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DIET OF BREEDING WEDGE-TAILED EAGLES *Aquila audax* IN SOUTH-CENTRAL QUEENSLAND

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The diet of the Wedge-tailed Eagle *Aquila audax* was studied in south-central Queensland, an area of low rabbit density, by means of prey remains (n = 795 prey animals) and pellets (total 2.26 kg) from 13 active nests at five sites (four sheep stations, one national park) over one breeding season. Nine clutches were all of two eggs, and a mean of 1.2 fledglings was raised per attempt. By biomass, the eagles' diet was dominated by macropods, especially in the national park, with few rabbits taken among a range of mammals, birds and lizards (total 28 species). Prey composition varied geographically, with habitat and land use, and seasonally. However, despite variation in density, lamb formed a similar (though minor) proportion of the diet across sites. Remains (orts, mostly post-cranial) represented 29 percent of estimated dietary intake, whereas pellets were found to represent only 6.1 percent of intake.

INTRODUCTION

The diet of the Wedge-tailed Eagle *Aquila audax* has been well studied in southern Australia, mostly in locations and times where the introduced European Rabbit *Oryctolagus cuniculus* formed a major food source, though also since the calicivirus (rabbit haemorrhagic disease) reduced rabbit densities in the inland (see Marchant and Higgins 1993 and Olsen 2005 for reviews; also Collins and Croft 2007; Silva and Croft 2007). There have been fewer studies in northern Australia, near or beyond the northern range limit for the rabbit (Aumann 2001; Brooker and Ridpath 1980; Burnett *et al.* 1996; Sharp 1997; Winkel 2007). All these studies show that Wedge-tailed Eagles prey primarily on mammals and that, where rabbits are scarce or absent, they mostly take small macropods, including juveniles (young at foot) of the largest kangaroo species.

Some previous studies have investigated the role of lambs in the Wedge-tailed Eagle's diet, and the controversy over the potential impact of the eagle on the sheep industry (e.g. Leopold and Wolfe 1970; Rowley 1970; Brooker and Ridpath 1980). Studies in southern Australia have largely exonerated eagles as a significant economic problem. However, in northern parts of the Australian sheep zone, where there are few or no rabbits, eagles may take more lambs. The only study in north-west Queensland found that Wedge-tailed Eagles did take a higher (though still minor) proportion of lamb, but caused only a small proportion of the deaths of viable lambs; the eagles mostly took other mammals including many small macropods (Winkel 2007).

Dietary studies on raptors rely heavily on the analysis of prey remains (orts) and regurgitated pellets in and under nests and nearby perches. Analyses may either combine orts and pellets (without double-counting prey individuals in both sources), or treat orts and pellets separately; both methods have their biases (see Collopy 1983; Real 1996; Seguin *et al.* 1998; Sharp *et al.* 2002; Winkel 2007). The counting of skulls only (e.g. Richards and Short 1998, from one eagle nest) may seriously bias results, by missing prey items that are represented in orts or pellets only by post-cranial or non-skeletal remains. Furthermore, results expressed only as numbers of prey individuals may underestimate the relative contribution of large items by biomass (see Baker-Gabb 1984; Olsen *et al.* 2006a,b). Some studies on the Wedge-tailed Eagle have omitted consideration of dietary biomass.

This study sought to determine the diet of the Wedge-tailed Eagle, including the role of lamb, in an area of low rabbit density (Wilson *et al.* 1992) in the pastoral zone of south-central Queensland. The only previous study in the region (Sharp 1997) concerned one eagle nest in a national park; diet (orts, and by inference biomass) was mostly small macropods, with some Goat *Capra hircus* and lizards; a few birds were possibly taken but not found in orts. The present study investigated the Wedge-tailed Eagle's diet in the same national park and on four sheep stations in the region, with emphasis on the eagles' dietary biomass profile in relation to land uses and land systems. Orts and pellets were also used to investigate possible biases in eagle dietary analysis. Sharp *et al.* (2002) have since discussed the subject and recommended that results for orts and pellets be presented separately (the approach taken here), because either method alone may over- or under-estimate some dietary components, or combining both methods may double-count some items.

STUDY AREA AND METHODS

Study area

The study area was located between Blackall (24°26'S, 145°28'E) and Charleville (26°24'S, 146°15'E) in Queensland. Ten active eagle nests were found, on four pastoral stations here coded as Sheep Sites 1, 2, 3 and 4. Idalia National Park (24°25'S, 144°42'E; 144 000 ha), with three active eagle nests, was chosen for comparison with the four sheep stations, owing to its location, topography and size. The Park is on the north side of the dingo barrier fence, where there are fewer sheep stations (Holden 1991), and the four stations studied were on the south side. Idalia, located on the Grey Range, has similar escarpments to those found on Sites 3 and 4, located on the Wallaroo Range. Such escarpment had rock outcrops, i.e. preferred habitat of feral goats (Parkes *et al.* 1996), which are common in the region.

The four pastoral stations were all mixed sheep and cattle grazing properties, with various stock numbers (estimates only) and theoretical carrying capacities (Table 1). The area is seldom harvested for kangaroo meat (Holden 1991); regular shooting on Sites 3 and 4 for skins results in the regular dumping of skinless kangaroo carcasses in paddocks, thus providing a source of carrion (for feral Pigs *Sus scrofa* as well as eagles). Feral goats can breed twice a year, often producing twins or triplets (Parkes *et al.* 1996), so kids are available year-round, at least in good years. Grassland and deep soils, preferred by rabbits (Williams *et al.* 1995), were more prevalent on Sites 1 and 2, whereas cracking clays were more prevalent on Sites 3, 4 and Idalia (Table 1; see Parker 2000). The average number of ewes, lambing season and carrying capacities of the four pastoral stations are given in Table 1. Idalia has small numbers of sheep that have either recently penetrated the boundary fence, or have been in the Park since its gazettal (1990); north of the dingo fence, ewes and rams are often run together and there is no defined lambing season. The closest station with lambs was Mt Grey, 20 kilometres from the nearest Idalia nest. Idalia supports high macropod densities, with no kangaroo harvesting or carcass dumps.

METHODS

Nests were visited in May, July, September and November 1999; where possible, the tree containing the nest was climbed. Otherwise, a vantage point was sought to enable a view of the nest via a 10x telescope. The condition of each nest and its occupants was noted and the nest was left untouched, to ensure minimal disturbance (to avoid desertion). Prey remains consisting of skulls, skeletal material, skin, fur and feathers left uneaten (orts), and egested pellets, were collected from beneath the nest and from beneath roosting trees found within 100 metres of the nest. After the chick(s) fledged, orts and pellets were collected from within the nest wherever possible; orts and pellets were found within the nest on three occasions.

Bimonthly spotlight counts to monitor the rabbit population were conducted on each site, one hour after sunset, along five-kilometre driving transects at a constant ten kilometres per hour, within a strip 50 metres wide either side of the vehicle (after Ridpath and Brooker 1986a). It could not be determined whether the low densities encountered were a product of the region's soils (Wilson *et al.* 1992) or the result of the calicivirus outbreak.

The 2831 orts were identified where possible to species level, by comparison with a reference collection of skeletal material obtained from the field site, or from specimens from the Macleay (University of Sydney) and Australian Museums. In some cases, post-cranial macropod remains could only be identified to genus. Where possible, prey remains were aged or length and width of skulls and bones were measured in order to determine the size of the prey animal, and its relation to other material in the collection; thereby, corresponding remains could be assigned to the same individual. The minimum number of individuals of each species found at each nest was then calculated from orts only.

From these measurements, the mass of prey animals was determined by comparison with museum data, weighed samples of the prey population, or from the literature (see Parker 2000 for details). The sizes of kangaroos and rabbits taken by the eagles were highly variable; therefore masses of individual kangaroos found in orts were determined from growth curves (Ealey 1967; Poole *et al.* 1982, 1985; Richards and Short 1998; Sadleir 1963; Sharman and Pilton 1964; Sharman *et al.* 1964). Where a mass could not be estimated from the remains, the

TABLE 1

Dominant land systems (minor representation in parentheses) adapted from Division of Land Utilisation (1978, 1980), stock numbers, carrying capacity and lambing times of the four pastoral stations.

