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Diet and Roost Site Characteristics of the Christmas Island Hawk-Owl *Ninox natalis*

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Summary: In a two year study, Christmas Island Hawk-Owls *Ninox natalis* chose to roost in the bottom third of the canopy of trees with particularly deep crowns, in areas with fewer low understorey and more mid-level understorey trees, suggesting a preference for sheltered, concealed, roost sites with easy escape routes below them. Analysis of regurgitated pellets, stomach samples and faeces showed the owls to be primarily insectivorous, eating a wide variety of medium to large insects, especially Orthoptera, Lepidoptera and Coleoptera. They supplemented this diet with vertebrates of which introduced Black Rats *Rattus rattus* were the most important in this study. Other studies have found native and introduced geckos as well as the Christmas Island White-eye *Zosterops natalis* in their diet. Owls snatched their prey from the understorey, hawked insects around streetlights, 'long-stay perch hunted' along roadsides and presumably also fed in and above the canopy.

The Christmas Island Hawk-Owl *Ninox natalis* (Norman et al. 1998) is a small (140-210 g, RH unpubl. data) threatened species of Australian raptor (Garnett 1993) that is restricted to Christmas Island in Australia's Indian Ocean Territories. To increase our knowledge of this little known owl, a two year study was undertaken (Hill & Lill 1998a,b). This paper reports the characteristics of roosts used by owls and the composition of their diet. Some observations on diet have been published previously (Kent & Boles 1984; Olsen & Stokes 1989; Phillips et al. 1991) but nothing on roosts.

Study area and methods

Christmas Island is in the Indian Ocean (10°25′S, 105°40′E) approximately 1400 km north-west of Australia. Unless otherwise stated, the data presented here were collected from two 1 km^2 study areas of plateau primary forests dominated by tall closed forest or closed forest, with small areas of secondary vegetation along tracks, roads and around mine clearings. A detailed description of the study areas is provided in Hill & Lill (1998a).

Roosting

Roosts were located by noting where an owl made its last call before dawn, then returning during the day to search for the owl, often assisted by the distinctive alarm calls given by Christmas Island White-eyes *Zosterops natalis* when they found a roosting owl. Roosts were also found by opportunistically following up these distinctive white-eye call and while radio-tracking owls.

The following structural and floristic characteristics were measured at all roost sites: forest height, species of tree used, tree height, girth at breast height (GBH), depth of canopy, projected cover (PC) within 1 m diameter over the roost, PC over the roost (within 10 m diameter), PC 1 m above the roost in a circle 1 m diameter from the roost site (Roost Cover Above), PC 1 m below the roost (Roost Cover Below), roost height (m), branch order of the roost site (1 = trunk, 2 = first branching from the trunk, etc.), branch diameter and visibility from ground (fully visible, partly visible and not visible). 'Total Roost Cover' was derived from the sum of Roost Cover Above and Roost Cover Below. The depth of the canopy was the estimated vertical height between the lowest leaves and the top of the tree. All heights were estimated by eye and calibrated with an inclinometer. Projected cover within 1 m was estimated by standing directly under the roost and estimating the cover within a 1 m radius circle around the roost from the roost to the canopy. Projected cover within a 10 m radius of the roost was estimated from four points 5 m from the roost tree, values for which were then averaged.

To investigate whether or not roosts were randomly located with respect to other trees or if owls selected a particular type of forest in which to roost, 10 m radius circular plots were established around ten randomly selected known roost sites, and around eight randomly selected sites within the two study areas from which roost data were collected. The roosting tree data set was then collected for all trees within the size classes used by owls for roosts. All trees greater than 10 cm GBH were measured, except for 'cane-like', shrubby, understorey species (e.g. *Aidia* aff. *racemosa*) for which trees down to 8 cm GBH were measured. Any *Pandanus* spp. or *Arenga listeri* with trunk > 1 m high was measured (GBH was not applicable to these plants). All GBH were converted to diameter at breast height (DBH), the standard forestry measurement. The data collected on each tree within each 10 m radius plot were: species if known, GBH, height, depth of crown and 'crown density' (sparse, moderate and dense) which was an estimate of how shaded it was within the crown. Crown density included all lianas and other species of plants which grew on or within the tree and thus contributed to the 'shadiness' within the crown.

