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The Consequences of Selective Logging for Bornean Lowland Forest Birds

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The consequences of selective logging for Bornean lowland forest birds

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SUMMARY

In lowland dipterocarp forest in Sabah, Malaysia, most primary forest bird species were present in areas selectively logged eight years previously. However, certain taxa, notably flycatchers, woodpeckers, trogons and wren-babblers, became comparatively rare. In contrast, nectarivorous and opportunistic frugivorous species were significantly more abundant. Few species appeared to change foraging height, but netting rates suggest that the activity of some species had increased, or that some birds ranged over larger areas after logging. Although there is still much to be learned about the survival of birds in logged forest, large areas of this habitat are important for bird conservation. However, the susceptibility of logged forest to fire, and our present incomplete understanding of bird behaviour and population dynamics in logged forests mean that they should not be considered by conservationists as alternatives to reserves of primary forest.

1. INTRODUCTION

Primary forests throughout Asia are rapidly being logged. In Malaysia, of an estimated 19.8 million hectares (ha)† of forest remaining in 1986, 14.8 million ha (74.7%) were reserved as production forest (Nectoux & Kuroda 1989), and subjected to selective logging, which, in theory, is repeatable on a 25–40-year cycle. However, logging practices in East Malaysia are such that it is questionable whether the process is sustainable (Nectoux & Kuroda 1989; Johns 1989*b*).

Sabah in East Malaysia has *ca.* 4.7 million ha of forest of which 2.7 million ha have been or will be logged in the next few years; only 229510 ha (0.5%) have been designated as permanent virgin forest reserve (Sabah Forestry Department 1989). In Sabah 3.5% of production forests are selectively logged annually. An increasing proportion of these forests has therefore been subjected to a first cycle of selective logging and is in the phase of regeneration. Soon, all production forest will be in this condition (Earl of Cranbrook, personal communication).

Few studies have investigated the avifaunas of regenerating forest. In Malaysia, such studies (McClure & Othman 1965; Wong 1985, 1986; Johns 1986, 1988*a*, 1989*a*, *b*, this symposium) have provided contradictory results. This paper documents an intensive study in which several census methods were used to compare birds in a selectively logged and an unlogged area. In this area hunting is negligible: hence the results are not complicated by hunting, which can be intensive in forests made accessible by networks of logging roads.

† 1 ha = 10^4 m²

2. STUDY SITES

The study was conducted between May 1989 and October 1990 within the 9782 km² Ulu Segama Forest Reserve, Sabah (see also Johns, this symposium). Trail systems were cut in two plots of similar undulating topography, dissected by numerous small streams. Study sites were located at similar altitude (180–240 m) and were adjacent to major rivers.

The primary forest plot (plot P), of *ca.* 33 ha, was situated adjacent to the Segama River and within the Danum Valley Conservation Area (see Marsh & Greer, this symposium). The vegetation of plot P was *Parashorea malaanonan* type forest (Lambert 1990*b*, Newbery *et al*, this symposium). The logged 1981 plot (plot L81), of *ca.* 30 ha, was adjacent to the Bole River, some 10 km from plot P. L81 had been selectively logged in February and March 1981 using tractors to extract the timber. When logged it was approximately 1 km from unlogged forest, but that area was itself logged in early 1983. Timber extraction was *ca.* 90 m³ ha^{-1} (Lambert 1990*b*). During the study the nearest unlogged forest to the plot was a 50 ha patch within logged forest, *ca.* 2 km from L81, whereas *ca.* 3 km distant was an unlogged area of 30 km².

Average damage levels within the concession area are reported to be severe: between 62% and 80% of trees greater than 30 cm girth were lost during and subsequent to logging (Johns 1988*b*, 1989*b*). At the time of my study, L81 was a mosaic of several distinctly different types of vegetation. Approximately half of L81 had been severely damaged and contained very few large trees. Those trees. that remained were mostly less than 10 m tall. Such areas resembled gaps within plot P attributed to treefalls. Vegetation was smothered with creepers and vines. Other areas suffered lower damage levels, and contained scattered trees up to 50 m tall and a relatively dense understorey of saplings.

Vegetation adjacent to the Bole River in L81 contained a higher density of taller trees and an understorey similar to that found in primary forest, reflecting the management practice of leaving 20–40 m belts of undisturbed forest along rivers. Where logging roads transversed L81 the vegetation was distinct, the verges being dominated by trees of *Macaranga* (Euphorbiaceae).

Further data were collected in a patch of *ca.* 3.5 ha of unlogged forest within an area selectively logged in March 1989 (plot L89). L89 was situated about 1 km from plot P, and was *ca.* 400 m from primary forest. Further description of the study areas and more detailed accounts of vegetation can be found in Lambert (1990*b*). In the present study it was assumed that L81 and L89 would originally have supported the same bird species as plot P.

3. METHODS

Between May and December 1989, approximately half of field time was spent in L81 and half in plot P. Between January and April 1990 around 90% of field time was spent radiotracking in plot P. During September 1990, *ca.* 30 h were spent censusing birds in L89. All bird species noted in the plots were recorded. Special searches for elusive species were made using tape recordings.

During 1989, birds were netted in both plot P and L81. Nets were set in lines along trails, opened before dawn and closed in the early afternoon, or earlier if it rained. Net positions and the timing of opening and closing each net were recorded. Nets were moved to new positions every 16–20 h (net time) because birds learn to avoid nets (Wong 1986; F.R. Lambert, personal observation). Ringing sessions alternated between plots and lasted three to four days. The total number of net hours in L81 was lower than in plot P because the nature of the vegetation made it difficult to set uninterrupted net lines, and because nets in open situations had to be closed early if exposed to sunlight. Each bird was banded with a numbered aluminium ring and released beside the net in which it was caught. Conspecifics caught in pairs or groups were released together.

From August 1989, birds were censused twice a month along transects in plots P and L81, except in June and July 1990 when no transects were walked, and September 1990 when three transects were walked in each plot. Transects were alternated between two routes at each site. All birds seen, except aerial insectivores (see Appendix 1), were recorded during a three hour period starting between 06h20 and 06h50. The transect distance varied between 1580 and 1620 m. For each perched bird observed, its height above the ground and perpendicular distance from the transect was estimated (cf. Burnham *et al.* 1980). Any bird observed was recorded regardless of whether it was specifically identified. Shy, elusive or rare species (specified in Appendix 1) were recorded whenever they were identified by call, and their distance from the transect estimated.

To compare the numbers of birds caught or observed during transects at the two sites, expected numbers (under the null hypothesis that logging had no effect) were generated using data from plot P. For the ringing data, it was assumed that the capture rates in plot P and L81 should have been equal. For transect data, it was expected that the number of independent sightings (treating groups of pairs as one observation) of a species observed in L81 should be the same as the number from plot P, as an equal number of hours were spent on equal length transects in each plot. Expected and actual numbers of individual birds from each feeding guild caught or observed were then compared by using a χ^2 test.

