Breeding-habitat and nest-site characteristics of Scarlet Robins and Eastern Yellow Robins near Armidale, New South Wales

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I studied the selection of breeding habitat and nest microhabitat in Scarlet Robins *Petroica multicolor* and Eastern Yellow Robins *Eopsaltria australis*, in remnant woodland on the New England Tablelands of New South Wales in 2000–2002. Yellow Robins used breeding territories ($n = 10$) with significantly higher densities of rough-barked saplings, acacias and other (non-*Acacia*) shrubs than Scarlet Robin breeding territories ($n = 10$) and plots lacking Yellow Robins ($n = 7$). Yellow Robins nested mostly in gully and lower-slope positions, with a southerly aspect, >40 m from the woodland edge, whereas Scarlet Robins nested mostly on upper slopes and ridges, with no preferred minimum distance from the woodland edge. Most Yellow Robin nests (86% of 58) had overhead foliage within 1 m, shielding them from above, whereas over half (58% of 54) of Scarlet Robin nests were in unconcealed positions. Yellow Robin nests had significantly greater density of cover, and the surrounding habitat was more complex, than for Scarlet Robin nests, in 0.13-ha plots centred on the nest. Breeding success and fledgling survival in the Yellow Robin were positively related to the density of acacias, non-*Acacia* shrubs and rough-barked saplings (but not gum saplings) in breeding territories. Fledging success and juvenile survival in the Yellow Robin were also positively related to habitat complexity around nest-sites (but not distance to nearest cover, or items of cover within 20 m). Scarlet Robins had exposed nests and suffered high nest predation, with too few successful nests for comparison with unsuccessful nests. Habitat conservation for the Yellow Robin should address the complexity of the ground, shrub and sapling layer in woodland remnants; that for the Scarlet Robin may need to address foraging substrate and ecologically based control of nest predators.

Key words: Woodland birds, Habitat fragmentation, Nest sites, Habitat quality, Breeding success.

INTRODUCTION

ASPECTS of habitat degradation and simplification in fragmented landscapes were among the specific mechanisms hypothesized by Ford *et al.* (2001) for the continued loss of some bird species from woodland remnants in the sheep–wheat belt of southern Australia. Loss of mature trees and shrubs, understorey and micro-habitat elements such as logs and coarse woody debris in habitat remnants may mean reduced availability of nest sites, shelter, resources for nesting, or food, and may lead to increased nest predation. Furthermore, there has been disproportionate loss of some habitat types (e.g., on more nutrient-rich sites) or habitat components (e.g., particular plant species providing specific resources) from the landscape, with habitat degradation tending to be worse in small fragments (Ford *et al.* 2001).

Support for the habitat-degradation hypothesis has been found in recent Australian studies, with habitat quality in remnants being a critical factor in the persistence of many bird species (Watson *et al.* 2001). Woodland bird abundance and diversity are related to habitat attributes such as tree cover, shrub cover, logs, coarse woody debris and litter (Ford and Barrett 1995; Major *et al.* 2001; Mac Nally and Horrocks 2002; Mac Nally *et al.* 2002; Recher *et al.* 2002; Seddon *et al.* 2003; Watson *et al.* 2001, 2003). Small or riparian remnants tend to be more degraded, with activities such as grazing affecting birds identified as decliners (Hobbs 2001; Jansen and Robertson 2001; Watson *et al.* 2001; James 2003; Saunders *et al.* 2003). Conversely, small patches of high-quality habitat can support high avian diversity (Fischer and Lindenmayer 2002). The demography of some specialized species, such as treecreepers *Climacteris*, reflects their dependence on specific resources such as hollows (Luck 2002a,b).

The Scarlet Robin *Petroica multicolor* and Eastern Yellow Robin *Eopsaltria australis* (hereafter Yellow Robin) build open, cup-shaped nests in the woodland tree and shrub canopy, and are two of the "focal" species having demanding thresholds for patch size, connectivity and habitat complexity (Ford *et al.* 2001; Seddon *et al.* 2003; Watson *et al.* 2001, 2003). The present study addressed the habitat-degradation hypothesis by measuring habitat variables at two spatial scales for each robin species: (a) macrohabitat among breeding territories, and (b) microhabitat at the nest-site. Previous studies or reviews have described various aspects of the foraging or breeding habitat and nest-site characteristics of these species, and for the Western Yellow Robin *E. griseogularis* (Marchant 1985; Robinson 1990, 1992; Recher and Davis 1998; Zanette and Jenkins 2000; Higgins and Peter 2003; Seddon *et al.* 2003; Watson *et al.* 2003; Cousin 2004a,b). These studies highlight the importance, for Yellow or Scarlet Robins, of tree or shrub density, dead branches, coarse woody debris, litter, logs, site productivity or habitat complexity, although

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Robinson (1990) and Zanette and Jenkins (2000) found no relationship between nest success and vegetation cover or concealment index for Scarlet or Yellow Robins respectively. Zanette *et al.* (2000) identified a relationship between fragment size and food supply for Yellow Robins, and thus inferred an effect of habitat quality on Yellow Robins via resource levels in large versus small fragments (Zanette 2001).