Diet

Pellet analysis was used to investigate the diet of the owl, supplemented by the analysis of stomach contents and faeces, and by direct observation. At regularly used roosts, nets of 'shade cloth' were placed to catch pellets as they were regurgitated and to protect them from land crabs which would have eaten them otherwise. These nets were checked regularly and any pellets collected. A collection of faeces from different seasons was also made. Pellets and faeces were stored in 70% alcohol. The stomach contents from all owls found dead during this study, and collected by Parks Australia North staff before this study, were removed and stored in 70% alcohol. Prey remains were sorted under a stereo dissecting microscope and recognisable invertebrate remains were separated along with bones, feathers, and fur. These were identified at least to Order and in some cases to the species level, using a reference collection made while on the island (CSIRO unpubl. data) and the assistance of the staff and collections at the Museum of Victoria. Faeces were examined under a dissecting microscope and any identifiable fragments separated and identified where possible. All pellets and faeces were examined for the characteristic wing scales of the Lepidoptera (C. McPhee pers. comm.). Feathers were identified by comparison with the barbule morphology of reference specimens. All observations of feeding by wild birds were noted.

Results

Roosting

Christmas Island Hawk-Owls left their roost at about sunset and returned to a roost at dawn. Owls were not seen to change roosts during the day except when they were disturbed by an observer. Owls normally roosted either alone or with a bird of the opposite sex, presumably the mate. However, on two occasions three owls were recorded roosting together. In one instance, the third bird was clearly the single offspring of the pair and in the other case, the third bird was probably the offspring of the pair. Owls often changed their roost site nightly and subsequent roosts were sometimes close together. For example, two roosts used by a male at Grants Well were within 20 m of each other and both were used only once during the 34 days the bird was radio-tagged. When preparing to breed, another male roosted within 150 m of its nest for the entire 47 days it

Table 1 Species and description of roost trees used by Christmas Island Hawk-Owls between March and November 1994.

Species	Common name	Description
Aidia aff. racemosa	Wild Coffee	Common understorey multi-stemmed shrub/small tree.
Barringtonia racemosa	Putat	Common emergent tree in Plateau Forest up to 45 m tall.
Maclura conchinchinensis		Common scrambling vine growing on edge of disturbed areas in Plateau Forest.
Pandanus elatus	Pandanus	Common understorey palm.
Inocarpus fagifer	Tahitian Chestnut	Common canopy tree in terrace and plateau forests.
Ochrosia ackeringae		Common understorey tree on terrace and plateau.
Leea angulata		Common understorey shrub especially on terraces
Ficus microphylla	Small-leaved Fig	Common canopy tree in terrace and plateau forests.
Planchonella nitida	Planchonella	Common emergent tree in Plateau Forest up to 40 m tall.

carried a transmitter, and used one or the other of two roosts for most of that time.

Most owl roosts were found in primary forest but two roosts were recorded in secondary vegetation. Roost sites in primary forest were frequently located in vegetation regrowing along the narrow ‘drill lines’, a grid network of mining exploration tracks established *c.* 25 years ago that cover most of the plateau primary forests. Owls roosted in common understorey trees and younger, understorey individuals of canopy tree species (Table 1). They roosted from low in the ground layer vegetation up into the canopy vegetation but tended to roost low in the understorey (Table 2). Roosts of radio-tagged birds were invariably visible to an observer on the ground. Roosts tended to be well-shaded from above and had, on average, about 60% projected foliage cover within 1 m above the roost. The position of the roost in the crown was investigated by using roost height, tree height, and canopy depth to attribute the roost position to the top, middle, or bottom of the tree crown. Roosts were significantly more likely to be placed in the bottom third of the crown than higher up ($\chi^2 = 10.00$, $d.f. = 2$, $P < 0.01$).

