Corella, 2007, 31(2): 41-49

FEEDING ECOLOGY OF THE WEDGE-TAILED EAGLE *Aquila audax* IN NORTH-WEST QUEENSLAND: INTERACTIONS WITH LAMBS

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Received: 4 August 2006

The diet of the Wedge-tailed Eagle *Aquila audax* was studied by analysis of pellets (n = 145) and prey remains from four sites in the north-west Queensland sheep rangelands, and one non-sheep site in north Queensland. Eagle behaviour around lambs was observed from a hide at sheep camps at three sites (total 216 h), and post-mortems were conducted on 29 dead lambs from three sites. In north-west Queensland the diet of breeding adult eagles, from remains (n = 216) at 12 nests, consisted of 53 percent mammals, 28 percent birds and 19 percent reptiles by number, and 89 percent mammals, 10 percent birds and 1 percent reptiles by biomass. Diet of breeding adults and non-breeding subadults combined, from pellets, consisted of 67 percent mammals, 25 percent birds and 8 percent reptiles by number, and 75 percent mammals, 24 percent birds and 1 percent reptiles by biomass. Eagles ate some lambs (17% by number and 15% biomass in remains, 33% and 21% in pellets); carrion could not be distinguished from live prey. The higher proportion of lamb in the pellet data may reflect a higher level of scavenging or predation on lambs by non-breeding immature eagles than by breeding adults. In north Queensland the eagles' diet at two nests consisted, by number, of 78 percent mammals and 22 percent birds in remains (n = 21) and 86 percent mammals and 14 percent birds in pellets; biomass contributions were 97–98 percent mammals and 2–3 percent birds. No attacks on lambs were observed; of 29 dead lambs, eagles killed one viable lamb (3%) and two lambs of unknown viability. The dietary data, together with differences between sites in eagle numbers, age classes, seasonal fluctuations and nesting activity, suggest the following interpretation: most of the few lamb deaths and injuries attributed to raptors were caused by non-breeding eagles, and that by their territorial defence adult eagles may exclude immatures and thus provide a measure of protection to lambing flocks.

INTRODUCTION

The diet and foraging of the Wedge-tailed Eagle *Aquila audax*, including the controversy over possible predation on lambs, have been investigated in many parts of southern Australia where introduced Rabbits *Oryctolagus cuniculus* provide a major food source for eagles (reviewed by Marchant and Higgins 1993 and Olsen 1995; also Olsen *et al.* 2006; Silva and Croft 2007; Collins and Croft 2007). However, there have been no detailed studies in northern Australian sheep lands where rabbits are absent and there may be increased potential for eagle predation on lambs. The only quantified study was in a national park, where lambs were not available within that study area (although feral Goats *Capra hircus* were); the eagles ate mostly small macropods and other mammals, including a few goats or kids (Sharp 1997). Otherwise, for northern Queensland there is an account of eagle predation on arboreal mammals in closed forest, i.e. non-sheep country (Burnett *et al.* 1996). Eagle diet on the subtropical east coast (a range of native mammals, birds and reptiles: Harder 2000), at sites where rabbits are scarce, suggests the likely prey profile farther north.

Raptor diets are commonly studied by examination of prey remains at nests, and by collection of regurgitated pellets at and away from nests (e.g. roosts). Both methods have potential biases, and the dietary profile can differ substantially in remains versus pellets for certain species eaten, especially large animals that may be fed on over several days, including sheep (e.g. Leopold and Wolfe 1970; Brooker and Ridpath 1980; Sharp *et al.* 2002). For instance, sheep was more prevalent in Wedge-tailed Eagle pellets than in prey remains and vice versa for reptiles, but other prey types were more similarly apportioned between remains and pellets (Sharp *et al.* 2002).

Owing to concerns raised by graziers and the Queensland Department of Primary Industries, this project was established to investigate the diet of Wedge-tailed Eagles and their interactions with sheep in the rangelands of north-west Queensland, where there are no rabbits as alternative prey. The region is marginal for sheep production, with high mortality of lambs (D. Maxwell pers. comm.). The aims of the study were to quantify the eagles' diet, including the contribution of viable lambs, to describe the eagles' behaviour around lambs, and to assess the vulnerability of lambs to eagle predation. This study also sought to compare the eagles' diet in a region of north Queensland where lambs are not available and rabbits are scarce.

STUDY AREA AND METHODS

Study sites

The main study area was the sheep rangelands of north-west Queensland in the region bounded by Cloncurry, Hughenden and Boulia. Stations in the region are increasingly converting from sheep to cattle, leaving sheep runs increasingly isolated and surrounded by cattle runs. Eagle dietary samples, observations of eagle behaviour, interviews with graziers, or samples of dead lambs for post-mortem analysis were obtained

from Richmond (20°45'S, 140°08'E; three sites), Julia Creek (20°40'S, 141°40'E; three sites), Kynuna (21°35'S, 141°55'E; one site), McKinlay (21°16'S, 141°17'E; one site), Cloncurry (20°41'S, 140°30'E; five sites), and Boulia (22°53'S, 139°53'E; three sites). The general landscape was flat to gently undulating Mitchell and Flinders grass downs (*Astrebla* and *Iseilema*) with scattered trees, mainly on watercourses and low ridges: Coolibah *Eucalyptus microtheca*, Carbeen *Corymbia tessellaris*, Whitewood *Atalaya hemiglauca*, Bauhinia *Lysiphyllum carronii*, and various acacias (Gidgee *Acacia cambagei*, Prickly Acacia *A. arabica*, Mimosa *A. farnesiana*, Boree *A. cana*). Land use was sheep and cattle grazing; of nine main study sites, five ran mostly sheep (one wethers only, i.e. no lambs), two ran sheep only, and two ran mostly cattle.

