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Roost selection by the north Queensland long-eared bat *Nyctophilus bifax* in littoral rainforest in the Iluka World Heritage Area, New South Wales

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Abstract The aim of this study was to describe the roosts of *Nyctophilus bifax* in littoral rainforest in Iluka Nature Reserve on the north coast of New South Wales. Radio-telemetry was used to track 17 bats in November 1988 (lactation season) and 11 in May 1989 (mating season) to 87 roosts in 49 trees within the littoral rainforest. The bats frequently changed roosts, which were clustered within a small area. During November, lactating females moved twins between diurnal roosts and some carried twins while foraging. Twins represented a load of up to 95% of their mother's bodyweight. Bats roosted communally in foliage and tree hollows, beneath peeling bark, among epiphytes, and between strangler figs and host trees. Hollows were used more frequently when bats were lactating, while the use of foliage roosts was greater during the mating season. Roosts were concentrated in four tree species, although a wide range of other tree species was used. Roost trees used in November were taller (17 m) than those used in May (8.2 m), and reflect selection of *Syzygium leuhmannii* and *Acmena hemilampra*, both trees of the forest interior. The converse applied for selection of *Cupaniopsis anacardioides*, a small tree of the littoral zone, in May. These results identify the need for conserving a diversity of roosts for this species of bat.

Key words: bats, littoral rainforest, roost selection.

INTRODUCTION

Until the work by Parnaby (1987), the taxonomy and distribution of the north Queensland long-eared bat *Nyctophilus bifax* had been confused with the morphologically similar Gould's long-eared bat *Nyctophilus gouldi*. *Nyctophilus bifax* was regarded as having a tropical distribution north of Rockhampton within both dry sclerophyll woodland (Fenton 1982; Allison 1983) and in rainforest (Crome & Richards 1988). Parnaby's (1986) record of *N. bifax* at Iluka Nature Reserve in northeast New South Wales (NSW) extended its distribution south by 750 km and added littoral rainforest to the list of its habitats. It is currently listed as an endangered species under NSW legislation because of a reduction in its distribution and numbers.

Information on the roosting ecology of *N. bifax* is scant. Both Hall and Richards (1979) and Allison (1983) described the diurnal roosts as hollow trees as well as buildings. By comparison, there is considerable information on the similarly sized *N. gouldi*, which is broadly sympatric with *N. bifax* (Parnaby 1987). Roost selection by *N. gouldi* in southern NSW showed a preference for hollows in large trees in unlogged gullies (Lunney *et al.* 1988). Similar-sized microchiropterans from the neotropics use a variety of roosts, including rainforest foliage (Morrison 1980), tree hollows (Morrison 1979) and caves (Fleming 1988).

The principal aim of this study was to locate and describe the diurnal roosts of *N. bifax* in the littoral rainforest at Iluka on the north coast of NSW. This included an examination of whether female *N. bifax* moved their young between diurnal roosts, the pattern of roost movements and aspects of communal roosting. The investigation took place during the period of lactation in November and again during the mating season in the following May.

Study site

The study was conducted in the littoral rainforest of Iluka Nature Reserve (29°24′S, 153°22′E) on the north

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coast of NSW. The 136 ha nature reserve contains the largest remaining stand of littoral rainforest (a distinctive coastal variant of sub-tropical rainforest) in NSW (Adam 1987).

The rainforest in Iluka Nature Reserve contains two distinct communities (Nicholls 1966). Along the seaward side is a littoral zone (with a canopy height of 10–20 m) dominated by tuckeroo (*Cupaniopsis anacardioides*) and coastal banksia (*Banksia integrifolia*). This low seaward fringe merges into a taller forest (with a canopy height of 23–30 m) dominated (74% of all canopy trees) by *Acmena hemilampra*, *Syzygium leuhmannii* and *Mischocarpus pyriformis* (Nicholls 1966).

METHODS

The study was conducted in two periods: 3–15 November 1988, during parturition and early lactation; and 3–12 May 1989, during mating of *N. bifax*, assuming a similar reproductive cycle to *N. gouldi* (Phillips & Inwards 1985). Both periods fell in the dark phase of the moon. Bats were captured in harp traps set on walking tracks through the reserve, and on fire trails in adjacent forest. There were 87 trap nights in November 1988 and 57 in May 1989. Traps were set by day and cleared at 22.00–24.00 h and 06.00–09.00 h.