We then investigated whether roost trees were different from trees selected at random on the basis of the roost tree descriptor variables. Roost trees were not significantly different to randomly selected trees with respect to DBH, or tree height but did have significantly deeper crowns ($t = 4.9$, $d.f. = 38$, $P < 0.001$) (Table 3).

Table 2 Summary of the characteristics of roost sites used by Christmas Island Hawk-Owls.

	Mean ± SD	Range	*n*
Forest height (m)		15-45	
Tree height (m)	9.4 ± 6.3	3-25	35
Tree DBH (cm)	15.9 ± 18.5	2.5-91	30
Canopy Depth (m)	5.9 ± 4.8	1-20	34
Branch Order	2.1	1-5	32
Projected Cover 1 m (%)	86 ± 13	50-100	35
Projected Cover 10 m (%)	64 ± 12	40-90	35
Roost Cover Above (%)	62 ± 21	20-100	35
Roost Cover Below (%)	7 ± 8	1-30	35
Total Roost Cover (%)	69 ± 23	25-90	35
Roost Height (m)	5.1 ± 4.2	1.2-21	34
Branch Diameter (cm)	3.7 ± 2.3	2-14	33

* See methods for definitions of these characters.

We then investigated whether or not trees were distributed randomly with respect to different forest structure characteristics, but found no significant difference in tree densities around roost sites compared to sites chosen randomly in the forest (Table 3). A significant difference in the distribution of tree size classes between roost sites and randomly chosen sites was found ($\chi^2 = 24.2$, $d.f. = 12$, $P < 0.05$), with roost sites tending to have fewer trees less than 3 m high than other sites, and more trees between 6-9 m high than other sites. Discriminant function analysis was then used to investigate whether or not trees around roost sites and trees from randomly selected areas could be separated using a multivariate model of tree height, DBH, and relative crown depth (crown depth divided by tree height). The model was non-significant, correctly attributing only 54% of trees to their actual group. Thus, there was no significant difference between roost areas and other areas on the basis of these variables.

Diet and hunting techniques

Twenty-five collections totalling approximately 40 regurgitated pellets were made during May 1994 and November 1995 (Table 4). Of these, 24 samples were collected from owls in plateau forest and one in terrace forest (see Hill & Lill 1998a for an explanation of these terms). Pellets were rarely found under roosts because the abundant Red Crabs *Gecarcoidea natalis* rapidly consumed anything that fell to the ground, so pellets were regularly collected in nets under roosts. The pellets rapidly fell apart and it was often unclear how many pellets a sample represented. Invertebrates were the most important prey by number (Table 4). Most prey were tentatively identified as the gryllacridid cricket *Gryllacris rufovaria*, the only member of this family of tree crickets recorded on Christmas Island

Table 3 A summary of the variables, mean ± *s.d.* and (*n*), collected in 10 m radius quadrats around roost sites and randomly selected sites. DBH, Height and Canopy Depth values only from size classes of trees used by owls as roosts. Roost = trees from plots around roost sites, Random = trees from randomly selected areas.

	Roost	Random
DBH (cm)	15.90 ± 18.50 (30)	12.56 ± 16.75 (311)
Tree height (m)	9.40 ± 6.30 (35)	8.47 ± 7.16 (340)
Canopy depth (m)	5.90 ± 4.8 (34)	3.08 ± 2.51 (304)
Tree density	0.16 ± 0.07 (10)	0.15 ± 0.06 (8)

Table 4 Contents of 25 samples (approx 40 pellets) of Christmas Island Hawk-Owls, showing *n*, the total number of food items, % total, the number of a particular food item as a percentage of the total number of food items recorded, and % samples (*n* = 25) in which a particular food item was recorded. Pellets were collected from May to November in 1995 and 1996.