Location	Land systems	First lambs	Carrying capacity	No. ewes
Idalia	Dissected residuals, Wooded downs, Undulating Gidgee lands, Alluvial Mitchell grass plains	Not applicable	-	-
Site 1	Wooded downs, Undulating Brigalow lands (Mulga shrublands on red earths)	Early June	1 sheep per 1.6 ha	6000
Site 2	Wooded downs, Undulating Brigalow lands (Undulating Mitchell grass downs)	Mid May	1 sheep per 1.2 ha	8000
Sites 3/4	Undulating Gidgee lands, Dissected residuals, Alluvial Mitchell grass plains, Mulga shrublands on red earths (Wooded downs)	July /August	1 sheep per 2.0 ha / 1 sheep per 2.8 ha	2200

average mass of individuals found at that nest was used. Large kangaroos that appeared to be carrion were given the nominal mass of 10 kilograms. Although a shot kangaroo may have had a live mass greater than 50 kilograms, it is unlikely that a nesting pair of Eagles would be able to utilise more than 10 kilograms because of the simultaneous presence of other scavengers (Brooker and Ridpath 1980). Data from orts were presented in two ways: percentage frequency of individuals, and percentage biomass, to ensure that the role of smaller species in the diet was not overestimated.

In order to calculate biomass consumed, we used the prey wastage factors determined by Brown and Watson (1964) for the Golden Eagle *Aquila chrysaetos*, and adapted for the Wedge-tailed Eagle by Brooker and Ridpath (1980): 50 percent for adult sheep, 25 percent for other mammals, and 20 percent for birds and reptiles. Brooker and Ridpath (1980) suggested an average daily intake of 350 grams of meat per bird as the requirement to maintain a Wedge-tailed Eagle in the wild; this species has been successfully bred on a diet of 365 grams per day (R. Webb pers. comm.). However, the latter figure was for captive, inactive eagles, and a more realistic figure for active, breeding adults in the wild may be 500 grams per day (Olsen *et al.* 2006b). The intake suggested by Olsen *et al.* (2006b) gives a yearly consumption of 182.5 kilograms per bird. Using this figure, the likely consumed biomass of collected remains was compared with bimonthly-expected consumption, for a nesting pair, of 60 kilograms prehatching, 90 kilograms for one chick, and 120 kilograms for two chicks.

Skeletal material and feathers in pellets were identified by comparison with the reference collection or museum specimens. Mammalian hair was identified using cross-sectional analysis and microscopy (Brunner and Coman 1974), and comparing hairs from pellets with those from reference skins from the study area. Where hair from more than one species was in a pellet, percentage composition of components was estimated by counting the hairs of each animal contained within the cross-sections taken from random points within the petri dish. In these calculations, hairs of less than 20 microns in diameter were ignored because their origin was uncertain. In cases of non-mammalian remains (feathers and scales), the percentage composition was estimated by eye. Percentage of pellet mass was then assigned to species within the pellet (cf. Yalden and Warburton 1979). The data from pellets were presented and analysed by percentage frequency of occurrence, and percentage mass of species within pellets (Doncaster *et al.* 1990; Dickman *et al.* 1991).

Statistical analysis

Differences in the diet were examined using chi-squared analysis (cf. Reynolds and Aebischer 1991) by site and by collection period (Sites 3 and 4 combined, owing to their proximity and common management). Analysis with respect to time was possible only for Idalia and Site 1, owing to missing data for nests on other properties. This lack of continuous data also negated the pooling of collection dates for each property. Pellets and orts were analysed separately, using both frequency of species and mass contribution. The separate approach was chosen to ascertain differences between dietary composition indicated by pellets and orts. Chi-squared analysis was undertaken on calculated biomass values (kilograms) for each prey type relative to total calculated biomass per nest, or grams of each prey relative to total grams of pellet material per nest (Zar 1999). Percentages are given in the results purely for illustrative purposes. Given the methods employed for calculating prey biomass, the results should be treated cautiously.

TABLE 2

Breeding success of the Wedge-tailed Eagle nests studied.

Location	Nest	Breeding status	Tree species
Idalia	1	2 chicks; siblicide; 1 fledged	Brigalow *Acacia harpophylla*
	2	2 eggs; 1 chick fledged	Gidgee *Acacia cambagei*
	3	1 fledged	Mtn Yapunyah *Eucalyptus thozetiana*
Site 4	1	2 chicks fledged	"
	2	Fertile; no data	"
Site 3	1	2 chicks fledged	"
Site 1	1	1 chick fledged	Bloodwood *Corymbia erythrophloia*
	2	2 infertile eggs	"
	3	2 chicks fledged	Eastern Grey Box *Eucalyptus moluccana*
	4	2 chicks fledged	Ironbark *Eucalyptus drepanophylla*
Site 2	1	2 infertile eggs	Bloodwood *Corymbia erythrophloia*
	2	2 chicks; siblicide; 1 fledged	Ghost Gum *Eucalyptus papuana*
	3	1 chick; dead after fledging	Coolibah *Eucalyptus microtheca*

RESULTS

Breeding

Eagle nests were located on sites of locally high elevation, in the upper parts of catchments, and tended to be located near open Mitchell Grass plains. The nests on Idalia, Site 3 and Site 4 were located on the slopes of scarps, near rock outcrops close to goat habitat. Sites 1 and 2, with highest sheep densities, supported the highest densities of nesting pairs (Tables 1, 2); nests on Idalia were located towards the boundary with neighbouring pastoral stations, rather than deep within the Park (see Parker 2000).

Of 13 nests, nine observed clutches were all of two eggs (two clutches failed to hatch); in six observed cases both chicks hatched (siblicide occurred in two nests); and 14 chicks were reared to fledging (1.2 fledglings per attempt; six broods of one chick, four broods of two chicks: Table 2). The remains of one (single) fledgling were found within 100 metres of one nest. Nests on Sites 1, 3 and 4 raised broods of two fledglings; siblicide (indicated by the discovery of pecked chick remains within or outside the nest) or broods of one occurred on Idalia and Site 2.

Rabbit density

Spotlight surveys revealed universally low rabbit densities, as rabbits were seen only while travelling to and from study areas and none was seen on repeated transects. Rabbits were likely to have been at higher density on Sites 1 and 2 than on the other sites (cf. Study area, above), but nevertheless far lower than the critical threshold of 1.6 rabbits per kilometre suggested for successful breeding of the Wedge-tailed Eagle in southern Australia (Ridpath and Brooker 1986). Rabbit densities were too low to detect by the standard spotlighting method.

Prey remains

Twenty-eight species, among a minimum of 795 individual animals, were taken as prey by the Wedge-tailed Eagle (from orts: Table 3, which gives scientific names). Of the 2837 orts collected, most (68%) were post-cranial; only a small proportion (10%) were complete skulls, with damaged skulls and cranial fragments accounting for 22 percent of orts and 68 percent of cranial remains (Figure 1). The nature of remains found differed for each species (e.g. for most birds only post-cranial remains, and no complete skulls, were found). On the few mammal skulls found, lines of breakage were not along suture lines; it appeared that eagles commonly tore through the skull via the auditory canal to expose the brain. Eagles appeared to swallow the heads of smaller avian prey (e.g. mandibles of Australian Ringneck and Australian Magpie in pellets).

Rabbits of various sizes were taken, but most orts were of individuals weighing more than 1650 grams, i.e. adults. Euros from pouch young to eight-kilogram juveniles were taken, whereas adults of large mammals appeared only to be taken as carrion; bullet-damaged skulls of adult kangaroos, scavenged from carcass dumps, were found beneath some nests. No lamb orts had the hoof membranes intact, thus suggesting that they had walked and were not neonates or stillborn (Rowley 1970), although the membrane may have decayed on some desiccated remains.