A secondary study area, for comparison of eagle diet where lambs were not available, was in cattle rangeland at Mt Fox (18°49'S, 145°47'E; two sites), 40 kilometres south-west of Ingham in north Queensland. The landscape was hilly with tall eucalypt grassy woodland: mainly Pink Bloodwood *Corymbia intermedia* and Carbeen, with spear grasses *Heteropogon* and kangaroo grasses *Themeda*.

Methods

In north-west Queensland, 12 eagle nests across four locations (Cloncurry, Julia Creek, Boulia and McKinlay) were sampled for prey remains and pellets on the ground, and under nearby perching trees, in July–August 1993. If the nest was intact and had been active in the preceding two years, the tree was climbed and prey remains and pellets were collected from the nest. Pellets were also collected by searching under trees where eagles were regularly seen perching, by searching under shade trees at sheep camps, and by checking isolated trees on the downs that were potential eagle perches or roosts. Some pellets away from nests were collected in March–April 1993, in conjunction with behavioural observations. In north Queensland, prey remains and pellets were collected from the ground around two eagle nests and their associated known, regular perching trees, in October 1993. Feeding debris at active nests originated from breeding adult eagles, whereas pellets probably originated from both breeding adult and non-breeding subadult eagles.

Hair, feathers and scales in pellets were identified by means of manuals (Brunner and Coman 1974; unpublished key to hair of north Queensland mammals by A. McIlwae), and by comparison with museum material and reference to bird and reptile field-guides. Prey remains were identified by comparison with museum specimens, by consulting reference books and field-guides, and by consultation with experts. The minimum number of prey individuals from each site sample was calculated separately for remains and pellets. The smallest (eaglets') pellets from under eagle nests were disregarded if they could not be distinguished confidently from those of other raptor species that might have perched in the tree.

Age-classes of eagles were distinguished as juvenile/immature ('buff'), maturing subadult ('brown') or adult ('black'), according to the criteria of Ridpath and Brooker (1986) and Marchant and Higgins (1993). Field observations (n = 216 h) on the behaviour of eagles were conducted from a camouflaged hessian hide situated near water sources and shade ('camps') used by lambing flocks, at three sites (Richmond, Cloncurry and Boulia) in March–April 1993. Where possible, the hide was placed on high ground with a wide view, and erected at least one day before observations commenced. The hide was entered at dawn, before the ewes and lambs arrived at the camp, and vacated at dusk, after they had departed to graze at night. Time-budgets of eagles were determined by recording the frequency of observation, by time of day (0700–1030 h, 1100–1500 h, 1530–1930 h), of three activity classes: flying and soaring, feeding, and perching.

Graziers were interviewed on nine properties at Richmond, Julia Creek, Cloncurry and Boulia, by oral questionnaire via telephone, about their observations of interactions between eagles and lambs and other property-related matters such as lambing percentages (see Winkel 1993 for details of the survey questions).

Lamb mortality was investigated at three sites (Richmond, Cloncurry and Boulia) by performing post-mortem examinations on lamb carcasses (n = 29), by a combination of the methods used by McFarlane (1965) and Rowley (1970). According to their criteria, lambs were classified as viable, non-viable, or (if the viscera were missing) of unknown viability. Lamb wounds were assigned to predator species by the criteria of Rowley (1970).

Chi-squared tests were used to compare dietary parameters (prey proportions in remains versus pellets, and dietary proportions by site), and three-factor ANOVA (Tabachrich and Fidel 1989) was used to compare eagle time-budgets by site, activity class (flying/soaring, perching or feeding) and time of day (morning/midday/afternoon). Measurements of pellets are presented as mean ± standard deviation.

RESULTS

Diet

Pellets averaged 8.7 ± 6.0 grams, and 61.7 ± 17.0 x 31.2 ± 9.9 millimetres (n = 145), the largest being 39 grams and 131 x 50 millimetres. Small pellets under occupied nests were most likely from eaglets. In north-west Queensland, by weight, pellets consisted (on average) mostly of lambs' wool (36% of total pellet mass), Red Kangaroo *Macropus rufus* fur (26%), Pig Sus *scrofa* hair (10%) and Australian Bustard *Ardeotis australis* feathers (10%), with smaller amounts (<10% each) of the other prey types listed in Table 1. These proportions varied across the study region, e.g. lamb 13 percent of pellet mass at Cloncurry to 61 percent at Boulia; kangaroo nil at Boulia to 50 percent at Julia Creek; pig less than 1 percent at Boulia to 29 percent at Cloncurry; Bustard less than 1 percent at Boulia to 17 percent at Cloncurry and Julia Creek; Long-haired Rat *Rattus villosissimus* nil at two sites (Julia Creek and McKinlay) to 23 percent at Boulia; Bearded Dragon *Pogona vitticeps* nil at Cloncurry to 11 percent at Boulia.

Eagles in the north-west Queensland sheep rangelands ate mainly juvenile Red Kangaroos, with some lambs, piglets, birds (notably Bustards) and Bearded Dragons; there were regional differences in dietary composition, and in the composition of prey remains (at nests) versus pellets (Tables 1, 2). For instance, kangaroos were taken especially at Julia Creek and McKinlay; lambs and Bustards at Julia Creek; piglets at Boulia; birds at McKinlay; and dragons at Cloncurry and Boulia (the two westernmost sites). Bustards and lambs were represented mainly in pellets; birds (other than Bustards at some sites) and

TABLE 1

Diet of the Wedge-tailed Eagle at four sites in north-west Queensland. C = Cloncurry, J = Julia Creek, B = Boulia, M = McKinlay. For each prey species, upper row = n (%) individuals and percent biomass in prey remains at nests, lower (italicised) row = n (%) individuals and percent biomass in pellets. Mass = mean mass of prey species; weights under site codes = mass of pellet material collected at site. Sources of prey weights: Badham (1976); Jordan and le Feuvre (1989); Rose (1978); Sharman *et al.* (1964); Strahan (1993); Whittemore (1987); R. Bedford, G. Czechura, D. Geaney and G. Shea (pers. comm.).

