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Food and Hunting of Eight Breeding Raptors Near Canberra, 1990–1994

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Summary

Prey remains, pellets and observations of hunting habits, gathered from eight species of breeding raptors (White-bellied Sea-Eagle *Haliaeetus leucogaster*, Brown Goshawk *Accipiter fasciatus*, Wedge-tailed Eagle *Aquila audax*, Little Eagle *Hieraaetus morphnoides*, Australian Hobby *Falco longipennis*, Peregrine Falcon *F. peregrinus*, Powerful Owl *Ninox strenua* and Southern Boobook *N. novaeseelandiae*), include the first quantitative account of the diet for inland Sea-Eagles and the first reports of the diet of the Brown Goshawk, Powerful Owl and Boobook in the Australian Capital Territory. We found seven new prey species for three of the raptors. The geometric mean prey weight calculated for the five raptor species with acceptable sample sizes (>10 items)—Sea-Eagle, Goshawk, Hobby, Peregrine Falcon and Boobook—correlated positively with mean mass of the raptor, except that Peregrines took more large prey items relative to their weight.

Introduction

Comparative diets of breeding raptor assemblages in Australia have been described for arid areas of Victoria (Baker-Gabb 1984a) and the Northern Territory (Aumann 2001). In the Southern Tablelands near Canberra, Australian Capital Territory (ACT) (34°45′–35°47′S, 148°40′–149°50′E), only the diets of the Wedge-tailed Eagle *Aquila audax* (Leopold & Wolfe 1970), Little Eagle *Hieraaetus morphnoides* (Bollen 1989, 1991a; Mallinson *et al*. 1990), Peregrine Falcon *Falco peregrinus* (Olsen 1992; Olsen *et al*. 1993; Olsen & Stevenson 1996; Olsen & Tucker 2003; Olsen *et al*. 2004) and Nankeen Kestrel *F. cenchroides* (Olsen *et al*. 1979; Bollen 1991b) have been well studied. For other species there is only limited, mainly anecdotal information (Collared Sparrowhawk *Accipiter cirrhocephalus*: Metcalf 1981; Metcalf & Metcalf 1986; Australian Hobby *Falco longipennis*: Metcalf 1989), and there are no published analyses of the food habits of local Brown Goshawks *Accipiter fasciatus*, Powerful Owls *Ninox strenua* or Southern Boobooks *N. novaeseelandiae*. Similarly, there is no published information on the diet of inland-nesting White-bellied Sea-Eagles *Haliaeetus leucogaster*.

The role of prey size has been well studied for raptors elsewhere in the world (Nilsson 1984; Jaksic & Delibes 1987; Gil & Pleguezuelos 2001; Marti *et al*. 1993a, b; Reif *et al*. 2004; Scheibler 2004). One straightforward method of estimating raptor prey size is to calculate the mean prey weight. The frequencies of prey weights of most raptor species, however, do not follow normal distributions, and are usually skewed to one side of the mean. This poses a problem for using traditional arithmetic mean prey weights, since this statistic is not representative of the central tendency of skewed populations and it is therefore unreliable as an estimator of the overall prey size. In an attempt to overcome this problem, Jaksic

& Braker (1983) proposed the use of the geometric mean prey weight (GMPW), obtained by summing the products of the number of prey items in each category multiplied by the respective $\log_e$-transformed weight and dividing this by the total number of prey individuals in all categories. This simple procedure has since been proposed as the standard method to estimate raptor prey size (see Marti 1987), but it has seldom been used for Australian raptors (see McDonald *et al.* 2001).

In this paper we present information on the food habits of six species of diurnal raptors (Falconiformes) and two owls (Strigiformes) nesting in the Canberra region between 1990 and 1994, additional to the dietary information given by Olsen (1992), Olsen *et al*. (1993), Olsen & Rehwinkel (1995), Olsen & Tucker (2003) and Olsen *et al*. (2004). This study includes the first reported diets for inland-nesting Sea-Eagles and for Brown Goshawks, Powerful Owls and Boobooks in the ACT. In addition, we noted observations of hunting in the study area, though not necessarily at these study nests unless specified. Finally, we calculated the GMPW for the five raptor species with adequate sample sizes (>10 items), and correlated these values with the mean mass of the raptor.

Study area and methods

Study area

We collected prey items mainly in five areas, including two reserve systems in the ACT:

(1) **Canberra Nature Parks** (Brown Goshawk, Little Eagle, Australian Hobby, Southern Boobook), comprising former grazing land, open forest and tall woodland with dominants of Scribbly Gum *Eucalyptus rossii*, Brittle Gum *E. mannifera*, Red Stringybark *E. macrorhyncha* and Blakely's Red Gum *E. blakelyi*, with Red Box *E. polyanthemos* and Yellow Box *E. melliodora* in more open areas, bordered in places by the Murrumbidgee River (NCDC 1988);

(2) **Namadgi National Park** (Powerful Owl), a 106 000-ha reserve covering much of the Brindabella Range in the south and west of the ACT, with peaks up to 1900 m, and mostly tall wet sclerophyll forest, dense shrub understorey, alpine woodland at the highest elevations, and open, drier forest with open grassy valleys at lower elevations (Taylor & COG 1992; Olsen & Rehwinkel 1995);

(3) **Googong Dam** in New South Wales (NSW) to the east of the ACT (Sea-Eagle), a water catchment and recreational area dominated by grazing land and dry sclerophyll forest;

(4) **Burrinjuck Dam** in NSW to the west of the ACT (Sea-Eagle, Wedge-tailed Eagle, Peregrine Falcon), an irrigation-storage dam and recreation area dominated by grazing land and scattered Yellow Box and *Casuarina*; and

(5) **Western ACT/NSW border** (Wedge-tailed Eagle) on the Murrumbidgee River, grazing land dominated by Yellow Box, Red Stringybark and *Casuarina*.