The density of understorey vegetation and the height of the lowest canopy was assessed at every net site. Understorey vegetation density was scored on both sides of each net at 2 m intervals. Scores were based on the distance from the net for which it was possible to see the ground on a line perpendicular to the net axis. Three points were awarded when the distance was greater than 10 m, two for 5–10 m, one for 2–5 m and half for less than 2 m. Whether the canopy directly above each net site was multi-layed or single-layered was also noted.

4. RESULTS

(*a*) *Species richness*

Appendix 1 lists all species recorded during the study at the three plots, and gives scientific names of all birds mentioned in the text. Species have been sorted according to their principal feeding guilds (adapted from Wong 1986; Erard 1989), based on personal observations. Nomenclature follows Smythies (1981).

In plot P, 195 species, including nine northern migrants, were recorded. Of these, all but 29 species were recorded in L81 (Appendix 1). A total of 177 species, including eleven migrants, were found in L81. The brief survey in L89 located 92 species, including three migrants within the 3.5 ha patch. Appendix 2 lists lowland species observed in Ulu Segama outside the three study plots; in total, 207 species including eleven migrants were recorded in primary forest, compared to 199 species, including 16 migrants, in selectively logged forest.

(*b*) *Foraging height*

Foraging height data are derived largely from transect counts. Although there was a tendency for mean foraging heights to be lower in logged forest (*t*-test), for those species with sufficient data the difference was significant for only three of 16 species considered (table 1). Some species caught in L81 (red-bearded bee-eater, chestnut-backed scimitar babbler and dark-throated oriole) were perhaps foraging at lower levels

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Table 1. *Foraging heights of birds in unlogged (plot P) and selectively logged forest (plot L81)*

species	foraging height / m P mean ± s.d. (n)	L81 mean ± s.d. (n)	t-test
Phaenicophaeus chlorophaeus	20.33 ± 11.53 (9)	15.71 ± 6.16 (7)	$t_{12}=1.03$, n.s.
Meiglyptes tristis	18.86 ± 12.05 (7)	9.00 ± 6.04 (5)	$t_9=-1.06$, n.s.
Eurylaimus ochromalus	15.57 ± 12.55 (7)	8.62 ± 7.93 (8)	$t_{13}=1.30$, n.s.
Pycnonotus erythrophthalmus	10.10 ± 6.05 (10)	7.29 ± 5.51 (52)	$t_{60}=1.45$, n.s.
Criniger phaeocephalus	3.95 ± 2.16 (20)	5.27 ± 3.02 (14)	$t_{32}=1.50$, n.s.
Hypsipetes criniger	8.37 ± 7.09 (19)	5.85 ± 2.58 (13)	$t_{32}=1.42$, n.s.
Chloropsis sonnerati	29.67 ± 11.78 (6)	10.78 ± 6.04 (9)	$t_6=3.62$, $p=0.011$
Irena puella	23.2 ± 10.18 (5)	20.10 ± 3.40 (10)	$t_{13}=0.45$, n.s.
Trichastoma bicolar	2.63 ± 1.77 (8)	1.90 ± 0.99 (10)	$t_{10}=1.04$, n.s.
Malacopteron affine	6.29 ± 3.59 (35)	6.67 ± 3.31 (21)	$t_{45}=-0.40$, n.s.
Malacopteron magnirostre	5.80 ± 3.71 (10)	3.78 ± 1.86 (9)	$t_{13}=1.53$, n.s.
Malacopteron magnum	9.26 ± 7.23 (27)	5.36 ± 2.29 (19)	$t_{32}=-2.62$, $p=0.013$
Stachyris erythroptera	5.70 ± 3.66 (40)	3.67 ± 2.08 (55)	$t_{57}=3.15$, $p=0.0026$
Macronous ptilosus	3.86 ± 5.05 (7)	2.17 ± 1.47 (12)	$t_6=-0.87$, n.s.
Philentoma pyrrhopterum	3.69 ± 2.35 (13)	4.14 ± 2.34 (7)	$t_{18}=-0.41$, n.s.
Hypogramma hypogrammicum	5.18 ± 3.28 (11)	3.90 ± 1.85 (10)	$t_{16}=1.11$, n.s.

than is usual in unlogged forest (F.R. Lambert, personal observation).

(*a*) *Trophic structure*

Data on vegetation density from netting sites indicate that the understory in L81 was significantly thicker than that of plot P (Mann–Whitney–Wilcoxon, $W=37117.5$, $n_1=201$, $n_2=114$; $p< <0.001$). Netting sites in L81 were typically in more open situations than those in plot P: canopy was absent above 30.7% of nets ($n=114$) in L81 as compared to 5.5% ($n=201$) in plot P. More sightings of birds in flight were made in L81 (21.56%) compared with plot P (9.23%).

There was no significant difference ($t_{1155}=1.22$, $p=0.22$; using log-transformed data) between the mean distance of observation data sets, even when the data were partitioned into those in the understorey (no more than 3 m: $t_{313}=1.12$, $p=0.26$) and those at higher levels (greater than 3 m: $t_{806}=0.12$, $p=0.91$). Mean estimated distance from transect for birds at estimated heights of 3 m or less was 4.45 ± 4.18 m in plot P compared with 4.15 ± 4.85 m for L81. For birds at estimated heights greater than 3 m respective mean distances from the transect were 9.7 ± 13.2 m and 11.3 ± 22.6 m. Therefore, no correction factors have been applied to the transect data, and all inferences are from direct comparison.

A total of 130 species were observed, and a further seven heard during the 75 h spent walking transects in plot P , whereas in L81, 116 species were observed and 11 more heard during the same time period (Appendix 1). During a total of 3008 (12 m) mist-net hours, 518 birds, comprising 406 individuals (i.e. excluding re-traps) of 66 species, were trapped in plot P. In L81, 561 birds, comprising 474 individuals of 67 species were caught during 1465 mist-net hours (table 2). Overall capture rates were more than twice as high in L81 as compared with plot P. Sample size for most species was small, making comparisons of captures for species between the two study plots questionable. Indeed, interpretations of differences in captures of some species appear ambiguous when contrasted with data from transect counts. Nevertheless, some clear and consistent differences in community structure are apparent, and these are recorded below.

The ringing results suggest that, in the understorey at least, community structure with respect to feeding guilds was significantly different at the two plots ($\chi_8=587.2$, $P<0.001$: table 3). χ_2 values indicate that the two groups which contribute most to this difference are the nectarivore–insectivores and arboreal foliage-gleaning insectivores–frugivores, both of which were more abundant in L81. Transect data support this conclusion ($\chi_{10}=1309.8$, $p<0.001$), and also suggest that there is a significant increase in abundance of nectarivore–insectivore–frugivores in selectively logged forest (table 3).

(*d*) *Changes in abundance of species and taxa*

Population densities of many bird species apparently changed after logging, but data for the majority are inadequate. Tentative conclusions about changes in abundance of species following logging are suggested in Appendix 1.

Trogons, woodpeckers, wren-babblers and flycatchers appear to be deleteriously affected by selective logging, in so far as most resident species in these groups were much less abundant in L81 than in plot P, or absent from L81.

