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FORAGING BEHAVIOUR OF THE BROWN GOSHAWK (*Accipiter fasciatus*) IN SOUTHEASTERN AUSTRALIA

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ABSTRACT.—Five search and four attack techniques were identified for the Brown Goshawk (*Accipiter fasciatus*) foraging in southeastern Australia. Twenty (37%) of 54 observed attacks of known outcome were successful. Adults were significantly ($\chi^2 = 13.8$, $P < 0.001$) more successful than first-yr juveniles. Trapping efforts indicate most foraging activity occurs in early morning and late afternoon and that female and first-yr goshawks forage in more open habitat than males and adults.

The Brown Goshawk (*Accipiter fasciatus*) is common and widespread in Australia (Blakers et al. 1984). A medium-sized raptor (mass: female $\bar{x}$ = 561 g, N = 121, male $\bar{x}$ = 349 g, N = 82; Aumann 1988a) with long tarsi and relatively long, pointed wings (Wattel 1973), the species lacks the extremely long middle toe characteristic of the small bird-eating accipiters (Brown and Amadon 1968). In this study Brown Goshawk foraging behaviour is described, and considered in terms of the morphology of the species.

STUDY AREA AND METHODS

During February 1980–March 1985 approximately 7500 hr was devoted to a field study of Brown Goshawk biology in a rural (65% cleared to pasture) area at Macclesfield (37°54′S, 145°30′E), 50 km east of Melbourne, southeastern Australia. In addition to chance observations of foraging activity made in the course of this project, five known foraging sites were monitored from hides for a total of approximately 40 hr in the early morning and late afternoon. These sites were Common Starling (*Sturnus vulgaris*) nocturnal roosts (two) in streamside vegetation, hedges (two) used by House Sparrows (*Passer domesticus*) and a concentration of grazing European Rabbits (*Oryctolagus cuniculus*) on pasture adjacent to a two ha woodlot. Supplementary observations totalling approximately 30 hr were undertaken from hides at Werribee and Lysterfield Lake, respectively 40 km southwest and 35 km southeast of Melbourne. The former area has a large rabbit population throughout the year, and the latter a large Common Starling roost in a reedbed. While observations at Macclesfield were conducted more or less uniformly throughout the year, Werribee and Lysterfield Lake observations were restricted to winter.

Observed instances of foraging activity were categorized using nomenclature and definitions for search and attack techniques of Fox (1981) and Baker-Gabb (1980) with minor modifications. On occasions an attack was difficult to classify. For example, a "direct flying attack" could develop into a "chase" if the prospective prey took flight. In such instances only the initial attack technique was recorded. Some attacks involved several attempts to catch prey. For example, a Brown Goshawk seen to make several passes through a flock of birds with capture attempts on each pass was regarded as having made one attack. If an attack was then abandoned (by perching or flying away) any subsequent resumption constituted additional search and attack observations.

Trapping data were used to investigate temporal and habitat related aspects of Brown Goshawk foraging at Macclesfield. Trapping occurred during early March–late August 1980 and 1981, late February–late July 1982 and late January–late April 1983. Traps used were similar to those of Kenward and Marcström (1983), baited with live, white Feral Pigeons (*Columba livia*). Between eight and 12 traps were set at any one time for a total of approximately 15 000 hr. Placed on the ground in 49 randomly scattered positions over a 64 km^2 area, traps were set for 60–90 hr at a time and checked three times/d: at 1030 H, 1530 H and sunset (all times ±45 min). Trapping positions were categorized using three habitat classes, and capture times (i.e., the times when captured goshawks were removed from traps) were grouped into three intervals based on checking times. Trapping data were recorded only for goshawks at first capture in order to prevent bias resulting from repeated captures of individuals. Captured and observed goshawks were aged as "first year" or "adult" on the basis of plumage characteristics and sexed by size (Aumann 1988a).

RESULTS

Brown Goshawks used five search and four attack techniques in 54 instances of foraging of known outcome (Table 1). Perch hunting was the most commonly used search technique (23 records) followed by ground hunting (12 records) and fast contour hunting (10 records). Direct flying attacks represented nearly 50% of all observed attacks, and were used in conjunction with four search techniques.