Species	Mass (kg)	C (352 g)		J (184 g)		B (375 g)		M (289 g)		Total (1256 g)	
		n (%)	%b	n (%)	%b	n (%)	%b	n (%)	%b	n (%)	%b
Red Kangaroo *Macropus rufus (juv.)*	8.98	18 (23)	49	21 (30)	55	6 (9)	27	2 (40)	82	47 (22)	53
		4 (17)	*22*	*22 (38)*	*51*			*21 (27)*	*43*	*47 (20)*	*29*
Long-haired Rat *Rattus villosissimus*	0.1					12 (19)	1			12 (6)	<1
		1 (4)	*<1*			*10 (14)*	*<1*			*11 (5)*	*<1*
Lamb *Ovis aries*	3.5	9 (12)	10	16 (23)	16	11 (17)	19	1 (20)	16	37 (17)	15
		4 (17)	*9*	*10 (17)*	*9*	*31 (42)*	*43*	*31 (40)*	*25*	*76 (33)*	*21*
Pig *Sus scrofa* (juv.)	14	5 (6)	21	2 (3)	8	7 (11)	49			14 (6)	20
		6 (26)	*52*	*3 (5)*	*11*	*3 (4)*	*17*	*5 (6)*	*16*	*17 (7)*	*24*
Cat *Felis catus*	4.35	2 (3)	3	3 (4)	1					5 (2)	1
				2 (3)	*2*	*1 (1)*	*2*	*1 (1)*	*1*	*4 (2)*	*1*
Australian Bustard *Ardeotis australis*	8.97	5 (6)	14	7 (10)	18					12 (6)	8
		3 (13)	*17*	*11 (19)*	*26*	*10 (14)*	*36*	*7 (9)*	*14*	*31 (13)*	*23*
Galah *Cacatua roseicapilla*	0.31	4 (5)	<1	2 (3)	<1					6 (3)	<1
		1 (4)	*<1*							*1 (<1)*	*<1*
Other birds[a]		18 (23)	1	10 (14)	1	10 (16)	2	2 (40)	2	40 (19)	2
		4 (17)	*<1*	*7 (12)*	*<1*	*7 (9)*	*1*	*7 (9)*	*<1*	*25 (11)*	*<1*
Gould's Monitor *Varanus gouldii*	1.15	1 (1)	<1	2 (3)	1					3 (1)	<1
Central Bearded Dragon *Pogona vitticeps*	0.32	16 (20)	2	3 (4)	<1	16 (25)	3			35 (16)	1
				1 (2)	*<1*	*11 (15)*	*1*	*5 (6)*	*<1*	*17 (7)*	*<1*
Centralian Bluetongue *Tiliqua multifasciata*	0.26			3 (4)	<1	2 (3)	<1			5 (2)	<1
				2 (3)	*<1*	*1 (1)*	*<1*			*3 (1)*	*<1*

[a]Including Emu *Dromaius novaehollandiae* chick (3.32 kg), Nankeen Kestrel *Falco cenchroides* (170 g), Little Button-quail *Turnix velox* (40 g), Little Corella *Cacatua sanguinea* (690 g), Budgerigar *Melopsittacus undulatus* (30 g), crow *Corvus* spp. (550 g), Zebra Finch *Taeniopygia guttata* (10 g) and unidentified spp.

reptiles contributed little by biomass. Among prey remains at eagle nests, lamb formed 12–23 percent of the diet by number and 10–19 percent by biomass across the various sites (mean 17% and 15%, respectively, for the region; Table 1). In eagle pellets, lamb formed 17–42 percent of the diet by number and 9–43 percent by biomass (mean 33% and 21%, respectively). It was not possible to determine whether these lambs were taken live or as carrion or, if live, whether they were viable.

Eagles in cattle rangeland in north Queensland, where no lambs were available, took a variety of mammals and birds: mainly small macropods, with some arboreal mammals; there were again some differences in the composition of prey remains versus pellets (Table 3). By weight, pellets consisted mostly of Red Kangaroo (10% of total pellet mass), other macropod (56%) and Cat *Felis catus* fur (20%), and feathers (14%).

Eagle behaviour

There was regional variation in the proportion of eagle age-classes observed, with juveniles prevalent at most sites, particularly Cloncurry and Boulia; abundance (sightings per hour) also varied across sites (Figure 1). Eagles were seen perching, flying or feeding throughout the day, often soaring during the middle of the day. As a proportion of total eagle sightings, perching and feeding peaked early and late in the day, with significant differences in the frequency of flying versus other activities, in activity levels by time of day, and in activity levels at Cloncurry versus Richmond (though not between other sites) (Figure 2, Table 4).

Ewes and lambs arrived at sheep camps usually around 0730 hours (0705–0945 h) to drink and rest in shade, then they became active (drinking and grazing) at the camps usually around 1430 hours (1400–1550 h), before leaving the camp usually around 1620 hours (1550–1730 h) to graze. No eagle attacks on lambs were observed in 216 hours of dawn-to-dusk observations, although the behaviour of ewes and lambs could have made lambs vulnerable to attack. For instance, although young lambs stayed close to their mothers, grazing ewes sometimes left their lambs in a crèche of up to nine lambs with a single ewe in attendance; resting lambs were often easily separated from their grazing mothers, and startled ewes often lost track of their lambs temporarily. Ewes appeared not to fear or avoid eagles, and none was seen to react to eagle presence or to an eagle feeding on a lamb carcass.