The present study sought to compare the breeding habitat and nest microhabitat of the two robin species where they breed sympatrically in remnant woodland, and to investigate relationships between habitat variables and nest success, fledging rate, and survival to independence. It did not directly test the habitat-degradation hypothesis, but did investigate aspects of robin breeding in relation to habitat features that are frequently degraded by human activities. Details of robin nest-sites and breeding biology are given elsewhere (Debus 2006a,b). This study also sought to compare the habitat where Yellow Robins naturally occurred with the habitat at a site where Yellow Robins were experimentally translocated, after they had become extinct there (Debus and Ford, unpubl. data), to test the suitability of habitat for reintroduction.

STUDY AREA AND METHODS

Study site

The study site was Imbota Nature Reserve (formerly Eastwood State Forest), 10 km south-east of Armidale (30°30'S, 151°40'E) on the New England Tablelands of New South Wales. This woodland patch of 270 ha, including contiguous woodland on private land, has been described by Ford *et al.* (1985, 1986), NPWS (2002) and Hunter (2003). Imbota is gently undulating with low local relief (elevation range 60 m; Fig. 1); through the robin breeding season cool drizzle comes from the south-east and cold, violent weather from the west or south-west.

In 2000–2002 the reserve supported 10–12 pairs of Scarlet Robins, distributed fairly evenly throughout, and 8–12 pairs of Yellow Robins, distributed patchily though with similar numbers in each half (north and south) of the reserve (Debus 2006a). In the years before gazettal (1999), the patch had been grazed intermittently and with declining intensity by domestic stock, and is still grazed by rabbits and kangaroos (pers. obs.). The reserve had been unburnt for several decades, until four small-scale (1 ha), low-intensity controlled burns in different sites and seasons in 2000–01. These burns impinged on the territories of robins (three Scarlet, one Yellow), but not while nests were active, and did not affect nest plots except marginally for one Yellow Robin pair, which had one nest in a burnt plot a year after the fire. Some parts of Imbota were (until reservation) subject to frequent firewood collection, of both standing and fallen dead timber, by the public. The area of most intense firewood collection was concentrated around several Yellow Robin territories (pairs A, B, C, G; Debus 2006a). Density of breeding Pied Currawongs (*Strepera graculina*), the main nest predator, was fairly even in Imbota (Debus 2006c).

The Yellow Robin reintroduction site, Yina Nature Reserve (formerly Hillgrove Creek State Forest) 7 km north of Imbota, is woodland similar to that in Imbota (see Ford *et al.* 1985). Yina (150 ha) is more remote and difficult to access than Imbota and visited less frequently by the public, with no evidence of recent tree-felling or firewood collection. It has a similar grazing history to Imbota, with heavy grazing by sheep in the years before gazettal.

Habitat measurements and monitoring of nests

For each robin pair that had at least two known nests, a square of 1 ha was centred to enclose the maximum number of nests and to fall between any other nests, outside the 1 ha, for that pair (n = 10 plots for each robin species). Within the hectare thus deemed to be representative of each pair's nesting territory, the following items were counted systematically (as number of items per ha):

- rough-barked *Eucalyptus* trees (stringybarks, boxes);
- smooth-barked *Eucalyptus* trees (gums);
- rough-barked saplings (stringybarks, boxes);
- smooth-barked saplings (gums);
- shrubs >1 m tall (*Acacia*, non-*Acacia*);
- standing dead trees, saplings and shrubs that provided apparently suitable nesting forks for robins (based on the types of forks supporting >100 observed nests); and
- logs and rotting coarse woody debris more than 10 cm thick × 50 cm long (taken as the minimum size likely to offer foraging substrate and/or prey harbour).

Eucalypts were classified as saplings rather than trees if the trunk diameter was <10 cm and/or height <10 m, and growth form consisted of a single leader with no lateral forks suitable for a robin nest (versus side branches with suitable forks). Saplings were counted if they were large enough to support a robin nest.

Macrohabitat characteristics were also measured in 1-ha plots (n = 7) in central and eastern parts of Imbota where Yellow Robins did not breed (Fig. 1) and were not seen foraging during the

