaying and incubation phases of Pairs 1 and 2 during 40 h of observation. In the nestling period of Pair 1, the adults brought 14 prey items in 29.5 h (= 0.5 item/h): 10 by the male, three by the female and one where the sex of the adult was unknown. In addition, the female brought an item but took it towards the lookout tree where she apparently ate it (appearing later without prey). On different days, the female brought two items within 29 minutes, the male brought two items within 22 minutes, and the male left and returned with prey in 10 minutes. Until week 4, parental prey deliveries were approximately equal (three by the female, four by the male and one by parent of unknown sex in 16 h), but thereafter only the male was seen to bring prey (six items in 7.5 h in weeks 5–6). Observations lapsed in weeks 7–9 and were too sparse to record prey deliveries in weeks 10–12 (none seen in 6 h).

Diet and hunting

The Sea-Eagles took fish, waterbirds and freshwater turtles, with no conclusive evidence that they took mammals such as lagomorphs or macropods (Table 6, which gives scientific names). However, the landowner reported that Pair 2 sometimes scavenged on the carcasses of feral Pigs *Sus scrofa* left in the paddock after control measures (J. Stent pers. comm.). In addition to the items listed in Table 6 from the 2007 nesting events, there were older remains at two nests: two Eastern Snake-necked Turtle carapaces (adults, dating from a pre-2007 nesting event) under Nest 2, and four adult Eastern Snake-necked Turtle carapaces, four adult Murray Turtle carapaces and weathered fragments of at least six others, representing years of accumulation, under the current nest, perch-trees and old nest of Pair 4. It was apparent that turtle carapaces greatly outlasted other orts, and that up to the largest Murray Turtles were taken.

It was not possible to quantify the percentage contribution of each prey type, by number or biomass, to the diet, because of the great discrepancy between prey items observed brought to nests (n = 17), and those found in orts or pellets

Table 6

Diet of White-bellied Sea-Eagle at four nests (as in text) in northern inland New South Wales during the 2007 breeding season: minimum number of prey individuals in fresh (i.e. 2007 season) orts (R) and pellets (P), and observed caught or delivered to nests; I = introduced.

Prey species	*Nest*				*Total*
	1	*2*	*3*	*4*	
Orts and pellets:					
RAustralian Wood Duck *Chenonetta jubata*	1	1	1	1	4
RHardhead *Aythya australis*				1	1
PAustralasian Grebe *Tachybaptus novaehollandiae*			1		1
RGreat Crested Grebe *Podiceps cristatus*	1				1
PEurasian Coot *Fulica atra*		1			1
REastern Snake-necked Turtle *Chelodina longicollis* (juvenile)			1	1	2
RMurray Turtle *Emydura macquarii* (juvenile)			2		2
RIGoldfish *Carassius auratus*			1		1
RIRedfin Perch *Perca fluviatilis*	1				1
RGolden Perch *Macquaria ambigua*		1			1
Total	3	3	6	3	15
Observed:					
Pacific Black Duck *Anas superciliosa*	1				1
Fish	8	6			14
Unidentified (turtle?)				1	1
Unidentified (fish?)		1			1
Total					17

(n = 15 prey items). Most observed items were fish (82%), but fish were scarcely represented in orts (and then possibly only the largest individuals), whereas birds and turtles were represented in pellets (birds only) and orts, but rarely seen delivered to nests (birds 6% of observed prey). Without calibrating orts and pellets against the observed frequency of those species (versus fish) being captured, results would be biased towards the more robust, persistent remains. It was apparent that fish formed the bulk of the prey seen brought to nests, but it was not possible to identify the species or accurately estimate their weight. Among the fish orts, the Goldfish and Redfin were possibly ~1 kg, and the Golden Perch was possibly ~2 kg (A.B. Rose pers. comm.). Among the fish observed as prey, those caught by Pair 2 were small (~25 cm long and totally consumed by the adults in usually 4–8 minutes), and those delivered to Nest 1 were larger (~40 cm long and often lasting more than one chick-feeding session, with remains dumped). These differences may have been selective, according to food demands at the respective stages of the breeding cycle, or related to availability at the different sites (possibly the latter, given the number of observed attacks on birds by Pair 2: see p. 184). Following Clancy (2005), the fish sizes at Nests 2 and 1 correspond with weights of <500 g and >800 g, respectively.