Wedge-tailed Eagles fed at lamb, sheep or kangaroo carcasses (carrion, n = 71 records), along with Black Kites *Milvus migrans* and Black-breasted Buzzards *Hamirostra melanosternon*. Eagles usually perched, in trees or on the ground, near the carcass between feeding bouts of 2–20 minutes; in all cases more than one eagle visited a carcass, but there was little aggression over food. One or more eagles usually waited until the feeding eagle moved away, then another took its place. Twice, a juvenile eagle tried to approach a feeding subadult, but retreated when the latter 'mantled', raised its hackles and lowered its head. The smaller raptors waited until the feeding eagle(s) relinquished the carcass.

Graziers interviewed on nine sheep properties in the study area reported seeing Wedge-tailed Eagle attacks on juvenile kangaroos (six attacks at four sites), piglets (one site), Bustard (one site) and lambs (three sites); that is, eight attacks on other prey and three on lambs. Graziers on five of the properties reported eagle talon scars on live lambs (weaners) at marking time: mostly a few lambs (typically 'one or two'), but one sheep-only property at Cloncurry reported talon scars on 146 (15%) of 1000 live lambs, and another (mostly cattle) property claimed that there were talon scars on 19 percent of an unstated number of live lambs (Table 5). Graziers on six properties (67%; four of these having mostly sheep, plus the above sheep-only property) reported seeing no eagle attacks on lambs. Lambing percentages across these properties were generally better than 50 percent: commonly up to 70 percent or more (exceptionally 91%) for older experienced ewes, but usually 40–48 percent (sometimes 35%) for maiden ewes (Table 5).

Graziers on all nine properties reported that eagle numbers tended to increase during lambing time (autumn to spring) and decrease afterwards (generally from November to April). Their reports showed no consistent relationship between eagle numbers and lambing percentages (Table 5). Indeed, properties with active eagle nests had fewer reported eagle sightings (Table 5).

TABLE 2

Results of chi-squared tests comparing the dietary contribution (frequency) of individual prey species in remains versus pellets, for data in Table 1. Species for which sufficient sample size only; n = sample size.

Factor	df	x^2 value	n	*P* value
Red Kangaroo	3	30.628	94	<0.001
Lamb	3	31.214	113	<0.001
Pig	3	6.663	31	0.083
Cat	3	4.140	9	0.247
Bustard	3	12.418	43	0.006
Bird spp.	3	10.588	72	0.014
Bearded Dragon	3	18.968	52	<0.001
Site x prey species	24	155.070	462	<0.001

TABLE 3

Diet of the Wedge-tailed Eagle at Mt Fox in north Queensland: number, percent by number and percent biomass in prey remains at nests, and in pellets. Sources of prey weights as in Table 1.

Species	Mass (kg)	Remains			Pellets (59 g)		
		n	%	%b	n	%	%b
Possums[a]		3	13	6			
Red Kangaroo *Macropus rufus* (juv.)	8.98				1	10	20
Other macropods[b]		14	61	89	5	56	49
Rabbit *Oryctolagus cuniculus*	1.7	1	4	3			
Cat *Felis catus*	4.35				3	20	28
Birds[c]		5	22	2	4	14	3
Total		21	100	100	13	100	100

[a]Greater Glider *Petauroides volans* (1.3 kg), Common Brushtail Possum *Trichosurus vulpecula* (1.5 kg)

[b]Agile Wallaby *Macropus agilis* (juv., 4.5 kg), Eastern Grey Kangaroo *M. giganteus* (juv., 4.5 kg), Sharman's Rock-Wallaby *Petrogale sharmani* (3.7 kg)

[c]Including Pheasant Coucal *Centropus phasianinus* (360 g), Tawny Frogmouth *Podargus strigoides* (370 g), Blue-winged Kookaburra *Dacelo leachii* (310 g), Australian Magpie *Gymnorhina tibicen* (250 g), crow *Corvus* sp. (550 g) and unidentified spp.