Differences among sites

Significant differences in diet composition (biomass from orts) were found both between sites (Figures 2–5; see also Appendix 1) and between dates of collection. The proportion of biomass contributed by rabbits differed significantly among sites during July ($\chi^2 = 17.5$, d.f. = 3, $P < 0.05$); on Sites 1 and 2 rabbit constituted 31 percent and 29 percent of biomass respectively, as opposed to 1 percent and 4 percent on Idalia and on Sites 3 and 4, respectively. Significance was approached but not attained for rabbit in the September collections, in which the trend had shifted with Sites 3 and 4 having the highest proportions of rabbit in the diet. Statistical analysis of numbers of individuals in the orts (Appendix 1) did not yield any significant differences for rabbits, suggesting that numbers of individuals is too insensitive a measure to be used in an overall analysis.

The proportion of kangaroo in the diet also differed among sites. Eagles on Idalia (73% of ort biomass) and Sites 3 and 4

TABLE 3

Prey species of the Wedge-tailed Eagle identified in orts.

Mammals:

Common Brushtail Possum *Trichosurus vulpecula*
Eastern Grey Kangaroo *Macropus giganteus*
Euro *Macropus robustus*
Red Kangaroo *Macropus rufus*
Yellow-footed Rock-Wallaby *Petrogale xanthopus*
Swamp Wallaby *Wallabia bicolor*
*European Rabbit *Oryctolagus cuniculus*
*Sheep *Ovis aries*
*Feral Goat *Capra hircus*
*Feral Pig *Sus scrofa*
*Feral Cat *Felis catus*
*Red Fox *Vulpes vulpes*

Birds:

Emu *Dromaius novaehollandiae*
Little Black Cormorant *Phalacrocorax sulcirostris*
Brown Goshawk *Accipiter fasciatus*
Australian Bustard *Ardeotis australis*
Crested Pigeon *Ocyphaps lophotes*
Galah *Cacatua roseicapilla*
Sulphur-crested Cockatoo *Cacatua galerita*
Australian (Mallee) Ringneck *Barnardius zonarius*
Tawny Frogmouth *Podargus strigoides*
Laughing Kookaburra *Dacelo novaeguineae*
Australian Magpie *Gymnorhina tibicen*
Australian Raven *Corvus coronoides*
White-winged Chough *Corcorax melanorhamphos*

Lizards:

Central Bearded Dragon *Pogona vitticeps*
Common Bluetongue *Tiliqua scincoides*
Shingleback *Tiliqua rugosa*

*Introduced species.

TABLE 4

Comparison of biomass represented by orts with estimated dietary intake. Nests numbered as in Table 2.

Location	Nest	Date	Biomass represented by orts (kg)	Estimated dietary intake (kg)	Percentage of estimated intake represented by orts
Idalia	1	May	14.6	60	24.3
	2	"	23.4	60	39
	3	"	15.6	60	26
Site 1	1	"	52.8	60	88
	2	"	9.5	60	15.8
Idalia	1	July	32.7	90	36.3
	2	"	9.3	90	10.3
	3	"	16.2	90	18
Site 1	1	"	8.3	90	9.2
	2	"	40.1	90	44.6
	3	"	2.4	120	2
	4	"	34.3	120	28.6
Site 2	1	"	7.8	60	13
Site 3	1	"	37	120	30.8
Idalia	1	Sept.	24.5	90	27.2
	2	"	19.8	90	22
	3	"	42.6	90	47.3
Site 3	1	"	13.7	120	11.4
Site 4	1	"	61.8	90	68.7
Site 1	1	"	38.7	90	43
	2	"	11	90	12.2
	4	"	10.5	120	8.8
	3	"	19	120	15.8
Site 2	3	"	34.9	90	38.8
	2	"	56.8	90	63.1
Idalia	1	Nov.	25.5	90	28.3
	3	"	22.4	90	24.9
	2[a]	"	27.7	90	30.8
	2	"	31	90	34.4
Site 4	2	"	38.4	90	42.7
	1	"	34.8	90	38.7
Site 3	1	"	35.1	120	29.3
Site 1	1[a]	"	20.1	90	22.3
	1	"	52.7	90	58.6
	2	"	7.5	90	8.3
	3	"	13.1	120	10.9
	4[a]	"	29.7	120	24.8
	4	"	57.3	120	47.8
Site 2	3	"	29.8	90	33.1
	2	"	18.2	90	20.2
Total			1080.4	3720	29
Median					27.8
Mean					30
S.D.					18.2

[a]Collected within the nest

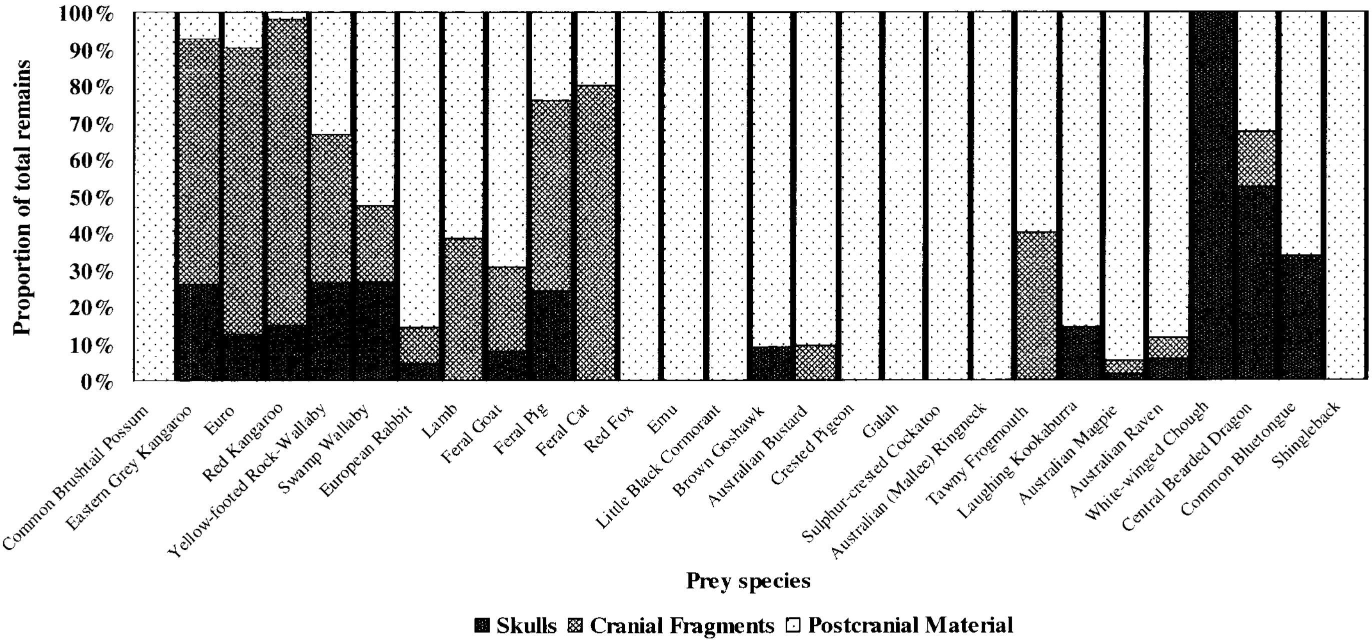

Figure 1. *Anatomical nature of orts (n = 2837) in and below 13 Wedge-tailed Eagle nests, south-central Queensland, 1999.*

(86%) consumed far more kangaroo than on Site 1 (37%) and Site 2 (41%) (χ^2 = 26.7, d.f. = 3, P <0.05). Kangaroo ort biomass also differed during September; the proportion of total biomass on Idalia (70%) was far greater than on Sites 3 and 4 (45%), Site 1 (40%) and Site 2 (30%) (χ^2 = 14.7, d.f. = 3, P <0.05). Differences among properties were also significant for numbers of individuals (total kangaroos; Appendix 1) in the orts (χ^2 = 38.3, d.f. = 3, P <0.05).