Low perches such as earth mounts and paddock fence posts were used by female Brown Goshawks foraging for rabbits and rodents at Werribee. Although perches used were exposed, each could be reached unseen by low level approach flights within the confines of nearby irrigation channels. Prey were attacked while grazing on roadsides 0–8 m from fencelines, and escape to heavier vegetation within

Table 1. Brown Goshawk foraging methods and success rates in southeastern Australia [% successful attacks (N attacks of known outcome)].

SEARCH/ATTACK TECHNIQUE	PREY	MALE		FEMALE			
		FIRST YR	ADULT	FIRST YR	ADULT	UNKNOWN	ALL
Perch Hunting							
Direct flying attack	mammal	—	—	0 (2)	50 (2)	—	25 (4)
Direct flying attack	bird	0 (1)	—	0 (3)	67 (3)	100 (1)	38 (8)
Glide attack	mammal	0 (1)	—	20 (5)	100 (3)	—	44 (9)
Chase	bird	—	—	0 (1)	100 (1)	—	50 (2)
Fast Contour Hunting							
Direct flying attack	mammal	—	—	0 (1)	50 (2)	—	33 (3)
Direct flying attack	bird	—	25 (4)	—	—	—	25 (4)
Chase	bird	0 (2)	—	—	100 (1)	—	33 (3)
Soaring and Prospecting							
Direct flying attack	mammal	—	—	0 (1)	—	—	0 (1)
Direct flying attack	bird	—	—	0 (1)	100 (1)	—	50 (2)
Direct flying attack	reptile	—	—	—	100 (1)	—	100 (1)
Flushing from Cover							
Direct flying attack	mammal	—	—	0 (1)	—	0 (1)	0 (2)
Direct flying attack	bird	—	100 (1)	—	—	—	100 (1)
Ground Hunting							
Pounce and snatch	insect	29 (7)	—	40 (5)	—	—	33 (12)
Unknown							
Direct flying attack	bird	—	0 (1)	—	—	—	0 (1)
Chase	bird	—	—	—	100 (1)	—	100 (1)
All Techniques	mammal	0 (1)	—	10 (10)	71 (7)	0 (1)	32 (19)
All Techniques	bird	0 (3)	33 (6)	0 (5)	86 (7)	100 (1)	41 (22)
All Techniques	all	18 (11)	33 (6)	15 (20)	80 (15)	50 (2)	37 (54)

paddocks was prevented by attack direction. When hunting Common Starlings at Lysterfield, goshawks of both sexes perched in eucalypts (*Eucalyptus* spp.) bordering the lake, in a single Swamp Paperbark (*Melaleuca squarrosa*) emerging from the reedbed starling roost or on the ground within the reedbed itself. Such positions were often occupied >30 min prior to evening starling arrival. Elsewhere, foraging goshawks occupied perches for one to five min before transferring to another position. Most (21 of 23) attack flights launched from perches were <50 m in length and approximately half were <20 m long.

Table 2. Temporal trapping rates for Brown Goshawks captured at Macclesfield, southeastern Australia [% captured/time interval (number captured)].

TIME INTERVAL[a]	MALE		FEMALE		ALL
	FIRST YR	ADULT	FIRST YR	ADULT	
Early morning	34 (17)	22 (7)	35 (24)	34 (18)	32 (66)
Midday	8 (4)	25 (8)	10 (7)	17 (9)	14 (28)
Late afternoon	58 (29)	53 (17)	55 (38)	49 (26)	54 (110)

[a] Time intervals defined on the basis of trap check times: early morning—goshawks removed from traps at 1030 H (±45 min); midday—goshawks removed from traps at 1530 H (±45 min); late afternoon—goshawks removed from traps at sunset (±45 min).

Table 3. Habitat differences in capture rates for Brown Goshawks trapped at Macclesfield, southeastern Australia [number of captures/100 trap hours for each habitat].

		MALE		FEMALE		
HABITAT[a]	TRAP HR	FIRST YR	ADULT	FIRST YR	ADULT	ALL
Type 1	9709	0.4	0.2	0.6	0.4	1.5
Type 2	4680	0.2	0.3	0.2	0.3	1.1
Type 3	992	0.2	0.1	0.1	0.2	0.7

[a] Habitat type 1: trap on pasture with some isolated trees; no woodland >2 ha within 500 m of trap; habitat type 2: trap on pasture with some isolated trees; unbroken woodland >3 ha within 100 m of trap; habitat type 3: trap within an area of woodland >4 ha; no cleared land within 200 m of trap.

