# Heavy Extinctions of Forest Avifauna in Singapore: Lessons for Biodiversity Conservation in Southeast Asia

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**Abstract:** *The consequences of rapid rainforest clearance on native avifauna are poorly understood. In Southeast Asia, Singapore, a newly developing country, has had 95% of its native lowland rainforest cleared. Most of the rainforest was lost in the mid- to late-nineteenth century. We compared avifauna checklists from 1923, 1949, and 1998 to determine the extent of extinctions between 1923 and 1998 in Singapore. Of 203 diurnal bird species, 65 were extirpated in Singapore in the past 75 years. Four of these species were nonforest-dependent species, whereas 61 (94%) were forest bird species dependent on the primary or old secondary forest to survive. Twenty-six forest bird species became extinct between 1923 and 1949, whereas 35 forest species disappeared after 1949. We compared the body lengths, feeding guilds, and vertical feeding zones between extinct and extant forest bird species to determine whether extinction patterns were dependent on these characteristics. Larger forest bird species went extinct between 1923 and 1949. Body sizes, however, did not affect the loss of forest bird species between 1949 and 1998. We observed high losses of insectivorous birds; the insectivore-carnivore and insectivore-granivore guilds lost >80% of the species present in 1923. The highest losses were among birds that fed in the canopy. None of the forest bird species are currently common (>100 individuals/species) within Singapore. Our study shows that more than half the forest avifauna became locally extinct after extensive deforestation. Based on this fact, the countries within Southeast Asia should reconsider their heavy deforestation practices.*

Extinciones Mayores de Avifauna de Bosque en Singapur: Lecciones para la Conservación en Asia Sudoriental

**Resumen:** *Las consecuencias de la tala rápida del bosque lluvioso sobre la avifauna nativa son poco conocidas. En Asia sudoriental, Singapur, un país en desarrollo, un 95% de su bosque nativo de tierras bajas ha sido talado. La mayoríia del bosque se perdió entre mediados y finales del siglo diecinueve. En este trabajo comparamos las listas de avifauna de 1923, 1949 y 1998 para determinar la extensión de las extinciones en Singapur entre 1923 y 1998. Sesenta y cinco de las 203 especies diurnas de aves fueron extirpadas de Singapur en los últimos 75 años. Cuatro de estas especies fueron especies no dependientes del bosque, mientras que 61 (94%) fueron especies de aves del bosque (especies que dependen del bosque primario o secundario viejo para sobrevivir). Veintiséis de las especies de aves del bosque se extinguieron entre 1923 y 1949, mientras que 35 especies del bosque desaparecieron después de 1949. Comparamos las longitudes del cuerpo, los gremios de alimentación y las zonas de alimentación vertical entre especies de aves de bosque extintas y existentes para determinar si los patrones de extinción fueron dependientes de estas características. Las especies de aves grandes del bosque se extinguieron entre 1923 y 1949. Sin embargo, el tamaño del cuerpo no afectó la pérdida de especies del bosque entre 1949 y 1998. Observamos altas pérdidas de aves insectívoras; los gremios de insectívoros-carnívoros e insectívoros-granívoros perdieron >80% de las especies que estaban presentes en 1923. Los números más altos de pérdidas fueron de aves que se alimentan en el dosel. Ninguna de las especies de aves del bosque es común en la actualidad (>100 individuos/especie) dentro de Singapur. Nuestro estudio muestra que más de la mitad de la avifauna del bosque se ha extinguido localmente después de una deforestación extensiva. Con base en este hecho, los países dentro de Asia Sudoriental deberían reconsiderar sus prácticas de intensa deforestación.*

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## Introduction

The global assessment of biodiversity, especially in zones of high species richness such as the tropical biome, should be an urgent priority for conservation biologists. The tropical belt holds more than half the world's biota (Lanly 1982; Raven 1988), yet the native habitats in this area are being lost at an alarming rate (Myers 1986; Whitmore 1992). Although numerous studies of the effects of native habitat loss on biodiversity have been conducted (e.g., Bierregaard & Lovejoy 1989; Laurance 1990, 1994; Pimm & Askins 1995), few have been done in Southeast Asia (e.g., International Tropical Timber Organization 1990; Brooks et al. 1997). Nevertheless, the loss of the tropical rainforest is continuing at an unprecedented rate in Southeast Asia. In Singapore in particular, 95% of the native lowland rainforest has been cleared in the past 180 years. In light of this heavy deforestation, how species become extinct or adapt to habitat change is a major concern of conservation biologists (Turner 1996).

If used cautiously, bird checklists can indicate faunal change over time (Kattan et al. 1994; Remsen 1994; Droege et al. 1998). We compared bird checklists to assess the loss of species between 1923 and 1998 on the island of Singapore. Further, we tested whether extinction patterns of forest bird species were determined by body size and/or feeding characteristics (diet and vertical feeding zones). Studies have shown that the body size and feeding characteristics of a species are critical determinants in the extinction process (Karr 1980; Brash 1987; Kattan et al. 1994). We also classified the abundance status of all surviving bird species so that future conservation efforts can be directed toward currently threatened species. We hope the heavy avian losses within Singapore following extensive rainforest deforestation will serve as a lesson for neighboring countries such as Malaysia and Indonesia and encourage them to reconsider their heavy deforestation practices.

## Methods

### Study Area

Singapore (lat 1°20′N, long 103°50′E) is a small island of 585 km$^2$ situated at the southern tip of Peninsular Malaysia (Fig. 1). Singapore is the most densely populated nation in the world with 6615 people/km$^2$. Singapore's proximity to the equator accounts for its humid, warm climate and lack of seasonality. A variety of natural and human-made habitats occur within the island, including coast and estuary, freshwater wetlands, mangrove, rainforest, secondary growth, scrub, grassland, plantations, and urban and rural areas.

The forested areas of Singapore can be divided into three categories: (1) small remnants of primary forest (barely 200 ha; Corlett 1992) in the Central Catchment Area and Bukit Timah Nature Reserve; (2) old secondary forest (50–80 years old) found mainly in the Central Catchment Area; and 3) young secondary forest (<50 years old) found mainly in parks. Only 2000 ha of primary and mid- to late-secondary forest exist on the island (Turner 1994). These areas represent the last available habitat to support forest avifauna. This refuge is not a continuous forest and is isolated (>100 m) from other relevant forest patches.