(6) We collected prey from an additional Peregrine Falcon nest near **Goulburn, NSW**, in mountainous grazing land and dry sclerophyll forest dominated by Red Stringybark.

Prey collection and analysis

Except where indicated, we estimated diet by analysing pellets and prey remains collected during the breeding season from inside and under stick-nests, tree-hollows, cliff-ledges, and under roosts.

White-bellied Sea-Eagle We made seven collections from the ground below, and from within, two active Sea-Eagle nests: one at Burrinjuck Dam and the other at Googong foreshores, in 1991, 1992 and 1993.

Brown Goshawk We made four collections from two territories located on the northern side of Canberra inside Canberra Nature Parks in 1991, and one in 1992.

Wedge-tailed Eagle In 1991 JO recorded prey seen in a nest with a single 6-week-old nestling at Burrinjuck Dam, and made similar observations by telescope at another nest on the Murrumbidgee River in 1991 while fostering a captive-bred Wedge-tailed Eagle (Olsen 1995).

Little Eagle We collected pellets and prey remains from three Little Eagle nests in Canberra Nature Parks in 1991 and 1992.

Australian Hobby We collected prey remains and pellets from under the nest and roosts at one territory in grazing/bushland in northern Canberra during the 1991–92 breeding season. Incidental observations of kills and prey deliveries were also recorded, and included in the diet calculations, when the items we saw delivered did not show in the pellets or remains for that day or the next.

Peregrine Falcon We collected food from seven cliff-nests between 1990 and 1993: six at Burrinjuck Dam (with a total of seven food collections in 1990 and 1991), and one near Goulburn, NSW (one collection each year from 1990 to 1993).

Powerful Owl We collected food material from one active nest located near Blundell's Creek in the Namadgi National Park in 1991.

Southern Boobook We collected from three nests and roosts in Canberra Nature Parks: one in 1993, another in 1994 and a third in 1993 and 1994.

We identified and counted body parts to estimate the minimum number of prey items (MNI) in a pooled sample of pellets and prey remains, in order to minimise biases in the food estimations (Collopy 1983; Simmons *et al*. 1991; Seguin *et al*. 1998). We did not assume that one pellet represented one individual prey item. Collected materials were then sorted and analysed in the laboratory. Feathers were identified by comparison with feather collections and museum specimens when necessary. Bones, hair and scales were identified by microscopy (following Brunner & Coman 1974 for mammalian hair) and by comparison with museum reference material.

For those species with acceptable sample sizes (>10 items), we estimated the dietary mass by multiplying the MNI by the average weight in each prey category. Numbers represent biomass captured since no correction factors were incorporated. We calculated geometric mean prey weights (GMPW) following Marti (1987), and estimated a ratio of prey size relative to predator size by dividing the GMPW by the average weight of both sexes for each raptor species, to account for dimorphism. The mean or median weights of predators and prey were taken from the literature, mainly from Marchant & Higgins (1993) and other *HANZAB* volumes. The Spearman correlation coefficient was used to evaluate the relationship between predator and prey size, since the data did not conform to the assumptions of parametric correlations and the sample size was small.

Results

White-bellied Sea-Eagle

Sea-Eagles that we observed hunting made long, flat dives at prey near the water's edge or in the water, or made short, twisting dives to take waterfowl off the surface of the water or fish from near the surface. One pirated an Australasian Grebe *Tachybaptus novaehollandiae* knocked into the water and killed by a Peregrine Falcon (J. Olsen pers. obs.).

Prey identified from the two Sea-Eagle nests included nine species from three major taxa: birds, reptiles and fish. The main species taken was the Australian Wood Duck *Chenonetta jubata* (30.8% by number and 44.3% of dietary mass). Birds as a group also dominated the diet: 76.9% of the total prey items and 71.2% of the biomass (Table 1).

Brown Goshawk

Goshawks that we observed hunting tended to ambush prey, such as Eastern Rosellas *Platycercus eximius*, Common Starlings *Sturnus vulgaris* and Rabbits *Oryctolagus cuniculus*, from the edge of Red Stringybark woodland. They also flew through forest to surprise prey, sometimes slamming into low foliage after

Table 1

Number (n) and percentage of prey items and biomass from two White-bellied Sea-Eagle nests between 1991 and 1993.

Prey species		*Mass (g)*	*n*	*% by number*	*% by mass*
Birds:					
Australasian Grebe	*Tachybaptus novaehollandiae*	165	1	7.7	2.3
Australian Wood Duck	*Chenonetta jubata*	808	4	30.8	44.3
Egret sp.	Ardeidae	504	1	7.7	6.9
Eurasian Coot	*Fulica atra*	545	1	7.7	7.5
Galah	*Cacatua roseicapilla*	335	1	7.7	4.6
White-winged Chough[n]	*Corcorax melanorhamphos*	334	1	7.7	4.6
Common Starling[i n]	*Sturnus vulgaris*	75	1	7.7	1.0
Reptiles:					
Long-necked Turtle	*Chelodina longicollis*	700	1	7.7	9.6
Fish:					
Carp[i]	*Cyprinus carpio*	700	2	15.4	19.2
Total			**13**	**100**	**100**

[i]Introduced species
[n]Species not previously reported (Marchant & Higgins 1993)

Crimson Rosellas *Platycercus elegans* and Starlings, pulling them from foliage with their long legs (J. Olsen pers. obs.). Quarry close to cover, or in cover, was not immune from attack.