Taxa	*n*	% total items	% samples
Orthoptera			
?Gryllacrididae *Gryllacris rufovaria*	204	51	80
Blattodea			
Blaberidae *Pycnoscelis surinamensis*	1	0.25	4
Coleoptera			
Buprestidae *Chrysodema ?simplex*	1	0.25	4
Cerambycidae	10	2.5	28
Lucanidae *Aegus sp.*	1	0.25	4
Lucanidae *?Aegus*	1	0.25	4
Lucanidae	1	0.25	4
Elateridae	1	0.25	4
Curculionidae	1	0.25	4
Unidentified beetles	50	12.5	44
Hemiptera	1	0.25	4
Unidentified insects	122	30.5	84
Rattus sp.	5	1.25	8
Bird	1	0.25	4
Total prey items	400	100	

(CSIRO unpubl. data). Remains of *Rattus*, presumably the Black Rat *R. rattus* (ANCA 1994), were found in 8% of pellet samples. On the basis of jaw and/or teeth sizes, all of these were juveniles. One fragment of bird bone was found, but it could not be further identified. Prey and pellet remains were also collected from a nest. Only eight food items were identified of which seven were Coleoptera: two Cerambycidae, one Elateridae (Lanelater 270, CSIRO unpubl. data) and four unidentified; one unidentified lepidopteran was 50 mm in length.

The contents of seven stomachs of Christmas Island Hawk-Owls were examined. Five of the samples were collected between April and July; the dates of collection of the other two were unknown. Forty-one different items were identified, primarily insects and notably Lepidoptera, but including reptiles and owl feathers (Table 5). Samples of faeces were collected in May, August, September, October and November. The frag-

Table 5 The contents of seven stomachs of Christmas Island Hawk-Owls, with an actual or size estimated * (e.g. up to 20 mm) of the food item where possible. Per cent in samples is the number of samples in which a food item was recorded.

Taxa	Total	Per cent in samples	Length* (mm)
Araneida			
Lycosidae?	1	12	12
Blattodea			
Blaberidae *Pycnoscelis surinamensis*	1	12	→ 20*
unidentified	1	12	20
Mantodea			
Hierodula dispar	4	24	→ 50
Orthoptera			
Tettigoniidae *?Conocephalus*	3	12	→ 30*
Gryllidae *?Gryllodes*	2	12	→ 20*
Gryllidae	1	12	
Gryllacrididae *Gryllacris listeri*	1	12	40*
Tettigoniidae	1	12	40
Acrididae *Valanga sp.*	2	24	→ 70*
Unidentified	6	36	
Hemiptera			
Cicadidae *Platypleura calypso*	1	12	35
Coleoptera			
Scarabaeidae *?Anomala*	3		10
Cerambycidae	1	12	
unidentified	1	12	
Lepidoptera			50
Geometridae/Noctuidae	1	12	20
Sphyngidae	1	12	40*
Geometridae/Noctuidae	1	12	
(caterpillar)	1	12	50
(moth)	2	24	35,15
Unidentified	2	24	
Vertebrates			
Gekkonidae	1	12	
unidentified reptile	1	12	
Rattus sp.	1	12	
Ninox natalis	1	12	
Total food items	41		

ments of prey in the faeces were mostly from insects but could not be further classified. No wing scales of Lepidoptera were found in any of the faeces collected.

Four hunting attempts were observed. In three cases the owl was in understorey vegetation of primary forest and was observed swooping down onto a shrub or small tree, striking the outside of the foliage then flying up to a new perch. This 'snatching' was at 5 m, 2 m and 7 m high, respectively. In each case it was not possible to observe whether the hunting attempt was successful. In the fourth case an owl was observed apparently 'long-stay perch hunting' (Hogdon 1996) along a roadside, perching in regrowth vegetation 5-10 m high for 10-15 minutes, then flying along the road for 30-50 m, and perching again. On two occasions owls were observed perched 2-4 m high along roadsides apparently searching for prey in the short (< 1 m high) roadside vegetation.

