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# The future for Sundaic lowland forest birds: long-term effects of commercial logging and fragmentation

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The lowland forests of the Sundaic region are disappearing at immense speed, and whatever survives of them will inevitably suffer the effects of internal degradation (from logging in particular) and of fragmentation. A review of the various studies of the impact of logging and fragmentation on the avifaunas of forested sites throughout the region consistently indicates that large areas of logged forest retain the majority of species present prior to logging, but that forest fragments—apparently even relatively large patches with a high proportion of primary forest—lose a significant number of species. Of 274 resident forest bird species confined to the lowlands of the Sundaic region (excluding Palawan), 83 (30% of the avifauna) are adversely affected by fragmentation and 26 (9.5%) negatively affected by logging, with forest-interior sallying insectivores, terrestrial insectivores and woodpeckers being particularly susceptible to both threats. In total, available data suggest that at least 91 and possibly 132+ species, or 33–50% of the lowland forest avifauna, respond negatively to the effects of these processes in some parts of their range. In the Sunda region, however, fragmentation would seem to be a much more serious threat to the survival of certain forest bird species than the selective logging of continuous forest. This conclusion suggests that the area of forest estate set aside for the production of timber is likely to have important (albeit secondary) conservation potential if (but *only* if) strict management regimes eliminate/ minimise fire, further clearance and penetration by settlers and hunters (and possibly only if contiguous areas of primary lowland forest are left intact.

## INTRODUCTION

The Sundaic region, comprising southern Peninsular Thailand, the Malay Peninsula and the Greater Sunda Islands of Borneo, Sumatra and Java, plus Palawan (Philippines), supports a diverse resident landbird avifauna. Many species are shared between islands (e.g. Borneo shares 61% of species with Java; the Greater Sunda Islands share 74–87% of birds with the Malay Peninsula), but there is also a modest degree of insular endemism (e.g., 10% in Java and Borneo; 6% in Sumatra: MacKinnon and Phillipps 1993), largely but not exclusively based on montane elements (see, e.g. Stattersfield *et al.* 1998). There is a considerably larger level of endemism in the region as a whole: using figures presented in MacKinnon and Phillipps (1993) but excluding Palawan, 138 (24%) out of a total of the region's 577 resident landbird species are endemic to it. The majority of resident Sundaic landbirds occupy forested habitats, and 68% of the 240 resident species found mainly to exclusively in lowland inland forests are Sunda region endemics (Wells 1985). Censuses of 2 km$^2$ study sites in Malaysia indicate that such areas of lowland inland forest typically support c.190 (presumably all resident) bird species (Wells 1999).

Sundaic forests have suffered enormous damage and destruction in recent decades, and pressure on the relatively small remaining pristine areas is intensifying (Scotland *et al.* 1999, McCarthy 2000, Jepson *et al.* 2001; also BirdLife International 2001: 943-947). Moreover, there is no real prospect of bringing back tropical moist forest through rehabilitation once significantly altered or cleared (Lovejoy 1985). In this region, much the most pressing conservation issue for birds is simply forest loss, but this is set to change: as areas of remaining natural forest contract to a point where they can to some degree be defended and rendered stable, it is forest degradation and isolation that will increasingly emerge as the dominant problems. Substitutes for natural forest have negligible conservation significance, since few forest birds survive in the plantation monocultures—oil palm, rubber, acacia, etc.—that are replacing Sundaic forests (Lenton 1984, Mitra and Sheldon 1993, Danielsen and Heegaard 1994, Thiollay 1995).

Degradation of forests occurs as a consequence of many factors, most notably logging, shifting cultivation, the use of fire and fuelwood collection. During the 1980s and 1990s, Asia experienced logging rates that were typically twice those found in other parts of the tropics, with exceptionally high rates in Malaysia and Indonesia (Whitmore 1997). These rates remain high, with about one million ha of forest being logged per year in Indonesia (Scotland *et. al.* 1999). In particular, the astonishing rate of forest loss and fragmentation in Sumatra and Kalimantan (Indonesian Borneo) has been confirmed by a recent satellite image study (Holmes 2000, World Bank 2001). Dry inland mixed dipterocarp forests of the lowlands and foothills have been the main focus of logging, conversion and fire in the Sunda region: yet it is precisely these forests which also support the most diverse bird assemblages in the region, with avian diversity beginning to attenuate at 150–200 m despite the fact that, in vegetational terms, 'lowland' forest extends to 900–1,000 m (Wells 1985, 1999, D. R. Wells *in litt.* 2002). In the Sundaic region, 42% of bird species are endemic to lowland inland forests (Wells 1999); in Borneo, half of the 40 species endemic to the island are dependent on lowland forest (Duckworth *et al.* 1996). Hence profound changes are occurring in the distribution and quality of forests available to a significant proportion of restricted-range bird species, and their long-term survival prospects require evaluation.

Unfortunately, however, the enormity of the biodiversity crisis in the Sundaic lowlands is paralleled by the enormity of the ignorance in which those concerned about its effects are compelled to operate. The intricacies of biological pattern and process as forests deteriorate are poorly understood and, given the speed at which that deterioration is occurring (the problem has commonly been to find a study site guaranteed to be in the same condition at the end of the project as at the start), the scope for improvement of the knowledge base in this massive subject area is negligible. For example, forests, particularly those that have been commercially logged (Woods 1989), have suffered from extensive fires during recent decades, but (despite Kinnaird and O'Brien 1998, Anggraini *et al.* 2000) the survivorship of birds in burnt forests has not been adequately studied. Moreover, although both commercial logging and fragmentation are precursors of other threats to birds, most notably involving increased levels of trapping and hunting (Bennett and Dahaban 1995, Bennett and Gumal 2000), there has been very little systematic investigation of this problem. Indeed, it is owing to insufficient data that the avifauna of Palawan is not discussed in this paper. Nevertheless, by reviewing the various studies of Sundaic birds in logged and fragmented forests it is possible to arrive at a fairly robust list of the species that are most likely to be affected by the new circumstances in the region (constituting 50% of the resident lowland forest avifauna); and by considering the characteristics of the protected area network in the region it is possible to see how urgently and comprehensively the situation needs to be addressed if the fullest spectrum of biological diversity in Sundaic forests—not just the bird component—is to stand any chance of being preserved.

Scientific names of Sundaic bird species are only given in the text if the species in question does not appear in the Appendix.

## FRAGMENTATION, LOGGING AND THEIR EFFECTS ON FOREST BIRDS: A REVIEW

### Rates of deforestation in the Greater Sunda Islands

Rates of forest loss in the Greater Sunda Islands are of global concern. Java retains only 2.3% of natural lowland forest, yet there is still a slow process of attrition from the lower edges upwards, even in its best-known protected areas (FRL pers. obs., R. F. A. Grimmett verbally 2002). In contrast, Sumatra and Borneo were well forested until relatively recently, but both islands have been subject to intense clearance in the past two decades. Data in Table 1 obscure the fact that forest loss has not been uniform: in Sumatra, for example, the southern provinces have lost most of their lowland forests (albeit including much non-dryland—mostly peatswamp—forest), whilst some extensive areas remain in the north. What is also not apparent is the proportion of logged or otherwise degraded forest to primary areas. Most lowland forests, including those in the protected areas of Indonesia, have been or are being logged (DFID 1999) or otherwise degraded through shifting cultivation, mining and other activities (Achard *et al.* 1997). In Indonesia, therefore, very few Sundaic lowland forests survive, and fewer still are likely to survive, in a pristine form (see, e.g., Jepson *et al.* 2001, Whitten *et al.* 2001).

The late D. A. Holmes (*in litt.* 1999; also Holmes 2000, World Bank 2001) showed that it is now mainly the non-swampy forests below the hill-foot boundary that are vanishing from Sumatra and Borneo. Without immediate and fundamental changes in land-use policies and forest management, and implementation of existing legislation, it is predicted that virtually all such forests will have disappeared from Sumatra by 2005 and from Kalimantan by 2010. Threats to swampy lowland forests are less immediate, but even these might disappear by 2015 if no changes in timber extraction and conversion rates occur; indeed, Anderson (1999) noted that 'the fires of 1999 have reinforced the view that the wetlands of Sumatra are the areas at greatest risk from controlled burning and wildfires'. Even protected areas are not immune to complete clearance: in South Sumatra province alone, six protected areas—Air Padang Sugihan Game Reserve, Bentayan Game Reserve, Dankku Game Reserve, Benakat Hunting Reserve, Suban Jeruji Hunting Reserve and Gunung Raya Game Reserve (with a combined minimum original area of 258,000 ha)—no longer possess any forest cover whatsoever (Holmes 2000). Moreover, in western Indonesia many areas classified as permanent production forest (forest set aside for production of timber on a permanent basis) or protection forest (forest set aside to provide a specific ecological function such as soil and riverbank stabilisation) have been so badly degraded (Scotland *et al.* 1999) that they are likely either to be converted to economically productive plantations or to be lost through future fire events.