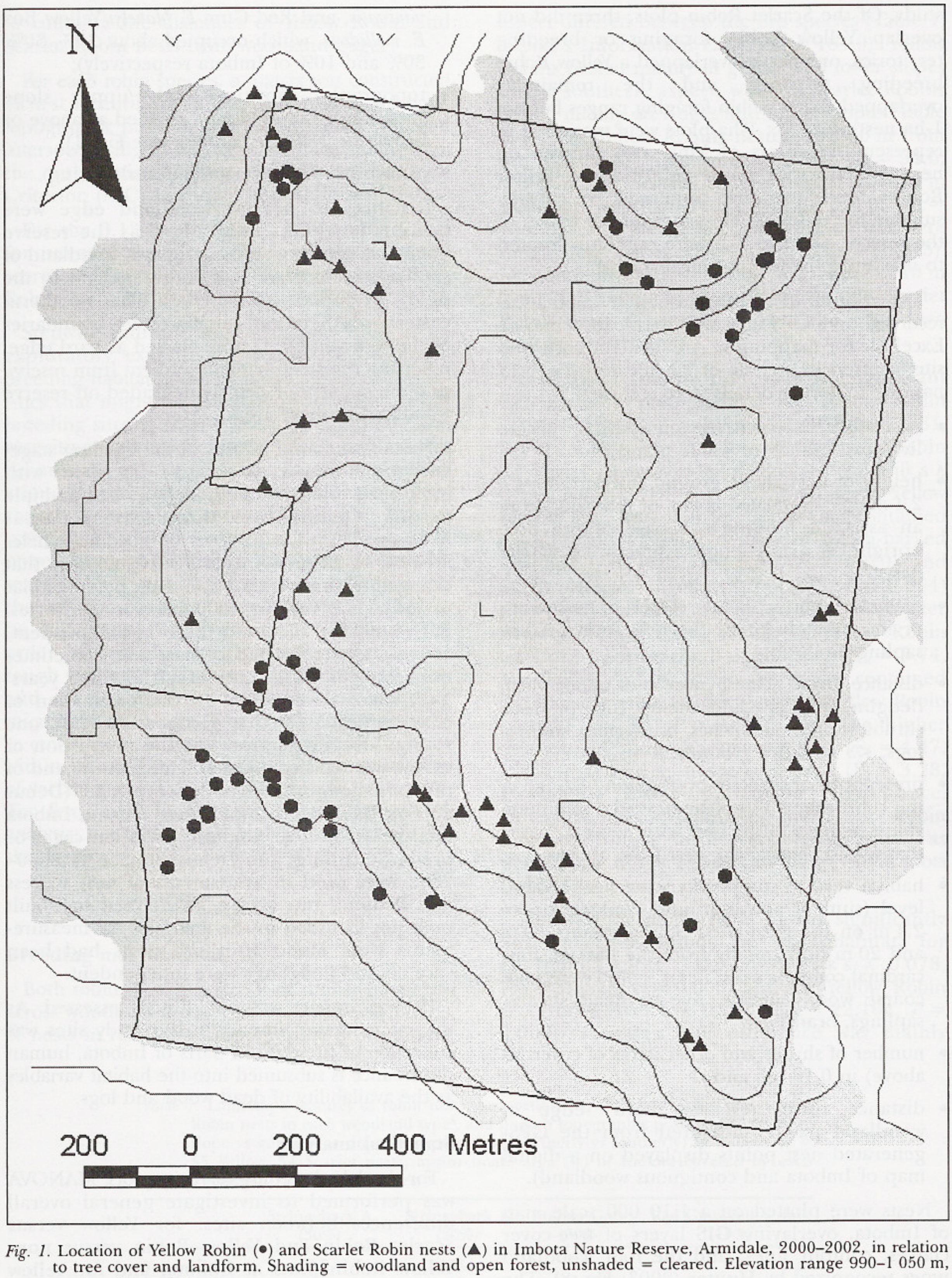

Fig. 1. Location of Yellow Robin (●) and Scarlet Robin nests (▲) in Imbota Nature Reserve, Armidale, 2000–2002, in relation to tree cover and landform. Shading = woodland and open forest, unshaded = cleared. Elevation range 990–1 050 m, contour interval 10 m.

study. Of the Scarlet Robin plots, three did not overlap Yellow Robin foraging or breeding territories, one partly overlapped a Yellow Robin breeding territory, and the remainder overlapped Yellow Robin foraging ranges but not 1-ha nest plots. Six 1-ha plots were measured in representative parts of Yina: two centred on nesting territories where reintroduced Yellow Robins bred, two that appeared structurally suitable for Yellow Robins, in opposite halves of the reserve, and two that were randomly located to maximize the geographical spread.

The position of each robin nest at Imbota was recorded on a GPS unit and downloaded into an Excel file for mapping in ArcView. For each nest site, centred in a circle of 20 m radius (= 0.13 ha), the following details were recorded:

- nest substrate type (tree/sapling/shrub, species, live/dead branch or whole plant);
- height of nest above ground (measured on a 2.4-m pole graduated in cm, or estimated from an assistant holding the base of the pole upright, at arm's length, directly below the nest);
- diameter at breast height (DBH) of nest plant, or immediately below the nest fork if a low sapling or shrub;
- distance (m) to nearest cover in or under which fledgling robins could shelter (live or dead shrubs, saplings, branches, brush-piles, stumps, logs, <3 m above ground);
- presence or absence of overhanging foliage in the cubic metre above the nest (the minimum value being a branchlet with several leaves that would conceal the nest from above);
- habitat vertical complexity score near ground level (sum of above-ground contacts up to 2.4 m on the graduated pole at points 10 m and 20 m horizontally from the nest on four cardinal compass axes; items scored were logs, coarse woody debris, live or dead shrubs, saplings, branches);
- number of shrubs and other items of cover (as above) in 0.13 ha; and
- distance from nest to "hard" edge of woodland patch (measured from the GPS-generated nest points displayed on a digital map of Imbota and contiguous woodland).

Nests were plotted on a 1:10 000 scale map of Imbota, overlaying GIS layers of tree-cover classes, contour lines, and the four woodland types recognized by Hunter (2003: Fig. 8). The number of nests of each robin species was counted in each habitat category:

- grassy woodland class (Stringybark *Eucalyptus caliginosa* on deep soils, Stringybark on shallow rocky soils with sparse grass, Manna Gum *E. viminalis*, and Red Gum *E. blakelyi*/Yellow Box *E. mellidora*, which occupied about 30%, 30%, 30% and 10% of Imbota respectively);
- topographic position (ridge/upper slope versus gully/lower slope), defined as above or below the 1 020 m contour (see Fig. 1);
- aspect (northerly versus southerly facing).

Distances to nearest woodland edge were measured, taking "hard edge" as the reserve boundary except where contiguous woodland of similar structure and quality (as judged in the field) extended off reserve. The northern, eastern, southern and lower western boundaries of the reserve (Fig. 1) were classed as hard edge, reflecting the steep habitat gradient from reserve to open country or heavily degraded off-reserve woodland in these areas.