Discussion

Roosting

Radio-tagged Christmas Island Hawk-Owls rarely stayed at one roost site for more than two successive days. They had numerous roost sites which they used only once and a small number which were used a number of times. The Southern Boobook *Ninox novaeseelandiae* tends to return frequently to a small number of roosts, using several roosts in rotation and one roost for several days to several weeks (Schodde & Mason 1980; Olsen & Bartos 1997). Norfolk Island Boobooks *N. n. undulata* also have reasonably regular roosts although there appear to be lots of potential roost sites in their fairly dense forested habitat (P. Olsen pers. comm.). Both owls prefer sheltered concealed positions for roosting (Schodde & Mason 1980; Olsen & Bartos 1997; Higgins in prep.) and the Christmas Island rainforests probably provide many more such locations than the eucalyptus forests and woodlands which are the typical home of Southern Boobooks (Schodde & Mason 1980). Yet our results suggest that, even in the dense shaded rainforest understorey, Christmas Island Hawk-Owls prefer to roost in certain types of vegetation.

Christmas Island Hawk-Owls' roost sites tended to have dense vegetation immediately above them and to be in the bottom third of particularly deep crowns, indicating a preference for roost sites sheltered from above. This is consistent with owls selecting roost sites which sheltered them from rain and possibly sun, and probably also reduced their chances of detection by other birds. Protection from rain may be quite important during the long wet season when heavy rainstorms are frequent. A roost well-concealed from above would reduce the chances of owls being seen by Christmas Island Goshawks *Accipiter fasciatus natalis* which tend to search for prey from higher up in the understorey or the canopy (RH pers. obs.). A female goshawk weighs approximately 450 g, more than twice the weight of a Christmas Island Hawk-Owl (RH unpubl. data), and might pose a threat to the owl. Forsman et al. (1984) suggested that Spotted Owls *Strix occidentalis caurina* chose well shaded roosts which provided shelter from rain and snow. In hot weather Spotted Owls and Powerful Owls *Ninox strenua* are known to choose roost sites low in the forest understorey presumably to avoid solar radiation (Forsman et al. 1984; McNabb 1996). Southern Boobooks choose 'the shelter of dense, leafy branches in trees' (Schodde & Mason 1980). The Christmas Island Hawk-Owls' choice of sites with more trees in the 6-9 m size class is perhaps related to their preference to roost in trees surrounded by dense vegetation at or just above their mean roost height; thus, the shaded sites they chose were perhaps a combination of the roost tree plus the surrounding trees and not the roost tree alone.

Christmas Island Hawk-Owls chose to roost below rather than within dense vegetation suggesting that access to and from the roost site was also a variable influencing their choice of roost site. They are small agile birds and it is unlikely that access to a densely vegetated roost site would be difficult. Thus, their preference for a relatively clear area underneath the roost may be to facilitate escape from the roost if the bird is threatened. Fleay (1968) suggested that Powerful Owls chose roost sites with unhindered escape routes below.

Diet

The results suggest that, for the period May to November at least, the Christmas Island Hawk-Owl is primarily insectivorous and eats a wide range of insects, supplemented with vertebrate prey. The pellet samples were, by total number of individuals in the overall sample, dominated by remains which were tentatively assigned to *Gryllacris rufovaria*, the only known species of Gryllacrididae (Orthoptera) recorded from Christmas Island. This large tree cricket (up to 40 mm) is widespread in forest habitats (CSIRO unpubl. data).