Goshawks mainly captured birds (59.1%), followed by insects (22.7%) and mammals (18.2%: Table 2). The Rabbit (18.2%) and Red-rumped Parrot *Psephotus haematonotus* (13.6%) were the most common prey species, but Rabbits dominated the dietary biomass (66.3% of total).

Table 2

Number (n) and percentage of prey items and biomass from two Brown Goshawk nests in 1991 and 1992.

Prey species		*Mass (g)*	*n*	*% by number*	*% by mass*
Mammals:					
Rabbit juvenile[i]	*Oryctolagus cuniculus*	500	4	18.2	66.3
Birds:					
Crimson Rosella juvenile	*Platycercus elegans*	131	1	4.5	4.3
Eastern Rosella	*Platycercus eximius*	106	1	4.5	3.5
Red-rumped parrot	*Psephotus haematonotus*	61	3	13.6	6.1
Parrot sp.	Psittaciformes	99	1	4.5	3.3
Robin sp.	Petroicidae	15	1	4.5	0.5
Common Starling[i]	*Sturnus vugaris*	75	2	9.1	5.0
Unidentified		81	4	18.2	10.7
Insects:					
Beetle	Coleoptera	2	3	13.6	0.2
Grasshopper	Acrididae	2	2	9.1	0.1
Total			**22**	**100**	**100**

[i]Introduced species

Adult Little Eagle

Plate 8 Photo: Jerry Olsen & Susan Trost

Wedge-tailed Eagle

The Wedge-tailed Eagles observed hunting usually made long angled dives, from a soaring position or a perch, at ground quarry in the open, mainly Rabbits and Brown Hares *Lepus capensis*. One pirated a Rabbit kitten from a Brown Falcon *Falco berigora*.

The freshly killed carcasses of one Little Eagle, one lamb *Ovis aries* and one Red Fox *Vulpes vulpes* were identified in the Burrinjuck Dam nest. Three fresh adult Rabbits were brought by adult Eagles to the Murrumbidgee River nest.

Little Eagle

Little Eagles made long, angled dives at Rabbits, Galahs *Cacatua roseicapilla* and other birds on the ground. Males, in particular, showed considerable agility around cover.

The eight prey items identified from three Little Eagle nests were one unidentified ibis *Threskiornis*, one Galah, three Rabbits (including two juveniles), two Christmas beetles *Anoplognathus* and one cicada (Cicadidae).

Australian Hobby

Hobbies were bird-catchers but, unlike the Peregrine Falcons that we observed, they also caught many insects (Table 3). They caught all birds and insects in mid air, by direct attack from a perch, or in fast contour-flying over the tree-canopy or

Table 3

Number (n) and percentage of prey items and biomass from one Australian Hobby nest in 1991.

Prey species		*Mass (g)*	*n*	*% by number*	*% by mass*
Birds:					
Budgerigar	*Melopsittacus undulatus*	28	6	6.3	3.7
Crimson Rosella	*Platycercus elegans*	135	6	6.3	17.9
juvenile		131	1	1.1	2.9
Eastern Rosella	*Platycercus eximius*	106	3	3.2	7.0
White-throated Needletail	*Hirundapus caudacutus*	116	2	2.1	5.1
Red-capped Robin	*Petroica goodenovii*	9	1	1.1	0.2
Golden Whistler	*Pachycephala pectoralis*	26	1	1.1	0.6
Skylark[i]	*Alauda arvensis*	39	1	1.1	0.9
Rufous Songlark	*Cincloramphus mathewsi*	27	1	1.1	0.6
Brown Songlark	*Cincloramphus cruralis*	54	1	1.1	1.2
House Sparrow[i]	*Passer domesticus*	27	8	8.4	4.8
Red-browed Finch	*Neochmia temporalis*	11	3	3.2	0.7
Common Starling[i]	*Sturnus vulgaris*	75	31	32.6	51.3
Small passerine		30	1	1.1	0.7
Unidentified		57	1	1.1	1.3
Insects:					
Christmas beetle	*Anoplognathus porosus*	2	3	3.2	0.1
Christmas beetle	*Anoplognathus* sp.	2	2	2.1	0.1
Stag Beetle	*Lamprisma latreille*	2	1	1.1	0.0
Beetle	Coleoptera	2	1	1.1	0.0
Cicada	*Psaltoda moerens*	2	16	16.8	0.7
Mole cricket	Orthoptera	2	1	1.1	0.0
Grasshopper	Orthoptera	2	4	4.2	0.2
Total			**95**	**100**	**100**

[i]Introduced species

between trees or buildings. Around the study nest (J. Olsen & S. Trost unpubl. data), males and females caught prey then returned to (separate) perches to pluck birds and dismantle insects. They consumed some insects on the wing. We did not see them land on the ground with birds that they had caught. Even fast-flying birds, such as White-throated Needletails *Hirundapus caudacutus*, were captured (Table 3).