Nests were found (mostly at the building stage) and monitored as previously described, with most birds colour-banded; all pairs had multiple nesting attempts over three seasons (Debus 2006a,b). There was turnover of breeding females in most territories, including five females that changed territories, thus removing potential bias of individual females in particular territories. Each breeding event was taken as independent, as most territories had at least one, sometimes two, changes of females over the three years. Nest success was taken as the proportion of clutches initiated that fledged at least one young; juvenile survival was the proportion of colour-banded fledglings still alive at the end of the post-fledging dependence period (Debus 2006a). Data for all unprotected nests in Imbota (i.e., not subject to predator-exclusion cages or predator culling; see Debus 2006c) in 2000–2002 were used in assessments of nest success and fledging rate. Nests abandoned half-built were not included in the analyses. All measurements were made after the nests had been vacated and fledglings were independent.

Human impact was not directly assessed. As the main human impact in the study sites was collection of firewood in parts of Imbota, human disturbance is subsumed into the habitat variables as the availability of dead wood and logs.

Statistical analysis

For the 1-ha breeding-territory plots, MANOVA was performed to investigate general overall differences between sites: for Yellow versus Scarlet Robin and Yellow Robin versus non-Yellow Robin plots at Imbota, and for Yellow Robin territories at Imbota versus Yina plots and all Imbota plots versus Yina. Associated one-way ANOVAs were performed to investigate specific differences between sites for each of the individual habitat components measured. Two-sample *t*-tests for unequal variances were used to compare the distances of Yellow Robin and Scarlet Robin nests from woodland edge.

For each robin species, a matrix was constructed of nest location by habitat class (woodland type, topographic position and aspect), and compared interspecifically by means of log-linear modelling, the test statistic being Akaike's Information Criterion (AIC; Burnham and Anderson 2002).

For the 0.13-ha nest plots, two-sample *t*-tests for unequal variances were performed on the scores obtained for Yellow Robin versus Scarlet Robin nests, for each variable measured.

Stepwise multiple regression was used in an exploratory exercise to identify Yellow Robin breeding-habitat and nest microhabitat characteristics that might be associated with measures of breeding success (nest success, fledging rate and recruitment to independence). This method was deemed the most appropriate, based on consideration of the data (breeding-outcome scores rather than simple succeed/fail). The habitat components tested were those that approached or reached significance in the ANOVAs for nest macrohabitat and *t*-tests for nest microhabitat; that is, elements of the understorey inferred to be important. For breeding macrohabitat, the order of variables entering the regression was rough saplings, smooth saplings, wattles (*Acacia*), and other shrubs (non-*Acacia*). For breeding microhabitat, the order of variables was distance to cover, vertical complexity, and items of cover within 20 m. The possibility of intercorrelation of variables is avoided by the stepwise procedure. Too few Scarlet Robin nests were successful for analysis; most were built high in trees, above the shrub layer.

RESULTS

Breeding macrohabitat

Both robin species nested with similar frequency across woodland types. However, the distribution of nests in relation to topographic position and aspect differed between the two species (Table 1; Akaike's Information Criterion = 164.9). Yellow Robins nested mainly in gullies and lower slopes with a southerly aspect, whereas Scarlet Robins nested mainly on ridges and upper slopes (Table 1, Fig. 1). Yellow Robins nested 40–380 m from the woodland edge (mean 218 m, sd = 94.6, $n = 58$), and Scarlet Robins nested 10–530 m from the woodland edge (mean 250 m, sd = 165, $n = 54$). Mean nest-to-edge distances were similar for each species ($t_{83} = -1.25$, $P = 0.213$). However, no Yellow Robin nests were <40 m from the woodland edge, whereas five Scarlet Robin nests were <30 m from the edge (two <10 m, two <20 m).

Overall, at Imbota there was no significant difference in macrohabitat for Yellow Robin versus Scarlet Robin (MANOVA: Wilk's λ 0.381, $F_{8,8} = 2.236$, $P = 0.108$) or Yellow Robin territories versus non-Yellow Robin plots (Wilk's λ 0.359, $F_{8,8} = 1.784$, $P = 0.215$). However, Yellow Robins used breeding territories that contained a significantly higher density of rough-barked saplings (ANOVA: $F_1 = 6.57$, $P = 0.020$) and wattle (*Acacia*) shrubs ($F_1 = 10.85$, $P = 0.004$) than Scarlet Robin territories, and the higher density of non-*Acacia* shrubs in Yellow Robin territories approached significance ($F_1 = 3.74$, $P = 0.069$). Yellow Robin territories contained significantly more wattles than non-Yellow Robin plots ($F_1 = 7.65$, $P = 0.014$), and the higher densities of rough-barked saplings ($F_1 = 4.47$, $P = 0.052$) and non-*Acacia* shrubs ($F_1 = 3.28$, $P = 0.090$) also approached significance. Otherwise, Yellow Robin plots and Scarlet Robin plots were similar in the variables measured, as were Yellow Robin versus non-Yellow Robin plots (Table 2).