Another significant component of pellets was introduced rodents that were presumably Black Rats. No other rodent has been reliably recorded since the apparent extinction of the two native rodents early this century (ANCA 1994). All five records were of juvenile animals, suggesting that owls were selecting the smaller individuals. The biomass of each animal would, nonetheless, be substantially more than the individual biomass of any invertebrate prey the owls were recorded eating. All records of Black Rats came from one roost which was regularly used by two birds in the breeding season of 1994. One of these owls, radio-tracked in 1994 (Hill & Lill 1998a), appeared to spend a considerable amount of time along the edge of an old mined area covered with low regrowth vegetation. Black Rats were considered to be quite uncommon on Christmas Island except in regrowth vegetation and coastal fringe vegetation and are rarely seen in primary forests (Tidemann 1988 cited in Tidemann et al. 1994; RH unpubl. data). Thus it seems likely that this pair of owls was hunting Black Rats in regrowth vegetation. The other vertebrates recorded in the diet in this study were an unidentified gecko, an unidentified reptile and an unidentified bird. Native and introduced species of gecko are widespread in the primary forests of Christmas Island (Cogger et al. 1983; RH pers. obs.).

The Lepidoptera were a major component of stomach samples but were not recorded in pellets or in faeces. It is probably not surprising that these soft-bodied insects were not recorded in pellets; however, we would have expected that the faeces of owls eating Lepidoptera would have contained the wing scales typical of most Lepidoptera. The stomach samples were collected in the late wet/early dry season and the pellets and faeces in the early to late dry season. Large Leptidoptera appeared to be more common in the wet season (RH pers. obs.), which perhaps explains why the faeces, primarily collected in the dry season, did not contain their remains. The Lepidoptera is a large order of insects on Christmas Island with at least 350 species recorded (CSIRO unpubl. data). Some species, such as members of the Sphyngidae, can reach up to at least 40 mm in total length and may be important prey items for owls. These results highlight the importance of not relying solely on pellet analysis for investigating the diet of birds where soft-bodied prey may be eaten.

The results are similar to and complement previous observations on the diet of Christmas Island Hawk-Owls. Phillips et al. (1991) found that the contents of ten pellets collected between September and December in primary rainforest were exclusively insect and primarily small beetles (1-2 cm long) in the families Elateridae, Tenebrionidae, Cerambycidae, and Chrysomelidae. The chrysomelids, cerambycids, and elaterid beetles were all described as foliage-dwelling species and the tenebrionid beetles were ground-dwelling species also found on logs and tree trunks (Phillips et al. 1991). These authors also recorded the tree cricket *Gryllacris rufovaria* in four out of the seven pellet samples collected. Kent & Boles (1984) described the contents of three stomachs from Christmas Island Hawk-Owls found dead near human habitation. These contained an introduced gecko *Hemidactylus frenatus* and an introduced cockroach *Periplaneta americana*, as well as unidentified beetle and grasshopper fragments. From seven stomach samples, Gibson-Hill (1947) described the diet of the Christmas Island Hawk-Owl as being primarily insectivorous but also included to a lesser extent, reptiles (*Cyrtodactylus* sp. and *Lygosoma bowringii*) and Christmas Island White-eyes.

The limited number of observations of hunting preclude generalisations about the hunting techniques of the Christmas Island Hawk-Owl. Our observations are in agreement with Phillips et al. (1991) who inferred from their diet that Christmas Island Hawk-Owls snatched prey primarily from foliage rather than off the ground. It is likely that Christmas Island Hawk-Owls hunt in the upper layers of the forest and above the canopy as well as in the understorey. These areas are better lit than the dark understorey and light levels may be important in determining the feeding success of *Ninox* spp. owls (e.g. Schodde & Mason 1980 for Southern Boobooks). Insect diversity and biomass also tend to be higher in the canopy of the forest because most foliage biomass and flowering takes place there (Sutton & Hudson 1980). The edges of clearings such as roadsides also have high light levels and can have high insect abundances (RH pers. obs.), which may explain why owls have been observed hunting there. A number of owls are killed each year on roads indicating that they use roadsides to some degree. Christmas Island Hawk-Owls have also been observed hawking insects around street lights in the suburbs of the island (Stokes 1988).

Unlike many other raptors including many owls, the Christmas Island Hawk-Owl has little sexual dimorphism in body size; the female is slightly larger than the male. This lack of significant dimorphism suggests that there is probably not substantial partitioning of food resources between the sexes and is typical of insectivorous raptors (Olsen 1995).

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