Analysis of prey from the nest showed that Hobbies caught mainly birds (70.5% by number and 98.8% of biomass), with Common Starlings the most common prey species (32.6% by number and 51.3% of biomass). The next most commonly taken birds were House Sparrows *Passer domesticus*, followed by Crimson Rosellas and Budgerigars *Melopsittacus undulatus*(Table 3).

Peregrine Falcon

Peregrine Falcons captured birds in mid air, by direct attack from a perch, from contour-flying or from a stoop (J. Olsen pers. obs). As with the Hobbies that we observed, they often snatched prey and continued flying but, unlike the Hobbies, Peregrine Falcons sometimes struck down medium-sized birds such as grebes and Galahs, then circled around and retrieved them from the ground. Unlike Brown Goshawk prey, potential Peregrine Falcon quarry close to cover,

Juvenile Australian Hobby

Plate 9 Photo: Jerry Olsen & Susan Trost

Peregrine Falcon nestlings

Plate 10 Photo: Jerry Olsen & Susan Trost

Table 4

Number (n) and percentage of prey items and biomass from seven Peregrine Falcon nests between 1990 and 1993.

Prey species		*Mass (g)*	*n*	*% by number*	*% by mass*
Mammals:					
Rabbit[i]	*Oryctolagus cuniculus*	1500	1	1.9	15.4
Birds:					
Stubble Quail	*Coturnix pectoralis*	104	1	1.9	1.1
Nankeen Kestrel	*Falco cenchroides*	168	1	1.9	1.7
Rock Dove[i]	*Columba livia*	308	4	7.7	12.6
Gang-gang Cockatoo	*Callocephalon fimbriatum*	251	1	1.9	2.6
Galah	*Cacatua roseicapilla*	335	10	19.2	34.4
Crimson Rosella	*Platycercus elegans*	135	1	1.9	1.4
Eastern Rosella	*Platycercus eximius*	106	7	13.5	7.6
Red-rumped Parrot	*Psephotus haematonotus*	61	1	1.9	0.6
Red Wattlebird	*Anthochaera carunculata*	108	2	3.8	2.2
Noisy Friarbird	*Philemon corniculatus*	109	1	1.9	1.1
White-naped Honeyeater	*Melithreptus lunatus*	14	1	1.9	0.1
Eastern Yellow Robin[n]	*Eopsaltria australis*	20	1	1.9	0.2
Magpie-lark	*Grallina cyanoleuca*	90	1	1.9	0.9
Olive-backed Oriole	*Oriolus sagittatus*	100	1	1.9	1.0
Pied Currawong	*Strepera graculina*	270	1	1.9	2.8
Common Starling[i]	*Sturnus vulgaris*	75	14	26.9	10.8
Small passerine		46	1	1.9	0.5
Unidentified		143	2	3.8	2.9
Total			**52**	**100**	**100**

[i]Introduced species
[n]Species not previously reported (Marchant & Higgins 1993; Olsen *et al*. 2004)

or in cover, was immune from flying attack.

We found mainly birds in Peregrine Falcon nests in this study: 98.1% of the total number of prey items contributing 84.6% of the biomass (Table 4). Four species (Rock Dove *Columba livia*, Galah, Eastern Rosella and Common Starling) accounted for 67.3% of the number of items and 65.4% of the biomass.

Powerful Owl

We did not observe Powerful Owls hunting. Prey remains at the Powerful Owl nest were from a Greater Glider *Petauroides volans*, a Common Ringtail Possum *Pseudocheirus peregrinus* and a Squirrel Glider *Petaurus norfolcensis*. One Owl was perched on an additional fresh Greater Glider.

Southern Boobook

Southern Boobooks foraged for insects and birds, mainly in the forest-canopy, though some invertebrates, such as centipedes, were taken from the ground. At dusk, breeding males crashed into low foliage hunting for small roosting passerines, and delivered these to females. They snatched spiders and other invertebrates off the limbs and trunks of trees and perched on limbs to strip off bark and peer underneath. Pairs at the study sites commonly caught insects, such as moths, in mid air, and pulled other invertebrates from the outer foliage of eucalypts, often

Adult Southern Boobook

Plate 11 Photo: Jerry Olsen & Susan Trost

Fledgling Southern Boobook learning to hunt

Plate 12 Photo: Jerry Olsen & Susan Trost

Table 5

Number (n) and percentage of prey items and biomass from three Southern Boobook nests in 1993 and 1994.

Prey species		*Mass (g)*	*n*	*% by number*	*% by mass*
Mammals:					
House Mouse[i]	*Mus domesticus*	18	2	4.3	2.9
Bat sp.	Microchiroptera	20	1	2.2	1.6
Birds:					
Crimson Rosella juvenile[n]	*Platycercus elegans*	131	3	6.5	32.1
Spotted Pardalote[n]	*Pardalotus punctatus*	9	1	2.2	0.7
Striated Pardalote	*Pardalotus striatus*	12	1	2.2	1.0
Robin sp.[n]	Petroicidae	15	1	2.2	1.2
Black-faced Cuckoo-shrike[n]	*Coracina novaehollandiae*	105	2	4.3	17.1
Common Blackbird[i]	*Turdus merula*	95	1	2.2	7.7
Common Starling[i]	*Sturnus vulgaris*	75	4	8.7	24.5
Unidentified		63	1	2.2	5.1
Reptiles:					
Skink	Scincidae	15	1	2.2	1.2
Invertebrates:					
Wolf spider	Lycosidae	3	1	2.2	0.2
Spider	Araneae	3	1	2.2	0.2
Christmas beetle	*Anoplognathus* sp.	2	6	13.0	1.0
Scarab beetle	Scarabaeidae	2	1	2.2	0.2
Beetle	Coleoptera	2	11	23.9	1.8
Bug	Hemiptera	2	1	2.2	0.2
Moth/butterfly	Lepidoptera	2	5	10.9	0.8
Praying mantis	Mantodea	2	2	4.3	0.3
Total			**46**	**100**	**100**

[i]Introduced species
[n]Species not previously reported (Higgins 1999; Penck & Queale 2002)

hanging upside down to do so. They tended to hunt more invertebrates on warm nights and more vertebrates on colder ones (J. Olsen & S. Trost unpubl. data).