Yina (all six plots, Table 3) was significantly different from Imbota in macrohabitat, for all Imbota plots (MANOVA: Wilk's λ 0.078, $F_{8,8} = 30.828$, $P = 0.000$) and for Yellow Robin plots only (Wilk's λ 0.038, $F_{8,8} = 22.164$, $P = 0.000$). However, the difference was mainly

Table 1. Landscape features of robin nests: proportion (%) of Yellow Robin and Scarlet Robin nests in each woodland type^{A}, and in each topographic position (ridge/upper slope vs gully/lower slope) × aspect class (northerly vs southerly) in Imbota. N = 55 Yellow, 54 Scarlet nests; approximate area (%) of Imbota covered by each woodland type in parentheses.

	Stringybark A (30%)	Stringybark B (30%)	Manna Gum (30%)	Red Gum/Yellow Box (10%)
Yellow Robin	55	31	13	2
Scarlet Robin	39	43	19	0
	Yellow Robin:		Scarlet Robin:	
	North	South	North	South
Ridge	9	24	20	43
Gully	13	55	28	9

^{A}Stringybark type A = deep soils; stringybark type B = shallow rocky soils and sparse grass cover.

Table 2. Habitat characteristics of 1 ha plots in Imbota, in Yellow Robin nesting territories, Scarlet Robins nesting territories, and plots where Yellow Robins absent. Range (mean); rough = rough-barked eucalypts (*Eucalyptus* spp.).

Variable (number/ha)	Yellow Robin ($n = 10$)	Scarlet Robin ($n = 10$)	Non-Yellow Robin ($n = 7$)
Trees:			
rough	123–284 (189)	78–261 (172)	152–198 (172)
gums	2–86 (37)	4–103 (34)	15–56 (40)
total	164–286 (226)	116–265 (206)	173–243 (212)
Saplings:			
rough	40–591 (186)	21–114 (59)	40–90 (61)
gums	8–129 (62)	2–93 (43)	27–76 (41)
total	79–720 (248)	35–166 (102)	75–166 (102)
Shrubs[a]:			
Acacia	102–339 (183)	41–151 (96)	21–151 (66)
other	7–1 292 (370)	8–188 (65)	8–63 (28)
total	132–1 631 (554)	73–259 (161)	39–170 (123)
Standing dead[b]	25–209 (79)	17–156 (69)	41–91 (63)
Logs[c]	12–195 (107)	16–147 (85)	57–142 (100)

[a]More than 1 m high. [b]Trees, saplings, shrubs. [c]Includes rotting coarse woody debris more than 10 cm thick × 50 cm long.

Table 3. Habitat characteristics of 1 ha plots at Yina in two Yellow Robin nesting territories and four other plots (two that appeared suitable for Yellow Robins, two randomized): range (mean); rough = rough-barked eucalypts (*Eucalyptus* spp.).

Variable (number/ha)	Nest territories ($n = 2$)	Other plots ($n = 4$)	All plots ($n = 6$)
Trees:			
rough	131, 141	83–224 (160)	83–224 (152)
gums	5, 13	5–31 (21)	5–31 (17)
total	144, 146	113–240 (181)	113–240 (169)
Saplings:			
rough	181, 255	43–79 (58)	43–255 (112)
gums	63, 186	22–79 (53)	22–186 (77)
total	318, 367	65–158 (111)	65–367 (188)
Shrubs[a]:			
Acacia	47, 55	41–437 (210)	41–437 (157)
other	4, 30	35–145 (67)	4–145 (50)
total	51, 85	89–475 (276)	51–475 (207)
Standing dead[b]	21, 64	21–72 (44)	21–72 (43)
Logs[c]	188, 297	210–296 (247)	188–297 (245)

[a]More than 1 m high. [b]Trees, saplings, shrubs. [c]Includes rotting coarse woody debris more than 10 cm thick × 50 cm long.

attributable to the higher density of logs at Yina (versus all Imbota plots: ANOVA $F_1 = 35.69$, $P = 0.000$; versus Yellow Robin plots: $F_1 = 16.79$, $P = 0.001$). Yina also had marginally fewer gums than Imbota, a difference approaching significance (all Imbota plots: $F_1 = 3.74$, $P = 0.063$; Yellow Robin plots: $F_1 = 3.48$, $P = 0.083$). Otherwise, Yina was similar to Imbota in macrohabitat variables, particularly those that separated Yellow from Scarlet Robins at Imbota, or Yellow Robin from non-Yellow Robin plots at Imbota (Tables 2, 3).

Scarlet Robins occurred at similar density in Yina as in Imbota (pers. obs.; Debus 2006a) and occurred at over half the points in Yina surveyed by A. Harrison (unpubl. data). Habitat values at Yina were within or overlapped the range of values suitable for Scarlet Robins at Imbota (Tables 2, 3).

Nest microhabitat

Yellow Robins tended to nest in the middle and lower strata, in sheltered sites in saplings or shrubs, whereas Scarlet Robins tended to nest in the tree canopy or middle strata, in exposed sites (Debus 2006b). Most Yellow Robin nests (86%) had foliage shielding them from above, whereas over half (58%) of Scarlet Robin nests were not concealed from above (Table 4). However, Scarlet Robin nests (including those in dead trees or wattles; Debus 2006b) were located within or below the woodland canopy. Yellow Robin nests had significantly greater density of cover for fledglings ($t_{64} = 3.82$, $P = 0.000$) and greater habitat vertical complexity near ground level ($t_{67} = 3.71$, $P = 0.000$) than Scarlet Robin nest-sites, but nests for both species were at similar distances to nearest cover for fledglings ($t_1 = -1.29$, $P = 0.200$) (Table 4).