Bats were each fitted with an AVM model SM1 transmitter with a 30 cm antenna, powered by a mercury battery with an expected life of 15–20 days. Each transmitter package, sealed with epoxy resin, weighed 1.8 g, considerably lighter than the juveniles that females carried (see Results). Transmitters were attached mid-dorsally on the fur with rapid-setting cyanoacrylate glue ('Supaglue') with the antenna protruding posteriorly. The diurnal roost was located from the radio signals and was often confirmed by sighting the antenna or the bat. For each roost the tree species, diameter at breast height over bark (DBHOB) and tree height were recorded.

Two communal roosts, located on 9 and 10 November 1988, were examined in detail to determine the number and sex of individuals using the roosts. The bats were captured by hand and weighed. The number and weight of the young carried were noted.

The frequency of tree species used as roosts were compared between November and May, and were compared to trees measured in 30 randomly selected plots (10 × 10 m) located throughout the rainforest. Many small plots are more suitable for sampling the high density and heterogeneity of trees in littoral rainforests than fewer larger plots. A tree was any single-stemmed plant taller than 5 m. Height and DBHOB of roost trees were compared to the randomly measured trees using a single factor ANOVA, after $\log_{10}$ transformation to improve normality. Tukey's pairwise comparisons were used when a significant result was detected (Zar 1984).

RESULTS

Bats captured and tracked

In November 1988, 20 *N. bifax* were captured in rainforest (54 trap nights), 17 of which were females (Table 1). All females were breeding (one was pregnant, 14 were lactating and two had twins attached). Additional trapping in surrounding habitats caught five *N. bifax* in a mixed stand of melaleuca and bangalow palms (14 trap nights), one in open woodland (17 trap nights) and zero in heath (two trap nights). In May, 14 of the 32 captured bats were female, a sex ratio not significantly different from parity ($\chi^2 = 0.50$, d.f. = 1, $P = 0.48$). The weights of males, females (pregnant, lactating and with young attached) and detached juveniles are shown in Table 2.

Transmitters were fitted to only those bats caught in rainforest: 15 females and two males were tracked to an average of 3.8 ± 0.3 (± SE) roosts per bat in November 1988 and two females and nine males were tracked to 3.9 ± 0.3 (± SE) roosts per bat in May 1989. The disparate sex ratio of bats tracked in November mirrored the disparate capture success of the sexes at this time (Table 1). The skewed sex ratio of bats tracked in May arose because transmitters were attached during early trapping, when there was a distinct, but temporary, bias towards males. Due to low numbers of radio-tagged males in November and females in May, data for both sexes were pooled. Seasonal comparisons were therefore

Table 1. Number of trap nights, bats caught and tracked, and roosts utilized by *N. bifax* in Iluka Nature Reserve

	November 1988	May 1989
Trap nights	54	57
Bats caught	20	32
Sex ratio (M:F)	1:5.7	1:0.8
Bats radio-tracked	17	11
Roosts	52	35
Roost trees	24	25
Roost-tree species	11	11
Roosts in tree–vine association	1	3

Table 2. Bodyweight (g) of *N. bifax* captured at Iluka Nature Reserve

	November 1988	May 1989
Males	9.5 ± 0.5 (3)	9.2 ± 0.6 (18)
Non-reproductive females	—	10.8 ± 0.7 (14)
Pregnant females	14.9 (1)	—
Lactating females	10.1 ± 0.6 (14)	—
Females, sucking twins attached	18.0 ± 0.9 (3)	—
Detached juveniles	3.5 ± 0.6 (8)	—

Values are mean ± standard deviation; numbers in parentheses indicate number of individuals.

Table 3. Roosts used by *N. bifax* in Iluka Nature Reserve

	November 1988 % (*n*)	May 1989 % (*n*)
Bark	6 (3)	0
Foliage	15 (8)	63 (22)
Epiphyte	2 (1)	11 (4)
Tree hollow	27 (14)	6 (2)
Shallow depression	21 (11)	0
Crevice between strangler Fig and host	4 (2)	0
Trunk exposed	2 (1)	0
Not defined	23 (12)	20 (7)
Total roosts	52	35

n, Number of roosts used, pooled for all bats. Not defined refers to those occasions when the exact location of the bat within the tree could not be determined.

