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BREEDING SUCCESS, CLIFF CHARACTERISTICS AND DIET OF PEREGRINE FALCONS AT HIGH ALTITUDE IN THE AUSTRALIAN CAPITAL TERRITORY

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The nest-site characteristics, breeding density, fledging success and diet of the Peregrine Falcon *Falco peregrinus* in high-elevation forest in the Australian Capital Territory were studied at five active nests from 1991 to 1995. Breeding diet at five active nests at lower elevation near Canberra was also studied in 1991. At high-elevation sites the falcons' breeding diet consisted entirely of birds (37 identified species), mostly Rock Doves *Columba livia*, Galahs *Cacatua roseicapilla*, other parrots, and Common Starlings *Sturnus vulgaris*, with some larger species such as cockatoos *Cacatua*, magpies *Gymnorhina*, currawongs *Strepera*, and ravens *Corvus*. At lower elevation the breeding diet also consisted entirely of birds (12 species), but mostly Silver Gulls *Larus novaehollandiae*, Galahs, other parrots, and Starlings, with no large, potentially dangerous prey. Prey at high-elevation sites differed from that in other Australian studies in the high proportion of large, heavy items. Falcons at high-elevation sites nested at lower density, on higher cliffs that were more sheltered from the weather and had nestlings of lower weight and lower fledging success, than those at lower-elevation sites. Falcons at forested high-elevation sites appear to face a shortage of suitable prey or capture opportunities, as well as harsher weather.

INTRODUCTION

The nest-site characteristics, breeding density, fledgling productivity and diet of the Peregrine Falcon *Falco peregrinus* have been well studied in rural and coastal parts of south-eastern Australia, particularly in Victoria and in open, lower-elevation parts of the Australian Capital Territory and surrounding New South Wales (Olsen 1992; Marchant and Higgins 1993; Olsen *et al.* 1993; Emison *et al.* 1997; Rose 2001). Peregrines around Canberra inhabit most habitat types with cliffs, but few Peregrines in Australia have been found nesting in or above the sub-alpine zone. Mooney and Brothers (1987) considered 900 metres to be the altitudinal limit for breeding in Tasmania, and Emison *et al.* (1997) found no Peregrines nesting above 800 metres in Victoria. The reason for this altitudinal limit is unclear.

In contrast, Peregrines can nest at higher elevations in other countries, for example in the United States where they nest at elevations up to 3 050 metres (Bond 1946). During 1984–1985 Enderson *et al.* (1988) recorded 13 nesting attempts in southern Utah above 2 300 metres (at similar latitudes to south-eastern Australia), yielding 1.2 young per pair and 1.8 young per successful pair. In Europe, Peregrines breed in the Alps (Cade *et al.* 1988). Most Peregrine breeding cliffs in Britain lie below 640 metres, but the highest recorded nest cliff lies at 1 050 metres in the Cairngorm Mountains near Inverness in Scotland, a similar upper elevation to that found in south-eastern Australia but at a much higher and colder latitude. During 1986–1991 in the northern and western highlands of Scotland, inland falcons yielded 2.27 young per successful pair (Ratcliffe 1993).

At lower-elevation sites near Canberra, where there are contiguous cliffs, Peregrines nest 2 kilometres apart (Olsen and Olsen 1988), one of the highest recorded inland densities in the world (Ratcliffe 1993). With abundant food, but a shortage of suitable nest cliffs, Peregrines near Canberra will use lower cliffs than in most other parts of the world. Near Canberra, nesting Peregrines usually use cliffs with the following characteristics: vertical; at least 12 metres high; at least one suitable ledge; at least 2 kilometres away from other Peregrine nests; no water flowing over the cliff; not facing north-west; and free from excessive human disturbance (Olsen 1992).

By comparison, there has been no published quantified study of the Peregrine's breeding parameters in higher-elevation, forested parts of the region. The aim of this study was to quantify aspects of the Peregrine's breeding biology at nest-sites in the rugged, forested Brindabella and Tidbinbilla Ranges south and west of Canberra (elevation >1 000 m) and compare the results with data for the Canberra hinterland (elevation 500–800 m). As reproductive success in raptors is linked predominantly to the availability of food and nest-sites (Newton 1979), the results of such a comparison may shed light on the factors limiting Peregrine populations in the region.