Sea-Eagles used a combination of searching methods: long-stay perch-hunting; transect-hunting along the shoreline; high quartering; and soaring and prospecting. They also used a variety of attack methods: glide-attacks (at fish); direct flying attacks at waterbirds, either predatory in intent or in attempted piracy of their prey; harrying of swimming waterbirds; and tail-chasing of waterbirds that flew (rather than dived) when harried. The adults of Pair 1 were observed hunting on three occasions:

1. Prelaying period, after fog lifted on a winter morning: the male flew to a lakeside dead tree and perched for at least an hour, apparently watching for prey.
2. Prelaying period: the female had been soaring high, apparently in display, then soared high over the lake; she made an apparently opportunistic long, vertical dive to the water's surface, levelling out at the last moment as she struck at prey on the surface, but missed and flew along the lake shore.
3. Post-fledging period: an adult was first seen in a direct flying attack low across the lake surface, for >300 m, at a Great Cormorant *Phalacrocorax carbo* that had surfaced with a fish in its bill; as the Sea-Eagle struck, the Cormorant dived, and the Sea-Eagle harried it again as it surfaced, but after the Cormorant's second dive the Sea-Eagle gave up and soared, as the Cormorant surfaced and swallowed the fish.

As well as patrolling the lake or shore on many occasions, either quartering or transect-hunting, the adults of Pair 2 had perches near the dam wall and along the shore, on which they sat for long periods (up to ~1 h or more), watching the water. They regularly hunted at the upper extremity of the reservoir 1.5 km from the nest, and sometimes ranged farther (3 km) to a much smaller, ephemeral lake. They were observed hunting or capturing prey on 18 occasions, mostly in the incubation period (the first five incidents, in items 2–5 below, during the all-day watch):

1. Prelaying period: the female was quartering the lake, then flew a transect along the shoreline, then quartered again; she dived towards the ground near the shoreline, behind some trees, and an Australian Raven *Corvus coronoides* (her target) flushed in alarm. After perching near the shore, she made a low pass over a flock of ducks on the water; they flushed and flew off, and she perched in a lakeside tree.
2. After being relieved of incubation by the male, the female went to the lookout perch. After an hour, she launched a glide-attack at a group of ducks (Grey Teal *Anas gracilis*?) on the water; they flushed, but one was labouring, and as she reached striking range it dived into the water; she made repeated harrying swoops each time it surfaced, but the duck then managed to take off with the eagle pursuing in a tail-chase. The duck slowly gained height and distance, and the eagle gave up and perched.
3. After a changeover, the relieved male went hunting aerially, up and down the lake. He made a direct flying attack, tail-chase and swoop at a low-flying Australian Pelican; as he reached striking range, the Pelican flopped onto the water and turned to face him with open bill, and he gave up. The attack was determined, but may have been attempted piracy (or perhaps territorial defence) rather than attempted predation. The perched male then made a long, fast, shallow glide-attack >500 m across the lake at ducks on the water, but they flushed and escaped.
4. After a changeover, the female went to the lookout perch then launched a glide-attack, with a short final twisting strike, to take small prey (fish?) off the lake surface.
5. After a changeover, the male searched aerially then dived at swimming waterfowl cornered in a small embayment of the lake; he was foiled by a Whistling Kite that harassed him, but he returned and made repeated harrying dives at the waterbirds (which submerged at each swoop) for 2 minutes before giving up for 5 minutes, then trying yet again, unsuccessfully, for another 2 minutes.
6. After a changeover, the male flew a hunting transect along the lake shore; after a swoop at a Whistling Kite, he continued, then made a shallow circling dive to snatch a fish off the surface.

7. After a changeover, the female left on a low hunting flight out over the lake; she made a shallow circling dive to snatch a fish off the surface.

8. After a changeover, the female perched on the lookout tree, flew along the shore to a favourite lakeside hunting perch where she sat for 5 minutes, then flew a hunting transect along the lake shore; she made a flat circling dive to snatch a fish off the surface.