However, goshawks twice left perches and chased birds for distances >100 m.

When fast contour hunting for House Sparrows at hedges, male Brown Goshawks flew rapidly alongside the hedge (approximately 0.5 m below the top), crossing over the top once or twice on each pass. Females used a similar search technique at Werribee. By flying rapidly along the channels (just below ground level) and crossing over the top at frequent intervals surprise, short distance, direct flying attacks were launched at grazing mammals. Brown Goshawks at Macclesfield were twice observed to fly just within woodland bordering pasture and then suddenly dash out to attack prey.

During early autumn, first year Brown Goshawks were observed to forage for grasshoppers (*Teleogryllus* spp.) by walking around on well-grazed paddocks while peering from side to side and ahead. Pounce and snatch attacks involved a few quick steps at selected insects before jumping toward them with feet thrust forward.

Brown Goshawks were observed to make four attacks from "prospecting" flights 70–100 m above the ground. Other attacks were made after flushing rabbits or birds from cover by flying or jumping at sheltering vegetation.

Of search techniques recorded >10 times, perch hunting was used most by females and fast contour and ground hunting most by males. Females were observed to attack mammals more often and birds relatively less often than were males. Data were too few for statistical comparison, and no sexual differences were apparent in the use of attack methods. Ground hunting was observed only for first year birds, and no other age differences were apparent in searching behaviour (Table 1).

Twenty (37%) of 54 observed Brown Goshawk attacks of known outcome were successful. Adults were significantly ($\chi^2 = 13.8$, $P < 0.001$) more successful than first year birds (67% vs. 16%). There was no significant success difference between sexes. All search and attack techniques produced success rates of 30%–50%. No significant success rate differences for different prey types were found (Table 1).

More than 90% of observed instances of Brown Goshawk foraging behaviour occurred before 1000 H or after 1500 H. Pre-dawn and post-sunset foraging were seen on two and nine occasions, respectively. Of 204 goshawks trapped at Macclesfield, only 28 (14%) were first captured in the midday interval compared with 66 (32%) and 110 (54%) in the early morning and late afternoon intervals, respectively (Table 2). Temporal difference in trapping rate was significant ($\chi^2 = 49.4$, $P < 0.001$). There were no significant age or sex differences in trapping rate with relation to time of day.

Trapping rates for Brown Goshawks at Macclesfield were more than twice as high in open than in heavily wooded habitat (Table 3). First year goshawks were trapped significantly more often ($\chi^2 = 9.5$, $P < 0.05$) in open habitat and less often in wooded habitat than adults. Although females were trapped at approximately 1.7 times the rate of males in open habitat and at the same rate in more wooded habitats, the sexual difference was not significant ($\chi^2 = 3.1$, $P \not< 0.05$).

DISCUSSION

Studies on raptor foraging behaviour are usually biassed because techniques observed and capture success rates derived may be artifacts of the sites/seasons/time of day observations were made. Furthermore, data points are usually few in relation to those available for other avian groups. The major potential sources of bias in this study were as follows: 1) sites specifically used for foraging observation may have favoured the use of particular foraging techniques (e.g., perch hunting at Werribee and Lysterfield and fast contour hunting at Macclesfield hedgerows). Certain techniques may also be recorded disproportionately often in "random" observations (Newton 1987); 2) if different foraging techniques were appropriate at different sites the extent

of sexual niche partitioning with respect to technique utilization may have been exaggerated, since only females were observed at Werribee and only males at Macclesfield hedgerows; and 3) prey availability at Werribee and Lysterfield may have inflated capture success rates above the Brown Goshawk "average."

The impact of these potential bias sources was unknown because data were too few for each age/sex class to allow intersite comparison, and because the only previously published study of Brown Goshawk foraging with more than four data points was also for females wintering at Werribee (Baker-Gabb 1984).