Massive deforestation of the original lowland rainforest probably occurred in the mid- to late-nineteenth century by planters of gambier (*Uncaria gambir*; for the production of tannin) and Asian pepper (*Piper nigrum*) (Corlett 1992). At the beginning of this century, rubber (*Hevea brasiliensis*) plantations spread over the previously cleared agricultural areas and over newly cleared forests. After World War II, a shift in economic development promoted industrialization and urbanization of the island.

### Avifauna Records

We used birds for our study because they are considered excellent indicators of environmental health (Furness et al. 1993). We used three lists of avifaunal records. The oldest one was published by F. N. Chasen in 1923 and was the result of 2 years of field data collected over the entire island which included a synthesis of other bird records made by nineteenth-century ornithologists (A. O. Hume and H. R. Kelham). The second checklist was compiled by C. A. Gibson-Hill in 1949, who drew from diverse sources: published records, specimens in the Raffles Museum, and the author's and other naturalists' field records. To determine avian extinctions, we compared these two lists with a recent one published in 1997 by K. S. Lim and D. Gardner. We compared Lim and Gardner's checklist with our field surveys. We restricted our analysis to the resident and diurnal bird species found in all ecosystems of Singapore because nocturnal species may not have been sampled adequately for the previous lists. We also excluded the introduced bird species (e.g., Black-crested Bulbul [*Pycnonotus melanicterus*], Rock Dove [*Columba livia*], Red-collared Dove [*Streptopelia tranquebarica*], Yellow-crested Cockatoo [*Cacatua sulphurea*], Tanimbar Cockatoo [*Cacatua goffini*], Red-breasted Parakeet [*Psittacula alexandri*], House Crow [*Corvus splendens*], White-crested Laughingthrush [*Garrulax leucolophus*], Hwamei [*Garrulax canorus*], Crested Myna [*Acridotheres cristatellus*], and Japanese White-Eye [*Zosterops japonicus*]).

We considered the bird species extinct if they were found by Chasen (1923) but not by Gibson-Hill (1949) or by Gibson-Hill (1949) but not in 1998 (Lim & Gardner 1997, personal observation). We did not classify a spe-

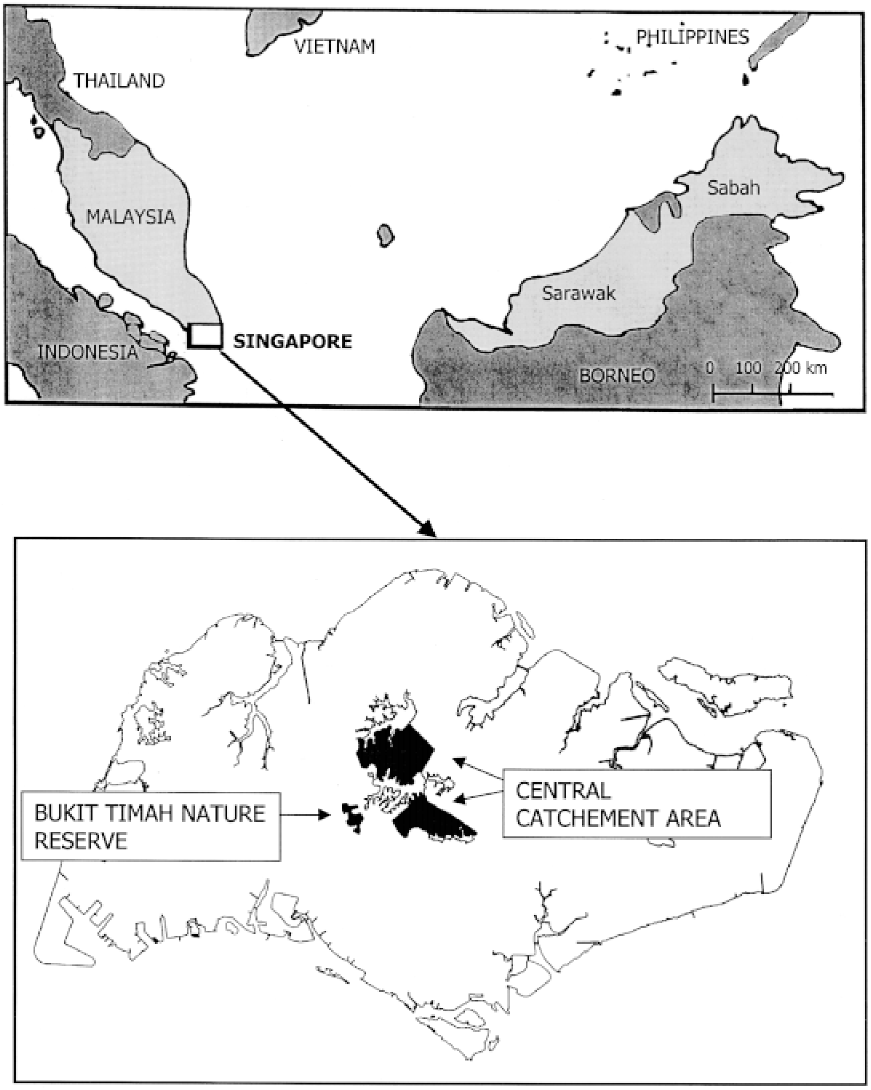


*Figure 1. A regional map of Southeast Asia with an inset showing the location of Singapore.*

cies as extinct if (1) there was probable failure in the recording of species that had ranges covering Singapore (e.g., Pacific Reef Egret [*Egretta sacra*], Black-headed Bulbul [*Pycnonotus atriceps*], Mangrove Whistler [*Pachycephala grisola*], and Short-tailed Babbler [*Trichastoma malaccense*] or (2) records were based on bird skins bought from bird traders (e.g., Green Junglefowl [*Gallus varius*]). Because Chasen (1923) included some records from earlier researchers, it is possible that some bird species listed in his checklist may have been extinct before 1923. To unify the nomenclature of different lists, we followed Inskipp et al. (1996) for common and scientific names.