During September, feral pigs also differed in proportions of ort biomass and numbers of individuals among sites (χ^2 = 8.5, d.f. = 3, P <0.05). The proportion of lamb (ort biomass) in the diet for each property did not differ significantly (χ^2 = 6.0, d.f. = 3, P >0.05).

Chi-squared analysis revealed no significant differences in composition between orts found within nests and below nests examined. Owing to the nature of the collections, statistical analysis of the four months was not possible for all nests; some nests were discovered late in the project, and others discovered early were later found to contain infertile eggs (see Table 2).

Differences among collection dates

The data from Idalia and Site 1 were analysed for differences over time. Lamb was not found to differ significantly between collection dates for either Idalia or Site 1, although both approached significance (χ^2 = 5.7, d.f. = 3, P >0.05, and χ^2 = 7.2, d.f. =3, 0.10>P>0.05, respectively). These differences did not follow the same pattern (Figures 2, 3); the proportion of lamb at the nests on Site 1 peaked in September, whereas the proportions of lamb on Idalia peaked in November. During July, when little lamb material was collected below nests, lamb was observed cached in nests (though not collected for examination, lest the eagles be disturbed).

There were significant differences over time in the proportion of kangaroo in the diet of the eagles nesting on Site 1. Kangaroos were a much greater component of the diet during May than at other times (χ^2 = 9.04, d.f. = 3, P <0.05). The only significant difference found between collection dates on Idalia was for feral cat, which appeared in the May collections and not again (χ^2 = 8.55, d.f. = 3, P <0.05).

Comparison with estimated intake

The estimated proportions of the required dietary intake (500 g of meat daily), represented by the collected orts for the two-monthly intervals, are shown in Table 4. Only one collection was close to the expected biomass consumed: 88 percent at Site 1, Nest 1, 27 May. The entire collection represented less than 30 percent of the calculated dietary requirement for all nests (mean = 30, range = 2–88, n = 40).

Pellets

A total of 395 or 2.26 kilograms of pellets was collected (54 mm ± s.d. 17.9 x 32 mm ± s.d. 8.3; mean dry mass 4.53 g ± s.d. 4.6). Only 22 of the 28 prey species identified in the orts were found in pellets (Appendix 2; mean no. of species per pellet = 1.5, s.d. 0.48).

The percentages of pellet mass composition are shown in Figures 6–9. For pellets collected in July, rabbit, lamb, goat, pig and kangaroo all differed significantly among sites (χ^2 = 28.6, 69.0, 51.6, 11.4 and 32.3, respectively, d.f. = 3, P <0.05). For pellets collected in September, the percentage mass of Emu, Australian Ringneck, Australian Bustard, lamb, goat, pig, kangaroo, and Bearded Dragon all differed significantly among sites (χ^2 = 10.3, 7.84, 9.5, 10.4, 76.8, 115.8, 10.4 and 35.3 respectively, d.f. = 3, P <0.05). Pellets collected in November once again showed a significant difference in the mass proportions of lamb, goat and feral pig among sites (χ^2 = 47.8, 13.9, 16.1 respectively, d.f. = 3, P <0.05). The mass of magpie within pellets was significantly different among sites in the collection for November (χ^2 = 13.7, d.f, = 3, P <0.05), but not at any other collection time.

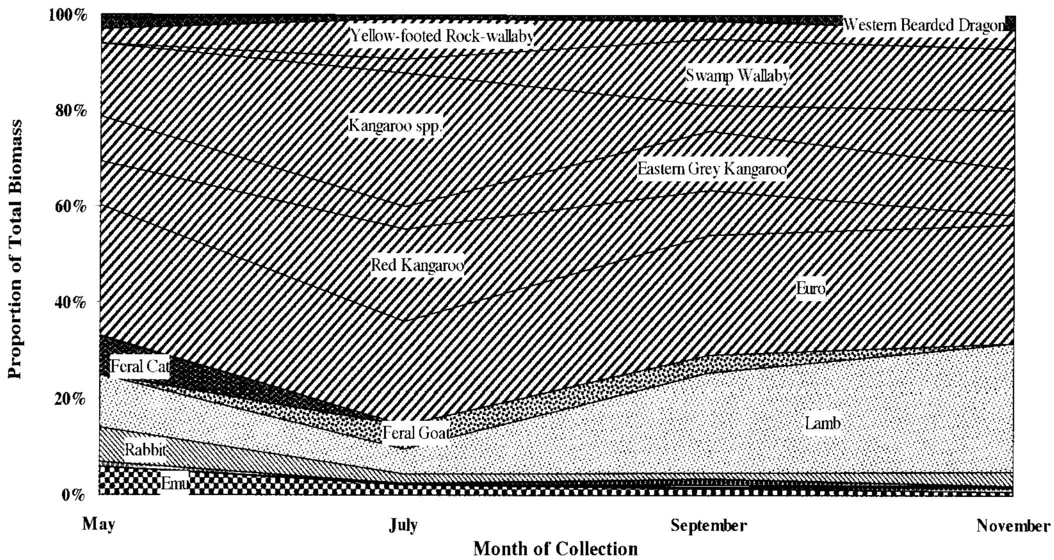

Figure 2. *Dietary biomass of Wedge-tailed Eagle by month in Idalia National Park, south-central Queensland, 1999, from orts.*

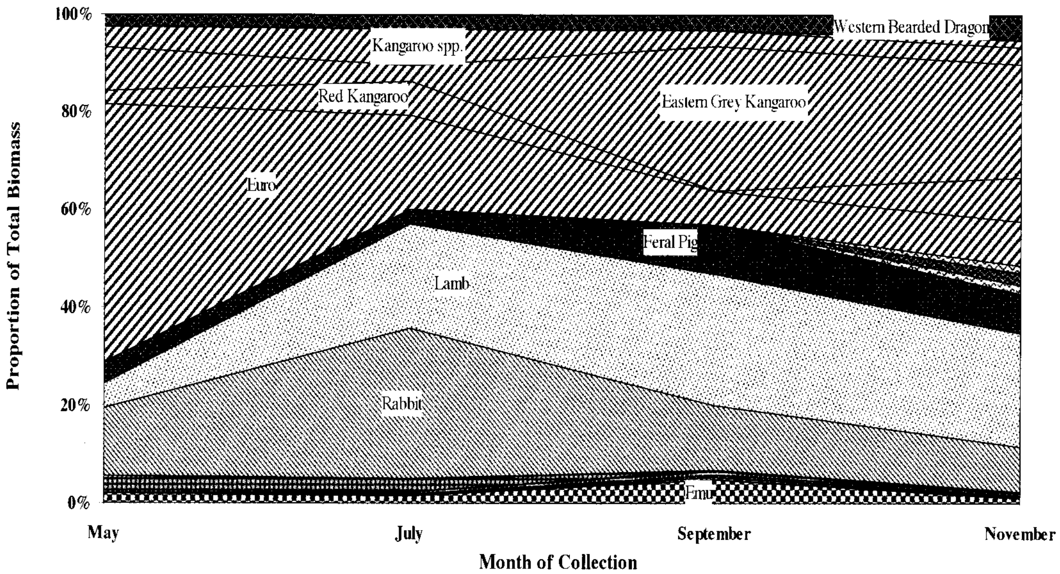

Figure 3. *Dietary biomass of Wedge-tailed Eagle by month at Sheep Site 1, south-central Queensland, 1999, from orts.*