Table 4. Characteristics of Yellow Robin and Scarlet Robin nest-sites: range (mean ± sd) in 0.13 ha nest-centred plots. Foliage score = % of nests with foliage present in 1 m^3 above nest; complexity score = sum of above-ground contacts on a 2.4 m graduated pole at points 10 m and 20 m from the nest on four cardinal axes; cover = number items in which a fledgling robin could shelter; distance = distance to nearest cover.

Variable	Yellow Robin	Scarlet Robin
Foliage score (%)	86	42
Complexity score[a]	0–29 (5.5 ± 8.2)	0–12 (1.3 ± 2.4)
Cover (n items)[b]	13–1000 (142 ± 150)	16–188 (64.2 ± 37.4)
Distance (m)	0–9 (2.1 ± 1.9)	0–10 (2.7 ± 2.3)
Total nests	58	54

[a] Items scored: logs, coarse woody debris, shrubs, saplings, branches. [b] Live or dead shrubs, saplings, branches, brush-piles, stumps, logs, <3 m above ground.

Habitat variables and breeding success

Within each Yellow Robin territory over three seasons, nest success (% attempts succeeding) ranged from zero to 83%, the number of fledglings ranged from zero to 1.83 per attempt, and the number of independent juveniles ranged from zero to 1.17 per attempt (Tables 5, 6). Of the four macrohabitat attributes tested, there was a significant positive relationship between elements of the understorey (shrub density, sapling density) and Yellow Robin nest success, fledging success, and juvenile survival to independence. Nest success was related to density of wattles (*Acacia*) ($P = 0.034$) and non-*Acacia* shrubs ($P = 0.001$; $r^2 = 0.72$); fledging rate (number fledglings per attempt) was related to density of rough-barked saplings ($P = 0.076$), wattles ($P = 0.038$) and non-*Acacia* shrubs ($P = 0.001$; $r^2 = 0.83$); and juvenile survival rate (number young surviving to independence per attempt) was related to density of rough-barked saplings ($P = 0.08$) and non-*Acacia* shrubs ($P = 0.001$; $r^2 = 0.80$) (Table 5). Density of gum saplings was not identified as a significant attribute.

Table 5. Yellow Robin breeding macrohabitat attributes (number stems in 1-ha plots) versus mean nest success, number fledglings per attempt, and number recruits to independence per attempt. Pair code (*n* attempts); saplings = rough-barked; shrubs = non-*Acacia*.

Pair (*n*)	Saplings	Wattles	Shrubs	Nest success	Fledglings	Recruits
A (4)	105	192	141	0	0	0
B (4)	128	135	21	0.25	0.5	0.25
C (6)	98	125	7	0.17	0.33	0.17
D (6)	148	102	44	0.33	0.5	0.5
E (6)	237	339	1292	0.67	1.17	1.17
F (6)	212	188	1165	0.83	1.83	1.17
G (4)	195	265	11	0	0	0
H (4)	591	127	671	0.5	0.5	0.25
I (2)	40	165	252	0.5	0.5	0.5
J (3)	107	195	99	0	0	0
Mean	186	183	370	0.33	0.53	0.4

Table 6. Yellow Robin nest microhabitat attributes versus number fledglings per nest and number recruits to independence per nest. Pair code (*n* nests measured): complexity = vertical habitat complexity score (see Table 3); cover = mean number of items in 0.13-ha nest plots for each territory. For several pairs, the number of nests that could be measured at the micro scale was slightly different from the number of nesting attempts in the respective 1-ha territory plot (cf. Table 5).

Pair (*n*)	Complexity	Cover	Fledglings	Recruits
A (4)	2.75	197	0	0
B (4)	1.75	67	0	0
C (6)	1.17	33	0.33	0.17
D (6)	0.83	97	0.5	0.5
E (6)	10.43	226	1.17	1.17
F (5)	13.0	234	1.6	1.2
G (4)	1.25	68	0	0
H (3)	8.33	133	0.33	0
J (3)	1.33	110	0	0
Mean	4.54	129	0.45	0.34

Of the three nest microhabitat attributes tested, there was a significant positive relationship between mean values within a territory and Yellow Robin fledging rate (number young fledged per attempt) and juvenile survival to independence (number independent young per attempt) for one factor. Fledging rate was positively related to mean habitat complexity in nest plots ($P = 0.006$; $r^2 = 0.64$), as was juvenile survival rate ($P = 0.02$; $r^2 = 0.50$) (Table 6). Distance to nearest cover or density of items of cover were not identified as significant factors.

There were too few successful Scarlet Robin nests to test for relationships between habitat variables and breeding success, owing to the high nest-predation rate (Debus 2006a,c).

DISCUSSION

This study was not a strict test of the habitat-degradation hypothesis, as it did not compare remnants of differing human-disturbance regimes and does not prove that any declines in robin populations are attributable to habitat degradation. However, for Yellow Robins it identified habitat features that are more prevalent near nests, and it compared aspects of breeding success within a remnant of variable habitat quality, and thus identifies some of the habitat-related factors that are correlated with reproductive success. Many of the habitat features found to be important, for example sapling and shrub layer, and vertical complexity, are those susceptible to degradation by human activities.