STUDY AREA AND METHODS

Namadgi National Park (106 000 ha) covers much of the Brindabella Range in the south and west of the Australian Capital Territory, with peaks up to 1 900 metres. The habitat is mostly tall open (wet

sclerophyll) forest with a dense shrub layer, with alpine woodland at the highest elevations and open, drier forest with open grassy valleys at lower elevations (see Taylor and COG 1992 for habitat descriptions and climatic parameters).

Cliffs in Namadgi National Park and Tidbinbilla Nature Reserve were identified on 1:25 000 topographic maps, then surveyed by helicopter (Bell 206 Jet Ranger) by Olsen and Hayes. Those cliffs so seen with 'whitewash' (accumulations of falcon droppings) were visited by driving as close as possible on four-wheel-drive tracks, then hiking to the sites. At these cliffs the presence of adults was noted, any nestlings measured and banded (with ABBBS* bands) and prey remains and pellets collected from the nest ledge and the area of cliff directly above and below the nest ledge. Physical characteristics of each eyrie (elevation, height of cliff face from base to top and whether quarry or natural site) were obtained from topographic maps or in the field as appropriate.

Active Peregrine nests were located and visited once in November (unless otherwise stated) of two or more years between 1991 and 1995 to collect food remains and monitor fledging success: Booroomba Rock 1991, 1993, 1994; Bendora Dam 1991, 1992 (December), 1993, 1994, 1995 (May and November); Coree Creek 1991 (December), 1992–94, 1995 (December); Mt Tidbinbilla 1991, 1994, 1995 (December); and Corin Dam 1994, 1995. These sites were also monitored for breeding success for varying periods: Booroomba Rock five years, Bendora Dam five years, Coree Creek four years, Mt Tidbinbilla five years, Corin Dam two years. For comparison, food remains were also collected from five active lower-elevation Peregrine nests in the Canberra area in 1991. A 'nesting attempt' was defined as eggs or nestlings seen, and 'successful' was defined as young fledged or having reached banding age, around four weeks, as young older than four weeks usually fledge successfully (J. Olsen, unpubl.). Nestlings were aged according to the criteria in Olsen and Olsen (1987).

Collected food remains were analysed in the laboratory by Alison Rowell and by A. B. Rose, microscopically as necessary, by comparison with museum reference material. The minimum number of prey individuals in each sample was calculated by counting parts or pairs of parts such as beaks, feet and bones. Species represented in pellets were counted only if they were not also represented in prey remains collected at the same time. For the purpose of analysis, results were pooled across years for each site. Prey weights were obtained from relevant literature, mainly Marchant and Higgins (1993) and earlier/later volumes.

RESULTS

Nest-site characteristics

Five nests were located in Namadgi National Park and none were located in Tidbinbilla Nature Reserve. The sites in Namadgi were at a mean elevation, measured at the top of the nest cliff, of 1 080 metres (range 1 000–1 200 m). One of the five was in a quarry. Suitable cliffs, i.e. as described above, are more frequently found in Namadgi than in lower-elevation areas used by Peregrines near Canberra, but the survey showed that those occupied by Peregrines in Namadgi tended to have taller vertical faces of between 30 and 91 metres (mean 56.2 m). Smaller cliffs in Namadgi, that otherwise fitted the formula for cliffs used by Peregrines at lower elevation in the region (Olsen 1992), were not used as nest-sites.

The pair at Coree Creek nested in a pothole, and the pair at Mt Tidbinbilla had an alternative nest that they used in some years. The Bendora Dam nest was inaccessible under a deep overhang but the cliff appeared to have several potholes and protected ledges. The nests at Coree Creek and Corin Dam were easily accessible to humans without the use of ropes and would have been vulnerable to terrestrial predators, but they were more sheltered from the weather than were other ledges.

*Australian Bird and Bat Banding Sheme

Breeding density

There were many potential nest cliffs available in the study area. The largest cluster of contiguous suitable cliffs in Namadgi was in the Bendora Dam–Mt Tidbinbilla–Tidbinbilla Peak area, where there were ten cliffs that appeared from the helicopter to be suitable as Peregrine nest cliffs. In this area the only two nests found, at Bendora Dam and Mt Tidbinbilla, were 4 kilometres apart, with several suitable nest cliffs in between.

Fledgling productivity

Nests in Namadgi were, on average, successful in 43 per cent of annual attempts (n = 21), fledging 0.81 young per pair per year with a mean brood size at fledging (= young per successful nest) of 1.89.

The skeleton of a five-week-old nestling was found at Booroomba Rock in 1992, and a freshly dead nestling about four weeks old was in the nest with two live five-week-old nestlings at Corin Dam in 1994, indicating possibly high nestling mortality at these sites.