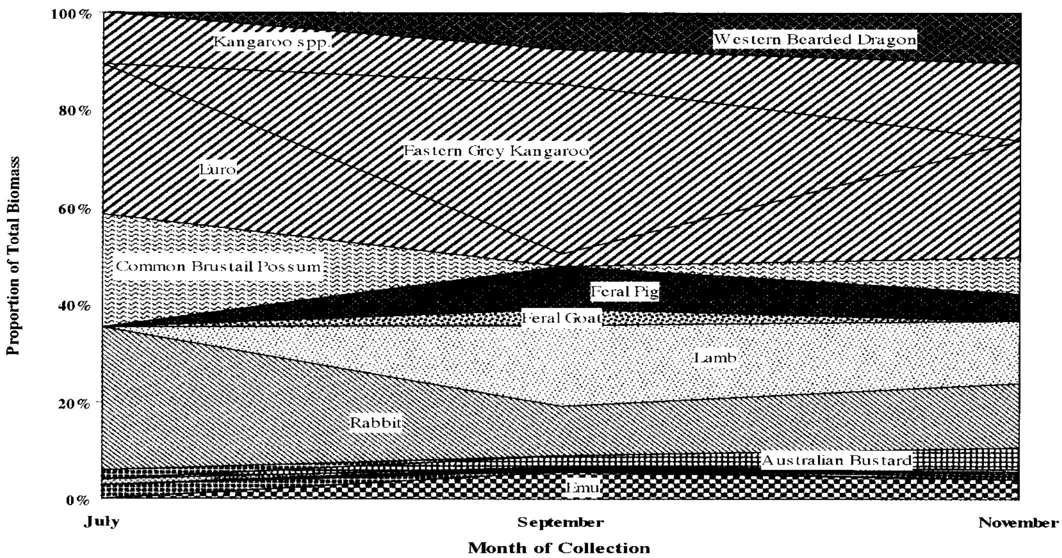

Figure 4. *Dietary biomass of Wedge-tailed Eagle by month at Sheep Site 2, south-central Queensland, 1999, from orts.*

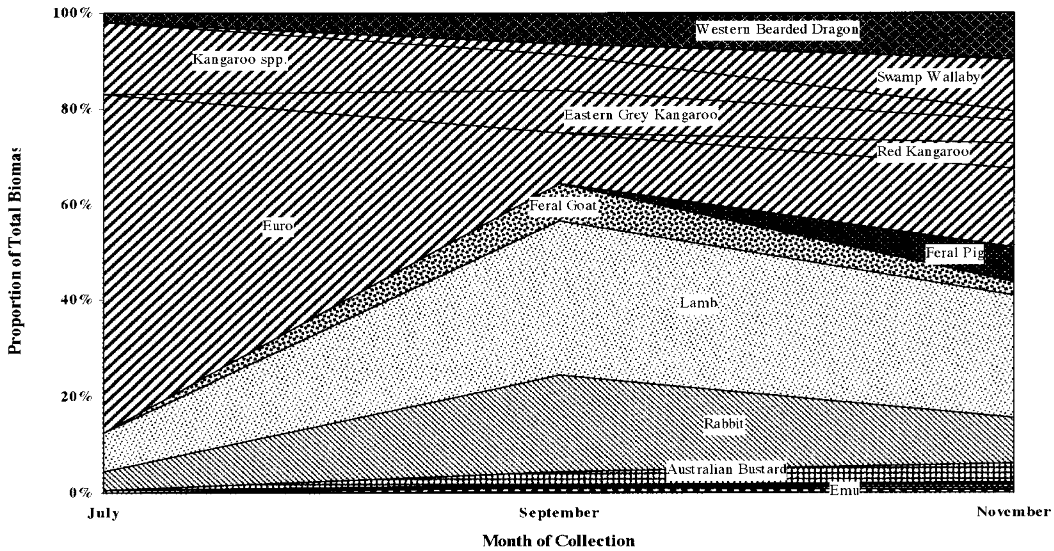

Figure 5. *Dietary biomass of Wedge-tailed Eagle by month at Sheep Sites 3 and 4, south-central Queensland, 1999, from orts.*

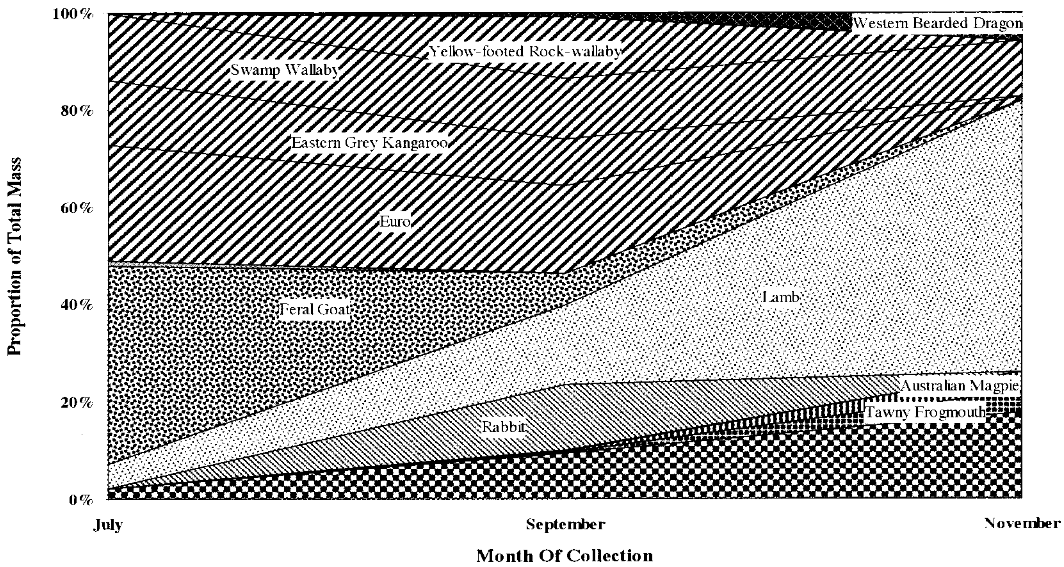

Figure 6. *Composition of Wedge-tailed Eagle pellets by month from three nests in Idalia National Park, south-central Queensland, 1999.*

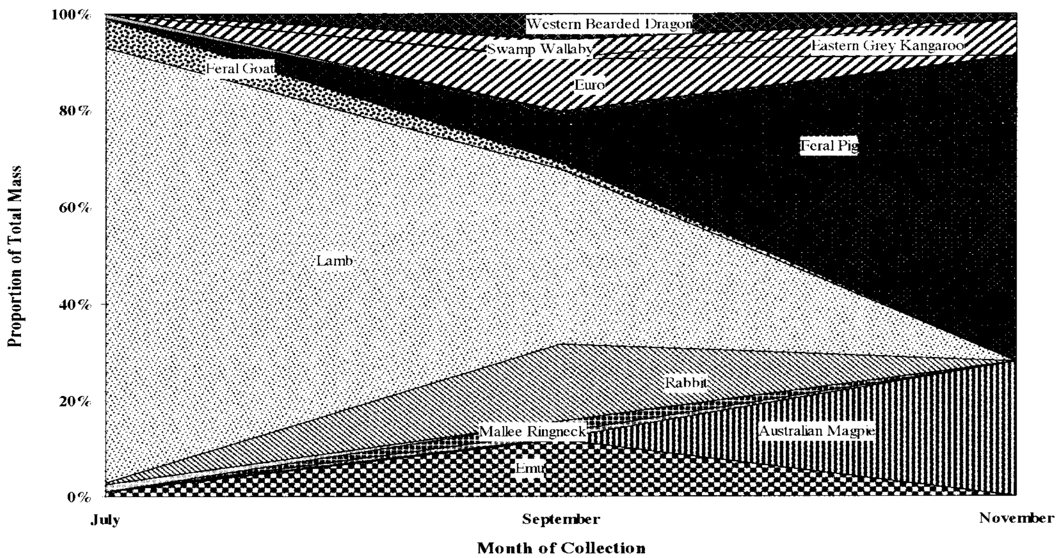

Figure 7. *Composition of Wedge-tailed Eagle pellets by month at Sheep Site 1, south-central Queensland, 1999.*