5. DISCUSSION

Interpretation of the data requires caution because sample sizes are mostly small and because of the assumptions made. One of the main problems in this

Table 2. *Net captures of birds in unlogged forest (plot P) and selectively logged forest (plot L81)*

(Percentages are of total number of individuals caught at each site. Rate is the number of individual birds (excluding retraps) caught per km of net per 10 h)

	mist net captures			
	P		L81	
bird species	no. ind (%)	rate	no. ind. (%)	rate
terrestrial insectivore				
Pitta bauda	2 (0.5)	0.55	3 (0.6)	1.70
Pitta venustra[a]	5 (1.2)	1.38	1 (0.2)	0.57
Enicurus leschenaulti	2 (0.5)	0.55	5 (1.1)	2.84
Enicurus ruficapillus	3 (0.7)	0.83	0	
Pellorneum capistratum	19 (4.7)	5.26	19 (4.0)	10.81
Kenopia striata	5 (1.2)	1.38	1 (0.2)	0.57
Napothera atrigularis	7 (1.7)	1.94	3 (0.6)	1.71
Ptilocichla leucogrammica	4 (1.0)	1.11	0	
Trichastoma malaccense	23 (5.7)	6.37	32 (6.8)	18.20
Trichastoma rostratum	0		2 (0.4)	1.14
*Erithacus cyane**	8 (2.0)	2.22	10 (2.1)	5.69
total	*78*		*76*	
arboreal foliage gleaning insectivore				
Cacomantis sonneratii	1 (0.2)	0.28	1 (0.2)	0.57
Cuculus fugax	1 (0.2)	0.28	0	
Sasia abnormis	6 (1.5)	1.66	13 (2.7)	7.39
Coracina fimbriata	1 (0.2)	0.28	1 (0.2)	0.57
Malacopteron sp.	1 (0.2)	0.28	0	
Malacopteron affine	5 (1.2)	1.38	12 (2.5)	2.84
Malacopteron cinereum	12 (2.9)	3.32	0	
Malacopteron affine/cinereum	0		1 (0.2)	0.57
Malacopteron magnirostre	8 (2.0)	2.22	7 (1.5)	3.98
Malacopteron magnum	9 (2.2)	2.49	4 (0.8)	2.27
Stachyris erythroptera	8 (2.0)	2.22	25 (5.3)	14.22
Stachyris maculata	3 (0.7)	0.83	1 (0.2)	0.57
Copsychus pyrrhopyga	7 (1.7)	1.94	0	
Copsychus malabaricus	10 (2.5)	2.77	8 (1.7)	4.55
Orthotomus atrogularis	2 (0.5)	0.55	2 (0.4)	1.14
Orthotomus ruficeps	0		1 (0.2)	0.57
Platylophus galericulatus	0		2 (0.4)	1.14
total	*74*		*78*	
understorey specialists				
Trichastoma bicolor	17 (4.2)	4.71	11 (2.3)	6.26
Trichastoma sepiarium	9 (2.2)	2.49	6 (1.3)	3.41
Stachyris leucotis	1 (0.2)	0.28	0	
Stachyris poliocephala	10 (2.5)	2.77	17 (3.6)	9.67
Macronous gularis	0		1 (0.2)	0.57
Macronous ptilosus	7 (1.7)	*1.45*	22 (4.6)	12.51
total	*44*		*57*	
bark gleaning insectivore/woodpecker				
Meiglyptes tukki	0		5 (1.1)	2.84
Blythipicus rubiginosus	3 (0.7)	0.83	0	
Pomatorhinus montanus	0		1 (0.2)	0.57
	3		*6*	
sallying insectivore				
Nyctyornis amictus	0		1 (0.2)	0.57
Cyornis caerulata	10 (2.5)	2.77	0	
Cyornis superba	4 (1.0)	1.11	0	
Ficedula dumetoria	3 (0.7)	0.83	0	
*Ficedula mugimaki**	0		1 (0.2)	0.57
*Ficedula narcissina**	0		1 (0.2)	0.57
Philentoma pyrhopterum	14 (3.4)	3.88	5 (1.1)	2.84

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Table 2 (*cont.*)

bird species	mist net captures: P no. ind (%)	P rate	L81 no. ind. (%)	L81 rate
Philentoma velata	1 (0.2)	0.28	0	
Rhipidura perlata	2 (0.5)	0.55	0	
Terspsiphone paradisi	5 (1.2)	1.38	2 (0.4)	1.14
Hypothymis azurea	0		5 (1.1)	2.84
Culicicapa ceylonensis	2 (0.5)	0.55	0	
total	*41*		*15*	
sallying substrate gleaning insectivore				
Harpactes duvaucellii	1 (0.2)	0.28	0	
Harpactes orrhophaeus	1 (0.2)	0.28	0	
Eurylaimus ochromalus	1 (0.2)	0.28	1 (0.2)	0.57
Rhinomyias umbratilis	2 (0.5)	0.55	0	
Dicrurus annectans	1 (0.2)	0.28	0	
Dicrurus paradiseus	3 (0.7)	0.83	1 (0.2)	0.57
total	*9*		*2*	
arboreal foliage gleaning insectivore/frugivore				
Pycnonotus atriceps	0		13 (2.7)	7.39
Pycnonotus brunneus	0		2 (0.4)	1.14
Pycnonotus cyaniventris	0		1 (0.2)	0.57
Pycnonotus erythrophthalmos	9 (2.2)	2.49	26 (5.5)	14.79
Pycnonotus eutilotus	1 (0.2)	0.28	3 (0.6)	1.71
Pycnonotus melanoleucos	0		1 (0.2)	0.57
Pycnonotus plumosus	0		5 (1.1)	2.84
Pycnonotus simplex	1 (0.2)	0.28	2 (0.4)	1.14
Hypsipetes charlottae	3 (0.7)	0.83	1 (0.2)	0.57
Hypsipetes criniger	16 (3.9)	4.43	18 (3.8)	10.24
Criniger bres	10 (2.5)	2.77	4 (0.8)	2.28
Criniger finschii	0		1 (0.2)	0.57
Criniger phaeocephalus	21 (5.2)	5.82	17 (3.6)	9.67
Alcippe brunneicauda	10 (2.5)	2.77	2 (0.4)	1.14
Oriolus xanthonotus	0		3 (0.6)	1.71
Platysmurus leucopterus	0		1 (0.2)	0.57
Prionochilus maculatus	12 (2.9)	3.32	10 (2.1)	5.69
total	*83*		*110*	
nectarivore/insectivore				
Anthreptes rhodolaema	1 (0.2)	0.28	0	
Anthreptes singalensis	3 (0.7)	0.83	2 (0.4)	1.14
Arachnothera affinis	1 (0.2)	0.28	1 (0.2)	0.57
Arachnothera crassirostris	0		1 (0.2)	0.57
Arachnothera longirostra	26 (6.4)	7.20	72 (15.2)	40.95
total	*31*		*76*	
nectarivore/insectivore/frugivore				
Chloropsis cyanopogon	5 (1.2)	1.38	4 (10.8)	2.28
Anthreptes simplex	2 (0.5)	0.55	3 (0.6)	1.71
Hypogramma hypogrammicum	11 (2.7)	3.05	10 (2.1)	*5.69*
Prionochilus xanthopygius	1 (0.2)	0.28	10 (2.1)	*5.69*
Dicaeum trigonostigma	0		3 (0.6)	1.71
total	*19*		*30*	
terrestrial frugivore/insectivore				
Zoothera interpres	6 (1.5)	1.66	5 (1.1)	2.84
total	*6*		*5*	
arboreal frugivore				
Calyptomena viridis	9 (2.2)	2.49	1 (0.2)	0.57
total	*9*		*1*	