Table 4. Percentage of trees used as roosts by *N. bifax* in November 1988 (24 roost trees) and May 1989 (25 roost trees) and the percentage of tree species found in 30 random plots

Tree Species	Percentage of Tree Species Roost (*n*) November	Roost (*n*) May	Random
Acmena hemilampra	20.8 (5)	12.0 (3)	44.6
Syzygium leuhmannii	25.0 (6)	8.0 (2)	21.3
Mischocarpus pyriformis	16.6 (4)	16.0 (4)	9.3
Ficus watkinsiana	4.2 (1)	4.0 (1)	1.2
Cupaniopsis anacardioides	0	28.0 (7)	2.4
Flindersia schottiana	0	4.0 (1)	1.2
Banksia integrifolia	0	8.0 (2)	<1.0†
Halfordia kendack	4.2 (1)	0	2.7
Arytera divaricata	4.2 (1)	4.0 (1)	3.9
Bridelia exaltata	4.2 (1)	0	0.8
Lophostemon confertus	8.3 (2)	4.0 (1)	0.4
Acacia aulacocarpa	4.2 (1)	8.0 (2)	7.4
Achronychia bauerlenii	4.2 (1)	0	<1.0†
Eucalyptus intermedia	4.2 (1)	0	<1.0†
Polyscias elegans	0	4.0 (1)	<1.0†
Parsonia latifolia/L. confertus	0	4.0 (1)	<1.0†
Parsonia latifolia/ B. integrifolia	0	4.0 (1)	<1.0†

n = Number of individual trees used, pooled for all bats; †, percentage of tree species not found in random plots, but taken from transects in Nicholls (1966).

Table 5. Tree height (m) and tree diameter (DBHOB in cm) of roosts in November 1988 and May 1989 and in random plots

	Tree height	DBHOB
Random	12.3 ± 7.5 (249)	21.9 ± 19.9 (249)
November 1988	17.0 ± 5.5 (23)*	38.1 ± 30.1 (23)*
May 1989	8.2 ± 2.5 (27)*	24.8 ± 20.0 (27)

Values are mean ± SD; *n* = number of trees; * = significantly different from random at $P<0.05$.

predominantly between females in November and males in May.

Description of roosts

Roost structures

Fifty-two roosts were located in November and 35 in May (Table 3). Roosts were predominantly in foliage, tree hollows and shallow depressions on trunks and limbs. They were also among epiphytes, under peeling bark and between strangler figs and their host tree. One bat roosted twice in an exposed position on the exterior of a tree limb. There were 19 instances where the roost tree but not the exact roost location on the tree was determined. The use of each roost structure differed between November and May (Table 3); however, sample sizes were great enough to demonstrate a statistical difference for foliage only ($\chi^2 = 5.4$, d.f. = 1, $P<0.025$). In November most roosts were in tree hollows (27%) or shallow depressions (21%), whereas in May foliage roosts were most common (63%).

Tree species

Sixteen tree species were used as roosts by *N. bifax*, four of which were used frequently (Table 4). Two species (*Acmena hemilampra* and *Syzygium leuhmannii*) were locally common and two (*Mischocarpus pyriformis* and *Cupaniopsis anacardioides*) were locally uncommon. Further, there was a shift in tree species preference from November to May (Table 4). This was most evident for *C. anacardioides*, a tree of the seaward edge (Nicholls 1966), which was not used in November, but was the most commonly used species in May. Conversely, *S. leuhmannii* and *A. hemilampra*, trees of the forest interior (Nicholls 1966), were more commonly used in November than May ($\chi^2 = 3.72$, d.f. = 1, $P = 0.05$). Other species of trees were used at similar frequencies each month, although sample sizes were very low for these (Table 4).

Tree height and diameter

In May, *N. bifax* roosted in trees that were significantly shorter than those in the random plots, whereas in November bats roosted in trees that were taller ($F = 9.69$, d.f. = 2, $P<0.001$; Table 5). The bats in November selected trees with larger DBHOB than random, but in May the bats were not selective for DBHOB ($F = 5.26$, d.f. = 2, $P = 0.006$; Table 5).

Communal roosts

On 9 November 1988 seven adult *N. bifax* were found roosting in a cluster 10.5 m above the ground in the vine-covered (*Clematis glycinoides*) foliage of an 11 m high Coogera (*Arytera divaricata*). Six were lactating

females, three with suckling twins and three with no young attached. The seventh adult eluded capture.

On 10 November seven adult *N. bifax* were found roosting together in a fallen hollow limb of an *A. hemilampra*, lodged 10 m above the ground in a fork of a *Mischocarpus pyriformis*. Four adult females were captured, three with suckling twins. One telemetered female and two adults of unknown sex escaped. Eight detached young were also present in the communal roost, probably offspring of the three bats which escaped and the female captured with no young. Thus the communal roost probably had seven females each suckling twins.

Day roosts and nightly movements

In November radio-tracked *N. bifax* regularly changed their diurnal roosts, with 68% ($n = 25$) of roosts occupied for one day only. In May there was a lower percentage (38%, $n = 21$) of daily roost changes ($\chi^2 = 4.11$, d.f. = 1, $P < 0.05$). Roosting sequences of a given bat were in close proximity to each other. Two patterns of consecutive daily roost usage are shown for two bats in Figs 1 and 2.