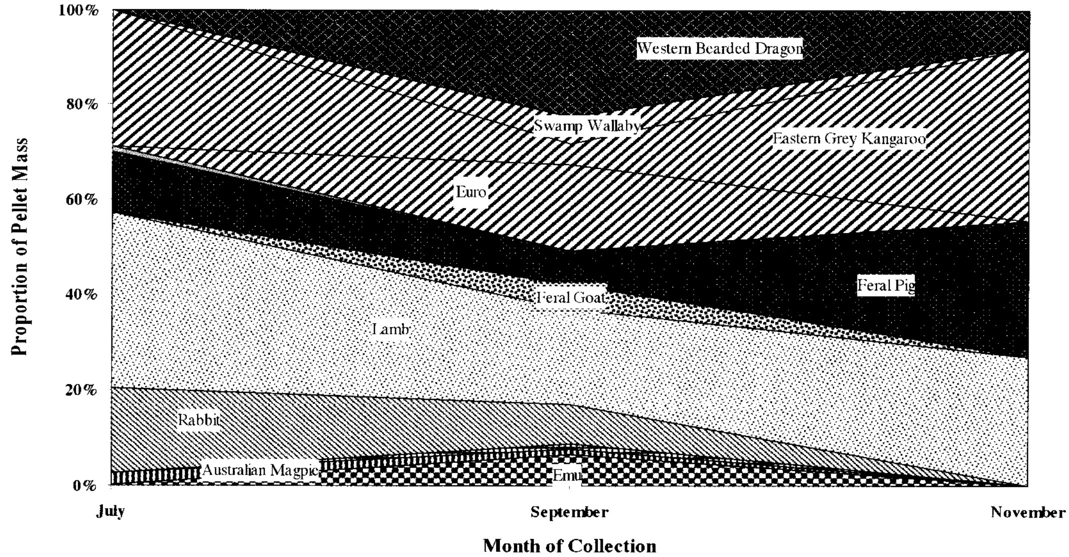

Figure 8. *Composition of Wedge-tailed Eagle pellets by month at Sheep Site 2, south-central Queensland, 1999.*

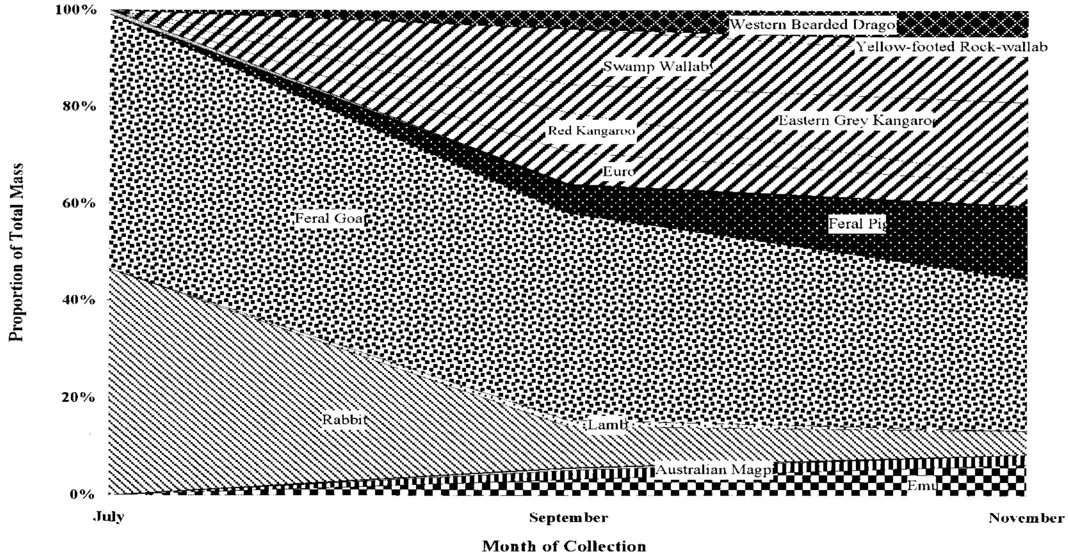

Figure 9. *Composition of Wedge-tailed Eagle pellets by month at Sheep Sites 3 and 4, south-central Queensland, 1999.*

Analysis of frequency of each species in pellets (Appendix 2) was not as sensitive as that of pellet mass. Only nine significant differences emerged when analysed by species frequency, in contrast to 16 significant differences in species mass within pellets. Unlike orts, analysis of pellet material within the nest against that collected below the nest yielded a significant difference; a greater mass of birds (other than Emu) was found in pellets within the nest than on the ground below ($\chi^2 = 6.8$, d.f. = 1, $P < 0.05$).

Analysis of differences in pellet mass composition between collection dates was possible with the data from Idalia and Site 1. The masses of lamb, goat and kangaroo differed significantly with time on Idalia ($\chi^2 = 16.5$, 24.8 and 8.8 respectively, d.f. = 2, $P < 0.05$). The masses of magpie, bird, rabbit, sheep, pig and kangaroo differed significantly among the dates of collection from the nests at Site 1 ($\chi^2 = 31.6$, 6.7, 8.8, 44.3, 32.3 and 7.3 respectively, d.f. = 2, $P < 0.05$).

DISCUSSION

Breeding

Clutches of two eggs are typical for the Wedge-tailed Eagle (Marchant and Higgins 1993). Reproductive success for a small sample in one year was at the high end of the recorded range, despite low rabbit densities (cf. Ridpath and Brooker 1986; Robertson 1987; Marchant and Higgins 1993). Low success recorded by Collins and Croft (2007) and Silva and Croft (2007) at a rabbit-poor site, where the eagles ate many macropods, may have been caused by human disturbance. In northern Australia the diversity and abundance of small and juvenile macropods, rather than rabbits, may influence breeding success.

Diet

In an area of low rabbit abundance, kangaroo (independent of carcass dumps, as indicated by the size of remains) formed the main food of Wedge-tailed Eagles. As expected, from other studies in the tropical and subtropical rangelands (Brooker and Ridpath 1980; Sharp 1997; Winkel 2007), the eagles around Charleville took mostly small macropods, a few other mammals such as cats, foxes, pigs, goats and lambs, some birds (notably Emu and Bustard), and some dragon lizards.

The low to moderate numbers of rabbits taken probably varied with their inferred availability across the various sites; the high proportion of adult rabbits taken was as expected (cf. Brooker and Ridpath 1980), although the relative availability of smaller rabbits is unknown.

Lamb was taken regularly across all sites, in amounts (by biomass) at least as important as rabbit (as might be expected, cf. Winkel 2007). The peak in lamb orts lagged behind the lambing season, suggesting either that eagles were preying on advanced lambs rather than scavenging dead or non-viable newborns, or that lamb orts accumulated in eagle nests for some time before being removed by the parent eagles. The trend over time in the proportion of lamb eaten on Site 1 is consistent with lambs growing too large and wary of predators by November, and with a decline in juvenile mortality from other causes (and hence in lamb carrion) as lambs mature. The late peak in lamb on Idalia is consistent with stock management on neighbouring properties. Eagles on Idalia took as many lambs as those on sheep stations, suggesting either that the eagles were efficient at finding the few feral lambs or the eagles commuted 20 kilometres, approximately two eagle home-range widths (cf. Marchant and Higgins 1993), to the nearest source. It must be noted that the minimum number of individual lambs taken, indicated by orts, only totalled 65 across all 13 nests, whereas the estimated number of productive ewes on the pastoral stations was over 16 000. The eagles also took 16 feral pigs during the monitoring period, lessening the population of a species that is a substantial pest in lambing paddocks (Choquenot *et al.* 1996).

The high proportion of macropod in the diet at Idalia was as expected, given the different land-management regimes (and hence relative prey abundances) on the various sites, and the prior results of Sharp (1997). The high proportion of kangaroo in the diet on Sites 3 and 4 may be attributable to a high number of juveniles orphaned by shooters. Goats were not taken as often as expected by eagles nesting in goat habitat. The lack of pigs in the diet at Idalia may be explained by the lack of food (kangaroo carrion) for pigs. The only control method for pigs used in the park was opportunistic ground shooting (C. Morgan pers. comm.), whereas commercial harvesting was undertaken at the other sites. Possums were taken where suitable woodland habitat (Site 2) supported arboreal mammals.