To validate the existence and status of current avifauna in the forests of Singapore, we collected data from 20 forest patches, including the Central Catchment Area and Bukit Timah Nature Reserve (7–935 ha). We completed transect surveys every 2 months for 18 months in each of the six late secondary–primary forest patches (>50 years old), six young secondary-growth patches (<50 years old), and eight woodland patches (abandoned exotic plantations). To supplement these data, we mist netted birds between March 1997 and November 1998 in the two larger forest remnants of Singapore, Nee Soon (935 ha), and MacRitchie (483 ha), both in the Central Catchment Area. Along existing trails, we erected 10–14 nets (2.5 $\times$ 12.0 m, 30 mm mesh) between 0700 and 1300 hours. Total mist-netting hours conducted were 1442.0 and 1412.5 in Nee Soon and MacRitchie, respectively.

Based on our field observations, we classified all birds either as forest dependent (species that require primary or mature secondary forest to survive) or nonforest dependent (species that do not require the forest to survive). Because many nonforest bird species are extinct in Singapore, we focused only on the forest birds. Currently, these forest species are restricted to the primary or secondary forests in the Central Catchment Area and Bukit

Timah Nature Reserve. In our surveys, therefore, we considered all appropriate lowland rainforest in Singapore.

We tested whether the pattern of extinction was random or selective—whether proportionally more forest bird species than nonforest-dependent species went extinct. To predict the loss of forest-dependent bird species, we used a species-area equation: $(A_{new}/A_{original})^Z$ (Brooks et al. 1997), where $A_{new}$ and $A_{original}$ refer to the proportion of forest area available before and after (5% for Singapore) forest loss, respectively, and $Z$ is an empirically derived constant. We used $Z = 0.25$, as recommended by Brooks et al. (1997). Based on this equation, we predicted that 47% (or 43 of 91 bird species) of the forest bird fauna in Singapore has been lost.

### Index of Abundance, Feeding Characteristics, and Body Size

Based on our surveys, we classified birds as common (C), uncommon (U), or scarce (S) according to their estimated number of individuals (>100, 50–100, and <50, respectively). Extinct (E) birds no longer survive in Singapore. We determined foraging guilds by our field observations and defined vertical feeding zones based on those of Gregory-Smith (1996), with modifications based on our field observations (e.g., White-bellied Woodpecker [*Dryocopus javensis*] was classified as a middle canopy–upper layer feeder by Gregory-Smith [1996], whereas we classified it as a strict canopy feeder). Discrepancies arise from the fact that the forests in Peninsular Malaysia are more mature than the rainforest remnants of Singapore. We defined five vertical zones for Singapore forests: aerial, space above the canopy; canopy, crown of trees >10 m tall; middle layer, woody stems between 1 and 10 m tall; lower layer, shrub level of woody vegetation <1 m tall; and ground level of litter and herb layer.

Based on our own observations of foraging, we classified the feeding guilds as follows: carnivore, frugivore, granivore, insectivore, and nectarivore. For some of the species, the diet was attributable to two or three combined guilds, such as insectivore-granivores or insectivore-frugivore-nectarivores. Similarly, some species fed in multiple zones, for example, in both the canopy and middle layer (CM) or in both the middle and lower layer (ML). To determine if there were differences in the distribution of feeding guilds, we compared the extant forest birds in Singapore with those in similar continuous forests (>2000 ha) in Peninsular Malaysia (Endau Rompin and Taman Nagara). Bird lists for Malaysian forests were obtained from Bransbury (1993), and feeding guilds for Malaysian birds were assigned according to Smythies (1981) and Jeyarajasingam and Pearson (1998). We did not compare the vertical distribution of extant forest birds of Singapore with those in continuous Malaysian forests because Malaysian forests are more mature.

Body-size measurements (from the tip of the bill to the tip of the tail) of all the extinct and extant forest bird species were obtained from MacKinnon and Phillipps (1997). When sexes differed in the body length for a given species, an average of male and female measurements was calculated.

## Results

### Local Extinctions

During the past 75 years, 65 out of 203 bird species have become extinct in Singapore. Out of 91 forest species, 61 (67%) have disappeared (Appendix). Proportionally more bird extinctions have occurred among forest (93.8%, 61/65) than nonforest-dependent bird species ($\chi^2 = 49.98$, df = 1, $p = 0.001$). The number of forest species has declined since 1923 (Fig. 2). Overall, the loss of species was higher in Singapore than was predicted (61 vs. 43), but the two values did not differ significantly

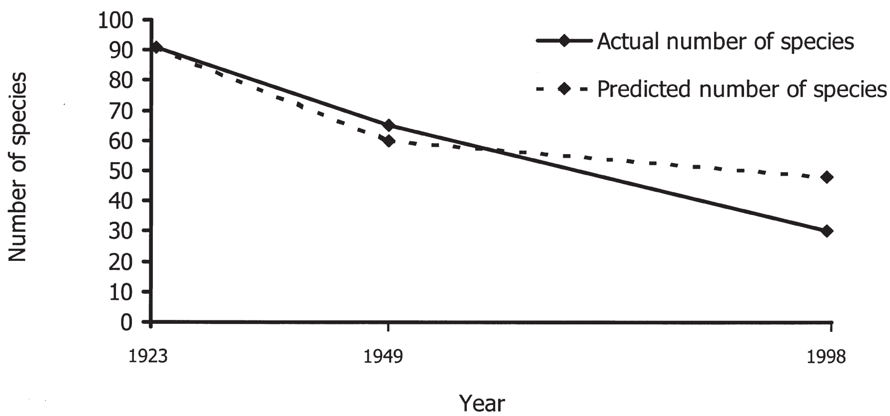


*Figure 2. Predicted and observed loss of forest bird species in Singapore since 1923. Predicted numbers were calculated based on a species-area equation (see methods) and assuming that forest clearing started in 1819 in Singapore.*

($\chi^2$ = 3.12, df = 1, $p$ = 0.08). The predicted versus observed number of extinctions did not differ for 1949 ($\chi^2$ = 0.22, df = 1, $p$ = 0.64), but there were fewer extinctions in 1998 than predicted ($\chi^2$ = 4.15, df = 1, $p$ = 0.04). In 1998, however, proportionally more forest species were uncommon than were nonforest dependent species ($\chi^2$ = 15.51, df = 1, $p$ = 0.001; Fig 3). None of the forest bird species was common (Fig. 3).

Between 1923 and 1949 (pre-war period), 28.6% (26/91) of the forest bird species became extinct. Between 1949 and 1998 (post-war period), another 38.5% (35/91) of the forest species became extinct (Fig. 3).