Prospects for forest conservation in Malaysia may appear somewhat less bleak at present, but the forces that determine forest exploitation are outside the control

**Table 1**. Mean rate of deforestation in Sumatra and Kalimantan; source: Holmes (2000) based on interpretation of satellite imagery.

| | ± 1985 | | ± 1997 | | Deforestation | | |
|---|---|---|---|---|---|---|---|
| | Extent of forest (million ha) | % total area | Extent of forest (million ha) | % total area | Decrease 1985–1997 (million ha) | % loss | Million ha/year |
| Sumatra | 23.3 | 49% | 16.6 | 35% | 6.7 | 29% | 0.6 |
| Kalimantan | 40.0 | 75% | 31.0 | 59% | 9.0 | 22% | 0.7 |

of central government (D. R. Wells *in litt.* 2002) and emerging threats reveal that the situation is not stable. In Sabah a major project has recently been initiated to convert 20–30% of the Ulu Segama Forest Reserve (arguably—and in our view incontrovertibly—the most important remaining area of lowland forest in Borneo and indeed, with the exception of Taman Negara in Peninsular Malaysia, in the entire Sundaic region) into *Acacia* plantation, a development which would seriously undermine the conservation value of the area, and lead to a permanently elevated risk of forest fire (J. R. MacKinnon *in litt.* 1999, BirdLife International 2001: 945). Such a plan reveals the weakness of policy with respect to safeguarding the sustainable use of natural resources. (If the full story of the Ulu Segama conversion ever emerges, the driving force is likely to prove to be a major crisis in the finances of agencies whose remit it is to support Ulu Segama.)

Fire has accounted for a considerable proportion of the forest loss and damage in the region, particularly during El Niño drought years. In 1983, 4.5 million ha of forest were burnt in Borneo (Beaman *et al.* 1985), whilst the fires of 1997/98 affected 4.6 million ha of land in Sumatra and Kalimantan, of which 30% were forests and bush areas, and 20% peatswamp forests (CRISP [Centre for Remote Imaging, Sensing, and Processing, Singapore] cited in Schweithelm 1998). These fires primarily arose as a consequence of land-use policies that have made it most profitable to use fire for large-scale land-clearance operations (Baber and Schweithelm 2000, Dennis 2000). This land-clearance has inadvertently affected many areas, as the fires commonly spread unchecked into adjacent logged forests. Many protected areas have been affected by fire. For example, Berbak, a major protected area of about 170,000 ha of freshwater and peatswamp forests, lost 18,000–24,000 ha in fires that occurred during the drought of 1997 (Holmes 2000). The fires expose the great fragility of peat soils when subject to disturbance, drainage or drought, since peat soils themselves burn during drought if they are dry enough (as when drained); the fires can move underground, smouldering for months, and are extremely difficult to extinguish (S. E. Page *in litt.* 2002; also G. Fredriksson *in litt.* 2002).

Rates of tree mortality after drought and fire are in the range 19–71% in unlogged forests but 38–94% in logged forests (Woods 1989). Saplings suffered mortality rates exceeding 80% in both forest types. Logged and burnt forests also exhibit severe canopy loss, resulting in a ground cover dominated by grasses or creepers. In burnt primary forest, however, canopy loss is less severe and grass density is low. Whilst the prospects for recovery of forest structure appear to be relatively good for burnt primary forest, the prospects for recovery following fire in logged forests are poor. Even without further burning (which frequently occurs), recovery of populations of upper-canopy tree species is likely to take in excess of a century, and reversion to pre-fire species composition is unlikely over any intelligible time-frame (Woods 1989): Whitmore (1984) reported that a lowland dipterocarp forest damaged by storm and fire in 1880 still had a depauperate canopy tree diversity 73 years later.

**Commercial logging**

Commercial logging usually involves the removal of selected trees, but causes considerable damage to vegetation, soils, microclimates and biodiversity (e.g. Johns 1988a, 1997, Douglas *et al.* 1992, 1999, Counsell 1999). The most important immediate effect is a reduction in basal area and number of tree stems and saplings (Appanah and Weinland 1991, Bennett and Dahaban 1995, Johns 1996) but, perhaps more seriously, logging has been reported to contribute to a recruitment failure for dipterocarp species (Curran *et al.* 1999). Logged forests in South-East Asia have experienced very high extraction levels compared to elsewhere in the world (Putz *et al.* 2000): in Sabah some 120 $m^3$/ha of timber are typically extracted, in Sarawak 90 $m^3$/ha and in Peninsular Malaysia 52 $m^3$/ha (Johns 1989b, 1996, Marsh and Greer 1992). Such rates result in more or less continuous vegetation typical of natural gaps, with relatively undisturbed forest patches persisting as small isolated fragments (Lambert 1990).

Forests are subjected to a variety of natural disturbances that contribute to the heterogeneity of forest structure (Whitmore 1990), and the high biodiversity value of rain forest is maintained in part by disturbance (Connell 1978). It has been suggested that if selective logging could only imitate natural disturbance regimes—e.g. through the careful use of helicopters taking out trees as if they were wind-throws—then it could be undertaken without eliminating all the components of biodiversity (Uhl *et al.* 1982, Whitmore 1990, Haila *et al.* 1994). However, such management on a large scale would seem to be wishful thinking, since it requires what would be regarded as uneconomical (or at least uncompetitive) levels of restraint (Johnson and Cabarle 1993; see also Poore *et al.* 1989); experience shows that the freedom helicopters have to go anywhere eliminates any sense of restraint (D. R. Wells *in litt.* 2002). In South-East Asia, the majority of accessible forests have already been logged in a manner incompatible with full biodiversity retention, so the potential area that could now be logged in a sustainable manner is already greatly reduced.

Scotland *et al.* (1999) noted that overcapacity (too many sawmills, pulpmills and chainsaws) has created a severe problem with over-harvesting and illegal logging in the natural forest estate of Indonesia, making it highly unlikely that many selectively logged areas will ever recover a commercially viable volume of timber for a second cutting cycle within even the most restrained of time-frames. In Indonesia, 35-year cutting cycles were developed on the assumption that the average annual diameter increment for commercial species was 1 cm, but research has now shown that the real increment rarely exceeds half that (DFID 1999). Furthermore, fires have ravaged many natural forests in both Sumatra and Borneo. Hence long-term survival of the region's forest plants and animals will depend, outside of intact protected areas, in part on their ability to persist in degraded and fragmented landscapes and in part on improvements in the management practices in these areas. Unfortunately, the first of these factors is a matter of evolutionary circumstance beyond human capacity to influence, while the second is a towering challenge which past performance suggests is never likely to be met.

## Studies of birds in logged forests of South-East Asia

A number of studies have investigated the avifaunas of commercially logged Sundaic forests. Some of these have made direct comparisons between the avifaunas in logged and unlogged areas. All have been conducted in lowland and hill forests. No comprehensive data exist on survivorship of birds in disturbed submontane or montane forests.

As pointed out by Danielsen (1997), different methodological approaches (e.g. Johns 1989a, 1996 *versus* Lambert 1990, 1992) have been used by different authors, making comparisons between studies somewhat difficult; caution therefore needs to be applied to the interpretation of results and to the conclusions reached. The best-documented studies (Johns 1986, 1989a, 1996, 1997) are considered to have suffered from bias relating to the use of logging roads as transects (Lambert 1990, Bennett and Dahaban 1995, Danielsen and Heegaard 1995). Another complicating factor is that of observer experience and competence. A high degree of skill is necessary to detect and observe some skulking forest-interior species, and these are among the very birds that one might expect to be most affected by logging, because they are typically adapted to microclimates of the dark damp interiors that typefy primary forest and that disappear when the canopy is opened. A further major problem is that, even in primary forest, sites only a few kilometres apart may appear superficially very similar but support slightly different species assemblages (G. W. H. Davison *in litt.* 2000, D. R. Wells *in litt.* 2002, FRL pers. obs.).

Finally, it should be borne in mind that these studies were undertaken in logging concessions where management regimes largely followed government regulations, and therefore where conditions were probably already relatively favourable for the survival of lowland forest avifauna. In many areas, and especially in Indonesia, the condition of logged forests may be much worse than those that have been studied. In particular, Sundaic forests in Indonesia have been subject to over-logging, illegal logging, hunting, trapping, fire and the opening-up of areas by subsistence farmers—conditions leading to serious impoverishment of the forest (if not its complete elimination), and undermining any possibility of sustainable timber extraction over the long term. Such forests are now widespread, and the avifaunas they support may lack many of the species present in forests that have been logged according to existing government regulations (which are themselves subject, in Malaysia, to relaxation in response to the ever-straitening circumstances of the logging industry: D. R. Wells *in litt.* 2002).