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Table 2 (*cont.*)

	mist net captures			
	P		L81	
bird species	no. ind (%)	rate	no. ind. (%)	rate
terrestrial frugivore				
Chalcophaps indica	2 (0.5)	0.55	14 (3.0)	7.96
total	*2*		*14*	
miscellaneous insectivores				
Ceyx erithacus	6 (1.5)	1.66	4 (0.8)	2.28
Lacedo pulchella	1 (0.2)	0.28	0	
total	*7*		*4*	
total captures	406		474	

[a] Taxonomy (*Pitta venusta*) follows Van Marle & Voous (1988).

Table 3. *Comparison of differences in trophic structure of the avifauna of two vegetation types*

(χ^2 values derive from comparing observed with expected number of captures (ringing) and independent sightings (transect) of birds in L81. Expected values were generated from data from plot P. Feeding guilds were combined if either expected or observed values were less than 5.)

	χ^2 ringing	χ^2 transect
terrestrial insectivore	38.03	6.31
arboreal foliage gleaning insectivore (AFG)		2.16
bark gleaning insectivore/woodpecker (BG)		15.61
AGF + BG + miscellaneous insectivores	54.20	
understory foliage-gleaning insectivore	59.04	
sallying insectivore (SI)		19.78
sallying substrate gleaning insectivore (SSI)		16.30
SI + SSI	2.22	
nectarivore/insectivore	245.62	697.22
nectarivore/insectivore/frugivore	46.55	286.91
terrestrial frugivore/insectivore (TFI)		
arboreal frugivore/insectivore (AFI)		220.09
TFI + AFI	4.43	
arboreal frugivore/predator		2.06
arboreal + terrestrial frugivore	17.34	43.18
arboreal foliage gleaning insectivore/frugivore	119.78	
miscellaneous insectivore + raptors + TFI		0.22
total χ^2	587.2	1309.8

respect is that the comparisons of net and transect data sets assume that selective logging does not significantly change the activity budget or the size of horizontal or vertical foraging space utilized by individual species. Shifts in foraging height would affect the probability of trapping non-terrestrial species, whereas quantitative changes in foraging time could invalidate comparisons of birds trapped or observed along transects.

The more open nature of logged forest canopy resulted in more sightings of birds in flight and perhaps more chance of seeing canopy species during transect counts. In contrast, the thicker understory would be expected to make it more difficult to see understory and terrestrial species in logged forest, although this should not have had any major effects on net captures. Although one might therefore expect a difference in the mean estimated distance of birds observed during transect counts in the two forest types, data suggested that there was no significant difference.

Despite these problems associated with interpretation, the data do provide some results which are consistent with those of other studies and which form a baseline for future research.

(*a*) *Trophic structure*

An increase in relative and real abundance of species which include nectar in their diet was the most noticeable change in avifauna following logging. This change was primarily associated with an increase in the number of both specialised nectarivores (spiderhunters, sunbirds, blue-crowned hanging parrot), and more generalist species which include nectar in their diet (orange-bellied flowerpecker, yellow-rumped flowerpecker and the leafbirds). These species exploit the flowers of plants that colonized disturbed land, such as *Mezoneuron* and gingers (Zingiberaceae).

The apparently large increase in the proportion of terrestrial frugivores in logged forest reflects a single influx of emerald doves associated with mass fruiting of *Macaranga* trees during late 1989. Black-headed bulbuls were also unusually abundant during this period. These species are nomadic (Medway & Wells 1976; Wells 1988).

Other species of bulbul, in particular species of *Pycnonotus*, also increase in abundance in logged forest. It is their increase which largely accounts for the significant change in numbers of arboreal foliage-gleaning insectivores–frugivores. These species are opportunistic foragers which exploit the abundant small-fruited plants which colonize logged forest (see also Lambert 1989*a*–*c*, 1990*a*).

Ringing data suggest that the feeding guilds contributing least to the overall change in trophic structure in the understorey were the combined sallying insectivore guilds. However, this conceals the fact that there were large changes in species composition within these feeding guilds.

(*b*) *Species persistence*

Three major studies in Malaysia have investigated birds in logged forest. Wong (1985, 1986) conducted a ringing programme at Pasoh Forest Reserve (Peninsular Malaysia), comparing the understorey bird community of 600 ha of virgin forest with an adjacent area that had been logged 23–25 years previously. Johns (1986, 1988*a*, *b*, 1989*a*, *b*, this symposium) documented changes in mammal and bird populations in selectively logged forest at various stages of regeneration at Sungai Tekam (Peninsular Malaysia), and at Ulu Segama. His studies, however, relied almost entirely on counting mammals and birds simultaneously along old logging roads. The highly disturbed vegetation along these roadways is very different from the vegetation generally prevalent in logged areas. This survey method is therefore likely to be seriously biased towards more visible species, and those species which frequent *Macaranga*. Although Johns (1989*b*) trapped birds in Sabah none were ringed, and nets appear to have been moved only once, or not at all, during 1000 h of trapping at each site.

Whatever their short-comings, these and other studies (McClure & Othman 1965; Driscoll & Kikkawa 1989) have consistently shown that most forest bird species use logged forest. This study supports that conclusion, and provides evidence that more species than previously supposed survive in, or use, selectively logged forest. For instance, Johns (1988*b*, 1989*a*, *b*) failed to find several elusive bird taxa in logged forest: partridges and pittas at Tekam, even 12 years after logging; and reddish scops owl, bristlehead, striped wren babbler, Bornean wren babbler, giant pitta, red-naped trogon, cinnamon-rumped trogon and Storm's stork in Ulu Segama. My study demonstrates that all these species use selectively logged forest.

The ability of most species to use or persist in selectively logged forest is probably largely attributable to the mosaic of habitats. Unlogged patches of forest of various sizes, but mostly less than 1 ha, typically exist in selectively logged forest, and larger patches, such as that in L89, also occur. This latter patch, within an area logged 18 months previously, acted as a refuge for species which apparently could not continue to survive in seriously degraded forest (at least in the early stages of regeneration) such as scaly-breasted partridge, red-naped trogon, large-billed blue flycatcher, white-throated jungle flycatcher and Bornean wren babbler.