## Body Size and Extinctions

Between 1923 and 1998, there was no significant difference in the body length of the extinct (25.93 ± 2.65 cm [SE]) and extant (20.47 ± 1.70 cm) forest bird species (Mann-Whitney $U$ = 771.5, df = 30, 61, $p$ = 0.22). During the pre-war period, however, extinct forest species had, on average, longer body length (33.65 ± 5.65 cm) than the extant forest species (20.32 ± 1.08 cm) ($U$ = 609, df = 26, 65, $p$ = 0.04). During the post-war period, there was no significant difference in the body length between extinct (20.2 ± 1.40 cm) and extant (20.47 ± 1.70 cm) forest bird species ($U$ = 514.5, df = 30, 35, $p$ = 0.89).

## Extinctions among Feeding Guilds and Zones

Comparing the percentages of total extinct forest species within each guild, we observed a preponderance of losses within insectivorous birds. When we calculated extinctions relative to the number of species present within each guild (Fig. 4c), we determined that insectivorous birds were vulnerable, with a 76% loss of all species present in this guild. The most vulnerable feeding guilds were insectivore-carnivore and insectivore-granivore, with 80% and 100% losses of bird species present within each guild, respectively (Fig. 4c). During both pre- and post-war periods, the distribution of extinctions was not even among feeding guilds ($\chi^2$ = 24.38, df = 4,

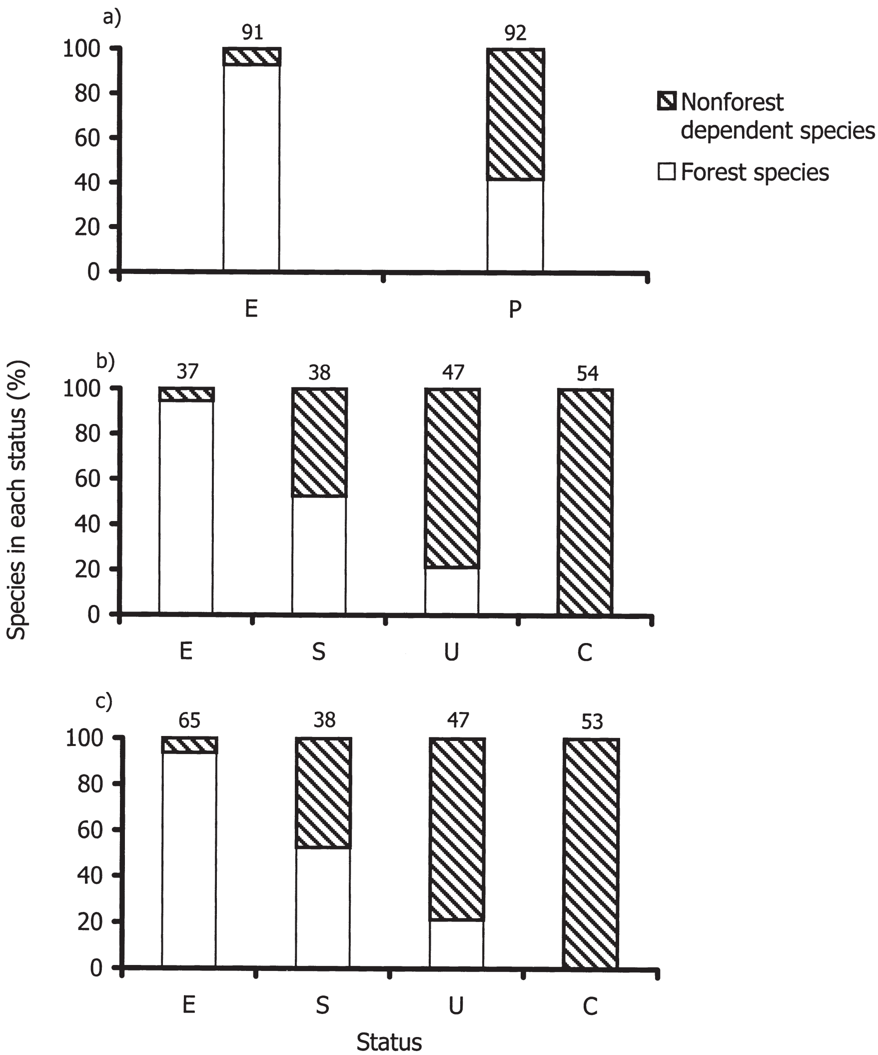


*Figure 3. The proportion of forest- and nonforest-dependent bird species in relation to abundance status (E, extinct; P, present; S, scarce; U, uncommon; and C, common) in (a) 1923–1949, (b) 1949–1998, and (c) 1923–1998. Because no bird abundance data were available for 1923–1949 comparison, only extinct and present categories are used. Number of species is indicated at the top of each bar.*