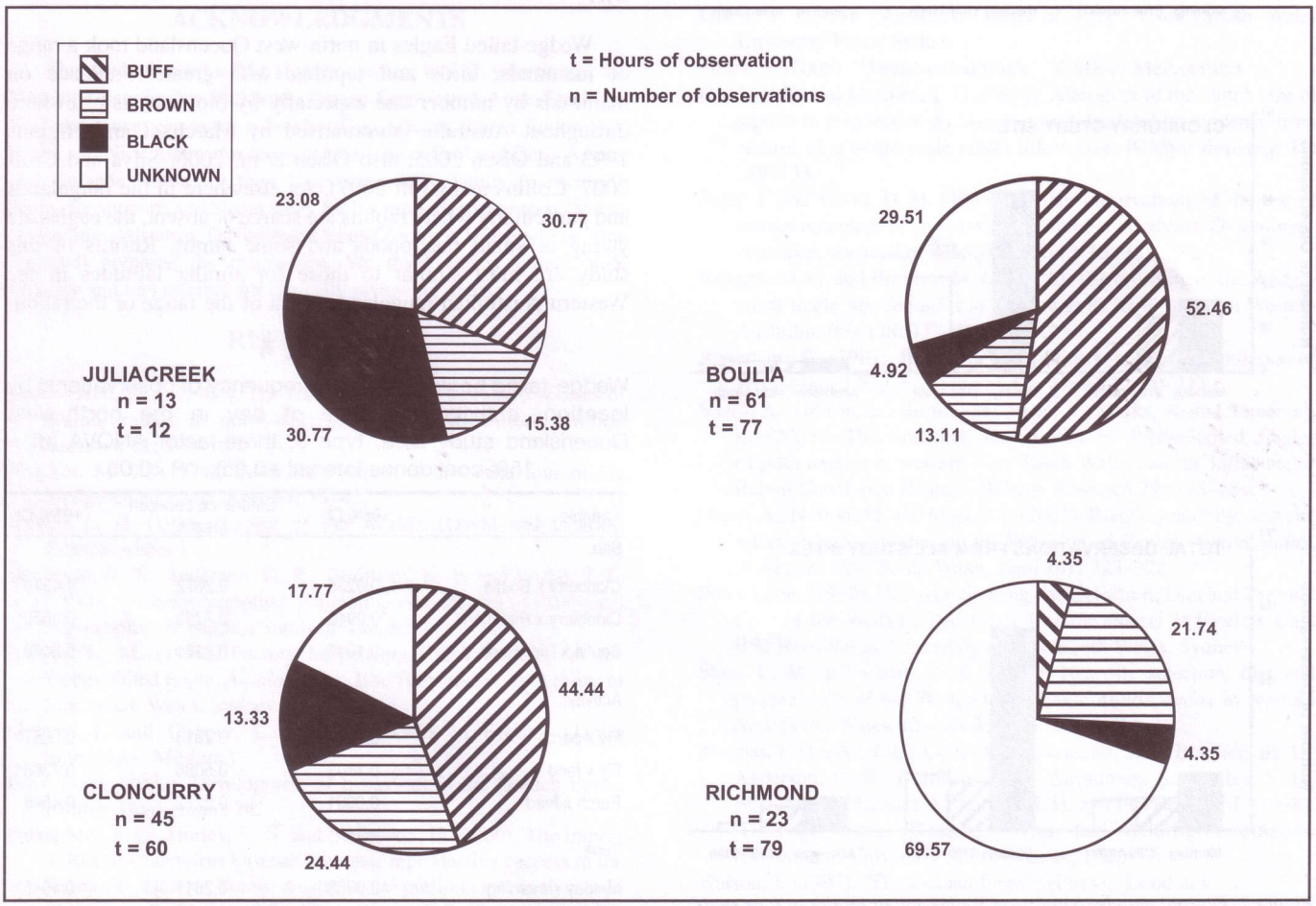

Figure 1. *Proportions of Wedge-tailed Eagle plumage classes observed at four study sites in north-west Queensland, March–April 1993 (buff = juvenile/immature, 'brown' = subadult, 'black' = adult; see text).*

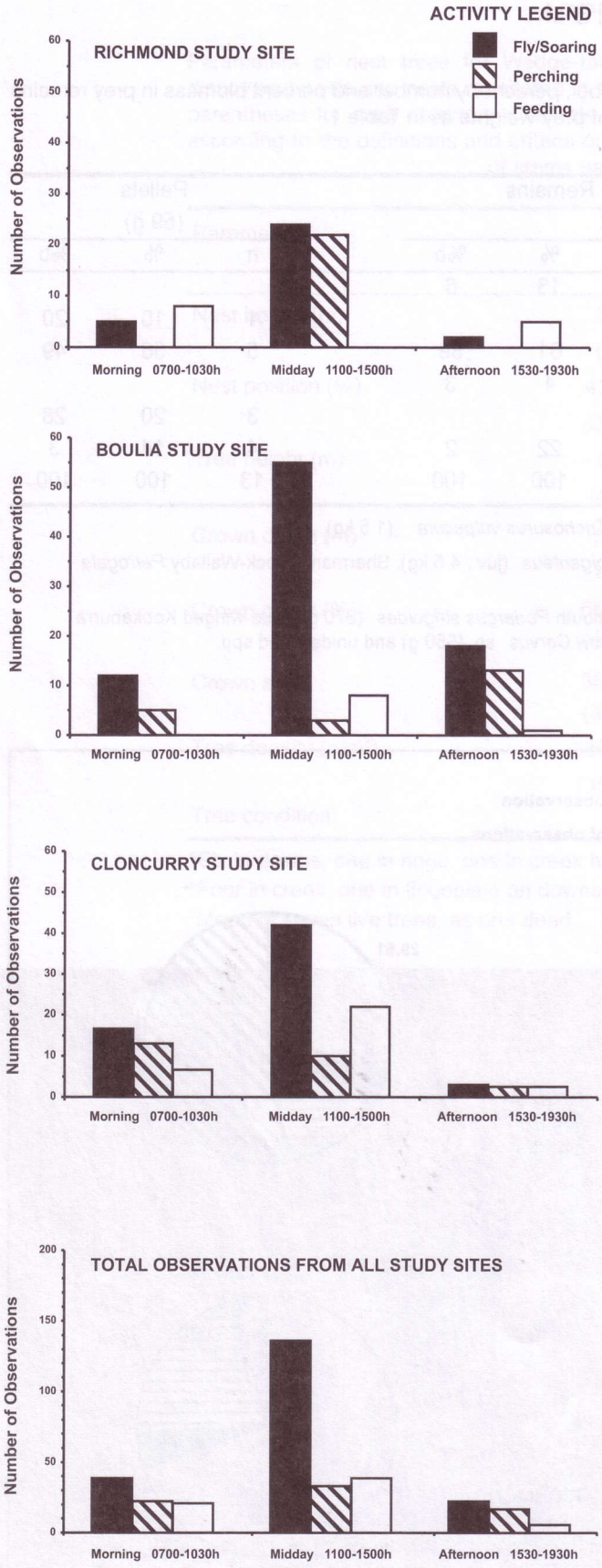

Figure 2. *Diurnal activity patterns of Wedge-tailed Eagles at four study sites in north-west Queensland, March–April 1993, in three time periods (0700–1030 h, 1100–1500 h, 1530–1930 h).*