Johns (1989*b*, personal communication) speculated that during regrowth these patches act as centres of avian recolonization for more degraded areas of forest. However, the dispersive powers of many forest species may be under-estimated, and successful re-colonization could be primarily dependent on the persistence of individuals in larger unlogged forest blocks (Lambert 1990*b*).

An examination of past studies clearly shows that results from one area cannot necessarily be used to predict the effects of logging on the avifauna of another, even when original species composition is almost the same. Some of the species never recorded in logged forest in this study, such as Malaysian honeyguide, olive-backed woodpecker and rufous-chested flycatcher were trapped by Wong (1986) in regenerating forest at Pasoh. Johns (1986, 1989*a*) did not record species of pitta or large wren babbler *Napothera macrodactyla* in logged forest at Sungai Tekam, yet trapping at Pasoh (Wong 1986) suggests that large wren babbler and garnet pitta *Pitta granatina* were probably as common in regenerating forest there as in adjacent primary areas. How the occurrence of species in logged forest varies with the time since logging, or is influenced by pre-logging distribution, is not yet clear.

(*c*) *Factors affecting survival*

It should be borne in mind that results of this study refer to birds in forest selectively logged 8–10 years previously. Population densities of species are likely to vary as logged forest regenerates, and may also be influenced by distance to the nearest unlogged forest patch and by damage levels.

Present evidence indicates that time elapsed since logging is an important determinant of species composition. The virgin and regenerating forest, logged 23–25 years previously, of Wong's (1986) study did not differ significantly in the relative importance of feeding guilds either in terms of species richness or in terms of individual abundance. This contrasts strongly with the results obtained in the present study based on data from a plot logged eight years previously.

The preponderance of nectarivorous birds and opportunistic frugivores in Sabahan lowland forest eight to nine years after logging may be only a transient situation. Wong (1986) found that unlogged forest contained three times as many plants with flowers visited by birds, and five times as many plants with bird dispersed fruits than forest logged 23–25 years previously.

Although the exact reasons why some species decline in numbers after logging are unknown, a reduction in foraging area or availability of food resources could provide the explanation for a number of taxa. Most species which are rare in logged forest are insectivorous. Although little is known about the effects of selective logging in invertebrates (see Holloway *et al*, this symposium), Wong (1985) found that in forest logged 23–25 years previously insects were less abundant overall and periodically scarcer than in adjacent primary forest. In forest near the Bole River, Pseudoscorpiones and Psocoptera were trapped in significantly higher numbers in primary forest than in logged areas, whilst Coleoptera, Diptera, Hymenoptera (including Formicidae) and Isopoda were trapped in significantly higher numbers in forest logged ten years previously (Korthals 1990). However, De Vries (1989) suspected that increased arthropod activity in logged forest, resulting in higher trapping rates, might explain some of these results. Further research into invertebrate activity and abundance in logged forest is needed before the effects on insectivore food resources can be assessed.

The loss of breeding sites, suitable nest materials, or an increase in nest predation in logged forest could also be important causes of decline for some bird species. Changes in micro-climate may be an important factor in eliminating some species from recently logged forest (Johns 1986), but the rapid growth of invasive plants may enable such species to recolonize quickly.

Selectively logged forests in Ulu Segama are near the extreme end of the damage spectrum: in other parts of Malaysia proportionally fewer trees may be taken during selective logging (Marsh & Greer, this symposium; Johns 1988*a*, 1989*b*). Hence results from this study may represent a 'worse-case scenario', although hunting does not complicate the situation in the Ulu Segama Forest Reserve as it does in many other logged areas.

(*d*) *Activity space*

Although foraging heights of some species are undoubtedly affected by logging, there was little evidence to suggest that this phenomenon applies to most species (table 1). In New Guinea and Australia, species of fantail *Rhipidura* shifted their foraging height, feeding lower more frequently in logged forest, but many of the species of unlogged forest retained their original vertical foraging ranges (Driscoll & Kikkawa 1989). Changes in foraging height are therefore unlikely to contribute significantly to the differences in trapping rates recorded between the two main sites in the current study.

For terrestrial species, foraging height is unaffected by logging. Hence, netting results for these species are enlightening (table 2). For seven of the eight terrestrial species trapped in both plots (excluding emerald dove, which is nomadic), there was a considerably higher capture rate in L81. These data are consistent with either an increase in population density or a change in activity or ranging behaviour. Although this study provides no evidence to support either of these explanations, data from Wong's (1985) study at Pasoh suggested that birds may be less sedentary, and therefore presumably range over larger areas, in logged forest. Such a change in behaviour might increase the probability of catching birds, and hence explain the increased capture rates observed in logged forest.

5. SELECTIVE LOGGING AND BIRD CONSERVATION

The current state of Malaysia's remaining forest has been outlined by Johns (1989*b*): three quarters of Malaysia's remaining forests are set aside as production forest. The ability of bird species to survive and reproduce in these forests is therefore of great interest to conservationists.

Although further research, in particular involving radiotelemetry and mark–release–recapture programmes, will be necessary to explain observed changes in avifauna, the ability of most species to use logged areas is now well proven. Certain taxa, however, may be dependent on a nearby unlogged forest block, or on undisturbed patches within the logged-forest mosaic. The patch size and dispersion necessary to support viable populations of such birds are at present unknown.

Whether all species present in logged forest are able to breed there is also uncertain. Wong (1985) reported lowered reproductive success in selectively logged forest in Peninsular Malaysia. Certain species, such as great argus, may survive the effects of logging, but be unable to breed (Johns 1986). The identification of birds in this category is obviously of importance, but problematic due to the extreme difficulty of locating the nests of tropical forest birds. The netting of juvenile birds could be used as an indicator of breeding if it was certain that they had fledged locally.

Whereas studies so far suggest that certain species may be prone to local extinction following logging (in particular species of understorey flycatcher, woodpecker and trogon and extreme specialists such as Malaysian honeyguide) all are likely to survive in logged forest, or to be able to recolonize if there is (i) an unlogged forest block from which colonization may occur, and (ii) if the area of logged forest is large enough that there are always some areas in an advanced stage of regeneration.

Large areas of selectively logged forest are therefore of importance to bird conservation, but they are unfortunately particularly susceptible to serious forest fires. At least 4.5 million ha of forest were burnt in Borneo in 1982/1983: in Sabah, between 66% and 85% of the burned areas were logged-over forest (Beaman *et al.* 1985). Nothing is known about the survivorship of birds in forest which has been both logged and burned, but judging by the very seriously degraded state of such areas (Woods 1989;

F. R. Lambert, personal observation), it seems probable that species which decline severely in logged forest may disappear entirely after serious drought and associated fires. Hence, although most species can survive the effects of selective logging, this is one reason why these areas should not be considered as alternatives to reserves of primary forest for bird conservation.