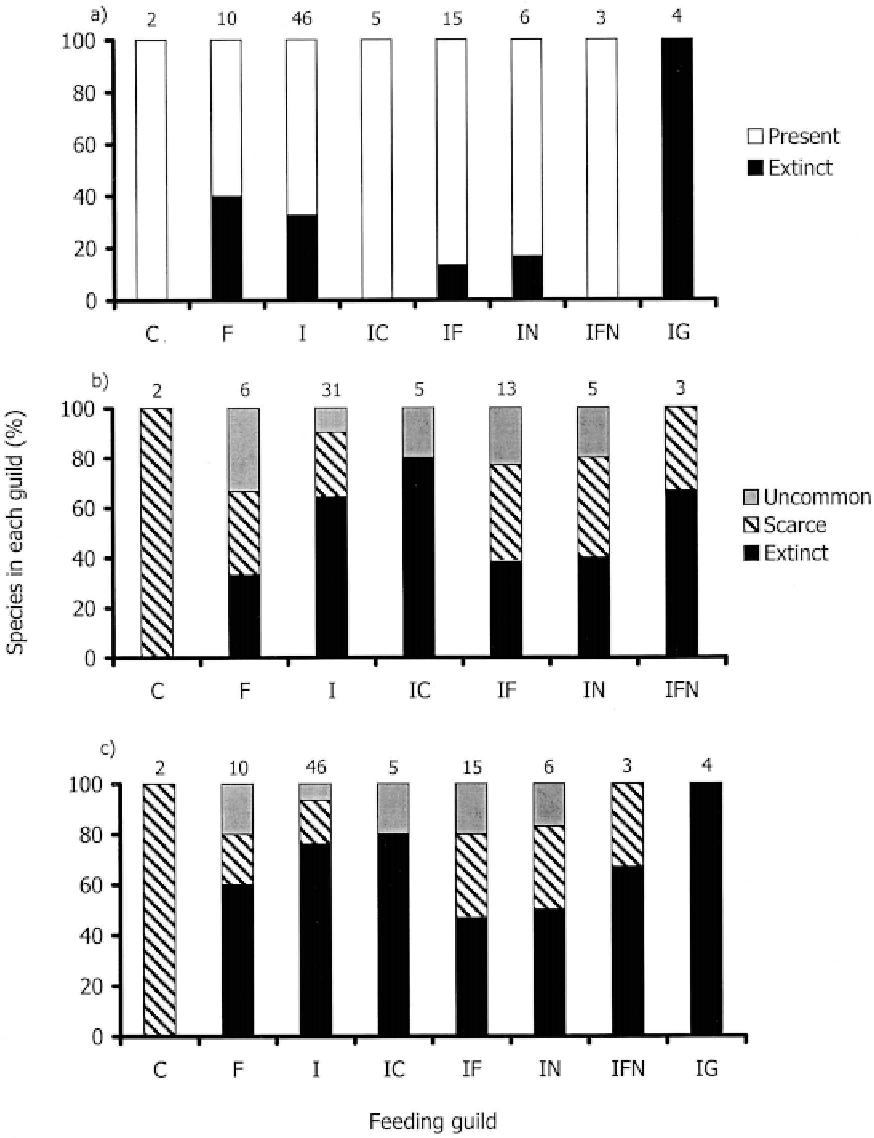


*Figure 4. The status of forest bird species among different feeding guilds (C, carnivore; F, frugivore; G, granivore; I, insectivore; and N, nectarivore; the presence of two or three guild symbols indicates mixed diets [IC, IF, IN, IFN, and IG]): (a) 1923–1949, (b) 1949–1998, and (c) 1923–1998. For definitions of abundance status abbreviations see Fig. 3. Number of species is indicated at the top of each bar.*

$p = 0.0001$, and $\chi^2 = 42.66$, df = 5, $p = 0.0001$, respectively), and similarly, 57.7% (15/26) of pre-war and 57.1% (20/35) of post-war extinctions were of insectivorous birds.

During the pre-war period, more monodiet guilds (e.g., frugivore 40% and insectivore 32.6%) than multidiet guilds were affected by extinctions (e.g., insectivore-carnivore, 0%; insectivore-frugivore-nectarivore, 0%; insectivore-frugivore, 13.3%; and insectivore-nectarivore, 16.3%; Fig. 4a). The exception was the insectivore-granivore guild, which lost all species (Fig. 4a). In the post-war period, however, all multidiet guilds lost some bird species (Fig. 4b).

The distribution of feeding guilds among extant forest birds of Singapore and those in two continuous forests of Peninsular Malaysia did not differ significantly ($G = 12.1$, df = 16, $p = 0.73$; Fig. 5). More insectivores, however, were present in continuous forests than in Singapore ($\chi^2 = 55.2$, df = 2, $p = 0.001$; Fig. 5).

We observed that 29.5% of the extinctions occurred within the tree canopy. The extinction pattern did not occur with the same probability within each vertical feeding zone between 1923 and 1998 or in the post-war period ($\chi^2 = 18.07$, df = 6, $p = 0.0061$ and $\chi^2 = 20.8$, df = 6, $p = 0.002$, respectively). During the pre-war period, however, the number of extinctions among the vertical feeding zones did not differ significantly ($\chi^2 = 9.55$, df = 5, $p = 0.09$). The middle, middle-lower, and ground zones experienced heavy losses relative to the number of species feeding in these zones (Fig. 6c). The surviving middle-lower and middle zone species, with only a handful of extant species, were all classified as scarce. In the pre-war period, higher percentages of extinctions occurred predominantly in the canopy (26.9%), middle layer (23.1%), and ground (23.1%). During the post-war period, extinctions occurred primarily in the canopy (28.6%), middle canopy (28.6%), and middle-lower canopy (22.9%).