9. The male had been on a favourite lakeside hunting perch for >6 minutes; he flew along the shore to the top of the lookout tree, and after 5 minutes made a long, low, fast glide-attack for ~500 m across the lake, ending in a circling dive to snatch a fish off the surface.

10. After a changeover, the male went to the lookout perch for 4 minutes, then swooped to the lake and made two circling dives in quick succession, taking a fish off the surface on his second pass. Ten minutes after finishing the fish, he harried a fishing Pelican, perhaps in an attempt to pirate fish (unsuccessfully).

11. The soaring male stooped at the woodland treetops on a hillside, apparently at a fledgling Australian Raven in the foliage canopy, under strong defence from the adult Ravens. He failed to dislodge the prey, and left on a hunting flight (patrolling the shore) up and down the lake. He took a fish from the lake surface, and 1 minute after eating it he again stooped at the Raven's treetop nest area, but was repelled.

12. After a changeover, the female soared over the lake, then dived at the lake surface, circled, and swooped again, harrying Great Cormorants (unsuccessfully), then sat on a favourite hunting perch for 6 minutes before leaving to soar.

13. After a changeover, the female spent 6 minutes on the lookout perch then left on a long, low flight directly across the lake to the opposite shore 800 m away, where she made a dive but was thwarted by attacks from a Whistling Kite and Australian Magpie *Cracticus tibicen*, and she retreated.

Thus, seven of 18 attack events (39%) by Pair 2 were successful. Notably, no observed strikes at birds were successful, and the few attempts at piracy of fish from waterbirds were unsuccessful, though all observed strikes at fish were successful.

In the post-fledging period, one of the adults of Pair 4 was observed unsuccessfully trying to catch a Black Swan *Cygnus atratus* cygnet: the eagle swooped at a family of cygnets huddled on the water between their two parents; at each swoop the adult Swans defended the brood by raising their heads, with open bills, and slapping with their wings (J. Fields pers. comm.).

Threats to eagles or habitat

In 1980 a pair of Sea-Eagles nested on Llangothlin Lagoon, which is adjacent to the current nesting area of Pair 4 on the smaller lagoon. The 1980 nest was in the top of an isolated live tree, with sparse upper foliage, on the lake shore. In the 1980s one of the adults was found dead, reportedly shot, and in 2007 the nest-tree was long dead and fallen. These events may have displaced the pair to Little Llangothlin Lagoon 1.5 km away.

All the pairs of Sea-Eagles in this study, in northern inland New South Wales, are subject to potential threats of various kinds. Private land in the vicinity of Pair 1 has been the subject of investigations for a possible windfarm, leading to the likelihood, if the windfarm goes ahead, of avian (including Sea-Eagle) collision deaths. Malpas Dam (Armidale's water supply) also experiences regular blooms in summer of toxic blue-green algae (cyanobacteria), including in February 2008: probably a consequence of its totally cleared catchment being top-dressed (with

superphosphate) cattle paddocks that provide nutrient-rich runoff.

The lake foraging grounds of Pair 2 (within 300 m of the nest), although surrounded by private land, are under pressure to be made publicly accessible for recreation, with its attendant disturbances and entanglement hazards (discarded fishing-line). The nest of Pair 3, although remote from public intrusion for the present, is in a new national park opened up for recreation (e.g. a walking track routed near the eagles' nest, with the likelihood of breeding failure or desertion). The nesting habitat of Pair 4, although safe from recreationists using the public land of the lagoon, is subject to a landholder who may wish, for example, to fell dead trees or conduct other activities in the vicinity.

Discussion

Breeding biology

Nest-sites and laying dates were generally consistent with previous information on the Sea-Eagle for south-eastern Australia (cf. Marchant & Higgins 1993; Olsen 1995; Thurstans in press b). The interval between nest-renovation and egg-laying was about twice as long as previously reported (6 weeks rather than 3 weeks, cf. Marchant & Higgins 1993).