This is not to say that a comparison of the results of these studies is not worthwhile, or that the studies cannot be compared. Whilst there may be some differences in conclusions (as one would expect in view of the differences in methodology, study sites, field skills, logging practices and time since logging) there is also considerable agreement in some of the results. The convergence of many conclusions concerning the degrees of resilience of certain bird species, bird families or feeding guilds to the effects of logging suggests that there are clear ecological (hence to some degree taxonomic) traits that we can identify without the need for undertaking more rigorous studies. The following section looks in detail at the results of the various studies mentioned above, and attempts to identify those species, families or guilds that are most vulnerable to the effects of logging.

## Resilience of birds to logging

In the absence of the intensive hunting pressure that sometimes accompanies and follows in the wake of selective logging operations (Robinson 1996), the majority of bird species that inhabit primary forests survive in the commercially logged forest estate of the Sunda region (McClure and Hussein 1965, Johns 1986, 1988b, 1989a,b, Lambert 1990, 1992, Bennett and Dahaban 1995, Danielsen and Heegaard 1995, Johns 1996, Round and Brockelman 1998). However, a serious qualification on the results of these studies is that the effect of nearby intact forest—specifically, the capacity it has to serve as a source for rapid reinvasion—has not been allowed for (it is time for a study of the avifauna of a typical logged forest which is isolated from sources of reinvasion to determine its true capacity to retain species: D. R. Wells *in litt.* 2002). However, even when areas of intact forest persist nearby, most studies have suggested that some species remain either absent from intensively logged areas or present at densities so low as to be ecologically extinct (i.e. no longer fulfilling their ecological role in the forest: Redford 1992, Bennett and Robinson 2000). Longer-term studies in Malaysia by Johns (1986, 1988b, 1989a,b, 1997) and by Lambert (1990, 1992) indicated that such reductions were commonly experienced by species of bird belonging to particular feeding guilds.

Both these studies revealed that terrestrial or understorey insectivorous species were particularly vulnerable to the effects of logging, and to a lesser extent some insectivores, particularly sallying species, that inhabit the lower to mid-levels of the forest. Birds typical of the canopy appeared to be much more resilient, and, with the exception of the highly specialised Green Broadbill (Lambert and Woodcock 1996), frugivorous and nectarivorous species were rarely suspected of declining in logged forest. Indeed, Lambert (1990, 1992) demonstrated that many nectarivores were *more* abundant in forest nine years after logging than in primary forest—not a surprising outcome, since such species are commonly dependent on dynamic turnover in forest structure and the recurrent availability of gap-phase vegetation (D. R. Wells *in litt.* 2002). It should be borne in mind, however, that no study has investigated the ranging behaviour or movements of these often highly mobile species in logged versus unlogged areas. Certainly some important fruit resources, such as strangling figs *Ficus*, occur at much lower densities in logged areas (Lambert 1991a), and this could conceivably induce changes in foraging behaviour, such as greater concentration of birds at fewer sites, without disclosing changes in abundance as measured in the Johns and Lambert studies.

In the lowlands of Riau province, Sumatra, Danielsen and Heegaard (1994, 1995) studied the avifaunas of (a) primary forest, (b) lightly logged forest 10 years after termination of logging, (c) heavily logged forest seven years after logging, (d) traditional rubber-enriched fallow, (e) a modern rubber plantation, and (f) a modern oil palm plantation. The highest number of species was found in heavily logged forest (129 species overall), followed by primary forest (119 species), lightly logged forest and rubber-enriched fallow (64–66 species). The key observed difference in species composition was that heavily logged forest apparently contained more sweeping insectivores, arboreal frugivores and arboreal insectivores than the primary and lightly logged forest. That the greatest number of species was found in heavily logged forest, seemingly suggesting that such forest is richer, masks the fact that no fewer than 31 bird species were found *only* in the primary and lightly logged areas. The higher overall number of species in heavily logged forest is in our view a reflection of (1) the fact that the avifauna there included many species of secondary habitats ('trash species') that do not usually enter closed forest, and, almost certainly, (2) the failure to detect all the true forest species in the limited time available, since as already noted many true forest species are highly unobtrusive, and occur at much lower densities, than those typical of more open, heavily logged forest.

The unpublished data from the study of Danielsen and Heegaard (1995) (kindly provided by F. Danielsen *in litt.* 1999; interpreted in the Appendix) strongly suggest that some species of terrestrial insectivore, at least one species of sallying understorey insectivore, and Green Broadbill, are particularly vulnerable to logging. Hence results of this study are in general agreement with those from Malaysia. However, in contrast to some studies (Lambert 1992, Round and Brockelman 1998), Danielsen and Heegaard's (1995) results suggested that numbers of woodpeckers generally increased in abundance with logging. This may be attributed to a difference in species composition or to the density of still-standing large trees or dead trees in the study areas. Johns (1986, 1989b) found that, whilst woodpeckers appear to survive well in recently logged forest, they later decline in abundance, and continue to decline in abundance even 12 years after logging.

Provisional results of a study of woodpeckers in Kalimantan (Lammertink 1999) suggest that woodpecker species richness in primary and logged landscapes does not vary significantly. However, average densities for nine out of 13 woodpecker species declined in logged patches when compared to primary forest areas and, within a logged, fragmented landscape, eight out of nine species were commoner in primary forest patches than in logged patches. One species, Checker-throated Woodpecker, which forages in more open areas of the lower storey (FRL pers. obs.), showed a significant preference for primary forest, whilst its close relative, Crimson-winged Woodpecker, almost disappeared from logged forest patches (although data were insufficient to demonstrate a significant decline: Lammertink 1999). Densities of three other species—Rufous, Buff-necked and Maroon Woodpeckers—declined by more than 50% in logged forest patches when compared to unlogged patches (although, in a regional variation which makes analysis all the more problematic, in the Peninsula Rufous is one of the few forest woodpeckers to have invaded non-forest habitats successfully!—D. R. Wells *in litt.* 2002).

Styring and Ickes (2001) compared woodpecker abundance in logged and primary forest at Pasoh in Malaysia, based on a three-month study in primary (600 ha) and adjacent surrounding forest (1,400 ha) logged c.42–43 years previously. Transect data furnished a significant difference between the woodpecker communities of primary and logged forest. Of the six most commonly encountered species, Buff-rumped, Orange-backed and White-bellied Woodpeckers were significantly commoner in primary forest. Only one species, Checker-throated, was significantly more abundant in the logged forest (see also Wong 1986)—a result that contradicts Lammertink's (1999) provisional findings from Kalimantan (this may be explicable in terms of the age of the logged forest area: D. R. Wells *in litt.* 2002). Three species present in primary forest (Rufous Piculet, Olive-backed Woodpecker and Great Slaty Woodpecker) were never recorded in logged forest at any time, although Wong (1986) and D. R. Wells (*in litt.* 2002) have trapped the first two in logged forest. Four of the five observations of Maroon Woodpecker made along transects were in primary forest.

One study has been conducted in the more seasonal semi-evergreen forests of lowland Peninsular Thailand, on the fringe of but still within the Sundaic region. Round and Brockelman (1998) compared the avifaunas of adjacent areas of seriously degraded logged and relatively lightly disturbed mature forest (tall forest from which local people had selectively removed certain large trees; this selectively logged forest was judged very similar to, and treated as, primary forest). Both areas lay within 30 $km^2$ of lowland forest and plantations that was contiguous with c.100 $km^2$ of hill forest. Despite the proximity of mature and degraded forest, 35 out of 162 species recorded in the study were observed only in mature forest. The results, in terms of identifying taxa that are intolerant of logging, show remarkable congruence with other studies. Amongst the species that Round and Brockelman (1998) found only in mature forest were one species of understorey flycatcher (and also Grey-headed Canary Flycatcher), two out of four trogons, five out of eight woodpeckers (notably Maroon Woodpecker), Scaly-crowned Babbler, three out of four drongos, Green Broadbill and Gold-whiskered Barbet. A brief study by Gro-Nielsen (1997), conducted in the same area of forest, provided similar conclusions, recording two trogons, three woodpeckers, Asian Fairy Bluebird, three owls, Yellow-crowned Barbet, Grey-bellied Bulbul, Grey-headed Babbler, Brown Fulvetta, White-crowned Forktail, Blue Whistling Thrush, Grey-headed Canary Flycatcher, and Hill Myna *Gracula religiosa* only in primary or mature secondary forest. This list of intolerant species is in broad agreement with other studies (Appendix).