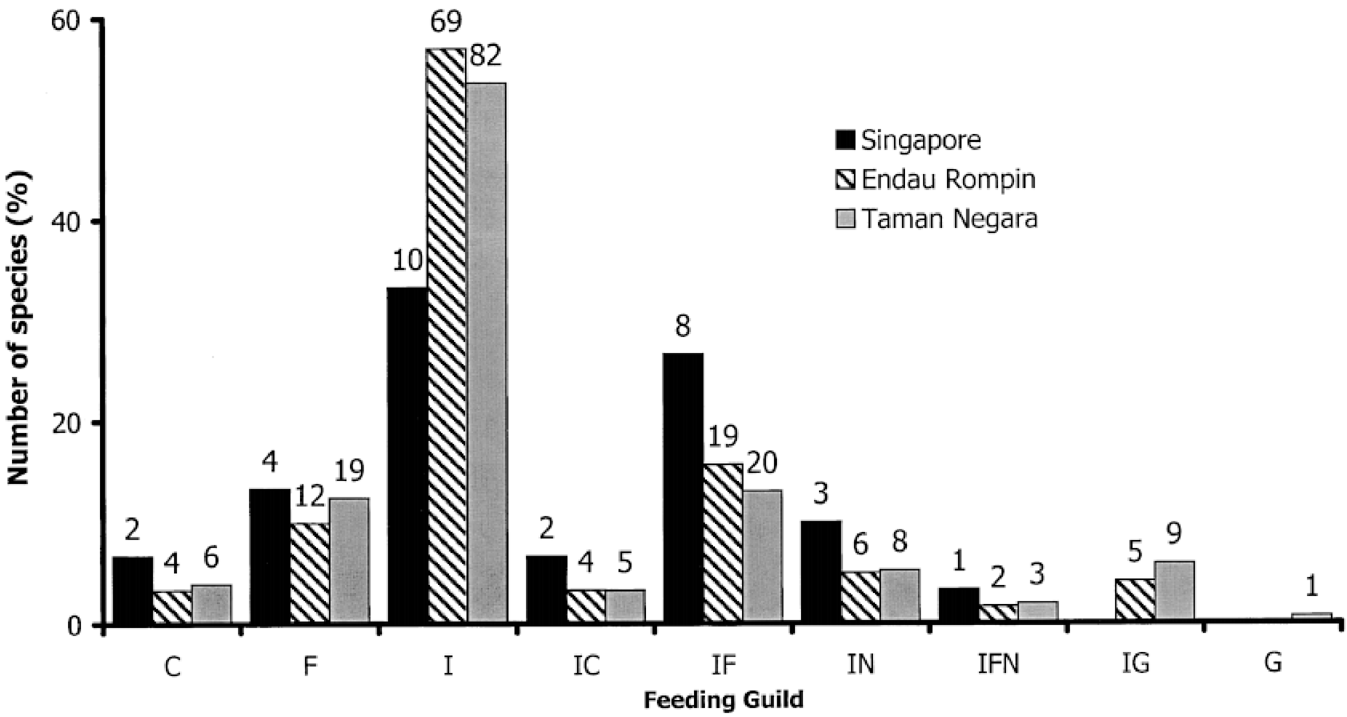


*Figure 5. A comparison of feeding-guild distribution among extant forest birds of Singapore and those present in two continuous forests in Peninsular Malaysia. For definitions of feeding guilds see Fig. 4. Number of species is indicated at the top of each bar.*

## Discussion

Numerous studies report the loss of forest bird species following forest loss (e.g., Newmark 1991; Magsalay et al. 1995). Our study shows that the loss of forest bird species in Singapore following deforestation was at least two-fold higher than the range of 20–33% for various tropical locations (e.g., Karr 1982; Diamond et al. 1987; Kattan et al. 1994; Christiansen & Pitter 1997). The predicted and observed number of extinctions did not differ for all the years combined, but there were fewer extinctions in 1998 than predicted. This suggests a relaxation—original fauna eventually falling to lower numbers following habitat loss—in the forest avifauna. Brooks et al. (1999) report that in tropical areas, such as Singapore, most extinctions occurred within 120 years of habitat loss.

Although there were some reports of bird extinctions within Singapore during the 1800s (Lim 1992), they are difficult to validate. The only endemic bird subspecies in Singapore (Common Iora [*Aegithina tiphia singaporensis*]) is not a forest species. There is no endemic forest bird species in Singapore (Lim & Gardner 1997), so all the extinctions of forest birds in Singapore following forest loss are local extinctions. The possible explanations for this high vulnerability to extinction for forest bird species in Singapore stem from a combination of factors. The extent of the forested areas in 1923 cannot be approximated because of the lack of forest surveys. This prevents an analysis of the relationship between the patterns of forest loss and forest bird extinctions. Extensive habitat destruction probably played a role in these extinctions in two ways. First, it probably contributed to the relatively immediate extinctions, primarily in the first half of this century, that affected large forest bird species (26 bird species were lost, including Trogonidae and Bucerotidae). This result is consistent with the observations made by Faaborg (1979) on the effect of extinction processes on species with large bodies. Second, extinctions continued in the second half of this century with the disappearance of 35 additional forest species. Possible explanations for these "delayed" extinctions are (1) land under shifting cultivation might still have retained some wooded areas that could act as refuges for forest birds; (2) the low probability that species will survive over long periods in small numbers; and (3) the initial resilience of species to an altered environment (Johns 1991; Heywood & Stuart 1992).

Species using the ground and middle layers were particularly affected, possibly because habitat loss may increase the probability of encounter with predators and thus result in high predation rates (Wong et al. 1998). Also, the requirement of large tracts of undisturbed forests by forest bird species probably prevents any durable adaptation to a changing environment. Currently, none of the forest bird species are common in Singapore. We