The incubation period of ~41 days was longer than the previous estimate of 35–40 days, but confirmed a loose estimate of ~6 weeks (cf. Marchant & Higgins 1993), and agrees well with 40–41 days stated by Olsen (1995) and 42 days at one nest (T. Dennis in prep.). This figure also agrees well with the better-studied *Haliaeetus* species elsewhere, especially in the 'southern' group (Madagascar Fish-Eagle ~41 days, African Fish-Eagle 42–43 days; cf. Brown 1980; Ferguson-Lees & Christie 2001). Much has been made of supposed differences in the incubation period of tropical versus temperate-zone eagles (Brown 1976, 1980), i.e. ~6 weeks versus ~5 weeks, and some of the 'northern' *Haliaeetus* species have been claimed to have incubation periods of as little as 35 days (some with an improbable range of 34–46 or 38–45 days: Ferguson-Lees & Christie 2001). As pointed out by Brown (1976) for *Aquila* eagles, the shorter estimates are in error, and recent research has found little or no difference between tropical and temperate-zone large *Aquila* species (all >40 days). The same probably applies to *Haliaeetus* species (including '*Ichthyophaga*'), and reassessment of the true incubation period of, for example, Bald and White-tailed Eagles is warranted. On the other hand, estimates of 42–45 days for the African Fish-Eagle, and the upper limits for some in the 'northern' group of 45–46 days (Ferguson-Lees & Christie 2001), may be per clutch rather than per egg.

A nestling period of 78–84 days agrees with the longer estimates, previously reported for this species, of 72, >70 and >77 days (cf. Breeden & Slater 1968; Cupper & Cupper 1981; Hollands 1984), 70–80 days (Olsen *et al*. 1993a), and ~80 days at two nests (T. Dennis in prep.). However, the accessibility (to humans) of the nest reported by Breeden & Slater (1968) may have encouraged premature fledging. The results of this study also agree well with *Haliaeetus* species elsewhere (70+ to ~90 days, cf. Ferguson-Lees & Christie 2001), with the proviso that the 'fledging period' may refer to a physical growth stage rather than a behavioural stage (i.e. first flight). The slightly smaller African Fish-Eagle leaves the nest at 70–75 days, after 'branching' behaviour from 65 days old (Brown 1980), or at a mean age of 76 days (Sumba 1988), and the Madagascar Fish-Eagle leaves the

nest at 86 ± 11 days (Rafanomezantsoa 2000). Fledging at reportedly 120 days in the Madagascar Fish-Eagle (Ferguson-Lees & Christie 2001) may, therefore, represent juveniles returning to the nest after unobserved fledging, or an error for the interval from *laying* to fledging.

A post-fledging dependence period of at least 2 months, with juveniles in the natal territory for up to 5–6 months after fledging, is similar to that previously estimated for this species (Hollands 1984; Marchant & Higgins 1993; Ferguson-Lees & Christie 2001). Juveniles may linger in the natal territory almost until the start of the next breeding season or 6 months after fledging, and perhaps without being expelled by their parents. The post-fledging period lasts 3 months for the African Fish-Eagle (Brown 1980) and 5–8 months for the Madagascar Fish-Eagle (Rafanomezantsoa 2000).

Although a small sample size, breeding productivity in northern inland New South Wales was similar to that previously recorded elsewhere in southern Australia (0.8 young per territory: Marchant & Higgins 1993; T. Dennis unpubl. data). Breeding productivity, including the incidence of broods of two fledglings, may be somewhat higher in protected areas of undisturbed habitat, such as at Jervis Bay (cf. Debus 1997, who reported that four of five pairs raised two young and the fifth pair at least one young in 1995).

Breeding behaviour

The Sea-Eagles' displays, courtship and copulation behaviour were much as previously described for this species (cf. Marchant & Higgins 1993), with this study adding some examples and detail. Much has been made of sea-eagles, in particular, being the raptors most likely to include talon-grappling and cartwheeling as part of courtship displays between mated pairs. However, most such behaviour in raptors is fighting between rivals (Simmons & Mendelsohn 1993). Claims of cartwheeling by mated pairs of White-bellied Sea-Eagles have not been supported by individually marked birds. Without such, it would be difficult to distinguish resident birds from intruders, as adults are very alike in plumage and the home-ranges of neighbouring males may overlap, with possible conflict near nest-sites (Wiersma in press).