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APPENDIX 1

Checklist of bird species recorded in the two main study plots (P,L81) and in the 3.5 ha patch of unlogged forest in plot L89

(The number of independent observations of species recorded during transect counts (O, observed; H, heard) are indicated, while p indicates a species was recorded at a study site but not on transect counts. Species for which vocalization were recorded during transect counts are those for which an entry occurs in the respective column. Migrant species are denoted by (M), or (m) if both resident and migrant individuals are expected to occur. Bornean endemics are denoted by (E). No entry denotes that the species was not recorded. Changes in abundance are indicated in the final column: + + indicates a higher abundance in the logged 1981 plot as compared with the primary plot; – – indicates lower abundance. + or – indicate a tentative conclusion, often based on general observations which could not be quantified.)

	P		L81		L89	
	O	H	O	H		change
raptor						
crested honey buzzard, *Pernis ptilorhynchus*	p		p			
Japanese sparrowhawk, *Accipiter gularis* (M)			p			
Blyth's hawk eagle, *Spizaetus alboniger*	p		p			–
Wallace's hawk eagle, *Spizaetus nanus*	p				p	–
hawk eagle, *Spizaetus* sp.	1		2			
rufous-bellied eagle, *Hieraaetus kienerii*			p			
crested goshawk, *Accipiter trivirgatus*	1		p			
crested serpent eagle, *Spilornis cheela*	4		1			
lesser fishing eagle, *Ichthyophaga nana*	p		p			
raptor sp.	2		3			
nocturnal predator						
reddish scops owl, *Otus rufescens*	p		p			
Sunda wood owl, *Strix leptogrammica*	p		p		p	–
buffy fish owl, *Ketupa ketupu*	p					
miscellaneous predators						
oriental darter, *Anhinga melanogaster*	p		p			
Sumatran heron, *Ardea sumatrana*	p		p			
little green heron, *Butorides striata* (M)	p		p			
terrestrial insectivore						
common sandpiper, *Actitis hypoleucos* (M)	p		p			
greater coucal, *Centropus sinensis*	p		3			+ +
stiped wren babbler, *Kenopia striata*	3		1			– –
short-tailed babbler, *Trichastoma malaccense*	24		25		p	
white-chested babbler, *Trichastoma rostratum*	p		p			
black-throated wren babbler, *Napothera atrigularis* (E)	2	9	p	0	p	– –
Bornean wren babbler, *Ptilocichla leucogrammica* (E)	9	10	p	2	p	– –
black-capped babbler, *Pellorneum capistratum*	16		20		p	
blue-headed pitta, *Pitta baudi* (E)	8	16	5	11		
giant pitta, *Pitta caerulea*	1	3	p	3		
banded pitta, *Pitta guajana*	p	1	0	0	?p	
hooded pitta, *Pitta sordida* (M)	p	1	p	1		
black-and-crimson pitta, *Pitta venusta*[1]	9	29	4	38	p	
forktail, *Enicurus* sp.	1		0			
white-crowned forktail, *Enicurus leschenaulti*	6		3			+
chestnut-naped forktail, *Enicurus ruficapillus*	2		p		p	–
Siberian blue robin, *Erithacus cyane* (M)	10	2	6	5	p	
grey wagtail, *Motacilla cinerea* (M)	p					
arboreal foliage gleaning insectivore						
green iora, *Aegithina viridissima*	7		5		p	
common iora, *Aegithina tiphia*			p			+
buff-rumped woodpecker, *Meiglyptes tristis*	4		8			+ +
banded bay cuckoo, *Cacomantis sonneratii*	2		p			
plaintive cuckoo, *Cacomantis merulinus*	p		1			
cuckoo, *Cacomantis* sp.	1		1			
violet cuckoo, *Chrysococcyx xanthorynchus*	1	3	3	4		
moustached hawk cuckoo, *Cuculus vagans*	p					
Hodgesons hawk cuckoo, *Cuculus fugax* (m)	p					
rufous-tailed shama, *Copsychus pyrrhopyga*	8	1	p	0		– –

Appendix 1 (*cont.*)

	P		L81		L89	
	O	H	O	H		change
white-crowned shama, *Copsychus malabricus*	10		24		p	+ +
lesser cuckoo-shrike, *Coracina fimbriata*	7		4			
bar-bellied cuckoo-shrike, *Coracina striata*	p					
large wood shrike, *Tephrodornis virgatus*	p		1			
drongo cuckoo, *Surniculus lugubris*	p		p			
Indian cuckoo, *Cuculus micropterus*	p	1	p	1		
striped tit babbler, *Macronous gularis*	0		6			+ +
fluffy-backed tit babbler, *Macronous ptilosus*	10		19		p	+ +
babbler, *Malacopteron* sp.	39		31			
sooty-capped babbler, *Malacopteron affine*	31		30			
scaly-crowned babbler, *Malacopteron cinereum*	55		5		p	– –
Moustached babbler, *Malacopteron magnirostre*	12		12		p	
red-crowned babbler, *Malacopteron magnum*	32		31		p	
babbler, *Trichastoma* sp.	1		0			
ferruginous babbler, *Trichastoma bicolor*	10		16		p	
Horsefield's babbler, *Trichastoma sepiarium*	11		10		p	
chestnut-winged babbler, *Stachyris erythroptera*	39		81		p	+ +
chestnut-rumped babbler, *Stachyris maculata*	8	3	p		p	–
rufous-fronted babbler, *Stachyris rufifrons*	0		1			+
white-necked babbler, *Stachyris leucotis*	p					
grey-headed babbler, *Stachyris poliocephala*	6		9		p	+
white-bellied yuhina, *Yuhina zantholeuca*	p				p	
speckled piculet, *Picumnus innominatus*	p					
rufous piculet, *Sasia abnormis*	10		8		p	+ +
crested jay, *Platylophus galericulatus*	9	10	4	6	p	
Arctic warbler, *Phylloscopus borealis* (M)	3		4			
malcoha, *Phaenicophaeus* sp.	3		1			
raffle's malcoha, *Phaenicophaeus chlorophaeus*	4	5	12	8	p	+ +
chestnut-breasted malcoha, *Phaenicophaeus curvirostris*	4		p			–
black-bellied malcoha, *Phaenicophaeus diardi*	1		p			
red-billed malcoha, *Phaenicophaeus javanicus*	2		0			– –
chestnut-bellied malcoha, *Phaenicophaeus sumatranus*	2		1			
minivet, *Pericrocotus* sp.	1		2			
fiery minivet, *Pericroctus igneus*	1		p			
scarlet minivet, *Pericrocotus flammeus*	1		1		p	
yellow-bellied prinia, *Prinia flaviventris*			p			+ +
dark-necked tailorbird, *Orthotomus atrogularis*	2		7		p	+
ashy tailorbird, *Orthotomus ruficeps*	0		20			+ +
red-tailed tailorbird, *Orthotomus sericeus*	p		p			
tailorbird, *Orthotomus* sp.	0		3			
Bornean bristlehead, *Pityriasis gymnocephala* (E)	p		p			–
Everetts white-eye, *Zosterops everetti*			p			+ +
bark gleaning insectivore/woodpecker						
orange-backed woodpecker, *Chrysocolaptes validus*	4		p			– –
rufous woodpecker, *Micropternus brachyurus*	2	1	1	0		
great slaty woodpecker, *Mulleripicus pulverulentus*	1	2	1	1		
grey-crowned woodpecker, *Picoides canicapillus*	1	1	0	0		–
crimson-winged woodpecker, *Picus puniceus*	p					– –
checker-throated woodpecker, *Picus mentalis*	p				p	– –
banded woodpecker, *Picus miniaceus*	p		p			–
woodpecker sp., *Picus/Dinopium*	p	8	p	4		
maroon woodpecker, *Blythipicus rubiginosus*	11	6	1	0	p	– –
olive-backed woodpecker,*Dinopium rafflesi*	1		0			– –
white-bellied woodpecker, *Dryocopus javanicus*	2	3	p	0	p	– –
buff-necked woodpecker, *Meiglyptes tukki*	1		3		p	+ +
grey-and-buff woodpecker, *Hemicircus concretus*	p				p	
chestnut-backed scimitar babbler, *Pomatorhinus montanus*	4		2		p	–
velvet-fronted nuthatch, *Sitta frontalis*	4		1			– –
sallying substrate gleaning insectivore						
Diard's trogon, *Harpactes diardii*	4	7	3	0		– –
scarlet-rumped trogon, *Harpactes duvaucelii*	5	8	p	0	p	– –
red-naped trogon, *Harpactes kasumba*	1	0	0	0	p	– –