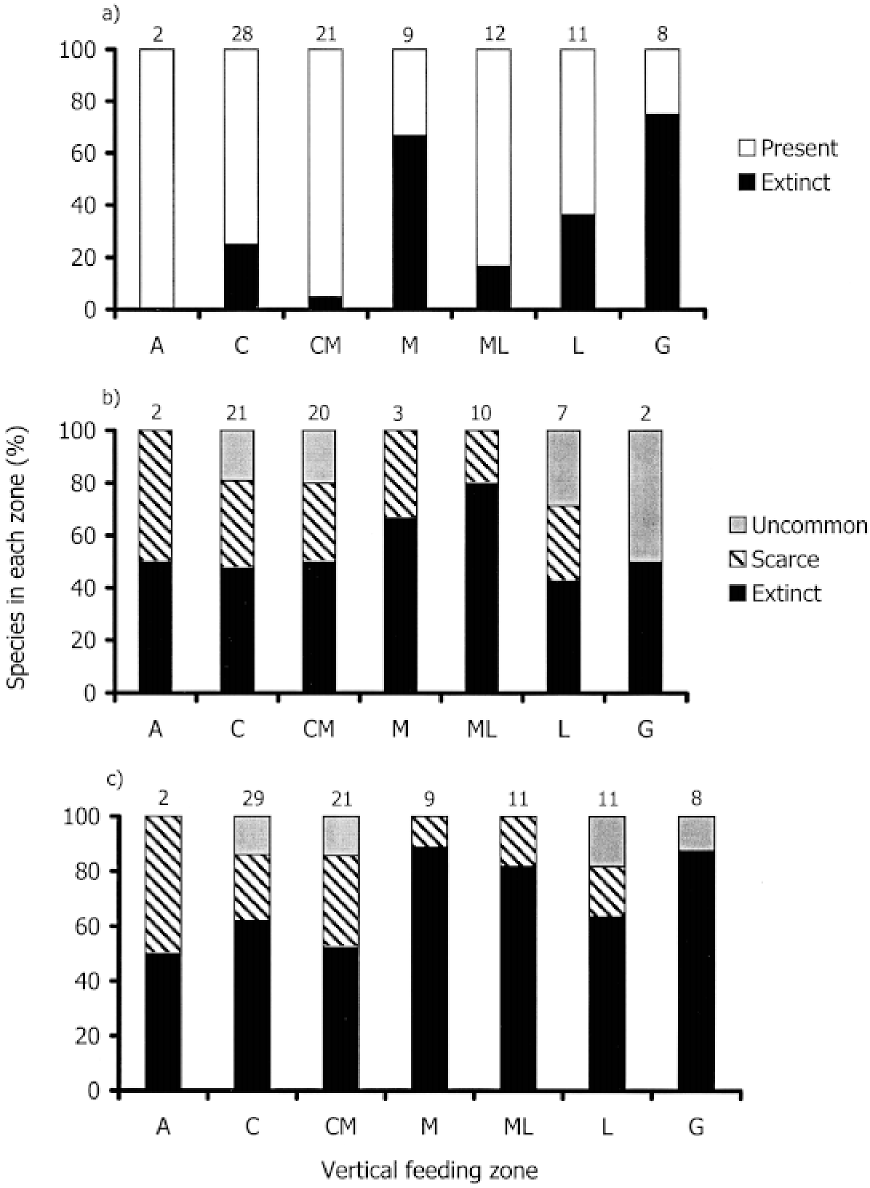


*Figure 6. The status of forest bird species feeding on different vertical feeding zones (A, aerial; C, canopy; M, middle layer; L, lower layer; G, ground; the presence of two or three symbols indicates combined vertical feeding zones [CM and ML]): (a) 1923–1949, (b) 1949–1998, and (c) 1923–1998. For definitions of abundance status abbreviations see Fig. 3.*

have also observed the presence of only one pair of the White-bellied Woodpecker (*Dryocopus javensis*) remaining in the Central Catchment Area; this species likely will soon go extinct in Singapore. A similar fate may be in store for some other forest bird species such as the Lesser-green and Greater-green Leafbirds (*Chloropsis cyanopogon* and *Chloropsis sonnerati*, respectively), whose population sizes may not be viable (<50 individuals). Therefore, although forest avifauna seemed to have relaxed, the extinction process will probably continue in Singapore unless conservation measures are implemented. Avian losses are known to continue over a long time following habitat disturbance (Robinson 1999).

In the pre-war period, the majority of the losses were observed within monodiet species such as frugivores or insectivores or within single-vertical-zones species inhabiting, say, the ground and middle layer. Generalist species are probably more adaptable than specialized species, which could explain their ability to survive. The phobia of forest birds of crossing even small gaps may have caused their isolation within fragments and prevented them from moving to search for food (Sieving et al. 1996). Thus, the limitation of food resources even for some generalist bird species might have eventually made them vulnerable to extinction (Karr 1982; Newmark 1991). In the post-war period, extinction reached all types of food habits and feeding zones, suggesting wide-ranging effects of deforestation.

Some studies show losses within understory insectivorous and large-canopy frugivorous birds (e.g., Kattan et al. 1994; Christiansen & Pitter 1997). Our results partially confirm these findings. Insectivorous birds were more affected than any others. Similar Malaysian continuous forests had more insectivorous forest species than were present in Singapore in 1998 (Fig. 5). Large-canopy frugivores, mainly the Bucerotidae family, disappeared during the pre-war period. Large body size implies the consumption of large amounts of food. The fruit supply may not be sufficient in fragments, which may have been the source of extinction pressure (Terborgh 1974). An interaction between body size and population size can also influence extinction patterns (Pimm et al. 1988). Because there is no data on the population size of different species for both 1923 and 1949, we were unable to evaluate this aspect.

Habitat destruction is not the sole cause of extinction of forest birds. During World War II and the Japanese occupation (1942–1945) some of Singapore's nature reserves were shelled. This may have had negative consequences for the avifauna, but how many species perished during the war is not known. Leck (1979) and Heywood and Stuart (1992) raised the question of illegal poaching as an important factor in bird extinctions. In Singapore, poaching has probably contributed in a large way to extinctions during this century. The bird skin trade was a powerful market, and Singapore was a hub. Chasen (1923) personally reported on the illegal hunting of the bird species by young sportsmen who had a rapid and unequivocal influence on the extinction process. Even under strict law, poaching still occurs, partly because of the small number of qualified rangers in the nature reserves. A closely related problem is human disturbances such as army exercises, which probably have a negative effect on the forest avifauna. Disturbance could push the shy birds back into an even smaller area of the forest and force nesting birds to abandon their nests.

### Conservation Implications

It can be argued that Singapore, being an island and containing a relic fauna, may not be an ideal location for indicating generalities of avian extinction patterns within Southeast Asia. Nevertheless, the same bird groups (e.g., pheasants, trogons, hornbills, and babblers) have been lost from forest fragments of Malaysia and Thailand (Round 1988; Ford & Davison 1996). This suggests that our study results could help predict, generally, the effects of forest loss on avifaunal diversity within Southeast Asia.

In insular Southeast Asia, deforestation of 1.3% per year is much higher than that in tropical South America (0.6%) and tropical southern Africa (0.8%) (Food and Agriculture Organization 1999). Therefore, a balance between the preservation of native habitats and economic development is urgently needed in light of the incomparable rate of deforestation in this area. Our study shows that a heavy loss of forest bird species occurs following tropical deforestation, which suggests that tropical deforestation will alter avian community composition. Extinctions occur over protracted periods of time, so for recently deforested areas there may still be time to conserve threatened species. To maintain a diverse avifauna in the lowland rainforests, conservation actions should account for critical resource requirements of the bird communities.

Is there any future conservation value in the remnants of rainforest within Singapore? According to Turner and Corlett (1996), conserving even the smaller remnants of rainforest is important. In addition to other benefits, small remnants can serve as seed reservoirs for the process of forest regeneration. We also support the creation of nature reserves in areas of secondary forests. In Singapore especially, the maturity of the secondary forest represents an excellent potential for maintaining current biodiversity. If the quality of habitat improves, there would probably be a lower extinction risk for the avifauna, and then bird reintroductions could be considered.