Diet

Thirty-seven identified species of birds, and no mammals or reptiles, were found in the prey remains from Namadgi (Table 1). Insect remains in a pellet from one site might have been from the gut of a starling in the same sample.

The falcons' breeding diet at Namadgi sites included about 15 per cent Rock Dove *Columba livia*, 17 per cent Galah *Cacatua roseicapilla* and nine per cent Common Starling *Sturnus vulgaris* as primary prey, or 17 per cent pigeons and 38 per cent parrots; 24 per cent were introduced birds. Preferred prey included flocking species, often with conspicuously flashing wing patterns in flight (Galahs, rosellas *Platycercus*, domestic varieties of Rock Dove). However, the sample also included many large and potentially dangerous prey items (ibis *Threskiornis*, Sulphur-crested Cockatoo *Cacatua galerita*, magpies *Gymnorhina*, currawongs *Strepera*, ravens *Corvus*). Of interest also is the capture of another raptor, albeit a male of a small species (Collared Sparrowhawk *Accipiter cirrhocephalus*).

For comparison, prey in the Canberra area was predominantly Silver Gull *Larus novaehollandiae* (18%), Galah and other parrots (39%) and starling (33%), and also included a small raptor (Nankeen Kestrel *Falco cenchroides*) (Table 2). Biomass contributions show the relative importance of large, dangerous prey at Namadgi versus smaller, less dangerous prey at Canberra (Tables 1, 2). At Namadgi, the primary prey (pigeons, small cockatoos and parrots, starlings) contributed 60 per cent of prey biomass, and large, dangerous prey (ibis, Sulphur-crested Cockatoo, magpies, currawongs, ravens) contributed 34 per cent of prey biomass. By contrast, near Canberra primary prey (gulls, Galahs, parrots, starlings) contributed 91 per cent of prey biomass, and no large, dangerous prey were taken. At Namadgi, the mean weight of identified prey species was 238 grams and of prey individuals was 275 grams, whereas near Canberra the figures were 171 grams and 165 grams, respectively.

TABLE 1

Breeding diet of the Peregrine Falcon *Falco peregrinus* at five sites in Namadgi National Park, Australian Capital Territory, 1991–95: minimum number of individuals in prey remains and pellets. *Introduced species.

Species	Weight (g)	n (%)	Biomass (g)	% biomass
Stubble Quail *Coturnix pectoralis*	104	2 (1)	208	<1
Australian Wood Duck *Chenonetta jubata*	808	2 (1)	1 616	4
Australian White Ibis *Threskiornis molucca*	1 666[a]	1 (<1)	1 666	4
Collared Sparrowhawk *Accipiter cirrhocephalus*[b]	126	1 (<1)	126	<1
Painted Button-quail *Turnix varia*	93	1 (<1)	93	<1
*Rock Dove *Columba livia*	308	25 (15)	7 700	17
Brush Bronzewing *Phaps elegans*	184	2 (1)	368	<1
Bronzewing *Phaps* sp.	242	2 (1)	484	1
Long-tailed Jaeger *Stercorarius longicaudus*	245	1 (<1)	245	<1
Silver Gull *Larus novaehollandiae*	303	1 (<1)	303	<1
Gang-gang Cockatoo *Callocephalon fimbriatum*	251	11 (7)	2 761	6
Galah *Cacatua roseicapilla*	335	29 (17)	9 715	21
Sulphur-crested Cockatoo *Cacatua galerita*	804	3 (2)	2 412	5
Australian King-Parrot *Alisterus scapularis*	211	6 (4)	1 266	3
Crimson Rosella *Platycercus elegans*	135	5 (3)	675	1
Eastern Rosella *Platycercus eximius*	106	7 (4)	742	2
Rosella *Platycercus* sp.	121	1 (<1)	121	<1
Red-rumped Parrot *Psephotus haematonotus*	61	1 (<1)	61	<1
Fan-tailed Cuckoo *Cacomantis flabelliformis*	49	1 (<1)	49	<1
Rainbow Bee-eater *Merops ornatus*	28	1 (<1)	28	<1
Spotted Pardalote *Pardalotus punctatus*	9	1 (<1)	9	<1
Red Wattlebird *Anthochaera carunculata*	108	2 (1)	216	<1
Noisy Friarbird *Philemon corniculatus*	107	2 (1)	214	<1
White-browed Babbler *Pomatostomus superciliosus*	39	1 (<1)	39	<1
Golden Whistler *Pachycephala pectoralis*	26	1 (<1)	26	<1
Magpie-lark *Grallina cyanoleuca*	90	2 (1)	180	<1
Grey Fantail *Rhipidura fuliginosa*	8	2 (1)	16	<1
Black-faced Cuckoo-shrike *Coracina novaehollandiae*	105	2 (1)	210	<1
White-browed Woodswallow *Artamus superciliosus*	35	1 (<1)	35	<1
Dusky Woodswallow *Artamus cyanopterus*	39	2 (1)	78	<1
Pied Butcherbird *Cracticus nigrogularis*	119	1 (<1)	119	<1
Australian Magpie *Gymnorhina tibicen*	329	7 (4)	2 303	5
Pied Currawong *Strepera graculina*	270	4 (2)	1 080	2
Australian Raven *Corvus coronoides*	645	3 (2)	1 935	4
Little Raven *Corvus mellori*	541	2 (1)	1 082	2
Raven *Corvus* sp.	593	9 (5)	5 337	12
White-winged Chough *Corcorax melanorhamphos*	334	1 (<1)	334	<1
Silvereye *Zosterops lateralis*	10	1 (<1)	10	<1
Bassian Thrush *Zoothera lunulata*	105	1 (<1)	105	<1
*Common Starling *Sturnus vulgaris*	75	15 (9)	1 125	2
Unidentified passerine	58	1[c] (<1)	58	<1
Unidentified bird	238	3[d] (2)	714	2
Total		167	45 864	100