These Thai studies were conducted in more disturbed areas of selectively logged forest—more hunting, more agro-planting, more forest-product extraction (FRL pers. obs.)—than those used in other Sundaic studies, and demonstrated some additional effects that have not been indicated in other work. These effects might perhaps be attributable to these higher levels of disturbance, and/or to the subtle influence of latitude, and/or—perhaps most compelling of the possibilities we can propose—to an area effect, since the size of lowland forest was very limited. One change that was noted in Round and Brockelman's (1998) study but not in most others was a general decline in the numbers of certain frugivores in logged forest, and of several specialised insectivorous taxa such as broadbills. Interestingly, the taxa that appear to be particularly intolerant of the seriously degraded forest according to Round and Brockelman (1998)—e.g. broadbills, barbets, woodpeckers, trogons and one hornbill—coincide strongly with those that have disappeared entirely from the isolated forests of Singapore (Corlett and Turner 1997). Here, perhaps, is an indication that species that are intolerant of severe degradation can also be expected to disappear early from isolated forest patches (experience in the Peninsula suggests that most interior-forest species are destined to vanish *eventually* from small fragments: D. R. Wells *in litt.* 2002), although the condition of the forest in question may also be a significant influence.

The time it takes for regenerating logged forest avifaunas to mimic those in the original unlogged forest is evidently an important consideration. Wong (1985, 1986) studied the understorey birds at Pasoh, Malaysia (this is also the study site of Styring and Ickes 2001), in forest logged some 25 years previously. The lower species richness and individual abundance of birds in logged forest suggests that recovery of the original avifauna was not complete although the large species overlap between the two study sites indicated that a recovery of sorts was well advanced. At the same site and at roughly the same time D. R. Wells (*in litt.* 2002) found the shade-layer species list to be more or less complete but population structure very different, with lower densities and productivity, from that of mature forest. These are interesting results in view of the fact that the logged area studied was contiguous with unlogged forest. It suggests that, even when there is a good source of colonists from primary forest, the time required for Sundaic forest avifaunas to re-establish viable populations may be remarkably long—the time it takes for the forest to re-establish its full niche complement—and, indeed, exceed the prescribed logging rotation cycles typical in the region: 25–40 years (although on current evidence such periods appear to be unobserved and possibly unobservable, given insufficient set-aside of intact areas, inadequate protection against illegal logging, and immense pressures to convert to oil-palm production).

## Forest fragmentation

A forest fragment is any patch of forest around which most or all of the original vegetation has been removed (after Saunders *et al.* 1987a). From the point of view of forest birds, important attributes of fragments include (a) time since isolation, (b) size and shape, (c) distribution in the landscape (distance from neighbour fragments and blocks), (d) edge effects, (e) surrounding habitat (matrix) type and (f) the degree of connectivity with other remnants by corridors. These factors are not independent, however, and can interact with each other (e.g. fragment size is likely to become more crucial with increasing isolation in both time and space; edge effects become more prevalent with decreasing size, or with more linear shape). A discussion of these factors is beyond the scope of this paper, but Saunders *et al.* (1991) provide a useful review, while Brooks *et al.* (1997) confirm the correlation between levels of deforestation and of species endangerment in South-East Asia based on the species/area relationship.

Fragments may themselves be internally fragmented, and indeed, many forest fragments are internally degraded (see, for example, Burgess and Mlingwa 1993). Therefore identifying the impacts of the various attributes of fragmentation *per se*, rather than the variously combined effects of degradation, disturbance and isolation, is not always possible. A study of forest fragments in Kakamega, Kenya, suggested that changes in vegetation structure, caused in part by local cutting, rather than distance between fragments or time since isolation, was responsible for many of the changes in avian abundance and distribution that were noted between fragments (Oyugi 1998). Hence there are often intrinsic difficulties in illuminating the real effects of fragmentation on forest birds. Another problem arises from the effects of increased disturbance (collection of firewood and non-timber forest products) and hunting, which typically intensify as a result of fragmentation—indeed, in the Indonesian parts of the Sunda region (as against the Malaysian, where logging companies commonly protect their concessions from invasion) hunting (including trapping) has been and remains so closely associated with fragmentation that an increase in hunting can usually be considered an integral part of the process (FRL pers. obs.).

Whilst degradation is a complicating factor in trying to unravel the effects of fragmentation on forest birds, the reality is that the great majority of forest fragments, excluding a small subset of those protected as conservation areas, will be used by man and hence become internally degraded. The following discussion largely has to ignore this problem because it is impossible to ascertain the degree of internal degradation that has occurred in the various forest fragments under discussion.

## Effects of fragmentation on Sundaic forest birds

The most compelling evidence relating to the serious deleterious effects of fragmentation on forest birds in the Sundaic region derives from Singapore and Java. The loss of 99.8% of primary forest in Singapore over the past 150 years correlates with the loss of a substantial fraction of the native biota, including 26% of the vascular plants, 44% of freshwater fish and 27% of the resident avifauna (Corlett and Turner 1997). Bird species that are known to have become extinct include three pheasants, three hornbills, two trogons, five broadbills and three kingfishers. In addition, most of the barbets (four out of five species), woodpeckers (7/11), babblers (7/13), bulbuls (5/10), spiderhunters (3/5) and malkohas (4/5) have also disappeared (Hails and Jarvis 1987, Corlett and Turner 1997, Lim 1997). However, some of the extinct species may have been extirpated by hunting pressure rather than through the natural processes that simplify faunas in forest fragments (Castelletta *et al.* 2000).

Forest bird species that survive in Singapore rely on the Bukit Timah Nature Reserve, a 50 ha piece of primary lowland forest isolated for at least 130 years (Turner and Corlett 1996, Lim 1997), and some 1,400 ha of adjacent but unconnected secondary (entirely regrowth) forests (Chin *et al.* 1995). Many species that were noted as once having been common residents in Singapore have become extremely rare (Barred Eagle Owl [which disappeared and has reinvaded: D. R. Wells

**Table 2.** Javan lowland forest birds most at risk from fragmentation. This table of 30 species is based on data in van Balen (1999a), but only includes birds he (a) found in five or fewer of the 19 forest patches he surveyed, and (b) considered to be 'forest interior' or 'forest edge' species ('woodland birds' are excluded, as are species that are either heavily trapped for trade or primarily dependent on higher-elevation forest; van Balen himself excluded raptors, nocturnal birds, seasonally conspicuous birds, and species with co-occurring migratory and resident populations from his analysis). Thus there are a few discrepancies between species in this list and those tagged 'vB' in the Appendix.

| Species<br>(* classified as forest-edge species by van Balen)<br>(+ Represented on Java by endemic subspecies) | | No. of forest patches (max 19) | Size of patch in which sp. found (ha) |
|---|---|---|---|
| Buff-rumped Woodpecker + | *Meiglyptes tristis* | 0 | |
| Scaly-breasted Bulbul + | *Pycnonotus squamatus* | 0 | |
| Yellow-eared Spiderhunter | *Arachnothera chrysogenys* | 0 | |
| Greater Flameback * | *Chrysocolaptes lucidus* | 1 | >50,000 |
| Long-billed Spiderhunter * | *Arachnothera robusta* | 1 | >50,000 |
| Violet Cuckoo * | *Chrysococcyx xanthorhynchus* | 1 | >50,000 |
| Blue-banded Kingfisher + | *Alcedo euryzona* | 1 | >28,500 |
| Thick-billed Flowerpecker + | *Dicaeum agile* | 1 | >28,500 |
| Large Green Pigeon | *Treron capellei* | 1 | >16,000 |
| Orange-backed Woodpecker | *Reinwardtipicus validus* | 1 | >16,000 |
| Asian Paradise-flycatcher | *Terpsiphone paradisi* | 2 | >16,000 |
| Maroon-breasted Philentoma | *Philentoma velatum* | 2 | >16,000 |
| Crimson-breasted Flowerpecker * | *Prionochilus percussus* | 2 | >10,000 |
| Rufous Woodpecker + | *Celeus brachyurus* | 2 | >2,000 |
| Green Imperial Pigeon *+ | *Ducula aenea* | 2 | >1,000 |
| Crimson-winged Woodpecker | *Picus puniceus* | 3 | >8,000 |
| Blue Whistling Thrush | *Myophonus caeruleus* | 3 | >4,200 |
| Banded Woodpecker *+ | *Picus miniaceus* | 3 | >2,500 |
| Crimson Sunbird * | *Aethopyga siparaja* | 3 | >2,500 |
| Fulvous-chested Jungle Flycatcher | *Rhinomyias olivacea* | 3 | >2,500 |
| Yellow-vented Flowerpecker | *Dicaeum chrysorrheum* | 3 | >2,500 |
| Checker-throated Woodpecker | *Picus mentalis* | 3 | >2,000 |
| Malaysian Cuckooshrike * | *Coracina javensis* | 3 | >6 |
| White-bellied Woodpecker | *Dryocopus javensis* | 4 | >5000 |
| Silver-rumped Swift * | *Rhaphidura leucopygialis* | 4 | >2,500 |
| Dark-throated Oriole | *Oriolus xanthonotus* | 4 | >2,000 |
| Asian Fairy Bluebird + | *Irena puella* | 4 | >1,000 |
| Cream-vented Bulbul * | *Pycnonotus simplex* | 5(?+) | >1,000 |
| Great Slaty Woodpecker | *Mulleripicus pulverulentus* | 5 | >1,000 |
| Lesser Cuckooshrike | *Coracina fimbriata* | 5 | >6 |

*in litt.* 2002], Yellow-eared Spiderhunter, White-bellied Woodpecker: Lim 1997) or are only visitors (including three frugivorous pigeons and Oriental Dwarf Kingfisher: Kang and Hails 1995). These rare species, and others such as leafbirds *Chloropsis*, may not have viable populations, so more extinctions are expected (Castelletta *et al.* 2000).