Males appeared to be the main provider of nesting material and did most of the building, at least in the prelaying and incubation periods; a male also brought greenery during the nestling period. Males took a greater share of incubation, brooding and chick care than implied in the literature and, contrary to the previously assumed strong sexual division of labour, females foraged when relieved of incubation or brooding duty, and brought some prey to the nest from the time the chicks hatched. Furthermore, in the nestling period the male brought food to the nest rather than calling the female off to receive the prey; in the pair observed by Hollands (1984), the female may have been foraging rather than collecting the male's prey. In the chick phase, the adults brooded little by day, as also found by Hollands (1984). Sea-Eagles appear to brood less by day than do Wedge-tailed Eagles and, correspondingly, leave small chicks unattended for a greater proportion of time (cf. Debus *et al*. 2007).

The results of this 'snapshot' study on breeding behaviour should be interpreted with caution, as sample sizes were small and sexing of adults was sometimes tentative at Nest 1. However, sexing of adults up to the hatching stage at Nest 2 was certain, and changeovers of duty were observed in the nestling period at Nest 1,

confirming that the male and female shared roles.

Juvenile development

There is little relevant information on the White-bellied Sea-Eagle with which to compare the nestling growth stages observed during this study. Nestling behavioural development was similar to that observed by Cupper & Cupper (1981) and Hollands (1984). Although sibling rivalry and siblicide sometimes occur (Marchant & Higgins 1993), such behaviour was not observed in this study at the one nest watched during the chick phase and which ultimately fledged two juveniles. This outcome may have been partly related to food supply, but the female also distributed food to both chicks alternately during her feeding sessions, thus ensuring that the younger chick obtained food. Nestling growth appeared to follow the patterns found by Brown (1980) and Sumba (1988) for the African Fish-Eagle, including fledging at adult size but with shorter wings.

Similarly, there is little other relevant information on Sea-Eagle post-fledging behaviour. Juveniles of Pair 1 appeared to wait for parental feeding on the hillside near the nest, where they overlooked the hunting grounds and later made short excursions towards the lake shore, during their first 2 months after fledging. Thereafter, they ventured more widely over the lake and attempted to forage. In these respects they appear to resemble the African Fish-Eagle (cf. Brown 1980) and Madagascar Fish-Eagle (Rafanomezantsoa 2000), so far as is known.

Diet and hunting

The diet of the Sea-Eagles in this study was, from observational data, dominated by fish, as also found by Cupper & Cupper (1981) and Hollands (1984). However, waterbirds and freshwater turtles were strongly represented in orts, whereas fish rarely appeared in orts, and only birds appeared in the few pellets (n = 2) found. From orts only, the diet was similar to that reported by Olsen *et al*. (2006a,b) for inland-breeding Sea-Eagles in south-eastern Australia. However, dietary studies that rely heavily on orts may be biased by the relative persistence of bird skeletal remains and, particularly, the hard carapaces of turtles. Therefore, such studies should be calibrated by observational data to determine correction factors for fish orts. Mersmann *et al*. (1992) found, for the Bald Eagle, that fish were under-represented in pellets; that small, soft-bodied fish were under-represented in remains (this bias increased with time between ort collections); and that multiple techniques, including observation, were required for an accurate dietary profile. Very large food items, i.e. carrion, may also be under-represented in pellets (J. Olsen pers. comm.). In the present study, there were insufficient data to assess possible selection of fish species by the eagles (other than surface-swimming types): an obvious subject for investigation (cf. Stewart *et al*. 1997).

Although data were not obtained for contiguous territories in the same year, it is apparent that Sea-Eagles in the New England region take smaller and more aquatic prey types than do the local, similarly sized Wedge-tailed Eagles, which mostly take terrestrial mammals of rabbit and hare size (Debus *et al*. 2007). These results are similar to those of Olsen *et al*. (2006a,b). With multiple investigation techniques (cf. Mersmann *et al*. 1992), the dietary parameters of the Sea-Eagle, e.g. geometric mean prey weight, will likely be found to differ from those of sympatric Wedge-tailed Eagles in northern New South Wales and elsewhere, as found for southern New South Wales by Olsen *et al*. (2006a,b: ~900 g for Sea-Eagle vs ~2 kg for Wedge-tailed Eagle).