Most prey items were invertebrates (60.9%), among which beetles (Coleoptera, 39.3%) and lepidopterans (10.9%) were the most abundant (Table 5). Birds, however, provided most of the dietary mass (89.4%), mainly Common Starlings (24.5%) and juvenile Crimson Rosellas (32.1%).

JO and ST saw Crimson Rosellas brought by female Boobooks to nestlings and fledglings; these parrots may have been captured by either sex. At a different nest on 21 December 2004, JO and ST watched a male leave his fledged brood at dusk to watch for several minutes, then capture, a roosting Rosella that squawked and fought while the male hung upside down from eucalypt leaves (as Boobooks did with invertebrates), the Boobook flapping his wings and dislodging the Rosella. The Boobook broke the Rosella's neck and presented the carcass to his mate. Either the male or female severed the head before the female shared the Rosella with fledglings.

Prey size

Table 6 shows the GMPW, average mass of the raptor, and the prey/predator

Table 6

Geometric mean prey weight (GMPW) (± standard deviation), predator mass and prey/predator ratio (GMPW/predator weight) for five species of raptor breeding in the Canberra area between 1990 and 1994 (order by decreasing GMPW).

Predator	*GMPW (g)*	*Predator mass (g)*	*Prey/predator ratio*
White-bellied Sea-Eagle	470.7 ± 2.1	3300	0.14
Peregrine Falcon	132.0 ± 2.3	745	0.18
Brown Goshawk	44.9 ± 6.8	440	0.10
Australian Hobby	20.8 ± 5.1	250	0.08
Southern Boobook	6.9 ± 5.2	283	0.02

ratio (GMPW/predator weight) for the five species with acceptable sample sizes (>10 items). There was a strong positive correlation between mean predator weight and prey size (Figure 1), though Southern Boobooks took smaller prey relative to their size, with a GMPW of 2% of their own body weight. Peregrine Falcons, on the other hand, took more prey that was larger relative to their size (18% of their own weight).

Discussion

Brown Goshawk

The diet of Brown Goshawks in this study was similar to that recorded in other studies in south-eastern Australia (Baker-Gabb 1984a,b; Aumann 1988):

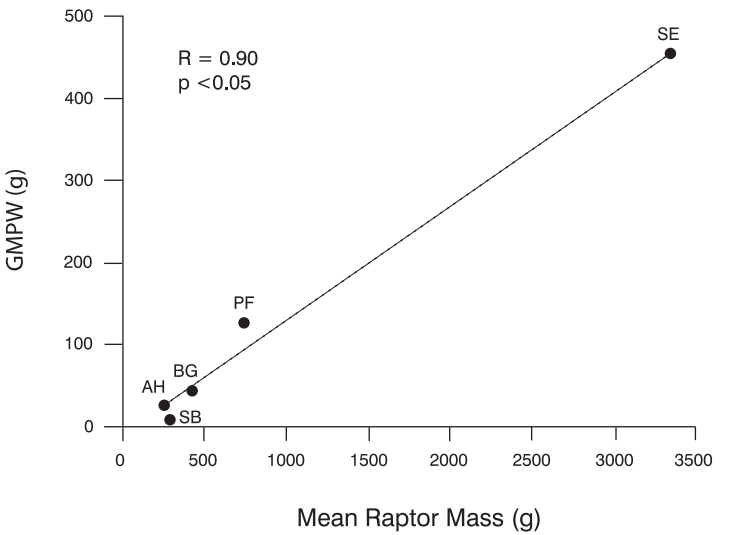

Figure 1. Correlation between predator and prey size, given by the mean raptor mass and the geometric mean prey weight (GMPW) respectively: White-bellied Sea-Eagle (SE), Brown Goshawk (BG), Australian Hobby (AH), Peregrine Falcon (PF) and Southern Boobook (SB). Dotted trendline added for perspective only.

predominantly birds and Rabbits by number and biomass. In the six studies from eastern and south-eastern Australia summarised by Marchant & Higgins (1993), mammals such as Rabbits and rats, and birds such as parrots, pigeons and passerines, made up 72–92% of items and accounted for 99% of biomass. In tropical and subtropical areas Goshawks tend to eat more reptiles (Aumann 2001), so Goshawks near Canberra may turn more to reptiles if global warming makes reptiles more available in the Goshawk breeding season.