[a]Presumed female (the lighter sex); [b]Male, i.e. small; [c]Mean of identified small passerines (<110 g); [d]Mean of identified birds.

TABLE 2

Breeding diet of the Peregrine Falcon *Falco peregrinus* at five sites near Canberra, Australian Capital Territory, 1991: minimum number of individuals in prey remains and pellets. *Introduced species.

Species	Weight (g)	n (%)	Biomass (g)	% biomass
Stubble Quail *Coturnix pectoralis*	104	2 (1)	208	<1
Nankeen Kestrel *Falco cenchroides*	168	1 (1)	168	1
Masked Lapwing *Vanellus miles*	360	1 (1)	360	2
Silver Gull *Larus novaehollandiae*	303	26 (18)	7 878	33
*Rock Dove *Columba livia*	308	4 (3)	1 232	5
Galah *Cacatua roseicapilla*	335	16 (11)	5 360	22
Crimson Rosella *Platycercus elegans*	135	19 (13)	2 565	11
Eastern Rosella *Platycercus eximius*	106	19 (13)	2 014	8
Red-rumped Parrot *Psephotus haematonotus*	61	3 (2)	183	1
Grey Shrike-thrush *Colluricincla harmonica*	70	2 (1)	140	1
Richard's Pipit *Anthus novaeseelandiae*	23	2 (1)	46	<1
*Common Starling *Sturnus vulgaris*	75	48 (33)	3 600	15
Unidentified passerine[a]	56	2 (1)	112	<1
Total		145	23 859	100

[a]Mean of identified passerines.

DISCUSSION

Breeding parameters

Peregrine nests elsewhere in the Canberra region were mostly in the Murrumbidgee–Molonglo River corridor (25% in quarries), at a mean elevation of 500 metres, on cliffs 13 to 60 metres high (mean = 25 m; n = 16) (Olsen 1992). They were at lower elevation and could be expected to be warmer sites than cliffs used in Namadgi. Cliffs in Namadgi were generally much higher and more numerous than cliffs elsewhere in the Canberra region, offering a wide choice of potential sites. All the lower-elevation Canberra sites required ropes for human access and, where there were contiguous cliffs, pairs nested about 2 kilometres apart (Olsen and Olsen 1989). It appears that at high elevations in Namadgi, Peregrines nest at lower density, on cliffs selected more for shelter than for inaccessibility to terrestrial predators, than at lower elevations. Despite the availability of cliffs in Namadgi, many cliffs exposed to extremes of cold or storms may be avoided.

Reproductive success in Namadgi was lower than for 30 sites over 12 years at lower elevations in the Canberra hinterland (Olsen and Olsen 1989). In the latter study, nests were successful in 58 per cent of attempts, producing 1.4 young per pair per year with a mean brood size at fledging of 2.14; pairs that nested in potholes or that had alternative nest-sites fledged more young than those that did not. The finding of dead nestlings, as at Namadgi, was a rare occurrence in the Canberra study (J. Olsen, pers. obs.). The reasons for lower success in Namadgi are unclear, but may be partly related to the harsher weather, as well as to a shortage of ideally sized prey, as discussed below.