The greatest distance between consecutive roosts was 262 m. The average distance between roosts was similar ($t = 0.94_{27}$; $P = 0.36$) for November (104 ± 14 m, $n = 25$) and May (87 ± 18 m, $n = 14$). The movements between roosts were not related to topographical features, such as creeks and ridges, because these are absent from the littoral rainforest at Iluka. Distances from trap site to roost and between shed transmitters and the last known diurnal roost ranged from 18 to 513 m, with 57% of movements less than 100 m. These measures of bat movements were similar ($t = 1.17_{12}$; $P = 0.27$) in November (131 ± 28 m, $n = 12$; mean $\pm$ SE) and May (197 ± 49 m, $n = 9$; mean $\pm$ SE). One male telemetered in November was recaptured in May and again fitted with a transmitter. It was found to be roosting in the same area as in November.

DISCUSSION

Nyctophilus bifax select a variety of roosts in littoral rainforest, with the most common being in foliage and tree hollows and on shallow depressions on tree trunks and limbs. This contrasts with the importance of hollows in large trees as roosts for *N. gouldi* in the eucalypt forests of southeast NSW (Lunney *et al.* 1988). Gaisler (1979) concluded in his review that nearly all free-roosting species are tropical, so the incidence of free roosting in *N. bifax* is consistent with its sub-tropical and tropical distribution (Parnaby 1987).

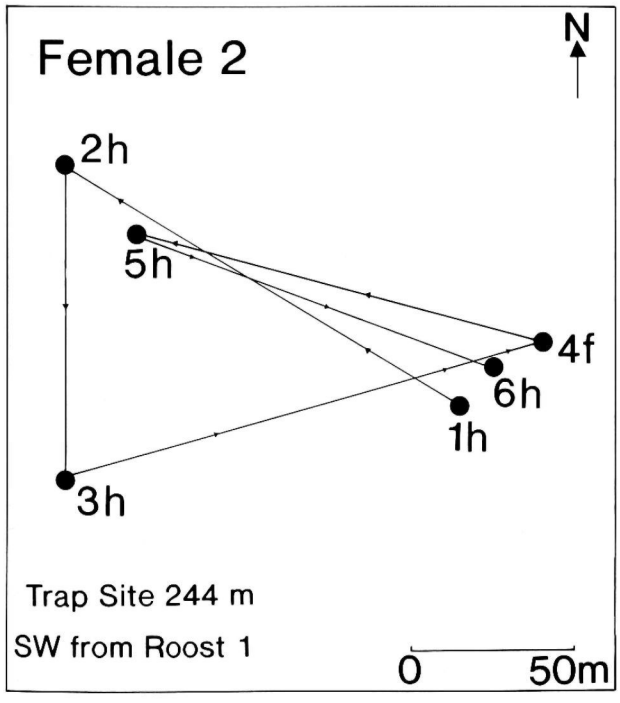


Fig. 1. Roost locations of Female 2 (tracked in November 1988) showing sequence of roosts used within littoral rainforest in Iluka Nature Reserve. Numbers refer to the days following the bat's release. f, Foliage roost; h, hollow roost; u, unknown roost type.