Breeding macrohabitat

Yellow Robins and Scarlet Robins selected different macrohabitats for nesting territories, with Yellow Robins nesting in the areas with a denser lower storey (i.e., those that had more rough-barked saplings, wattles and other shrubs). This difference is consistent with the Yellow Robin's preference for nesting in rough-barked saplings and live non-*Acacia* shrubs, and with its fledglings sheltering in low shrubs, whereas the Scarlet Robin nests in live or dead trees or dead wattles and its fledglings often shelter in trees (Debus 2006b). Such habitat selection by each species at Imbota is consistent with knowledge of their habitat preferences elsewhere: Yellow Robins prefer a dense shrub and sapling layer, whereas Scarlet Robins prefer a sparse shrub and sapling layer and open ground (Robinson 1992; Higgins and Peter 2003). The Yellow Robin's preference for gullies and lower slopes, with a southerly aspect, may be related to its requirement for moist litter and abundant invertebrates, or there may be more shrubs and saplings in such areas. Aspect preference appeared not to be related to exposure to wind or rain. Scarlet Robins were more willing to nest near the woodland edge and sometimes foraged in adjoining pasture particularly in winter, though also in the breeding season (pers. obs.).

Yina and Imbota had a wide range of values for the habitat variables measured. The difference in macrohabitat values — that is, more logs at Yina — is largely attributable to the high rate of firewood collection by humans at Imbota. The lower density of gums suggests that Yina may be less productive (Debus *et al.* 2006), although the greater abundance of coarse woody debris may provide more food or foraging substrate for robins. Otherwise, habitat values for Imbota and Yina are similar.

Yina has areas that are structurally suitable, in the tree and shrub layer, for Yellow Robin reintroduction, which succeeded (Debus and Ford, unpubl. data), thus reinforcing the value of studies of habitat suitability at potential translocation sites. The fact that the species was absent from the site until reintroduction suggests that habitat quality may not be the only reason that Yellow Robins are absent from several woodland remnants in New England.

Nest microhabitat

Yellow Robins and Scarlet Robins selected different microhabitats for nest-sites, with regard to foliage cover, vertical habitat complexity below 3 m, and density of shelter below 3 m for fledglings, with Yellow Robins nesting in more sheltered sites having more low cover in the vicinity of nests. This difference is consistent with the Yellow Robin's preference for low nests, in small-diameter plants, often in or near thickets where its fledglings hide, whereas Scarlet Robins nest high in exposed sites and their young can fly soon after fledging (Debus 2006b). These differences at Imbota are consistent with knowledge of the two species' nest-site characteristics elsewhere (reviewed in Higgins and Peter 2003).

Habitat and breeding success

Habitat variables related to reproductive success were more prevalent in territories used by Yellow Robins than in areas not used. The exploratory regression analyses identified positive relationships between breeding macrohabitat or nest microhabitat parameters (sapling and shrub density, habitat vertical complexity) and all measures of breeding success (nest success, fledging rate and recruitment to independence) for the Yellow Robin. However, further testing is required to establish the importance of the selected factors. Predator densities may also be important, although they appeared to vary little within Imbota. For instance, nesting currawongs were fairly evenly distributed (Debus 2006c), and the territories of individual pairs encompassed those of several robin pairs (pers. obs.).

The regression outcomes might be expected, in view of the Yellow Robin's association with the shrub layer (Ford and Barrett 1995; Higgins and Peter 2003; Debus 2006b). Zanette and Jenkins (2000) may have detected no relationship between nest success and nest cover or concealment because: (a) they measured cover in a different way from this study (% foliage cover vs stem density); (b) they measured lateral visibility, although visibility from above may be more important because large birds are the main nest predators (Debus 2006a,c); and (c) there may have been additional predators, such as mammals and reptiles, at their sites. Marchant (1985) considered that Yellow Robin nests were often built in precarious, unconcealed positions, though not easily seen (by humans), and probably sited to deter mammalian predators. Robin nests (especially Scarlet) are cryptic in side view, closely resembling their substrate, but unattended eggs are visible from above unless shielded by overhanging foliage (pers. obs.). In this study, the Yellow Robin nests that consistently succeeded, producing 1–3 fledglings from each of usually two successful nests per year, were those located in large *Cassinia* thickets >0.25 ha (pairs E and F; Debus 2006a).

Predation continues after fledging, so cover for fledglings is important in their survival to independence and recruitment as breeders or dispersers (Debus 2006a,b,c). Yellow Robin fledglings require cover (shrubs, logs, coarse woody debris) at ground level (Debus 2006b). In this study, those Yellow Robin territories consistently rearing 1–3 fledglings per brood, usually twice per year, to independence were those territories containing extensive *Cassinia* and *Olearia* thickets (pairs E and F; Debus 2006a). Conversely, four pairs that had consistently low fledging success and survival to independence, producing a combined total of three recruits from four successful nests in three years, were those territories lacking thickets and logs (pairs A, B, C, G; Debus 2006a). The latter four territories, around the part of Imbota most frequented by humans, were subject to firewood removal (pers. obs.). Furthermore, there were three and two changes of female in territories E and F, respectively, over the three years, suggesting that territory quality played an important role in the high success of those territories.

The consistently high nest-predation rate on Scarlet Robins precluded any assessment of habitat correlates. Their nests, including those on dead trees or branches, were within the outer woodland canopy, though often not shielded directly by overhanging foliage. Robinson (1990) found no relationship between nest success and concealment score for this species. Scarlet Robins appear to rely on well-camouflaged nests and behavioural strategies rather than cover to avoid nest predation (Debus 2006b). Although their nesting substrates may deter some mammalian predation, they are probably vulnerable to avian predation, as suggested for the Noisy Friarbird *Philemon corniculatus* at Imbota (Ford 1999).