Diet

The falcons' diet in Namadgi was essentially a subset of that reported for this species in south-eastern Australia generally, and in the Canberra region specifically, by Marchant and Higgins (1993), Olsen *et al.* (1993) and Rose (2001). The falcons in both local studies preferred parrots, such as Galahs and rosellas. However, the proportion of large, dangerous prey such as currawongs and ravens was much higher at the Namadgi sites than elsewhere, and ravens were not recorded as prey at lower-elevation sites around Canberra (Table 2; Olsen *et al.* 1993).

The proportions of prey types found in other Australian studies (reviewed in Marchant and Higgins 1993) were similar to those for the Canberra area, but different from those in Namadgi. Virtually all the species at Namadgi eyries have been recorded previously as Peregrine prey, but large heavy types such as ibis, Sulphur-crested Cockatoos and ravens are rarely recorded as prey elsewhere (Marchant and Higgins 1993).

The Long-tailed Jaeger *Stercorarius longicaudus*, a carcass at the Corin Dam eyrie, has not previously been recorded as prey in Australia. This normally pelagic species occurs inshore during strong onshore winds and rough weather (Higgins and Davies 1996). Presumably, the bird (found in November 1994) was blown 100 kilometres inland by the storm that apparently killed one of the Peregrine chicks at that site at the time.

Prey availability and weather

Ravens and currawongs are commonly seen flying above the tree canopy in Namadgi, whereas few other species do so (J. Olsen, pers. obs.). Conversely, many passerines or pigeons such as the Wonga Pigeon *Leucosarcia melanoleuca* are common in Namadgi (Taylor and COG 1992) but rarely fly above the canopy or enter open areas, and hence are rarely available as prey.

A shortage of preferred prey of an ideal weight range, or of capture opportunities in Namadgi, may force the falcons to take large birds that are particularly dangerous for the smaller male Peregrine to catch and kill (Olsen 1994). Although male raptors do most of the hunting during the nestling period (Newton 1979), difficulty in supplying enough prey, coupled with increased food demands in the nestling period, may mean that females are forced to hunt and carry larger prey. Female raptors normally brood and protect the chicks in the first half of the nestling phase but, if they are absent on hunting forays, their chicks are vulnerable to predators and extremes of weather, leading to increased mortality of nestlings (Newton 1986). Such a situation could explain the dead nestling falcons and a low fledging rate and apparently undernourished falcon nestlings, at Namadgi. Low temperatures, high altitude and storms may impose greater energy demands (and hence food requirements) on falcons at Namadgi than on those living at lower elevations. As a consequence, the falcon pairs at Namadgi may need to take more or larger prey than they do elsewhere.

Despite the remoteness of Namadgi, the falcons preyed heavily on introduced Common Starlings and Rock Doves, as well as on parrots that are common in rural areas. Rock Doves are transient, as flocks of domestic racing pigeons in transit, and do not breed in Namadgi (Taylor and COG 1992). It appears that the falcons were travelling long distances, to open areas at lower elevations, to capture much of their prey. This situation would increase the male's commuting time and hence lower the prey-delivery rate, with consequences for female foraging effort and parental attentiveness at nests.

Peregrines nesting in other countries at elevations above 1 200 metres, for example in southern Utah and the European Alps, may have more suitable prey available to them (e.g. grouse and ptarmigan, Tetraonidae) than do Peregrines nesting in south-eastern Australia, although this aspect may change with global warming. Brood sizes (young per successful pair) in the southern Utah study averaged 1.8 during 1984–1985, and in the northern and western highlands of Scotland 2.27 during 1986–1991, similar to the 1.89 young per successful pair found in this study, although clutch sizes tend to be larger in Utah and Scotland than in Australia (Enderson *et al.* 1988; Cade *et al.* 1988; Ratcliffe 1993).

In conclusion, it appears that scarcity of primary prey species, cold stormy weather, increased food requirements in the cold and difficulties in hunting over the forest canopy, could all have contributed to the lower food availability, increased capture of large prey and lower density and breeding success of Peregrines in Namadgi, compared with lower-elevation, riparian habitats. Emison

et al. (1997) similarly found a scarcity of primary prey species and a lack of Peregrine nests, above 800 metres elevation and in extensive densely forested areas in Victoria. Thus, the altitudinal limit for Peregrines in Australia may be imposed by availability of suitable prey.

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