The differences in the avian component of the diet, from pellets, may have been related to the different land systems of the properties: more birds were taken where open grassland predominated. The proportion of birds other than Emu increased in later collections, consistent with the age-classes of avian material found in orts: juvenile ravens and magpies were frequent prey in September and November, corresponding with eagles taking vulnerable new fledglings. Of the bird species taken by eagles, only the Emu breeds during early winter and therefore has chicks at that time (Marchant and Higgins 1990).

Prey selection

The eagles' diet across sites varied with habitat and the relative abundance (or inferred abundance) of some prey species, but the eagles also showed some possible prey preferences. Rabbits were probably taken in proportion to their local abundance (as found by Collins and Croft (2007) for a rabbit-poor area). Goats were apparently taken at levels below their relative abundance. Although lamb densities differed across sites, lambs were taken in similar (though minor as indicated by biomass) proportions across sites, suggesting that the eagles were selecting lambs to some extent, and perhaps commuted long distances to do so. Lamb (whether live-caught or carrion), or some other attribute of pastoral rangeland, may have played a role in eagle nesting density and dispersion, and perhaps breeding success. Eagles may concentrate on preferred prey, even at varying or reduced densities of such animals, and thus may be selective feeders (as for the Golden Eagle: Steenhof and Kochert 1988).

Feeding behaviour

The mammalian skull damage and hence inferred feeding behaviour is consistent with the observation that Wedge-tailed Eagles enter carcasses via the ear (Brooker and Ridpath 1980). For the majority of birds, only post-cranial remains were found; Golden Eagles also swallow the heads of avian prey (Bochenski *et al.* 1999). The high proportion of post-cranial remains, compared with skulls, in orts is likely a function of the feeding behaviour of eagles rather than the age of prey taken. For instance, eagles may behead and partly eat prey away from the nest and bring hindquarters to the nest, or discard bird legs or mammalian hindlimb bones at the nest.

Intake

The overall ort collection represented 29 percent of the estimated required dietary intake for the Wedge-tailed Eagle, which is considerably lower than the value of 51–59 percent for the Golden Eagle (Collopy 1980, who collected at six-day, not bimonthly, intervals). That is, 71 percent of the eagles' inferred dietary intake in this study is unaccounted for. Scavengers may remove orts; large (non-transportable) items of carrion may not appear in orts; some prey may be eaten away from nests or leave no orts; and parent eagles may remove orts from items cached in the nest and dump them elsewhere (Sharp *et al.* 2002). The important figure is the ratio of the various items. As the composition of orts within and below nests does not differ (Collopy 1983; this study), orts below nests probably were representative of the eagles' dietary proportions around Charleville.

Orts versus pellets

The results for pellets versus orts differed, as in other studies (Sharp *et al.* 2002; Winkel 2007), and in this study orts represented a larger proportion of the estimated required biomass of the eagles' diet than did pellets. However, in this study most of the site and temporal trends in diet, from pellet data, were consistent with those from orts. The large site difference in the percentage of rabbit does not coincide with the small difference found in orts, and is most likely an anomaly related to the nature of pellet production, as rabbit fur 'felts' easily (i.e. is 'sticky': Turner 1988); this factor may overestimate the importance of rabbit in pellets.

The low amount of kangaroo fur in pellets might be taken to indicate that the amount of kangaroo in orts is attributable to eagles feeding at skinned carcass dumps, or on large kangaroos. However, most orts were of small (non-harvestable) kangaroos, indicating that the eagles hunted live kangaroos. The low proportion of kangaroo fur in pellets may be related to eagle feeding behaviour, e.g. plucking or skinning macropod prey.

The proportion of lamb wool found in pellets was much higher than the amount of lamb found in orts at both Idalia and Site 1. Pellets composed of wool are likely to be more robust and impervious to weathering than those composed of shorter, stiffer hairs. Pellets were first collected at Site 1 in July and 15 of 19 pellets were entirely composed of wool (see Appendix 2). It is possible that these pellets had been previously overlooked or, as with rabbit (owing to the nature of the fibre), pellets may overestimate the proportion of lamb.

The proportion of birds found in pellets was far greater than that found in orts. For the Common Kestrel *Falco tinnunculus*, birds yielded more indigestible remains than did mammals of similar mass (Yalden and Yalden 1985), suggesting that pellets over-represent the role of avian prey. However, for kestrels avian prey is usually larger than mammalian prey, whereas for eagles the reverse is true (e.g. Marchant and Higgins 1993).

Limitations of pellet analysis

Six prey species identified in orts were absent from pellets, as might be expected (cf. Duke *et al.* 1975; Yalden and Yalden 1985; Seguin *et al.* 1998: pellet formation is dependent on prey species, with some prey readily forming a pellet whereas other prey is absent from pellets). The converse may also occur (Sharp *et al.* 2002). The high proportion of lamb and goat in the eagle pellets in this study may perhaps be explained by differences in hair or fur properties, e.g. lambs' wool and goat hair may be more difficult to pluck than kangaroo or rabbit fur; or, alternatively, the eagles may be eating (scavenging?) lamb or goat but not bringing it all to the nest.

The 2.26 kilograms of dry pellet matter collected may equate with an ingested mass of 45.2 kilograms dry matter (from Duke *et al.* 1975). If the findings of Yalden and Yalden (1985) are true for all diurnal raptors, the pellets represent 1 percent of the ingested prey (i.e. 226 kg) of the 13 eagle nests monitored, which is only 6.1 percent of the expected intake (182.5 kg per bird per year: from Olsen *et al.* 2006b).

Orts can withstand weathering, but eagle pellets, though containing some bone, consist mostly of fur, feathers and scales (Olsen 2005), which are presumably more likely to be lost to weathering. The small numbers of pellets collected in this study may be a product of pellets breaking down during the two-month interval between site visits. The same factors responsible for pellet formation (hair properties etc.) are probably responsible for the resistance of pellets to weathering. The high proportion of lamb and rabbit in the collected pellets may be attributable to the fibres of these two species (i.e. their ability to 'felt' and hence resist weathering).

CONCLUSIONS AND FUTURE RESEARCH

The importance of most major food types in the eagles' diet varied with land systems (i.e. habitat) and land management, and hence with inferred prey populations, and also over time with inferred changes in prey populations. The eagles preferred mammals within a certain size range (adult rabbits to small macropods), and appeared to select lamb at a consistent proportion across sites (on the basis of ort biomass, although pellet mass for lamb varied). Orts better represented the eagles' diet than did pellets, but orts also underestimated intake. Recent studies tend to combine orts, pellets and observations (without double-counting items), as the preferred method of estimating raptor diets (e.g. Seguin *et al.* 1998; Olsen *et al.* 2006a,b).

To elucidate the Wedge-tailed Eagle's prey preferences, it would be useful to contrast utilization with both availability and nutritional analysis of carrion and prey species, and necessary to sample prey densities. Previous data on eagle home-range and territory size (see Marchant and Higgins 1993) were obtained pre-calicivirus. As this study suggests a higher breeding density in sheep-farming regions than in an unstocked area (national park), it would be useful to establish whether patterns of breeding have changed following the outbreak of the calicivirus, and to determine home-ranges and foraging distances by radio-telemetry.

The persistence time of orts in the nest may vary with prey species, which could be investigated by observation of prey delivery to the nest (or remote video-monitoring: Collins and Croft 2007; Silva and Croft 2007). From such data the optimal collection interval could be determined, ensuring that possible bias towards larger or smaller species is minimized. It would also be useful to establish whether orts, pellets or a combination give best estimates of prey brought to the nest.