Lamb predation

Eleven dead lambs found on properties at Richmond and Cloncurry were all small (i.e. less than one week old); seven of 18 dead lambs from properties at Boulia were medium-sized (over one week old), and the remainder were small. Of these 29 lambs autopsied, most had walked but few had suckled, and about half had used fat reserves (Table 6). None showed evidence of abnormalities, and evidence of disease could not be ascertained. Most (76%) had wounds from predators or scavengers (all from raptors), but only three (10%) had bruising characteristic of eagle attack on a live lamb; 10 (35%) had no bruising, and 16 (55%) could not be assessed for bruising. Most (90%) of the 29 lambs died from starvation (mismothering); from wound characteristics, Wedge-tailed Eagles killed one viable lamb (3%) and two lambs of unknown viability (7%) in the sample (Table 7).

Graziers on all nine properties reported feral pigs as significant lamb predators when pigs were in high numbers. Foxes *Vulpes vulpes* and Dingoes *Canis lupus* were reported on one and two, respectively, of the nine interviewees' properties. Although not considered common, these canids were considered a serious threat to lambing percentages if 'rogue' (lamb-killing) individuals were present.

DISCUSSION

Diet

Wedge-tailed Eagles in north-west Queensland took a range of mammals, birds and reptiles, with greatest reliance on mammals by number and especially by biomass, as elsewhere throughout Australia (summarised by Marchant and Higgins 1993 and Olsen 2005; also Olsen *et al.* 2006; Silva and Croft 2007; Collins and Croft 2007). As elsewhere in the rangelands and particularly where rabbits are scarce or absent, the eagles ate young or small macropods and some lambs. Results of this study are most similar to those for similar latitudes in the Western Australian rangelands north of the range of the rabbit:

TABLE 4

Wedge-tailed Eagle behaviour (frequency of observations) by location, activity and time of day in the north-west Queensland study area: type 3, three-factor ANOVA (df = 159; confidence interval ±0.95). *P <0.05.

Variable	-95% CI	Difference between means	+95% CI
Site:			
Cloncurry x Boulia	-0.0235	0.2072	0.4379
Cloncurry x Richmond	0.0946	0.3253	0.5560*
Boulia x Richmond	-0.1047	0.1181	0.3409
Activity:			
Fly x perch	0.054	0.2813	0.5087*
Fly x feed	0.2803	0.5086	0.7368*
Perch x feed	-0.0001	0.2272	0.4546
Time:			
Midday x morning	0.0338	0.2611	0.4945*
Midday x afternoon	0.0379	0.2662	0.4884*
Afternoon x morning	-0.2325	-0.0051	0.2222

TABLE 5

Results of grazier interviews for nine properties in north-west Queensland; [E] = active eagle nest on property. Lamb % = lambing percentage (n lambs per 100 ewes at marking muster); talon scars = eagle talon scars on live lambs at marking; eagle attack = attack on lamb witnessed; eagles/day = n eagles seen per day during lambing.

Factor	Richmond			Julia Creek		Cloncurry		Boulia	
	1	2	3[E]	1[E]	2[E]	1	2	1	2[E]
Stock	mostly sheep	mostly sheep	sheep only	mostly cattle	mostly sheep wethers only	mostly cattle	sheep only	mostly sheep	mostly sheep
Lamb %	48 (1993)	70/40[a] (1993)				53–91[b]	30–79[c]	54/35, 50/39[d]	52 (1993)
Talon scars	few	few				on 19%	on 15%	no	few
Eagle attack	yes	no	yes	no		yes	no	no	no
Eagles/day	2–6	0–6	2–3	2	2–3	0–20	0–20	0–15	0–6

[a]Older ewes and maiden ewes respectively

[b]58% in 1991, 91% in 1992, 53% in 1993; average 41%

[c]79% in 1989, 70% in 1990 and 1991, 30% in 1992, 33% in 1993

[d]Older/maiden ewes, for 1992 and 1993, respectively

juvenile Euros *Macropus robustus* and some lizards in the Pilbara; Agile Wallabies *M. agilis* with some pigs and lizards in the Kimberley (Brooker and Ridpath 1980). They are also similar to results for other areas where rabbits are scarce: the dry west coast of Western Australia (Brooker and Ridpath 1980), and Idalia National Park (south-central Queensland) where goats substitute for sheep (Sharp 1997). The Zebra Finch *Taeniopygia guttata* (10 g), not previously recorded in the Eagle's diet, may have been robbed from a smaller raptor or scavenged. The proportion of lamb in the diet was higher than usually recorded elsewhere, except that Sharp *et al.* (2002) recorded a similarly high proportion of sheep or lamb in eagle pellets in arid New South Wales.

The difference in the composition of pellets versus prey remains in this study is also consistent with the findings of Sharp *et al.* (2002), particularly with respect to the relative contribution of sheep or lambs to the eagles' diet. The difference in composition of pellets versus remains may be partly explained by the foraging behaviour of eagles. Breeding adults may bring mostly live-caught prey and other small items, of a size they can carry, to the nest, whereas many pellets (e.g. in this study) may originate from immature, non-breeding eagles that eat much carrion and are not so constrained by prey or carcass size. Breeding adults may also scavenge away from the nest (Sharp *et al.* 2002). Further study is required on possible seasonal differences in pellet composition versus feeding debris at nests, and the diet of non-breeding versus breeding adults and subadults.