Eagles

Birds predominated among prey from an inland White-bellied Sea-Eagle nest; two species (Common Starling and White-winged Chough *Corcorax melanorhamphus*) have not been reported previously as prey of this eagle. Sea-Eagles near Canberra prefer, where available, fish such as European Carp *Cyprinus carpio* to other fish (JO pers. obs.) because of the abundance and the habit of these fish of lying near the surface. Hence, Sea-Eagle pairs at Burrinjuck Dam took Carp and birds. It is believed that there are no Carp in Googong Dam (T. Bell, M. Muranyi pers. comm.), where the local Sea-Eagles rely more on other vertebrates such as waterbirds and turtles, though they may be able to catch Carp from nearby farm dams (Fuentes, Olsen & Rose unpubl. data). Although Shephard *et al*. (2005) suggested that the spread of Rabbits has assisted the increase of inland populations of Sea-Eagles, we found no evidence in this study or others to support such a view. Layton (1996) attributed Rabbit remains to a pair of Sea-Eagles in the ACT, but those remains are referable to the Wedge-tailed Eagle which normally uses the nest concerned (JO pers. obs.).

Sea-Eagles are similar in size to Wedge-tailed Eagles and the two species live in the same areas, but there was no overlap in the diet of the two species in this study, though sample sizes were small. The diet of Wedge-tailed Eagles was similar to that previously recorded for south-eastern Australia. In the same area, 30 years earlier, Leopold & Wolfe (1970) found that mammals, including lambs, Foxes and Rabbits, accounted for 67% (Rabbits 45%) of items taken. Other studies in the wider region found, respectively: mammals 82% (Rabbits 49%) of prey in southern Victoria (Hull 1986); 76% (Rabbits 60%) on the Northern Tablelands of NSW (Debus & Rose 1999); and 71% (Rabbits 55–69%; 16–31% post-calicivirus) in western NSW (Robertson 1987; Sharp *et al*. 2002). Mammals accounted for 78% of the Wedge-tailed Eagle's diet in north-western Victoria, and all but 3% of this was Rabbit (Baker-Gabb 1984a). Elsewhere in Australia, mammals also predominate in the diet of this species (e.g. Marchant & Higgins 1993; Aumann 2001).

The finding of an adult Little Eagle carcass in a Wedge-tailed Eagle nest underscores the influence of Wedge-tailed Eagles on Little Eagle breeding success. Whereas both Sea-Eagle pairs in this study bred successfully near (~1 km apart) Wedge-tailed Eagle nests, Wedge-tailed Eagles often displace Little Eagles from breeding sites. When Wedge-tailed Eagles were displaced by human interference, however, pairs of Little Eagles moved into the vacated breeding sites (Olsen 1992, 1995; D. Mallinson pers. comm.). As Wedge-tailed Eagles breed earlier, compete for food, nests and nest-sites, and sometimes kill Little Eagles, they appear to prevent some pairs of Little Eagles from breeding successfully.

The predominance of mammals such as Rabbits and medium-sized birds in the diet of the Little Eagles in this study was similar to that reported by other researchers (Marchant & Higgins 1993). Baker-Gabb (1984a) found that Wedge-

tailed Eagles took adult Rabbits but Little Eagles took only juveniles, though one Rabbit taken by a Little Eagle in this study was classed as an adult based on the fur. Debus & Rose (1999) also noted similar local prey partitioning between these two eagle species. Debus (1998) noted that Little Eagles in southern Australia prefer young Rabbits, in northern Australia birds, and in the arid zone lizards such as dragons, goannas and large skinks. Aumann (2001) reported that reptiles in central Australia contributed 82% to dietary biomass, accounting for about half of the animals eaten by the Little Eagle. With global warming, reptiles may become more important in the Little Eagle's diet near Canberra.

Falcons

Four prey species (Rock Dove, Galah, Eastern Rosella and Common Starling) contributed 67.3% of the number of items and 65.4% of the biomass for Peregrine Falcons in this study, similar to the percentages recorded previously in south-eastern Australia (Marchant & Higgins 1993). Of the 988 prey items collected from Peregrine Falcon nests near Canberra by Olsen *et al*. (1993), 96% were birds representing at least 41 species. Galahs, Crimson Rosellas, Eastern Rosellas, Rock Doves and Common Starlings were the main prey, making up 90% of the diet by mass.

Prey items at the Hobby nest were mainly birds (70.5% by number and 98.8% of biomass), with the Common Starling the main prey species (32.6% by number and 51.3% of biomass). The only other study published for the species in south-eastern Australia produced similar findings (Debus *et al*. 1991). The Hobbies in Canberra took some unusual prey, such as Budgerigars. Surveys conducted in the ACT have rarely recorded Budgerigars (Veerman 2003), and Taylor & Day (1993) considered them rare aviary escapees, but the Hobby pair in the present study took at least six Budgerigars compared with eight of the much more common House Sparrow. Perhaps escaped domestic Budgerigars, and in particular colour mutants, are vulnerable to Hobbies. Another study also found a preference by Hobbies for this small parrot (Aumann 2001).

Though Peregrine Falcons and Hobbies preyed on some of the same bird species and both took the more abundant species in Canberra, such as Starlings and rosellas, most Hobby prey items weighed less than 100 g, and rarely more than 200 g. Hobbies tend to specialise on smaller birds, such as larks, pipits, finches, doves and swallows, as well as insectivorous bats and flying insects (Debus 1998). In contrast, Peregrine Falcons often took larger species such as Galahs and Rock Doves, which were not recorded to be taken by Hobbies. Galahs and Rock Doves are over the 200 g threshold suggested by Debus (1998).

Although Hobbies are about 33% the mass of Peregrine Falcons (Table 6), both they and Boobooks took many insects, so the GMPW for Hobbies in this study was about 16%, and for Boobooks 5%, that of Peregrines.