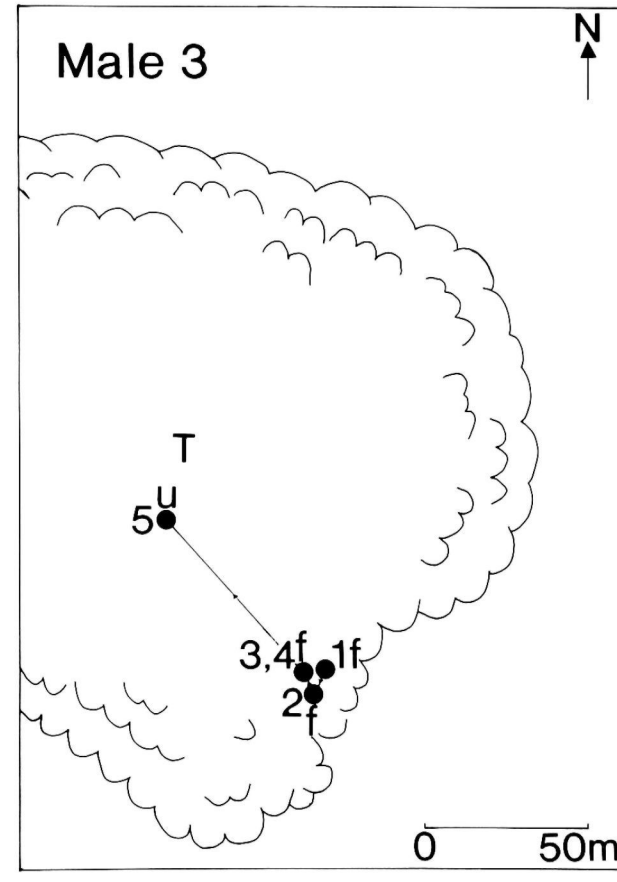


Fig. 2. Roost locations of Male 3 (tracked in May 1989) showing sequence of roosts used within littoral rainforest in Iluka Nature Reserve. Note the use of the forest edge by this male. Numbers refer to the days following the bat's release. T, trap site; f, foliage roost; h, hollow roost; u, unknown roost type.

The selection of the species, height and diameter of the trees, as well as the nature of the roosts used by *N. bifax* differed seasonally. The predominant roosts in May were among the foliage of small trees while in November hollows in tall trees were favoured. This corresponded to bats roosting in the low seaward-edge community of *C. anacardioides* in May and a shift to the taller, interior littoral rainforest community, dominated by *S. leuhmannii* and *A. hemilampra*, when the females were lactating in November. Further research is required to determine the cause of roost shifts, and to assess the extent to which it is an effect of sex or season. However, the movement to the centre of the rainforest may be a response to the change from winter to summer weather, with tree hollows in the rainforest interior providing a more buffered environment for lactating females and newborn young than elsewhere on the Iluka peninsula. A similar pattern of seasonal roost shift within the Iluka Nature Reserve was found for the year-round foliage-roosting common blossom bat *Syconycteris australis*; a shift to the rainforest interior correlated with warmer temperatures (Law 1993).

Communal roosts of *N. bifax* ranged from two to seven adults. In November, the two roosting aggregations that were closely examined contained only females. However, these aggregations were not binding as females moved between groups and sometimes roosted alone. Males were not observed roosting with females in November. In May, a male was observed sharing the same trees as a female on two consecutive days. Telemetered males were not found together, although on five occasions a telemetered male was seen sharing a roost with an untelemetered bat of unknown sex.

Like *N. gouldi* on the south coast of NSW (Lunney *et al.* 1988) and *S. australis* at Iluka (Law 1993), *N. bifax* changed roosts frequently and showed a strong fidelity to a cluster of trees (Kunz 1982). Lactating *N. bifax* repeatedly moved their young (usually twins) between roost sites. This behaviour was not found in captive *N. gouldi* (Phillips & Inwards 1985), although free-living lactating *N. gouldi* were found to move between roosts (Lunney *et al.* 1988). The weight of lactating *N. bifax* ranged from 10.0 to 12.5 g, with the two young representing an additional load of up to 95% of female body-weight. Despite this additional weight, lactating females changed their roosts more frequently than did bats during May. Moreover, lactating females did not move shorter distances between roosts, nor restrict nightly movements closer to their roosts than bats during May. These observations indicate that the energetic and aerodynamic stress of carrying a load (e.g. twins or transmitters) was not an impediment to bat movements.

The skewed sex ratio (M:F, 1:5.7) of captures in the littoral rainforest during November may reflect the greater foraging activity required by lactating females to meet their increased energetic expenditure (Barclay 1989). Alternatively, males may have used different habitats at this time of year. Barclay (1989) found that foraging females changed habitats as lactation developed, indicating that bats will forage in different habitats as reproductive status changes. Thus, a sex ratio heavily skewed towards females may indicate prime breeding habitat where resources are more plentiful.

Neither sex of *N. bifax* moved large distances. This is consistent with the small distances moved by *N. gouldi* in southeast NSW (Lunney *et al.* 1988) and observations of the highly manoeuvrable but slow flight of *Nyctophilus* species (Dwyer 1965; O'Neill & Taylor 1986). This suggests that *N. bifax* meet all their needs within the Iluka littoral rainforest where weather extremes are buffered (Nicholls 1966; Law 1993) and do not depend on the adjacent *Lophostemon–Eucalyptus* woodland for roosts or food. A shift in roost preferences within littoral rainforest, for hollows in November to foliage in May, identifies the need to conserve large habitat patches containing a diversity of roosting options. Moreover, a preference for foliage roosts in some seasons would make *N. bifax* susceptible to microclimate changes within the littoral rainforest following damage to the canopy. Maintenance of intact littoral rainforest is therefore critical for the conservation of *N. bifax* in NSW. These results also suggest that the great loss of littoral rainforest from sand mining and coastal development is a major threat for this species in NSW.

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