In Java, a meticulous 15-year study of lowland forest birds in 19 forest patches of different sizes (van Balen 1999a) has provided a unique insight into the effects of fragmentation. This study—which excluded from the analysis raptors, nocturnal birds, seasonally conspicuous birds, species with co-occurring migratory and resident populations, and a few species restricted to deciduous forests in East Java—determined that only reserves of 200,000 ha or more will contain all resident lowland forest bird species. None of the 19 lowland forest patches studied—including the two largest in Java, Meru Betiri at 50,000 ha (sea level to 1,223 m) and the Ujung Kulong peninsula at 28,600 ha (sea level to 140 m)—held the full complement of resident lowland forest birds. (It should be pointed out, however, that it is not known whether these patches ever supported the entire avifauna; also, Ujung Kulong was presumably extensively damaged during the eruption of Mt Krakatoa, whilst Meru Betiri lies in the east, where the avifauna may have been naturally less diverse.) Table 2 details Java's resident lowland forest bird species which, based on data provided by van Balen (1999a), would seem to be most threatened by fragmentation.

Van Balen's (1999a,b) study paints a dark picture of the likely effects of forest fragmentation elsewhere in the region. His 19 sites held between them all but three of the lowland forest birds considered in the study that were known to have occurred on Java (Table 2). Nevertheless, the largest site only supported 52 of the 65 species that van Balen (1999a) classified as forest-interior or forest-edge species: in effect almost a quarter (23.5%; taking account of the three species missing from all patches) of the true lowland forest-dependent avifauna considered in the study were missing from the largest lowland forest fragment. With one exception, 16 forest patches of sizes ranging from 6 ha to 10,000 ha contained less than 50% of the 68 species dependent on lowland forests. The exception, a 5,000 ha site (Gunung Aseupan), supported 44 (65%) of the 68 species, despite having been isolated for at least 40 years before the study; conditions in the area may merit investigation to determine why it should be so anomalously retentive.

In Java, one small fragment of woodland for which there is a good historical record of the avifauna is that of the 86 ha Bogor Botanic Garden (BBG), isolated from other forest areas for 60 years. BBG is essentially parkland, with small patches of tall forest and many open areas, rather than true forest. When isolated it had 62 resident bird species (although not all were forest birds). By 1986 it had lost a third of these, and others were almost extinct (Diamond *et al.* 1987). Eighteen of the 19 small species (weight < 20 g), 11 of the 22 medium-size species (20–49 g), and 13 of the 21 large species (>50 g) survived. Diamond *et al.* (1987) suggested that the avifauna was gradually coming to mirror those in the surrounding matrix of agriculture: 40 of 42 surviving species occurred in the surrounding countryside. Of the two species completely dependent on BBG, both numbered fewer than five pairs in 1986. The nearest forest patch, a 22 ha fragment some 5 km from BBG, suffered four extinctions of resident bird species from 1968/71 to 1980/81 (van Balen 1999a).

Van Balen (1999a) excluded raptors from his analysis of birds occurring in forest patches on Java because of their large home ranges and vagrant habits, which made it problematic to assign them to the smallest fragments surveyed; but Thiollay (1998) suggested that, of eight interior primary forest species in the Asian region, six (including four *Spizaetus* hawk eagles) were intolerant of logging and habitat fragmentation. However, these *Spizaetus* species do occur even in some small fragments (Ford and Davison 1995), and can regularly be observed outside of forest patches in Java and Sumatra (FRL pers. obs.). Furthermore, most Sundaic forest raptors also seem to survive in logged forests. It would therefore seem that more rigorous methodology and testing is needed to substantiate Thiollay's (1998) conclusions and to determine the spatial scale at which any negative effects of fragmentation might occur.

In Peninsular Malaysia, inventories of birds carried out by Ford and Davison (1995) in lowland forest patches suggested some congruence with the taxa that have been lost from Singapore. The three patches studied were 550–830 ha in extent and degraded, in particular in much of the understorey, by past logging. No resident forest species of pitta, flycatcher, fantail, cuckooshrike or pheasant (except for Red Junglefowl *Gallus gallus*), and only one species of hornbill (the smallest), was found in the patches. Babblers, the most diverse family in Malaysian forests, were represented by very few (and virtually no terrestrial) species, and the nocturnal avifauna was also depauperate.

Ford and Davison (1995) concluded that species of the ground and understorey and aerial feeders that live below the canopy are most vulnerable to the effects of fragmentation. They also noted that mixed-species flocks were rare, and that loose groups of more than three species were only seen in one (800 ha) patch. In contrast to the situation in Singapore, malkohas, barbets, broadbills and woodpeckers were better represented in the Malaysian patches; this might partly be explained by the relatively recent isolation of the patches under study compared to Singapore. Unfortunately, there was no comprehensive record of species definitely present in the area prior to isolation; of the two that seemed to have become extinct, Large Wren Babbler and Orange-backed Woodpecker, the latter would almost certainly have been present, being regular even old overgrown rubber estates (D. R. Wells *in litt.* 2002), but the former is likely to be a genuine case. In addition, G. W. H. Davison (*in litt.* 2000) reports that it is unlikely that Large Green Pigeon, two barbets, Red-bearded Bee-eater, Rail-babbler, Chestnut-backed Scimitar Babbler, two pittas and two forktails would have been overlooked if present. All of these species—indicated by '(FD)' in the Appendix—might be predicted to have occurred in the original forest, as would a number of other species that may have simply been overlooked.

One final source of relevant information is that of anecdotal bird lists made in a few well-watched forest fragments. The most useful of these is probably that of Sepilok in Sabah, now a fragment of some 4,000 ha (it was 4,540 ha in the 1970s: Fox 1973). Sepilok is reported to have some corridors to production forest (G. Noramly *in litt.* 2000), but is essentially a piece of lowland dipterocarp rain forest surrounded by agriculture. Comparison of lists of birds made at Sepilok at different times, always allowing that one-off surveys typically produce anomalous absences, strongly suggests changes in status for a number of species (K. Ickes *in litt.* 2000). For example, Yellow-breasted Flowerpecker was reported as common in 1984, but was not recorded in surveys during 2000; similarly, some highly vocal species such as Large Green-pigeon and Bushy-crested Hornbill were frequently encountered by C. Francis in 1984 but not found in 2000; and Helmeted Hornbill, a species with a far-carrying, unmistakable call, was present in 1984 but may now be extinct (K. Ickes *in litt.* 2000).

Way Kambas National Park is a forest fragment that was logged between 1968 and 1974. It covered c.80,000 ha in the 1970s (D. A. Holmes *in litt.* 2000) but, owing mainly to fire, is probably now only 50–60% forested (N. Drilling verbally 1999). Again, Helmeted Hornbill, along with Rhinoceros Hornbill, seems now to be exceedingly rare there (Parrott and Andrew 1996, N. Drilling verbally 1999, T. M. Brooks *in litt.* 2000, N. J. Redman *in litt.* 2000, FRL pers. obs.), although it was reportedly common in the 1970s (D. A. Holmes *in litt.* 2000). Parrott and Andrew (1996) noted that there is also anecdotal evidence of declines in other hornbill species at Way Kambas during the 1980s, and a number of other species that one might expect to have been reasonably common in the original forest of the area now appear to be very rare. These include Large Green Pigeon, Blue-banded Kingfisher, Diard's Trogon, Striped Wren Babbler, Maroon-breasted Philentoma, Crested Jay and several species of spiderhunter. Most of these have been shown to decline following logging or fragmentation of forest in other areas, but it is impossible to clarify whether either or both of these have been real effects at Way Kambas.