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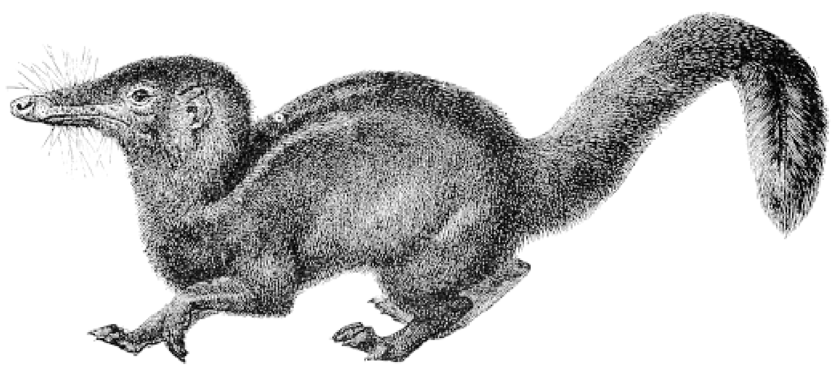

## Appendix

**Forest bird species that became extinct in Singapore between 1923 and 1998.**

| *Species* | *Vertical feeding zone*[a] | *Feeding guild*[a] | *Body length (cm)*[b] |
|---|---|---|---|
| Extinct between 1923 and 1949 (pre-war period) | | | |
| Black Partridge (*Melanoperdrix nigra*) | G | I G | 25 |
| Crestless Fireback (*Lophura erythrophthalma*) | G | I G | 49 |
| Malayan Peacock Pheasant (*Polyplectron malacense*) | G | I G | 40 |
| Great Argus (*Argusianus argus*) | G | I G | 90 |
| Red-billed Malkoha (*Phaenicophaeus javanicus*) | C | I | 46 |
| Raffle's Malkoha (*Phaenicophaeus chlorophaeus*) | M | I | 30 |
| Scarlet-rumped Trogon (*Harpactes duvaucelii*) | C | I | 23 |
| Red-naped Trogon (*Harpactes kasumba*) | M | I | 33 |
| Diard's Trogon (*Harpactes diardii*) | M | I | 30 |
| Rhinoceros Hornbill (*Buceros rhinoceros*) | C | F | 110 |
| Helmeted Hornbill (*Buceros vigil*) | C | F | 120 |
| Red-throated Barbet (*Megalaima mystacophanos*) | M C | F | 23 |
| Yellow-crowned Barbet (*Megalaima henricii*) | C | F | 21 |
| Maroon Woodpecker (*Blythipicus rubiginosus*) | L | I | 23 |
| Dusky Broadbill (*Corydon sumatranus*) | M | I | 27 |
| Black-and-yellow Broadbill (*Eurylaimus ochromalus*) | M | I | 15 |
| Puff-backed Bulbul (*Pycnonotus eutilotus*) | C | I F | 20 |
| Black-and-white Bulbul (*Pycnonotus melanoleucus*) | C | I F | 18 |
| Grey-breasted Babbler (*Malacopteron albogulare*) | L | I | 15 |
| Black-capped Babbler (*Pellorneum capistratum*) | G | I | 17 |
| Black-throated Babbler (*Stachyris nigricollis*) | L | I | 13 |
| Chestnut-rumped Babbler (*Stachyris maculata*) | L M | I | 17 |
| Striped Wren Babbler (*Kenopia striata*) | G | I | 14 |
| Fluffy-backed Tit Babbler (*Macronous ptilosus*) | L | I | 15 |
| Maroon-breasted Philentoma (*Philentoma velatum*) | M | I | 20 |
| Spectacled Spiderhunter (*Arachnothera flavigaster*) | C | I N | 21 |
| Extinct between 1949 and 1998 (post-war period) | | | |
| Black-bellied Malkoha (*Rhopodytes diardi*) | M C | I C | 34 |
| Whiskered Treeswift (*Hemiprocne comata*) | C | I | 15 |
| Silver-rumped Needletail (*Chaetura leucopygialis*) | A | I | 11 |
| Rufous-collared Kingfisher (*Halcyon concreta*) | L M | I C | 23 |
| Oriental Dwarf Kingfisher (*Ceyx erithacus*) | L | I C | 14 |
| Banded Kingfisher (*Lacedo pulchella*) | M | I C | 20 |
| Blue-eared Barbet (*Megalaima australis*) | C | F | 18 |
| Brown Barbet (*Calorhamphus fuliginosus*) | C | F | 17 |
| Crimson-winged Woodpecker (*Picus puniceus*) | M C | I | 25 |
| Checker-throated Woodpecker (*Picus mentalis*) | M C | I | 27 |
| Olive-backed Woodpecker (*Dinopium rafflesii*) | M C | I | 25 |
| Buff-rumped Woodpecker (*Meiglyptes tristis*) | M C | I | 15 |
| Buff-necked Woodpecker (*Meiglyptes tukki*) | L M | I | 21 |
| Great Slaty Woodpecker (*Mulleripicus pulverulentus*) | C | I | 50 |
| Grey-and-buffed Woodpecker (*Hemicircus concretus*) | C | I | 14 |
| Orange-backed Woodpecker (*Chrysocolaptes validus*) | M C | I | 30 |
| Green Broadbill (*Calyptomena viridis*) | L M | F | 18 |
| Banded Broadbill (*Eurylaimus javanicus*) | C | I | 21 |
| Garnet Pitta (*Pitta granatina*) | L | I | 17 |
| Fiery Minivet (*Pericrocotus igneus*) | C | I | 15 |
| Bar-bellied Cuckoo-Shrike (*Coracina striata*) | C | I | 28 |
| Large Wood-Shrike (*Tephrodornis gularis*) | M C | I | 18 |
| Green Iora (*Aegithina viridissima*) | C | I | 13 |
| Grey-bellied Bulbul (*Pycnonotus cyaniventris*) | M | I F | 16 |
| Spectacled Bulbul (*Pycnonotus erythropthalamos*) | L M | I F | 18 |
| Yellow-bellied Bulbul (*Criniger phaeocephalus*) | L M | I F | 20 |
| Bronzed Drongo (*Dicrurus aeneus*) | M C | I | 23 |
| Dark-throated Oriole (*Oriolus xanthonotus*) | C | I F | 18 |
| Black Magpie (*Platysmurus leucopterus*) | M C | I F C | 38 |
| Large Wren Babbler (*Turdinus macrodactylus*) | G | I | 19 |
| Rufous-winged Philentoma (*Drymophila pyrrhoptera*) | L M | I | 16 |
| Purple-naped Sunbird (*Hypogramma hypogrammicum*) | L | I N | 15 |
| Grey-breasted Spiderhunter (*Arachnothera affinis*) | M C | I N | 17 |
| Yellow-breasted Flowerpecker (*Prionochilus maculatus*) | L M | I F N | 10 |
| Plain Flowerpecker (*Dicaeum concolor*) | L M | I F N | 8 |

[a] *For definitions of vertical feeding zone and feeding guild abbreviations, see Figs. 6 and 4, respectively.*
[b] *Body length from MacKinnon and Phillipps (1997).*