Appendix 1 (*cont.*)

	P		L81		L89	
	O	H	O	H		change
cinnamon-rumped trogon, *Harpactes orrhophaeus*	2	0	1	0		–
orange-breasted trogon, *Harpactes oreskios*	1	0	0	0		– –
trogon, *Harpactes* sp.	2	1	1	2		– –
dusky broadbill, *Corydon sumatrana*	3	1	0	0		–
black-and-red broadbill, *Cymbirhynchus macrorhynchus*	1		p			
banded broadbill, *Eurylaimus javanicus*	7		2		p	
black-and-yellow broadbill, *Eurylaimus ochromalus*	12	11			p	
white-throated jungle flycatcher, *Rhinomyias umbratilus*	8	16	2	0	p	– –
bronzed drongo, *Dicrurus aeneus*	13		12		p	
greater racket-tailed drongo, *Dicrurus paradisi*	22		11		p	– –
crow-billed drongo, *Dicrurus annectans* (M)	p					
drongo, *Dicrurus* sp.		2		2		
tiger shrike, *Lanius tigrinus* (M)			p			+
sallying insectivore						
white-fronted falconet, *Microhierax latifrons*(E)	1		2			
whiskered tree swift, *Hemiprocne comata*	p		p			+
blue-throated bee-eater, *Merops viridis* (M)	p					
red-bearded bee-eater, *Nyctyornis amictus*	1	9	5	11	p	+
drongo cuckoo, *Surniculus lugubris*	p			p		
dollarbird, *Eurystomus orientalis*	p		2			+
black-winged flycatcher shrike, *Hemipus hirundinaceus*	3		1		p	
grey-headed flycatcher, *Culicicapa ceylonensis*	11		0			– –
large-billed blue flycatcher, *Cyornis caerulata*	9	3	0	0	p	– –
bornean blue flycatcher, *Cyornis superba* (E)	3		1			– –
pale blue flycatcher, *Cyornis unicolor*	p					– –
Malaysian blue flycatcher, *Cyornis turcosa*	p		p			
blue flycatcher, *Cyornis* sp.	3	6		1		
rufous-chested flycatcher, *Ficedula dumetoria*	1					– –
mugimaki flycatcher, *Ficedula mugimaki* (M)			p			
narcissus flycatcher, *Ficedula narcissina* (M)	p		p			
brown flycatcher, *Muscicapa latirostris* (M)			p		p	+ +
sooty flycatcher, *Muscicapa sibirica* (M)			2		p	+ +
verditer flycatcher, *Muscicapa thalassina*	1		2			
rufous-winged flycatcher, *Philentoma pyrhopterum*	21		10			–
maroon-breasted flycatcher, *Philentoma velatum*	6	2	1	0	p	– –
Asian paradise flycatcher, *Terpsiphone paradisi*	5		2		p	–
spotted fantail, *Rhipidura perlata*	8					– –
pied fantail, *Rhipidura javanica*			p			+
black-naped monarch, *Hypothymis azurea*	1		9		p	+ +
aerial insectivore						
black-nest swiftlet, *Collocalia maxima*	p		p		p	
white-bellied swiftlet, *Collocalia esculenta*			p		p	
brown needletail, *Chaetura gigantea*	p		p		p	
silver-rumped swift, *Chaetura leucopygialis*	p		p		p	
grey-rumped tree swift, *Hemiprocne longipennis*	p		p		p	
Pacific swallow, *Hirundo tahitica*	p		p			
arboreal foliage gleaning insectivore/frugivore						
brown barbet, *Calorhamphus fuliginosus*	2	2	1	0	p	–
red-throated barbet, *Megalaima mystacophanos*	5	4	1	4	p	–
slender-billed crow, *Corvus enca*	2	3	4	6	p	+
black-headed bulbul, *Pycnonotus atriceps*	3		48		p	+ +
spectacled bulbul, *Pycnonotus erythrophthalmus*	17		76		p	+ +
red-eyed bulbul, *Pycnonotus brunneus*	2		18		p	+ +
grey-bellied bulbul, *Pycnonotus cyaniventris*	p		4			+
scaly-breasted bulbul, *Pycnonotus squamatus*	p					
puff-backed bulbul, *Pycnonotus eutilotus*	1		6			+ +
olive-winged bulbul, *Pycnonotus plumosus*	p		10			+ +
black-and-white bulbul, *Pycnonotus melanoleucos*	0		1			
cream-vented bulbul, *Pycnonotus simplex*	2		7			+ +
straw-headed bulbul, *Pycnonotus zeylanicus*	p		p			
bulbul, *Pycnonotus* sp.	6		24			

Appendix 1 (*cont.*)