Owls

Ninox owls tend to hunt in woodland and forest, and Powerful Owls often take proportionally large (compared with the Owl's own mass) arboreal mammals, mainly from the forest canopy (Higgins 1999). Boobooks take proportionally smaller prey. In this first analysis of prey of Boobooks and Powerful Owls in the ACT, the diet did not overlap, though the sample for the Powerful Owl was very small. The Powerful Owl diet was similar to that reported elsewhere, predominantly

Greater Glider and Common Ringtail Possum (Kavanagh 2002). The Squirrel Glider has not been previously confirmed as a resident species in the ACT (D. Fletcher pers. comm.), so finding one here as Powerful Owl prey shows the importance of using raptor diets as an indicator of rare or unknown species in an area.

The Boobook diet in the ACT was similar to that reported by Higgins (1999) and König *et al*. (1999), though this study adds four new prey species: Crimson Rosella, Spotted Pardalote *Pardalotus punctatus*, robin (Petroicidae) and Black-faced Cuckoo-shrike *Coracina novaehollandiae*. Because Boobooks are the smallest owl in Australia, some writers may assume that they specialise on small invertebrate prey, as do the smallest owls in other regions of the world (König *et al*. 1999). However, Australia has only medium-sized and large owls; the Common Scops-Owl *Otus scops* of Eurasia and Elf Owl *Micrathene whitneyi* of North America are, respectively, about a third and a fifth the mass of the Boobook, and the Northern Hawk-Owl *Surnia ulula* and Long-eared Owl *Asio otus* weigh about the same as the Boobook. Though König *et al*. (1999) suggested that Boobooks catch birds up to the size of the House Sparrow, in this study they took prey up to the size of juvenile Crimson Rosellas.

Boobooks in this study hunted more invertebrates on hot nights but more vertebrates on cold nights. Riegert & Fuchs (2004) also found that mean temperature positively affected the abundance of the main insect groups, Ensifera and beetles, in the prey of Common Kestrels *Falco tinnunculus*, and that juvenile Kestrels ate more insects than adults did.

Reports differ as to whether Boobooks consume mainly vertebrates or invertebrates. For example, Higgins (1999) and König *et al*. (1999) reported that Boobooks prey mainly on birds and mammals, but del Hoyo *et al*. (1999) reported that they prey mainly on invertebrates. Some of these differences may relate to the view of Boobooks as small owls, but others to differing methods of prey analysis and collecting prey remains. Our study, and others, estimated diet mainly from prey remains and pellets. In contrast, Penck & Queale (2002) analysed stomach contents from 117 Boobooks in South Australia, mainly road-kills and window-strikes. They concluded that invertebrates made up 95.9% of the diet, and that estimates from pellets alone might underestimate invertebrates without hard, indigestible parts. Rose (1996), analysing both stomach contents and pellets, found proportionally more invertebrates in the former, and more vertebrates in the latter. He argued that pellets may not reflect the number of invertebrates that break down quickly and hence do not show in pellet analysis, but stomach contents may not reflect the number of vertebrates caught by breeding owls because samples of stomachs from road-kills and window-strikes probably come mainly from juvenile Boobooks that have been forced into marginal areas (where they are more at risk of mortality through collision, and eat proportionally more invertebrates than breeding adults do: Rose 1973).

Field observations during this study support the notion that adult Boobooks eat more vertebrates and juveniles depend more on insects. The same trend has recently been described for other raptors (Riegert & Fuchs 2004). Breeding adults brought birds, reptiles and mammals to the nest and to fledged broods, but fledged owls hunted only invertebrates after they reached independence (S. Trost & J. Olsen unpubl. data). In addition, photographic evidence of prey brought to nestlings and fledglings during 2002–03 showed that certain soft-bodied invertebrates, such as caterpillars, did not show in subsequent analysis of pellets,

but soft-bodied vertebrates such as geckoes, and larger items such as Crimson Rosellas, did not necessarily show either (Trost, Olsen & Rose unpubl. data). Both the analysis of stomachs from vehicle- and collision-killed owls, and analysis of pellets and prey remains from breeding owls, have biases. However, this study and most other evidence (see McNabb 2002) show that the diet of breeding Boobooks in south-eastern Australia is, by biomass, primarily vertebrates, particularly birds and mammals.

Prey size and raptor body mass

Other studies have reported positive correlations between the size of raptors and their prey (Jaksic & Delibes 1987; Poole & Bromley 1988; Marti *et al*. 1993a), a characteristic said to be a mechanism to partition available resources (Marti *et al*. 1993a). Sometimes only the female is correlated with prey size (Reif *et al*. 2004). The five raptors analysed in the present study tended to capture prey proportional to their mass (Table 6, Figure 1). However, Southern Boobooks and Australian Hobbies had the lowest prey/predator ratios (i.e. smaller prey relative to their body mass) because of the large number of insects in their diet, and Peregrine Falcons had the highest ratio. Though Peregrine Falcons are about three times the size of Hobbies or Boobooks, 28.8% of their prey taken was >300 g, whereas 12.6% taken by Hobbies and 10.9% by Boobooks was >100 g. This does not mean that Hobbies and Boobooks are mainly insectivorous predators (see above), just more insectivorous and less prone to taking large vertebrate prey than are Peregrine Falcons.