## DISCUSSION

Selective logging (and other forms of forest degradation) and fragmentation are both processes that are rapidly defining the future of forest bird communities in the Sundaic region, particularly in the lowlands, and especially in Borneo and Sumatra. From the point of view of forest conservation and management, it is therefore important to understand the effects that these two processes are having on bird communities. Unfortunately, rates of forest loss and change in the region are such as virtually to preclude further detailed research efforts aimed at answering the many questions we may have about intolerance to logging, minimum area requirements and other key issues. We must therefore attempt to draw conclusions from existing data. Fragmentation in particular is a critical issue, and its effect on forest birds and other biota is likely to form the core of much future disquiet.

One problem in the interpretation of fragmentation studies in South-East Asia arises from the fragments in question having mostly been degraded to some extent, often by logging. The Javan forest fragments studied by van Balen (1999a) include the only examples of fragments that contain areas still in pristine form. However, the reality is that the majority of forest fragments remaining in the lowlands of the Sundaic region will have been logged or otherwise seriously degraded; so the fact that this paper draws heavily on information from such forest fragments does not compromise the value of the general insights that derive from their use and comparison.

With respect to logging, Johns (1986) pointed out that, whilst many bird species persist in mosaics of primary and logged forest, it has yet to be demonstrated that largely intact avifaunal compositions can be maintained in selectively logged areas entirely discrete from primary forest. To date, studies of birds in logged forests have focused on larger areas in which there are remnant or adjacent areas of primary forest. Future landscapes in the Sundaic lowlands may deviate greatly from these situations. It seems increasingly likely that, in both Sumatra and Kalimantan, virtually all lowland forests, *including* those in protected areas, will have been logged within the next ten years. Furthermore, there is no reason to assume that forest fires will not continue to feature as regular events in the region; and it would seem justified to predict that such fires will doom to local extinction all populations of those species most intolerant of degradation.

### Relative effects of logging and fragmentation on Sundaic birds

The review of the various studies presented above indicates that, always accepting (a) the probably significant influence of nearby tracts of primary forest as populations sources, and (b) the long-term danger represented by fire to logged systems and their faunal composition, large areas of forest logged in a manner consistent with the terms of the concession will retain the majority of species that were present prior to logging, while by contrast forest fragments—apparently even relatively large patches with a high proportion of primary forest—invariably lose a significant number of species. In the Sunda region, therefore, fragmentation would seem to be a much more serious threat to the survival of certain forest bird species than the selective logging of larger areas of continuous forest.

These conclusions suggest that the area of forest estate that has been identified for the production of timber may have a useful secondary conservation value, provided that individual forest blocks are large in extent. In the Sundaic region, the area of logged forest set aside as permanent production forest is significant when compared to the area set aside as protected areas. In Sumatra and Kalimantan, for example, a total of 33.9 million ha are classified as 'production forest', compared to 23.6 million ha of 'protected forest' (Holmes 2000). Peninsular Malaysia has a total permanent forest estate of 4,730,216 ha, of which protected areas comprise 614,127 ha (Anon. 1998), whilst Sarawak has a total permanent forest of 4,664,000 ha (Anon. 1997). Unfortunately, however, almost none of the permanent forest estate in Malaysia is at plains level, and most protection forest is montane, in zones that are naturally marginal to the survival of most lowland forest bird species, cut off from core habitat, and in any case already degraded (D. R. Wells *in litt.* 2002).

The negative effect of fragmentation on populations of species that are highly dependent on fruit and/or nectar is very striking. This suggests that key food-plants become too rare or few to sustain some frugivore or nectarivore populations. Whilst this might be expected in species known to have wide-ranging requirements, such as hornbills (Kemp 1995), it is rather less so in smaller nectarivores or nectarivore/frugivores such as flowerpeckers, sunbirds and spiderhunters. Little is known about the ecology of any of these species, or indeed of their usual ranging requirements, but those that suffer most appear to be the canopy-epiphyte specialists, eliminated when their food-plants undergo temporal bottlenecks in productivity (a process whose speed correlates with size of fragment). Such specialists probably have ranging regimes which are much larger than might be expected for birds so small, and if the diets are highly species-specific, as has been indicated for at least one of the sunbirds (Lambert 1991b), then the situation is likely to be so much the worse. It is not helped by the fact that many canopy epiphytes are removed in the logging process (D. R. Wells *in litt.* 2002), thereby reducing the resource base in adjacent 'forested' areas. Whatever the reason, there are clearly concerns relating to ecosystem functioning if important pollinators and seed dispersers are being lost from habitat islands.

There would thus appear to be fundamental differences between the effects of logging and fragmentation on Sundaic lowland forest birds. Selective logging usually results in the loss or extreme rarefaction of certain insectivorous species, particularly those of the dark understorey and in terrestrial foraging guilds, and some species of woodpecker, but there is little evidence of intolerance in the majority of frugivorous species (an exception is Green Broadbill) and nectarivorous species (some of which may benefit from selective logging)—although if the letter of the law were observed in Malaysia, where logging rules stipulate that large figs shall be cut as part of the silvicultural treatment by the logger (D. R. Wells *in litt.* 2002), the consequences for frugivores would be incontestably more serious. By contrast, fragmentation affects a very broad range of species—omnivores, insectivores, frugivores and nectarivores—including virtually all species negatively affected by logging.

**Extent of intolerance amongst birds**

The Appendix provides a list of Sundaic lowland forest bird species for which evidence from the studies reviewed suggests a decline in abundance following logging, fragmentation or a combination of these processes. Unfortunately, since the studies cited above all differ in many respects (e.g. location, site condition, time-frame, methodology, original avifaunal composition, observer competence), it is difficult to be certain whether all of the observed effects are real: some may result from bias or apply only to a particular site and circumstance. Nevertheless, some patterns do appear to emerge, and an attempt has been made to identify those species or subsets of species most seriously affected. Highlighting with bold in column seven of the Appendix is used to indicate that the evidence for a negative effect is strong. Hence those species shown to decline or believed to have declined through the effects of logging or fragmentation in several studies, or in the longer-term studies (for which more robust data were collected), are highlighted as being particularly intolerant. It is these species that are used to quantify the impact experienced by avifaunas in the face of logging and fragmentation.

The Appendix reveals that a considerable proportion of the avifauna at any one site may be affected by logging and/or fragmentation, and that certain guilds or types of bird are more vulnerable than others. Taking Wells's (1985) figure of 291 species in lowland Sundaic forest and subtracting 17 species which now considered to have broader elevational distributions, there are 274 resident forest bird species confined to the lowlands of the Sundaic region (excluding Palawan), amongst which there is strong evidence that 83 (30% of the avifauna) are negatively affected by fragmentation and 26 (9.5%) negatively affected by logging (Appendix). In total, available data suggest that at least 91 and perhaps as many as 132 species (plus several undifferentiated groups such as partridges, frogmouths, hornbills, pittas and blue flycatchers), or 32–50% of the lowland forest avifauna, may respond negatively to the effects of these processes in some parts of their range. These figures very probably underestimate the situation, however, since there are many lowland forest bird species for which it is impossible to ascertain the effects of logging or fragmentation because of difficulties in censusing or because of their wide-ranging habits. Examples include low-density, poorly known species such as Bornean Peacock Pheasant *Polyplectron schleiermacheri*, Bornean Ground Cuckoo *Carpococcyx radiatus*, Malaysian Honeyguide *Indicator archipelagicus* and Short-toed Coucal *Centropus rectunguis* and wide-ranging species, including raptors (such as Wallace's Hawk Eagle *Spizaetus nanus*), *Rhyticeros* hornbills and Storm's Stork *Ciconia stormi* (the hawk eagle, peacock pheasant, coucal and stork are, however, treated as threatened in BirdLife International [2001]; and the ground cuckoo is reviewed in Long and Collar [2002], this issue).

Although certain species repeatedly turn up in the relic post-logging communities far more often than by chance, the responses of forest birds to logging and fragmentation are not wholly straightforward or predictable. Some species may be locally eliminated or survive only at very much reduced densities at a series of logged or fragmented sites, yet may be present and even relatively common at other sites also affected by these processes. The nested subset phenomenon observed in fragmented landscapes—that is, within a related group of fragments the species compositions of smaller faunas tend to be different subsets of larger faunas (Patterson 1987, Cutler 1991)—can explain this circumstance, but it makes it difficult to predict which species are really at most risk. One of several good examples would seem to be Maroon Woodpecker. Evidence from five studies suggests that this species is intolerant of logging, and it was the first woodpecker species to become extinct in Singapore; yet it remains relatively common in the taller stands of regenerating forest that were logged some 26–32 years ago at Way Kambas, and Wong (1986) trapped equal numbers in primary and 24–25-year-old logged forest at Pasoh. Thus it appears to be intolerant of logging and/or fragmentation under certain regimes but tolerant of them under others. Possible explanations of this circumstance relate to the density of suitable nest sites following logging, competition for nest sites with sympatric cavity-nesting species, competition for food with close relatives, or the density of suitable feeding sites (mainly rotten wood at low levels: Short 1978). Way Kambas differs from most of the sites sampled in other studies, being not only very flat and low-lying, but also containing significant areas of freshwater swamp forest (Parrott and Andrew 1996). These factors may have resulted in more than the usual density of untouched forest patches in the mosaic following logging, and such factors could have ameliorated the effects of logging on species such as Maroon Woodpecker.