	P		L81		L89	
	O	H	O	H		change
streaked bulbul, *Hypsipetes malaccensis*	p		p			
buff-vented bulbul, *Hypsipetes charlottae*	5		8		p	
hairy-backed bulbul, *Hypsipetes criniger*	30		21		p	
grey-cheeked bulbul, *Criniger bres*	13		8		p	– –
Finsch's bulbul, *Criniger finschii*	1		2			
yellow-bellied bulbul, *Criniger phaeocephalus*	28		26		p	
bulbul, *Criniger* sp.	1		0			
bulbul sp.	9		69		p	
brown fulvetta, *Alcippe brunneicauda*	20		6		p	– –
dark-throated oriole, *Oriolus xanthonotus*	3		11		p	+ +
black magpie, *Platysmurus leucopterus*	10	2	p	0	p	– –
yellow-breasted flowerpecker, *Prionochilus maculatus*	21		14		p	
arboreal frugivore/predator						
gold-whiskered barbet, *Megalaima chrysopogon*	4	6	p	1	p	– –
rhinoceros hornbill, *Buceros rhinoceros*	2	12	4	10		
helmeted hornbill, *Rhinoplax vigil*	2	7	1	6		
bushy-crested hornbill, *Anorrhinus galeritus*	2	4	4	3	p	
black hornbill, *Anthracoceros malayanus*	2	3	1	3		
white-crested hornbill, *Berenicornis comatus*	p	0	p	1		
wreathed hornbill, *Rhyticeros undulatus*	10	1	6	5	p	
wrinkled hornbill, *Rhyticeros corrugatus*	p	0	1	0		
hornbill, *Rhyticeros* sp.	5	2	5	6		
hornbill sp.	4	1	1	0		
arboreal frugivore						
long-tailed parakeet, *Psittacula longicauda*	p		p			
blue-rumped parrot, *Psittinus cyanurus*	8	6	21	2		+
jambu fruit dove, *Ptilinopus jambu*	1		0			
large green pigeon, *Treron capellei*	3	4	1	3		– –
thick-billed green pigeon, *Treron curvirostra*	2		5		p	
green pigeon, *Treron* sp.	2		2		p	
green imperial pigeon, *Ducula aenea*	2	3	1	0	p	– –
blue-eared barbet, *Megalaima australis*	1		2		p	
yellow-crowned barbet, *Megalaima australis*	1		2		p	
yellow-crowned barbet, *Megalaima henricii*	2	3	p	2	p	–
green broadbill, *Calyptomena viridis*	10	23	p	8	p	– –
fairy bluebird, *Irena puella*	12	37			p	+ +
hill myna, *Gracula religiosa*	2	6	11	3	p	+
terrestrial frugivore						
dusky munia, *Lonchura fuscans*	p		1			+ +
emerald dove, *Chalcophaps indica*	4		15		p	+ +
nectarivore/insectivore						
red-throated sunbird, *Anthreptes rhodolaema*	1		15			+ +
ruby-cheeked sunbird, *Anthreptes singalensis*	2		6		p	
crimson sunbird, *Aethopyga siparaja*	p					–
sunbird sp.	1		18			
yellow-eared spiderhunter, *Arachnothera chrysogenys*	1		13			+ +
thick-billed spiderhunter, *Arachnothera crassirostris*	p		8			+ +
long-billed spiderhunter, *Arachnothera robusta*	p		1			
grey-breasted spiderhunter, *Arachnothera affinis*	2		9		p	+ +
little spiderhunter, *Arachnothera longirostra*	30		118		p	+ +
spiderhunter, *Arachnothera* sp.	3		19			
flyeater, *Gerygone sulphurea*	p		p		p	
nectarivore/frugivore						
blue-crowned hanging parrot, *Loriculus galgulus*	2	2	34	3		+
nectarivore/insectivore/frugivore						
lesser green leafbird, *Chloropsis cyanopogon*	6		31		p	+ +
greater green leafbird, *Chloropsis sonnerati*	8		15		p	+ +
leafbird, *Chloropsis* sp.	5	9				

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Appendix 1 (*cont.*)

	P		L81		L89	
	O	H	O	H		change
plain sunbird, *Anthreptes simplex*	5		16		p	+ +
purple-naped sunbird, *Hypogramma hypogrammica*	21		21		p	
thick-billed flowerpecker, *Dicaeum agile*	1		p			
orange-bellied flowerpecker, *Dicaeum trigonostigma*	1		7			+ +
yellow-vented flowerpecker, *Dicaeum chrysorrheum*	p					
yellow-rumped flowerpecker, *Prionochilus xanthopygius* (E)	4		23		p	+ +
flowerpecker sp.	5		27			
spectacled spiderhunter, *Arachnothera flavigaster*	p		4		p	+
terrestrial insectivore/frugivore						
chestnut-breasted partridge, *Arborophila charltoni*	p	3	p	1	p	–
roulroul, *Rollulus roulroul*	1		1			–
great argus, *Argusianus argus*	p	19	p	3	p	– –
crested fireback, *Lophura ignita*	3	3	3	5	p	
chestnut-capped thrush, *Zoothera interpres*	p	1	1	2		
miscellaneous insectivore/piscivore						
Malaysian honeyguide, *Indicator archipelagicus*	p					– –
banded kingfisher, *Lacedo pulchella*	2	8	p	2		– –
black-backed kingfisher, *Ceyx erithacus* (m)	3	5	8	2	p	
stork-billed kingfisher, *Pelargopsis capensis*	p		p			
blue-eared kingfisher, *Alcedo meninting*	p				–	
Javan frogmouth, *Batrachostomus javensis*	p		p			
unidentified						
babbler sp.	12		5			
others	87		61			
total number of species:	193		176		91	

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

APPENDIX 2

Additional species recorded below 400 m altitude in the Ulu Segama Forest Reserve

(These are species which (i) were not present in research plots, or (ii) were present in the primary plot (plot P) and in logged forest but absent from logged plots. Asterisks indicate whether the species was recorded from primary (P) or selectively logged (L) forest.)

	P	L
Schrenck's bittern, *Ixobrychus eurhythmus* (M)	*[a]	
Storm's stork, *Ciconia stormi*		*
brahminy kite, *Haliastur indus*		*
Jerdon's baza, *Aviceda jerdoni*		*
bat hawk, *Machaeramphus alcinus*		*
Bulwer's pheasant, *Lophura bulweri*	*	
bay owl, *Phodius badius*	*	
barred eagle owl, *Bubo sumatranus*	*	
brown hawk owl, *Ninox scutulata*		*
Malaysian eared nightjar, *Eurostopodus temminckii*		*[b]
Pacific swift, *Apus pacificus* (M)		*
grey nightjar, *Caprimulgus indicus* (M)		*
large frogmouth, *Batrachostomus auritus*	*	
blue-throated bee-eater, *Merops viridis* (M)	*	*
grey-crowned woodpecker, *Picoides canicapillus*	*	*
chestnut-collared kingfisher, *Actenoides concreta*	*	
blue-eared kingfisher, *Alcedo meninting*	*	*
blue-banded kingfisher, *Alcedo euryzona*	*	
blue-banded pitta, *Pitta arquata*	*	
barn swallow, *Hirundo rustica* (M)	*	*
bar-bellied cuckoo Shrike *Coracina striata*	*	*
yellow-vented bulbul, *Pycnonotus goiavier*		*
grey wagtail, *Motacilla cinerea* (M)	*	*
slaty-breasted rail, *Rallus striatus*		*
white-bellied yuhina, *Yuhina zantholeuca*	*	*
magpie robin, *Copsychus saularis*		*
white-tailed flycatcher, *Cyornis concreta*	*	
yellow-vented flowerpecker, *Dicaeum chrysorrheum*	*	*
purple-throated sunbird, *Nectarinia sperata*		*
scarlet sunbird, *Aethopyga mystacalis*	*	
tree sparrow, *Passer montanus*		*

[a] Primary forest edge.
[b] Hunting over logged forest, but not necessarily roosting there.