Wedge-tailed Eagles in non-sheep country in north Queensland also took a range of vertebrates, again with greatest reliance on small macropods. This result is similar to that for north-western Australia (Brooker and Ridpath 1980), Idalia National Park (Sharp 1997), and rabbit-poor, non-sheep sites in northern coastal New South Wales (Harder 2000). Species not previously recorded in the Eagle's diet include the Greater Glider *Petauroides volans* and Pheasant Coucal *Centropus phasianinus*. The nocturnal, arboreal, hollow-denning glider is not an anomalous item in view of prior records of Wedge-tailed Eagles taking tropical ringtail possums *Pseudocheirus* spp. in closed forest (Burnett *et al.* 1996), and other arboreal mammals (e.g. Marchant and Higgins 1993; Harder 2000).

The types of biases discussed by Leopold and Wolfe (1970), Brooker and Ridpath (1980) and Sharp *et al.* (2002) probably applied to the dietary analyses in this study, and perhaps affected the pellet results most. Remains under eagle nests at Mt Fox were certainly removed by scavengers (canids, which left scats). The biomass estimates in this study are approximate, and possibly overestimate the contribution of larger prey species, because of the differential wastage factors discussed by Brooker and Ridpath (1980).

Behaviour

The eagles' diurnal routines were similar to those reported by Brooker (1974) and Aumann (2001), and seemed partly related to atmospheric conditions, e.g. thermals for soaring in the middle of the day. The differences in activity patterns at Richmond (easternmost site) versus Cloncurry (westernmost site) may be partly explained by differences in topography or vegetation (some ridges, trees and shrubs at Richmond, more open grassy downs at Cloncurry) and their possible influences on soaring conditions or eagle visibility. The eagles' feeding behaviour at carcasses is consistent with previous knowledge (e.g. Brooker 1974; Marchant and Higgins 1993; Olsen 1995, 2005).

The data on diet (e.g. pellets versus nest remains), and the regional and property-based distribution of eagle numbers, seasonal fluctuations, age-classes and active nests (Figure 1, Table 5), suggest the following interpretation. Mobile immature eagles congregate, particularly where they are not repelled by territorial adult eagles, around lambing paddocks to scavenge when conditions produce much lamb carrion; these inexperienced young eagles may attack lambs (sometimes

TABLE 6

Post-mortem results for 29 dead lambs found on the Richmond, Cloncurry and Boulia study sites (north-west Queensland): number (%). ? = uncertain (viscera eaten or partly eaten).

Criterion	Yes	No	?
Walked	23 (79)	6 (21)	0
Milk in gut	2 (7)	10 (34)	17 (59)
Kidney fat normal	5 (17)	5 (17)	19 (66)
Heart fat normal	3 (10)	3 (10)	23 (79)
Wounds	22 (76)	7 (24)	0
Bruising	3 (10)	10 (34)	16 (55)

unsuccessfully, leaving lambs to escape though scarred). Conversely, breeding adults take a variety of prey, but less lamb, to the nest, and their territorial defence may limit the presence of immature eagles in nearby lambing paddocks. Such an interpretation is consistent with the inferred situation at other sites, and with knowledge of the Wedge-tailed Eagle's movements, ecology and social behaviour (e.g. Leopold and Wolfe 1970; Ridpath and Brooker 1986; Marchant and Higgins 1993; Olsen 1995, 2005).

Lamb predation

In this study, Wedge-tailed Eagles were responsible for the deaths of only 10 percent of a sample of 29 lambs found dead; they were responsible for the deaths of three lambs, of which one was viable and two were of unknown viability. This result is consistent with previous findings that predators are responsible for only a small proportion of the deaths of viable lambs in open-range sheep lands, including western Queensland, and that losses to other causes such as starvation and mismothering are far more important (e.g. Smith 1965; Rowley 1970; Brooker and Ridpath 1980). The lack of lamb kills in 216 hours of observation is consistent with only two lamb kills in 367 hours of observation, reported by Brooker and Ridpath (1980), and supports the view that eagles mainly confine their attention to scavenging on lamb carcasses.

Graziers in this study tended to attribute low lambing percentages in some years to the high numbers of eagles present at those times, but an alternative interpretation is possible: seasonal conditions (and possibly other abundant, but nocturnal and inconspicuous predators) may have caused many lamb deaths, which may have attracted many scavenging eagles. Graziers observed more eagle attacks on animals other than lambs; one of the two graziers who associated eagles with low lambing percentages, and who reported talon scars on almost one in six weaners, had not witnessed an eagle attack a lamb.

Although lamb contributed more to the eagles' diet in north-west Queensland than is usually the case elsewhere in Australia, eagles nevertheless were responsible for a minor proportion of the deaths of viable or potentially viable lambs, and lambing percentages were often good to high. This result is consistent with similar assessments in Australia (Brooker and Ridpath 1980) and elsewhere (reviewed by Davies 1999). The greater problem, of the other 90–96 percent of lamb deaths, is probably

TABLE 7

Causes of death, and viability at birth, of 29 lambs found dead on the north-west Queensland study sites: number (%).

Cause of death	Viable	Non-viable	Unknown viability[a]
Mismothered	10 (34)	6 (21)	10 (34)
Eagle predation	1 (3)	0	2 (7)

[a]Viscera eaten by predator/scavenger before post-mortem

best addressed by attention to management of conditions for ewes and lambs to prevent mismothering (e.g. nutrition, shelter, minimising disturbance to lambing ewes, control of feral predators, regional co-ordination of lambing times).

ACKNOWLEDGMENTS

This study formed a BSc honours project; I thank my supervisor, Dr George Heinsohn, for his time, patience and suggestions. I also thank Debbie Maxwell (Sheep Husbandry Officer, Toorak Research Station) for getting the project started, and for continual help in north-west Qld; Robbin Greenwood for her hospitality and time; the many generous graziers for showing me eagle nests on their land and for accommodation; Birds Australia for an advance copy of the *HANZAB* eagle account; John Young for taking me to the eagle nests near Ingham; Greg Czechura (Qld Museum) for answering so many questions; and Rolf Jensen for help in identifying bird remains. The following also helped with identification of eagle food remains: D. Geaney, P. Johnson, D. Maxwell and J. Young. Dr Stephen Debus (Zoology, University of New England) edited my thesis into a draft paper, and Penny Olsen, Michael Brooker, Greg Clancy and Peter Smith commented helpfully on a draft.