Predicting high-quality habitat for robins

Given the results of this study, and the fact that high-quality Yellow Robin territories at Imbota were continually occupied whereas some apparently lower quality territories were not (Debus 2006a), high-quality habitat for Yellow Robins may be predictable. It appears that good habitat for Yellow Robins, in the context of remnant eucalypt woodland on the tablelands, has about 200 rough-barked saplings per hectare, 200 wattles per hectare, >1000 non-*Acacia* shrubs per hectare, and a habitat complexity score (as measured in this study) of >10 (Tables 5, 6). Remnants with these characteristics may predict a high likelihood of healthy population status and persistence for the Yellow Robin, or, if Yellow Robins are absent, such sites may be suitable for reintroduction.

Synthesis: habitat, nest predation and recruitment

The results of this study support the hypothesis that aspects of habitat quality or complexity, in the context of remnant grassy woodland types on the tablelands, are important for Yellow Robins, and thus indirectly support the habitat-degradation hypothesis. Habitat quality appears to affect breeding success. Degradation by human activities affects habitat quality, by removing key elements such as saplings and shrubs, and simplifying the near-ground structure. (However, "woody weeds" in other contexts, such as *Callitris* regrowth in previously overgrazed and degraded habitat on the inland slopes, may provide good robin refuge; Major *et al.* 2001.) As well as a structural component, habitat quality may be expressed through food supply, which can affect robin demographics and breeding performance (Zanette 2001).

The results of this study show that Yellow Robins at Imbota occurred and bred mainly in the downslope parts that had thickets of *Cassinia*, *Olearia* or bipinnate wattles, and Scarlet Robins occurred and bred in the more open mid-slopes to ridges. The results are consistent with the dependence of the Eastern Yellow Robin, Western Yellow Robin and Scarlet Robin on aspects of the shrub or ground layer (Robinson 1992; Ford and Barrett 1995; Recher and Davis 1998; Recher *et al.* 2002; Higgins and Peter 2003; Seddon *et al.* 2003; Watson *et al.* 2003; Cousin 2004 a,b).

The results of this study are also consistent with those on nest predation in the two robin species (Debus 2006c). Yellow Robins, using more cover than Scarlet Robins, appear to avoid nest and fledgling predation more frequently, and produce enough young to maintain an apparently stable population at Imbota (Debus 2006a). With a reduction in nest predation, they produce some recruits for dispersal to other patches (Debus 2006c; Debus and Ford, unpubl. data). The more open-nesting Scarlet Robin has poor recruitment and a shortage of females at Imbota, where its population may be maintained by immigration from more productive areas (Debus 2006a,b,c).

The Scarlet Robin's population decline in much of New South Wales, including New England (Barrett *et al.* 2003), may be attributable to poor fledging success and recruitment. For robins and other small passerines there is an interaction between habitat, food supply and abundance of nest predators (Zanette *et al.* 2000, 2003). Resources determine male foraging efficiency, which determines the foraging effort and nest attentiveness of breeding females (because males feed incubating and brooding females). Female foraging effort determines the length of time the nest is left uncovered, and hence its vulnerability to predation. Scarlet Robin nests appear to rely on the cover of cryptically plumaged females to shield them from predators (Debus 2006b). Thus, the Scarlet Robin may suffer disproportionately from an increased abundance of avian nest predators (Debus 2006c), particularly if its foraging efficiency is reduced by loss of foraging substrate (logs and coarse woody debris; Higgins and Peter 2003).

Management implications

The Yellow Robin appears to be maintaining its population in New England and in New South Wales, as it showed no decline in reporting rates between 1977–81 and 1998–2002 (Barrett *et al.* 2003). However, it has disappeared from some woodland remnants on the Armidale Plateau (Debus *et al.* 2006; Debus and Ford, unpubl. data), including some that are suitable, perhaps owing to chance extinction and failure to recolonize. It would benefit from a reduction in nest predation (Debus 2006c) and from regeneration of the indigenous shrub layer in rural woodlots and other remnant woodland (this study). Such changes to remnant woodland would produce more recruits to maintain existing subpopulations and found new subpopulations. It would also benefit from management of woodlands, for instance by judicious use of fire, to maintain cohorts of eucalypt saplings, wattles and other shrubs.

Although the Scarlet Robin is declining, it is still present in most remnants on the Armidale Plateau (pers. obs.; A. Harrison, unpubl. data) and there appear to be enough potential patches to provide emigrants to Imbota or Yina. Action is required to halt or reverse its general decline. As there is a synergistic benefit between increased food supply and reduced predators (Zanette *et al.* 2003), a solution should combine control of the Pied Currawong *Strepera graculina*, a major nest predator (Debus 2006a,c), with management of remnant woodland to maintain and ultimately restore the robins' foraging resources. Control of currawongs should be ecologically based, targeting eradication of their winter food sources of exotic, invasive berry-bearing plants (Debus 2006c). Management of remnant woodlands should address complexity of the ground layer (Ford and Barrett 1995), an issue that includes the control of firewood collection on public lands. Future research should focus on detailed foraging ecology, substrates preferred and microhabitat variables that increase foraging efficiency of robins.

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