A captive-feeding study could be coupled with the determination of dry-matter content of prey, in order to establish correction factors. Eagles may ingest particular bones for dietary calcium, and so remove them from the ort record. Biases in ort or cranial analyses could be elucidated by feeding known quantities of various prey types and monitoring pellets, and recording feeding habits (e.g. ingestion or discarding of heads).

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APPENDIX 1

Minimum number of individuals (% biomass) of prey species in Wedge-tailed Eagle diet across five sites (see text) and four collection months in south-central Queensland, from orts. Idalia = national park; Sites 1–4 are sheep stations.

Species	Idalia				Site 1				Site 2			Sites 3&4		
	May	July	Sept.	Nov.	May	July	Sept.	Nov.	July	Sept.	Nov.	July	Sept.	Nov.
Emu	5 (5.8)	2 (2.2)	2 (1.5)	1 (0.8)	2 (2.1)	2 (1.5)	6 (4.9)	2 (1.0)		8 (5.6)	3 (4.0)		1 (0.9)	1 (0.6)
Little Black Cormorant	1 (1.0)													
Brown Goshawk													1 (0.3)	
Australian Bustard					1 (3.4)	1 (2.5)				1 (2.3)	1 (4.5)		1 (2.8)	2 (3.9)
Crested Pigeon						1 (0.2)			1 (1.8)					
Galah						2 (0.5)	3 (0.7)			1 (0.2)	1 (0.4)			1 (0.2)
Sulphur-crested Cockatoo			2 (1.3)											
Australian Ringneck		1 (0.2)				1 (0.1)	1 (0.1)	1 (0.1)	1 (1.1)					
Tawny Frogmouth			1 (0.3)	3 (0.9)				2 (0.3)	1 (2.9)	1 (0.3)		1 (0.6)	1 (0.3)	2 (0.4)
Laughing Kookaburra								1 (0.2)						1 (0.2)
Australian Magpie				1 (0.3)		1 (0.2)	2 (0.5)	2 (0.3)		1 (0.2)	1 (0.4)		1 (0.3)	4 (0.8)
Australian Raven			1 (0.4)				1 (0.4)	1 (0.3)		1 (0.4)	1 (0.7)			
White-winged Chough											1 (0.6)			
Brushtail Possum								1 (1.4)	1 (23.1)		2 (7.6)			
Eastern Grey Kangaroo	3 (9.5)	2 (4.7)	6 (12.3)	3 (9.7)	2 (8.8)	2 (3.3)	8 (29.9)	11 (23.1)		6 (34.7)			3 (8.9)	3 (4.8)
Euro	10 (27.1)	7 (21.3)	8 (24.9)	7 (24.7)	12 (52.9)	6 (19.1)	6 (7.0)	5 (9.0)	2 (30.9)	2 (2.6)	2 (23.8)	6 (70.7)	3 (10.4)	8 (16.3)
Red Kangaroo	2 (9.0)	5 (19.4)	4 (9.6)	1 (2.0)	3 (2.8)	4 (7.1)		5 (9.1)						4 (5.3)
Kangaroo sp.	8 (15.3)	16 (27.9)	7 (5.5)	5 (12.2)	3 (4.2)	5 (7.5)	2 (3.3)	2 (3.6)	1 (10.6)	6 (7.2)	4 (15.9)	3 (15.0)	7 (7.7)	2 (1.9)
Yellow-footed Rock-Wallaby	1 (3.0)	3 (8.4)	2 (3.7)	2 (4.1)										
Swamp Wallaby		1 (2.9)	7 (13.6)	6 (12.9)				1 (1.3)					1 (2.3)	7 (11.0)
Rabbit	3 (7.2)	1 (2.0)	1 (1.3)	2 (2.9)	7 (14.1)	19 (30.7)	8 (13.3)	9 (9.4)	2 (29.5)	7 (10.2)	5 (13.4)	1 (3.7)	11 (19.9)	8 (9.6)
Sheep	2 (11.0)	1 (5.2)	6 (20.8)	7 (26.7)	1 (4.8)	6 (21.3)	7 (26.7)	10 (23.1)		5 (16.5)	2 (12.7)	1 (8.1)	8 (32.0)	9 (25.2)
Feral Goat		1 (5.2)	1 (3.5)							1 (3.3)			2 (8.0)	1 (2.8)
Feral Pig					1 (4.2)	1 (3.1)	3 (10.0)	4 (8.1)		3 (8.7)	1 (5.6)			3 (7.4)
Feral Cat	2 (8.2)							1 (1.7)						
Red Fox								1 (2.6)						
Bearded Dragon	5 (2.1)	2 (0.8)	5 (1.3)	10 (2.9)	7 (2.5)	11 (2.9)	11 (3.1)	29 (5.0)		29 (7.2)	22 (10.5)	3 (1.8)	19 (5.7)	46 (9.7)
Shingleback	1 (0.8)							1 (0.3)					1 (0.6)	
Bluetongue										1 (0.4)				
Total individuals	43	42	53	48	39	62	58	89	9	73	46	15	60	102

APPENDIX 2

Species frequency (percentage mass) in pellets in Wedge-tailed Eagle diet across five sites (see text) and four collection months in south-central Queensland. Idalia = national park; Sites 1–4 are sheep stations.

Species	Idalia			Site 1			Site 2			Sites 3&4		
	July	Sept.	Nov.	July	Sept.	Nov.	July	Sept.	Nov.	July	Sept.	Nov.
Emu	1 (.21)	13 (9.3)	3 (17.8)	2 (1.0)	19 (11.9)	1 (0.2)	1 (0.3)	5 (6.5)			10 (3.3)	4 (6.2)
Australian Bustard								1 (1.1)				
Galah					11 (1.2)		1 (0.0)				3 (0.3)	
Sulphur-crested Cockatoo												
Australian Ringneck		3 (0.3)			1 (2.3)						1 (0.1)	
Crested Pigeon				1 (1.6)							1 (0.1)	
Tawny Frogmouth		2 (0.3)	1 (4.4)									
Australian Magpie		1 (0.2)	1 (3.9)		5 (0.3)	2 (28.0)	1 (2.5)	1 (1.1)			1 (1.8)	5 (2.1)
Brushtail Possum											1 (0.4)	
Eastern Grey Kangaroo	1 (13.5)	6 (9.7)	1 (0.8)		1 (0.3)	1 (7.4)	3 (29.3)	2 (4.4)	1 (36.6)		4 (5.9)	7 (15.6)
Euro	3 (24.2)	17 (17.9)			8 (10.5)			7 (18.0)			9 (6.7)	5 (4.5)
Red Kangaroo											3 (8.0)	1 (1.1)
Yellow-footed Rock-Wallaby		9 (12.7)							0 (0.0)			1 (3.0)
Swamp Wallaby	2 (13.8)	9 (12.4)	1 (11.5)		6 (3.8)			1 (5.7)			8 (11.5)	5 (9.5)
Rabbit		7 (13.4)	1 (0.1)	1 (0.4)	13 (15.9)		5 (17.8)	4 (8.2)		2 (47.1)	1 6(8.6)	8 (4.9)
Sheep	1 (5.1)	10 (16.3)	12 (55.7)	15 (90.9)	28 (35.7)		3 (37.4)	5 (20.0)	1 (26.7)		2 (1.3)	
Feral Goat	1 (41.1)	7 (6.4)		3 (6.2)	1 (1.6)			3 (5.4)		4 (52.9)	33 (42.3)	17 (31.2)
Feral Pig					8 (9.3)	1 (63.2)	2 (12.8)	4 (7.0)	1 (28.5)		8 (5.8)	11 (15.0)
Feral Cat												
Bearded Dragon	1 (0.3)	5 (0.9)	2 (5.8)		32 (5.2)	1 (1.2)		15 (22.5)	1 (7.8)		33 (3.7)	23 (6.7)
No. individuals	10	89	23	22	135	6	15	47	4	6	131	87
No. pellets	9	52	17	19	60	3	10	27	4	4	66	48