Apart from data provided by Czechura (1979) and Baker-Gabb (1984), Brown Goshawk foraging has been known only from isolated observations. Nevertheless, there are anecdotal literature records for all search and attack techniques reported in this study (Carter 1903; Batey 1907; Fletcher 1918; Salter 1960; Stokes 1973; Mooney 1981, 1987; Hollands 1984). Perch hunting, the search technique most commonly recorded here, was also observed frequently by Czechura (1979) and Baker-Gabb (1984): four of four and 15 of 24 foraging records, respectively, in spite of other techniques being more "observable" (Newton 1987). In general perch hunting consumes less energy than techniques involving prolonged flight (Schmidt-Nielsen 1972; Gessaman 1973), even in the "short-stay" form reported here for the Brown Goshawk and previously for other accipiters (Kenward 1982; Newton 1987). Wattel's (1973) contention that perch hunting is a preferred foraging technique for heavy accipiters is supported by the results of this study, particularly in that perch hunting was more used by female than male Brown Goshawks.

Search techniques with a greater flight component (soaring and prospecting, flushing from cover and fast contour hunting) preceded less than a third of Brown Goshawk attacks observed in this study, and approximately a quarter of attacks by females. These techniques have all been reported for other accipiters (Schnell 1958; Smith 1963; Newton 1987) although fast contour hunting appears common only for smaller forms (Tinbergen 1946; Peeters 1963; Mordue 1982). Both large and small accipiters soar to prospect for prey, possibly locating concentrations prior to initiating other search techniques (Fox 1981; Newton 1987). In spite of high wing loading (Aumann 1988a) the Brown Goshawk soars well, and soaring may be under-represented in the search data since post-soaring attacks would have been difficult to see.

Foraging observations at Macclesfield and Lysterfield mostly involved short distance attacks on airborne birds or insects. Long tarsi presumably facilitate aerial capture by Brown Goshawks: although lacking the long middle toes thought to be correlated with taking prey in flight (Brown and Amadon 1968) the species eats numerous birds (>60% of dietary items, N = 1769; Aumann 1988b).

Brown and Amadon (1968) considered 25% an "average" capture success rate for raptors. However, bird and mammal eating species usually have lower success rates than those taking predominantly fish or insects (Wakeley 1978). On this basis, the 37% capture success rate recorded here for Brown Goshawks is high and possibly attributable to favourable conditions at foraging sites. Furthermore, the definition of "attack" used here inflates capture success rate in comparison to those estimated in studies where every flight deviation toward prey was considered an attack. Czechura (1979) found high capture success rates for three Australian accipiters hunting quail (Family Phasianidae and Family Turnicidae), although data were few.

While foraging success increases with age for some avian species (Recher and Recher 1969; Dunn 1971), there has been little quantitative evidence of foraging success increasing with age for raptors. The high success rate found here for adult in comparison to first year Brown Goshawks is interesting. Mueller and Berger (1970) reported adult Sharp-shinned Hawks (*A. striatus*) to select prey more "wisely" than younger birds, and Fox (1981) found more experienced accipiters to exhibit greater flexibility in use of search techniques.

As in this study, trapping data can be used to investigate temporal and habitat related aspects of foraging for and within species if it can be assumed that Brown Goshawks enter traps when and where they normally forage and if traps are placed more or less randomly over an area rather than where goshawks are expected. This method of investigating foraging is superior to the use of "random" observations in that: 1) far more data points can be obtained in a given time period; 2) trapped goshawks can be identified to species with certainty: most observers find it hard to distinguish male Brown Goshawks from female Collared Sparrowhawks (*A. cirrhocephalus*) where the two species are sympatric, 3) trapped goshawks can be sexed with certainty;

and 4) data is not derived solely from goshawk foraging in observer presence.

Given the requisite assumption, for the specific case of the Brown Goshawk, trapping data here supported long-held perceptions about accipiters: [e.g., that early morning and late afternoon are important foraging times (Brown and Amadon 1968) and that females and first year birds forage in more open habitat than males and adults (Opdam 1975; Marquiss and Newton 1981; Newton 1987)]. Trapping rate differences also provided preliminary evidence that the Brown Goshawk forages more in open habitat with some woodlots than within extensive woodland. While long-winged accipiters probably use more open habitat than short-winged forms (Wattel 1973), low trapping rates within woodland at Macclesfield may have been due to comparatively low trap visibility.

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