Despite such contradictions, there emerges a distinct subset of lowland forest birds which, in many parts of their Sundaic range, are intolerant of either logging or fragmentation or the two in combination. Such species may be able to recolonise logged forest as regeneration proceeds, but only if they can disperse from the nearest population or where small numbers survive within the diverse habitat matrix of logged forest. In logged forests, they may only survive where management practices have followed existing national laws that prescribe the leaving of untouched riverine corridors, or unlogged patches within the logging matrix. In fragmented landscapes, they may only survive in the very largest patches. The species that cause the most immediate concern are those for which evidence suggests a high level of intolerance also to degradation through logging. In the longer term, conservationists need to pay attention to all species that are intolerant of fragmentation, in particular those with very specialised niches or large range requirements, and those species largely confined to the lowlands. Game species, and perhaps some species of highly sought-after songbird, should also be of high concern, since hunting and trapping are typically prevalent in both logged and fragmented forest landscapes in the region, owing to increased access.

**Which forest bird species are most at risk?**

Nearly all the species listed in the Appendix are relatively widespread in the Sunda region, so that, provided a fully representative network of fully functioning protected areas persists, none is particularly likely to go extinct in the short term. However, some—perhaps many—must be destined to become very much rarer than they are at present, especially as many protected areas in the lowlands are probably not large enough to support the entire avifauna (based on van Balen 1999a). Van Balen's (1999a) study notably suggests that the maintenance of woodpecker assemblages in a highly fragmented environment might require management interventions. Eight of Java's 11 lowland woodpecker species are confined to fewer than five forest patches and another was not found in any patch (Table 2); a twelfth species (Olive-backed Woodpecker) may have become extinct during the nineteenth century. Whilst most endemic woodpeckers in the Sundaic region are widely distributed, three are confined to (or have their core populations in) the lowlands (Great Slaty, Crimson-winged and Buff-necked) and several apparently occur at very low density (especially Olive-backed, White-bellied and Great Slaty). These species may be more vulnerable than species that range into the mountains, but it is difficult to judge which might be most at risk of extinction in a fragmented landscape; Wells (1999) reported that White-bellied is susceptible to displacement by aggressive nest competitors such as Dollarbirds *Eurystomus orientalis* once the canopy is ruptured.

The Appendix shows that birds of all sizes are affected by both logging and fragmentation, and suggests that, in the long term, size may not be a particularly important determinant of vulnerability. In Singapore, the only site where avian extinction is well documented, there is no significant difference in the body length of extinct and extant species, although species going extinct prior to 1949 had longer bodies (on average) than extant species (Castelletta *et al.* 2000). Feeding guild and particular habitat requirements may therefore be more important than size in determining which species are more intolerant to logging and forest fragmentation. There is good evidence that a significant number of species of (lowland) forest interior sallying insectivores, several terrestrial insectivores and woodpeckers do poorly in both logged and fragmented landscapes. It may be that in logged forest the sallying and terrestrial insectivores lose the understorey and forest-floor microclimates critical to their respective food resource bases, and the woodpeckers lose major classes of tree. In fragments the terrestrial insectivores may suffer because their two-dimensional habitat predicates lower densities, and therefore often unviable population levels, than many other guilds; moreover, such birds are behaviourally locked into fatally small patches, being physiologically unadapted for full sun (e.g. they die within 15 minutes if left unattended in mist-nets) and thus incapable of dispersing across light gaps (D. R. Wells *in litt.* 2002).

Furthermore, almost all the species that typically excavate tunnels in rotting tree stumps or termite mounds (trogons, two forest kingfishers and one forest bee-eater) appear in the Appendix. Indeed, the availability of holes or excavatable timber for obligate cavity-nesting birds may be an important limiting factor (Newton 1994). Whilst suitable nest sites may increase immediately following logging owing to the increase in dead, dying or damaged trees, they may decrease with time. In Uganda unlogged forest contained more than twice as many cavities as nearby logged forest (Dranzoa 1995), and in Thailand cavity density was significantly reduced in mixed deciduous forests following selective logging (Pattanavibool and Edge 1996). At the Thai site, there was a preponderance of cavities in live trees, since dead wood was regularly destroyed by fires.

Java has a depauperate avifauna compared to Sumatra, Borneo and Peninsular Malaysia. In particular, lowland forests support only one species of trogon (versus 4–5 elsewhere in the region), only five bulbuls (versus 17–18), and ten babblers (versus 25–28). Fragmentation in other parts of the Sunda region may therefore have more effects on some of the species in these and other under-represented groups than would have been detected by van Balen (1999a). In particular, populations of trogons may require careful monitoring: on present evidence, this group of birds would seem to be more vulnerable than most to the changes that are occurring in Sundaic forests. The survival of four sympatric species of trogon in forests that have been seriously degraded by logging or fire would seem unlikely in the long term, as would be their survival in smaller forest patches. Three species—Diard's, Scarlet-rumped and Red-naped—are confined to the lowlands or low hills and may therefore be particularly vulnerable to local extinction in the emerging degraded, fragmented forest landscape. Their presence at low elevations on slopes appears to be no guarantee against habitat loss in the medium term (FRL pers. obs.).

Babblers are another well-represented group, with some 27 endemic species in the Sundaic lowlands. Round and Brockelman (1998) pointed out that the small number of babblers found on land-bridge islands suggests that these birds—predictably, given their typical ecological niche as understorey insectivores—possess poor dispersal abilities. This seems to be borne out by the Appendix, which contains nine species of babbler that exhibit strong negative responses to logging and fragmentation. Only four species in the family, all told, are heavily dependent on lowland forest, and of these only Striped Wren Babbler has been shown definitely to be affected by logging and fragmentation; from existing data it is not possible to say whether the other three species (Rail-babbler, Bornean Wren Babbler and White-chested Babbler *Trichastoma rostratum*) are particularly intolerant of logging and/or fragmentation. However, Bornean Wren Babbler has a fairly restricted distribution (see BirdLife International 2001) and ranges over relatively large areas (probably >100 ha: FRL unpublished radiotelemetry data), so it may ultimately only survive in large forest patches, and neither this species nor Rail-babbler seems likely to possess good dispersive capabilities (although the latter may in fact be able to persist at higher elevations than the former).

For the most part, impacts on raptors and other large, wide-ranging species such as waterbirds have not conclusively been demonstrated, but one might expect that fragmentation will affect these K-selected species as remaining forest blocks become more isolated, more degraded and smaller. The survival of the Javan Hawk Eagle *Spizaetus bartelsi* in the face of fragmentation may, however, be mitigated by its good dispersive abilities, a broad diet and altitudinal distribution (see BirdLife International 2001). Two other endemic Sundaic hawk eagles are more or less confined to the lowlands or low hills (for Wallace's see BirdLife International 2001): whether these two share an opportunistic diet and good powers of dispersal with their Javan relative is as yet unknown.

Amongst other larger birds not discussed above, fragmentation is likely to have a devastating effect on some of the larger species dependent on fruit. There is some evidence that Helmeted and Rhinoceros Hornbill may be extinction-prone in smaller forest fragments, but too little is known to say how large an area of forest is required to support viable populations of these species. Kemp (1995) stated that they occur at densities of one pair/0.5–3.0 $km^2$ and one pair/1.8–8.0 $km^2$, respectively, but even higher densities may be registered in optimal conditions: Anggraini *et al.* (2000) for example reported a density of 1.9 birds/$km^2$ for Helmeted Hornbills in Bukit Barisan National Park. The viability of hornbill populations presumably depends to some extent on the ability of the species to move between forest fragments during times of most extreme food resource scarcity. The dependence of hornbills on live emergent trees for nesting, and their high preference for dipterocarps at some sites (Poonswad 1995), would suggest that logged forest fragments will contain fewer suitable nest sites. Essential keystone fruit supplies such as figs (*Ficus* spp.) are also seriously reduced in abundance in logged areas (Lambert 1991a, Lambert and Marshall 1991). Two very serious complications arise. First, if certain tree species fruit aseasonally and unpredictably, the probability of a period of food unavailability (or of a food 'Allee effect'—where the energetic costs of *finding* it are too high) steeply increases as the number of such trees diminishes, resulting in starvation (the spatio-temporal problem that afflicts canopy-epiphyte specialists [see above] and is now identified as the cause of extinction of the Passenger Pigeon *Ectopistes migratorius*: Bucher 1992). Second, the concentration of such large and edible birds at fewer and fewer trees in ever more familiar and exploited habitats will render them peculiarly vulnerable to hunting (as many as 40 Visayan Wrinkled Hornbills *Aceros waldeni*, representing at least 25% of the global population, were reportedly shot in a single day at a single tree in 1997: BirdLife International 2001). Of course other large species such as Great Argus, even though more dispersed, will also face unsustainable levels of hunting in accessible areas of forest in some parts of the Sunda region (Bennett and Dahaban 1995, Bennett *et al.* 1997).