Foraging and attack behaviour of the Sea-Eagles in this study was consistent with that reported in the literature (cf. Marchant & Higgins 1993; Olsen 1999; Olsen *et al*. 2006b). It was also similar to that described for the African Fish-Eagle (cf. Brown 1980), though with a lower success rate than reported for that species by Sumba (1989), and higher than that for the Madagascar Fish-Eagle (cf. Berkelman *et al*. 1999, who calculated kills per searching event rather than per attack). The Sea-Eagles in this study were agile in the air, and expended much energy in failed attempts to catch waterbirds or pirate food from them. In the latter respect they also resemble the African Fish-Eagle (cf. Sumba 1989).

Conclusions

Behavioural aspects of the White-bellied Sea-Eagle's breeding cycle, and nestling and fledgling behaviour, seem (so far as is known) typical for similarly sized, ecologically equivalent *Haliaeetus* (or *Cuncuma*) species elsewhere (cf. Brown 1980; Rafanomezantsoa 2000; Ferguson-Lees & Christie 2001). Many aspects of White-bellied Sea-Eagle biology remain to be studied in detail and there is obvious scope for much better quantification, with greater sample sizes than in the present study, by a more rigorous approach that could include systematic observation in time-blocks throughout the day in all phases of the breeding cycle of several pairs. There is much potential for such studies in coastal areas with higher observer as well as eagle densities, and hence logistically more feasible than the prohibitive distances between inland sites. For instance, in the lower Clarence Valley on the New South Wales North Coast there are ~20 known nesting pairs in ~80 km of coastal plain (G. Clancy pers. comm.); historically there were 27 pairs in the Sydney region (~40 km of coastal plain: Bowden 1996), with a pair every ~3 km on the Hawkesbury River (N. Jarvis pers. comm.); and ~10 pairs in the Jervis Bay area (Debus 1997).

Colour-marking would shed light on social organisation and behaviour, though possibly adverse effects with, for example, wing-tags, should be avoided (cf. Baker-Gabb 1993); red (i.e. seemingly blood- or flesh-coloured) leg-bands may cause undue intraspecific harassment (attempted piracy of perceived 'prey' in a banded eagle's foot). Radio-telemetry would reveal details of the post-fledging period and dispersal not readily obtainable by other means, and banding and colour-banding studies would provide data on juvenile survival and recruitment.

Inland-breeding White-bellied Sea-Eagles are at the mercy of El Niño-associated droughts (Shephard *et al*. 2005a). With the prospect of more frequent and severe droughts associated with climate change, coastal populations will become critical to the future of the species, in southern Australia at least. However, if identified trends continue (cf. Emison & Bilney 1982; Dennis & Lashmar 1996; Dennis 2004; Threatened Species Unit 2005; Dennis & Baxter 2006; Thurstans in press a), the species will be under increasing pressure from people throughout coastal southern Australia, even in national parks (cf. Spencer & Lynch 2005). Given the Sea-Eagle's sensitivity to disturbance at the nest, the increase in human population and the property boom on Australia's south-eastern coastline, and therefore the likelihood of increasing incidence of breeding failure and nest abandonment, the Sea-Eagle must be regarded as increasingly under threat in densely human-populated areas. In southern Australia, viable breeding populations will likely become restricted to the larger coastal national parks, and thus become disjunct clusters of a few pairs, vulnerable to catastrophic events such as wildfires or severe storms. Displacement from coastal breeding habitat may also bring the

Sea-Eagle into increasing interspecific conflict with the Wedge-tailed Eagle over nest-sites, with possibly increased adult mortality. Windfarms may be an additional, and increasing, cause of mortality of Sea-Eagles.

The Sea-Eagle is already listed as Endangered in South Australia, and Vulnerable in Tasmania and Victoria. Extrapolating from the regional population of this study, the number of pairs studied in the Canberra region, Australian Capital Territory (Olsen *et al*. 2006a,b), densities on inland rivers (Marchant & Higgins 1993), and the sample coastal densities (p. 189), there may be ~100 pairs on the tablelands and western slopes, ~100 pairs in the Murray–Darling Basin, and 600 pairs on the New South Wales coastline (of ~1200 km) and in the coastal drainages, giving a New South Wales population of perhaps 800 pairs. The Sea-Eagle seems poised to decline into the Vulnerable category in New South Wales as well, thus making the need for knowledge, for conservation and management purposes, all the more urgent. For instance, the eagle is starting to show an apparent decline around Canberra (J. Olsen pers. comm.).