Some Peregrine Falcon prey, such as Galahs, are dangerous because they can peck and break a raptor's toes, and their neck vertebrae (and other bones) are relatively thick and hence more difficult for a falcon or owl to separate or break when it dispatches prey. Peregrine Falcons can knock down and disable larger prey with a blow from a stoop and, like the Orange-breasted Falcon *F. dieroleucos* that also takes medium-sized parrots (Cade 1982), the Australian subspecies *F. peregrinus macropus* has a larger beak than most similar-sized *Falco* species and Peregrine subspecies. They can therefore exert a larger bite force that allows them to break heavier bones and separate the larger neck vertebrae of cockatoos (Olsen & Hull 1990).

When compared with close relatives of similar mass, the prey size of the local ACT raptors showed different trends (Table 7). The White-bellied Sea-Eagle took smaller prey than the White-tailed Eagle *Haliaeetus albicilla* and Bald Eagle *H. leucocephalus*. These three congeneric species have very similar prey/predator ratios, however (Tables 6 and 7), indicating that they take prey of the same size relative to their body mass (14–15% of their mass).

The local ACT Brown Goshawks took larger prey than those in the Australian tropics (GMPW 44.9 vs 21.7 g), mainly because of the large number of insects taken by the latter (n = 165, 45.2% of total items: Burton & Olsen 1997), though the small sample size may be partly responsible for the limited number of insects found in this study. On the other hand, the ACT Goshawks took smaller prey than did the American Cooper's Hawk *A. cooperii*, which is of similar size (Tables 6 and 7). Cooper's Hawk captured mainly mammals (68.6% of total number) and birds (31.4%), but no insects (Marti *et al*. 1993a).

In terms of prey size, the Australian Hobby seems to be located between the

Table 7

GMPW, predator weight and prey/predator ratios for similar-sized or related raptors. Source: (1) Marti *et al.* 1993a, (2) Burton & Olsen 1997, (3) Beingolea & White 2003, (4) Olsen *et al.* 2004, (5) Martin *et al.* 1993b.

Species	*Location*	*GMPW (g)*	*Predator weight (g)*	*Prey/predator ratio*	*Source*
White-tailed Eagle *Haliaeetus albicilla*	Europe	703.2	4793	0.15	1
Bald Eagle *H. leucocephalus*	North America	657.0	4683	0.14	1
Cooper's Hawk *Accipiter cooperii*	North America	74.4	439	0.17	1
Brown Goshawk *Accipiter fasciatus*	Australian tropics	21.7	376	0.06	2
Northern Hobby *Falco subbuteo*	Europe	6.2	211	0.03	1
Merlin	Europe	28.5	187	0.15	1
F. columbarius	North America	27.7	185	0.15	1
Peregrine Falcon	Europe	181.4	889	0.20	1
F. peregrinus	North America	124.0	781	0.16	1
	South America	80.3	800	0.10	1, 3
	Australian highlands	202.1	745	0.27	4
	ACT, Australia	132.9	745	0.18	4
Long-eared Owl	Europe	21.1	255	0.08	1
Asio otus	North America	31.6	254	0.12	1
	Idaho, USA	26.3	254	0.10	5
Northern Hawk-Owl *Surnia ulula*	North America	24.9	295	0.08	1

closely related Northern Hobby *Falco subbuteo* and the Merlin *F. columbarius*, although it is the largest of these three falcons (Tables 6–7).

Peregrine Falcons at high elevations in south-eastern Australia had the largest GMPW and prey/predator ratio among the studies found (Table 7), because they captured several individuals of a few large bird species, such as Rock Doves, Galahs and especially ravens *Corvus* sp. (Olsen *et al*. 2004). The prey of the Peregrine Falcons in this study was within the prey size range reported for the species (Table 7), with only 28.8% of prey >300 g, compared with 50% of prey >300 g for Peregrine Falcons at high altitudes (Olsen *et al*. 2004).

The Southern Boobook had considerably smaller prey size and prey/predator ratio than the Long-eared Owl and Northern Hawk-Owl, apparently because of differences in dietary diversity and prey selection between the species. The local Boobooks had a diverse diet that included mammals, birds, reptiles and invertebrates, the latter being the most abundant (60.1% of total items). In contrast, the Long-eared Owl's diet was limited to mammals (Marti *et al*. 1993a) larger than the invertebrates taken by the Boobooks.

Conclusion

Diets for the eight raptors in this study were similar to those reported elsewhere, although seven new prey species were added. The addition of the Squirrel Glider to the fauna list of mammals recorded in the ACT shows how raptors can find secretive or rare animals missed in fauna surveys, even in areas like the ACT where spotlighting and research are common (see also Boles *et al*. 2004). More analysis of the diet of Brown Goshawks in urban settings may show that they fill a niche similar to urban Cooper's Hawks in North America (Mannan *et al*. 2004), and White-bellied Sea-Eagles living on inland lakes and rivers may fill a niche similar to the Bald Eagles on inland lakes and rivers in North America that combine fish and waterfowl as their main prey (Johnsgard 1990).

Whether Wedge-tailed Eagles have more dietary overlap and influence over breeding Little Eagles than they do over Sea-Eagles is worth investigating. Just as Wedge-tailed Eagles may displace Little Eagles, Peregrine Falcons may displace Hobbies, as both rely heavily on introduced bird species as prey and have some dietary overlap.

The conflicting accounts for Southern Boobooks as vertebrate or invertebrate specialists, in major volumes such as Higgins (1999), König *et al*. (1999) and del Hoyo *et al*. (1999), point to misconceptions about the size of these owls, and biases in collecting prey remains and estimating diets. These biases need further study.

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