REFERENCES

Aumann, T. (2001). Habitat use, temporal activity patterns and foraging behaviour of raptors in the south-west of the Northern Territory, Australia. *Wildlife Research* **28**: 365–378.

Badham, J. A. (1976). The *Amphibolurus barbatus* species-group (Lacertilia: Agamidae). *Australian Journal of Zoology* **24**: 423–443.

Brooker, M. G. (1974). Field observations of the behaviour of the Wedge-tailed Eagle. *Emu* **74**: 39–42.

Brooker, M. G. and Ridpath, M. G. (1980). The diet of the Wedge-tailed Eagle, *Aquila audax*, in Western Australia. *Australian Wildlife Research* **7**: 433–452.

Brunner, H. and Coman, B. J. (1974). 'The Identification of Mammalian Hair'. (Inkata Press: Melbourne).

Burnett, S. Winter, J. and Russell, R. (1996). Successful foraging by the Wedge-tailed Eagle *Aquila audax* in tropical rainforest in north Queensland. *Emu* **96**: 277–280.

Collins, L. and Croft, D. B. (2007). Factors influencing chick survival in the Wedge-tailed Eagle *Aquila audax*. *Corella* **31**: 32–40.

Davies, R. A. G. (1999). The extent, cost and control of livestock predation by eagles with a case study on Black Eagles (*Aquila verreauxii*) in the Karoo. *Journal of Raptor Research* **33**: 67–72.

Harder, M. (2000). Diet and breeding biology of the Wedge-tailed Eagle *Aquila audax* at three nests in north-eastern New South Wales. *Corella* **24**: 1–5.

Jordan, D. J. and le Feuvre, A. S. (1989). The extent and cause of perinatal lamb loss in 3 flocks of Merino sheep. *Australian Veterinary Journal* **66**: 198–201.

Leopold, A. S. and Wolfe, T. O. (1970). Food habits of nesting Wedge-tailed Eagles, *Aquila audax*, in south-eastern Australia. *CSIRO Wildlife Research* **15**: 1–17.

Marchant, S. and Higgins, P. J. (Eds) (1993). 'Handbook of Australian, New Zealand and Antarctic Birds', Vol. 2. (Oxford University Press: Melbourne.)

McFarlane, D. (1965). Perinatal lamb losses. I. An autopsy method for the investigation of perinatal losses. *New Zealand Veterinary Journal* **13**: 116–135.

Olsen, J., Fuentes, E. and Rose, A. B. (2006). Trophic relationships between neighbouring White-bellied Sea-Eagles (*Haliaeetus leucogaster*) and Wedge-tailed Eagles (*Aquila audax*) breeding on rivers and dams near Canberra. *Emu* **106**: 193–201.

Olsen, P. (1995). 'Australian Birds of Prey'. (New South Wales University Press: Sydney.)

Olsen, P. (2005). 'Wedge-tailed Eagle'. (CSIRO: Melbourne.)

Ridpath, M. G. and Brooker, M. G. (1986). Age, movements and management of the Wedge-tailed Eagle, *Aquila audax*, in arid Western Australia. *Australian Wildlife Research* **13**: 245–260.

Rose, M. (1978). Birth weight and survival in Merino sheep in north-west Queensland. P*roceedings of the Australian Society for Animal Production* **12**: 199.

Rowley, I. (1970). Lamb predation in Australia: incidence, predisposing conditions and the identification of wounds. *CSIRO Wildlife Research* **15**: 79–123.

Sharman, G. B., Frith, H. J. and Calaby, J. H. (1964). Growth of pouch young, tooth eruption, and age determination in the Red Kangaroo, *Megaleia rufa*. *CSIRO Wildlife Research* **9**: 20–49.

Sharp, A. (1997). Notes on the breeding season diet of the Wedge-tailed Eagle *Aquila audax* in Idalia National Park, south-central Queensland. *Sunbird* **27**: 105–108.

Sharp, A., Gibson, L., Norton, M., Ryan, B., Marks, A. and Semeraro, L. (2002). An evaluation of the use of regurgitated pellets and skeletal material to quantify the diet of Wedge-tailed Eagles, *Aquila audax*. *Emu* **102**: 181–185.

Silva, L. M. and Croft, D. B. (2007). Nest-site selection, diet and parental care of the Wedge-tailed Eagle *Aquila audax* in western New South Wales. *Corella* **31**: 23–31.

Smith, I. D. (1965). Role of avian predators in lamb mortality in Queensland. *Australian Veterinary Journal* **41**: 333–335.

Strahan, R. L. (Ed.) (1993). 'The Australian Museum Complete Book of Australian Mammals'. (Cornstalk Publishing: Sydney.)

Tabachrich, B. G. and Fidel, L. S. (1989). 'Using Multivariate Statistics', 2nd edn. (Harper and Rowe: New York.)

Whittemore, C. T. (1987). 'Elements of Pig Science'. (Longman Group: Hong Kong.)

Winkel, P. (1993). 'The Feeding Ecology of *Aquila audax* in North-western Queensland, with Particular Reference to Lamb and Sheep Predation.' BSc Hons thesis, James Cook University, Townsville.

S. Tredinnick

Half-feathered chick.

S. Tredinnick

Downy chick ~ 1 month old, with dorsal feathers emerging.