As the Sea-Eagle is federally listed in the *Environment Protection and Biodiversity Conservation Act* as 'migratory' (i.e. subject to the Bonn Convention and the China–Australia Migratory Birds Agreement), the Australian Government is obliged to protect its habitat and breeding sites. The Sea-Eagle may also warrant greater legislative protection at state level, by listing it as Vulnerable in New South Wales. Such a classification would obligate proponents of developments to conduct adequate assessment of impacts on breeding habitat, and on its local, regional and State populations. For management of populations where breeding failure or nest abandonment are likely, proposed buffer zones around breeding sites should incorporate the concept of 'viewsheds' (cf. Camp *et al*. 1997). Also, any BioBanking Scheme tradeoffs, to compensate for Sea-Eagle breeding sites lost to coastal developments, should ensure that offset areas support viable Sea-Eagle nests.

The Eastern Osprey *Pandion cristatus* is currently the iconic coastal raptor in some southern states (South Australia, New South Wales), but the Sea-Eagle, being the more sensitive and demanding in terms of breeding-habitat requirements, is an even more appropriate flagship and umbrella species for coastal conservation. Targetting Sea-Eagle breeding habitat for adequate reservation and protection would likely take in areas of high biodiversity value, and thus confer broader conservation benefits (cf. Sergio *et al*. 2006, 2008). However, a first step will be adequate survey to determine where core Sea-Eagle breeding populations, in the best coastal habitat, occur in Victoria and New South Wales, as has been done for South Australia and Tasmania. The Sea-Eagle would also be an appropriate flagship and umbrella species for conservation of inland wetlands and rivers, notably the troubled Murray–Darling Basin.

Acknowledgements

I thank Geoff Mitchell for showing me the Quipolly nest, and John Stent for access to it and for information on the eagles; Mike Porter (Armidale Dumaresq Council) and Ross Keen for permission and access to study the Malpas nest; John Courtney and Angus Newey for sharing the finding and/or watching of the Inverell, Llangothlin and Malpas nests; and particularly Sofia Dodds for providing a Tamworth base for visits to the Quipolly nest, and for sharing some of the nest-watches. I thank Shirley Cook (Birds Australia Northern NSW) and the Tamworth Birdwatchers Association for publicising my quest for eagle nests; Frank & Wendy Ball, Bert Makepeace, Steve Trémont (BANN), Eric Fair (TBA), Hugh Ford and Neil Jarvis for eagle sightings or information; John Fields for his observation of the swan

incident; and Paul Sheather (Dutton Trout Hatchery) for his information. Andrew Ley kindly made the telescope available, and Simon Cherriman kindly provided a copy of a paper. I am most grateful to Tony Rose for identifying many of the prey items, Terry Dennis and Jerry Olsen for comments on drafts and unpublished data, Andrew Ley for editing, and Ian Ladyman for his photographs. Martin Dillon prepared the map.

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Received 5 May 2008, revised 4 September 2008

Addendum

In 2008 Pair 1 had a feathered nestling, at fledging age, in the now larger nest on 15 November. Pair 2 fledged a single young, in mid October, from a new nest in the lookout tree; a month later the juvenile was starting to range solitarily away from the nest area, but returned to roost with its parents near the nest (J. Stent pers. comm.). The 2007 nest of Pair 3 was vacant, with no sign of recent attendance, in early October, suggesting either an early failure or a shift to a new (unknown) site. The 2007 nest of Pair 4 appeared built up in early October, but was unattended, with only old greenery on it, also suggesting either an early failure or a site shift. At Eden, in southern coastal New South Wales in 2008, a large feathered nestling was checked twice daily (dawn and early afternoon) over its last fortnight in the nest. Apart from the first morning, when an adult was tearing food on the nest, the young was always alone (i.e. little parental attendance at that stage), and on its last morning in the nest (2 November) it was flapping its wings before fledging by midday. ■

Notice—

Thank you, Graham Cam

On behalf of BOCA and the *AFO* editorial team, I extend to Graham Cam a belated thank you for his editorial service over the last few years.

Stephen Debus