The highly specialised frugivorous pigeons may be more mobile, but Large Green Pigeon, which was once common in the lowlands of the region (e.g. van Marle and Voous 1988, BirdLife International 2001), has become a rare bird outside of the largest forest patches. Lambert (1989, 1991a) and van Balen (1999a) suggested that this fig-eating specialist is highly threatened despite its assumed (nocturnal, long-distance) dispersive abilities. Whether other pigeons confined to the lowlands are also affected is still not clear, but Little Green Pigeon has not been recorded on Java for more than 50 years. Long-tailed Parakeet *Psittacula longicauda* is confined to forests below 400 m and, in Borneo at least, appears highly dependent on fruiting dipterocarps and leguminous trees; thus it may also have suffered significant population declines because of logging. The facts that, alone among the Sundaic forest avifauna, it (a) nests colonially and (b) ranges outside forest to forage (in oil palms) have been speculated to favour its survival in small fragments typical of parts of Peninsular Malaysia (Wells 1999), but the disruption and increasing rarity of its traditional food resources in Borneo (Curran and Leighton 2000) suggest that considerable vigilance is needed to assess its population trends in different areas.

Review of the species that are dependent on forests in the lowlands and hills below 1,000 m reveals that, in addition to those listed in the Appendix, there are only four which (a) have congeners intolerant of fragmentation or logging and (b) do not occur in the somewhat more secure protected areas of Peninsular Malaysia. These are Hose's Broadbill *Calyptomena hosei*, Blue-headed Pitta *Pitta baudi*, Blue-wattled Bulbul *Pycnonotus nieuwenhuisii* and Rueck's Blue Flycatcher *Cyornis ruckii* (the last two of these species are virtually unknown): based on present evidence, all of these species might be expected to be intolerant of fragmentation, whilst the broadbill and flycatcher may also be intolerant of logging. (The pitta and flycatcher are treated as threatened in BirdLife International [2001], where the bulbul is discounted as a probable hybrid [Williams 2002, this issue]; the broadbill is regarded as a slope specialist: D. R. Wells *in litt.* 2002.)

**Size and dispersion of forest fragments**

Brooks *et al.* (1999) showed that, in Kenya, bird species are still being lost from forest patches some 75–100 years after isolation. Van Balen's (1999a) work on Java reveals that even the largest protected areas appear to have lost significant numbers of species, and that, since some fragments were only isolated relatively recently, they are likely to continue to lose their diversity. These findings should compel conservationists to take a precautionary approach when assessing the value of forest fragments in the Sundaic region, since smaller fragments almost certainly harbour species that are destined to become extinct. However, it is impossible not only to predict which species might die out in an individual forest fragment but also to determine how large a fragment needs to be in order to safeguard a particular species in the long term. Van Balen's (1999a) study suggests that, on Java, woodpecker communities collapse in forest fragments of 2,500 ha or less, and that the loss of the two largest protected areas in the lowlands might result in the elimination of seven species of lowland bird. Patches less than 10,000 ha in extent (with one exception) had lost more than 50% of the lowland forest avifauna.

The situation in Singapore and Java presents a warning of what could happen if forest patches become too small and dispersed. It might be argued that these represent worse-case scenarios, but it remains essential to view the current situation from a highly precautionary standpoint. Despite the rapid loss of forest, it may be too pessimistic to think that none of the existing large lowland forest patches in the region will survive, but it is only realistic to expect that, in the long term, unless there are fundamental changes to forest management practices and land-use policies in the region, a large proportion of forest birds will persist only in the largest forest fragments, which is equivalent to saying that many lowland forest birds are likely to survive only within the existing protected area network. The real point to be made is that, from a precautionary standpoint, no forest patch should ever be considered unnecessarily large if it is expected to provide for the permanent preservation of the Sundaic lowland forest avifauna (and indeed all the other elements of the region's biological diversity).

**Priorities and prospects for lowland forest birds in the Sunda region**

Whilst Borneo is an enormous island, few extensive areas of forest have been set aside as protected areas in the lowlands, and all of these are suffering from illegal logging and/or fire. According to Holmes *et al.* (2001) Kalimantan has only four protected areas with significant areas of dry lowland forest, with the lowland portions of parks ranging in size from c.30,000 to c.270,000 ha. Two of these protected areas (Kayan Mentarang and Bentuang Karimum) have >200,000 ha of dry lowland forest. Another proposed protected area, Sebuku–Sembakung, has a large area (115,000 ha) of lowland dry forest, and concerted efforts to secure this area are needed before more of it is lost. Other lowland forest types (freshwater swamp, peatswamp and heath forests) are no better represented in the existing protected area system in Kalimantan, although some significant areas of swamp forest remain. In the Malaysian states of Sabah and Sarawak, protected areas are relatively small, but sometimes surrounded by large areas of natural forest, which greatly increases their value. Danum Valley Conservation Area (at 42,800 ha, the largest protected area in the lowlands of Sabah) and the Maliau Basin (39,000 ha) are both protected areas within the Ulu Segama Forest Reserve (>1 million ha). As we noted earlier, this area is now almost certainly the most important piece of dry lowland forest in Borneo (a) because it is so large and (b) because it is in the north, which is biologically the richest part of the island and supports the great majority of Borneo's threatened bird and mammal species; but its integrity is under serious threat (see earlier). Lowland forests in the few protected areas in Sarawak and Brunei are also relatively small in extent: for Sarawak, BirdLife International (2001: 945-946) cited A. C. Sebastian and E. L. Bennett as indicating that the amount of lowland dipterocarp forest below the hill-foot boundary in any reserve is very small, and that 'the total area of pristine dry lowland forest remaining in Sarawak may not exceed 200 $km^2$'.

In mainland Sumatra, only five existing protected areas contain significant areas of dry lowland forest. Three national parks (Kerinci-Seblat, Gunung Leuser and Bukit Barisan Selatan) contain lowland areas greater than 200,000 ha (Holmes and Rombang 2001), and one (Bukit Tigapuluh, only created in 2001) probably possesses over 100,000 ha, since its area is 126,789 ha (Holmes and Rombang 2001), but all the others have fewer than 25,000 ha of dry lowland forest. Extensive lowland peatswamp forest occurs in only one existing park (Berbak). Meanwhile, there are a number of remaining forest patches which are proposed as protected areas and which contain significant areas of dry lowland forest. The most important of these would seem to be Bukit Rimbang Baling and Teso Nilo in Riau, whilst Trumon-Singkil in Aceh and Sembilang in South Sumatra contain extensive areas of lowland peatswamp forest (Holmes and Rombang 2001). There are also significant areas of lowland forest in the logging concessions which border the southern edge of Bukit Tigapuluh National Park, in south and central Jambi (Bukit Panjang–Bukit Siguntang), and in northern South Sumatra province (P. Wood *in litt.* 2002). Nevertheless, the intensification of logging, and the setting of annual forest fires, in particular for clearance for oil palm, will rapidly change these areas.

Peninsular Malaysia supports some of the most impressive lowland forest protected areas in the Sundaic region (although conservation forest of all types has now dipped below 5% of the Peninsula's land area: D. R. Wells *in litt.* 2002). The already enormous importance of these sites will only increase as lowland forests elsewhere shrink in area. The relatively large size of several of these areas, in particular Taman Negara (431,500 ha: Elagupillay *et al.* in press), Endau Rompin Wildlife Reserve and State Park (89,100 ha), and the Krau Game Reserve (62,400 ha) and Belum State Park (117,000 ha) should ensure the survival of all the lowland forest species in the Peninsula that are dependent on dry lowland forests. However, it is important to stress that inside Taman Negara the biologically richest forest—i.e. that of the level lowlands, below the steepland boundary—probably occupies only around 10% of the park area, all of it in a few river valleys; one of these valleys (covering 4,000 ha) has already been lost to a reservoir, and any further mega-dam construction would result in the loss of others, compromising the entire viability of these core areas (D. R. Wells *in litt.* 2002). Apart from vigilance to ensure this never happens, perhaps the greatest current need in this sector of the Sundaic region is the protection of a tract of 'floodplain forest', which, despite its name, we take to be extreme lowland dryland forest: with the impending clearance of the last tracts of such habitat, none of it ornithologically surveyed, on the lower Perak river, a major refuge and indeed 'source' of birds (in particular Storm's Stork) is likely to be lost from the Peninsula (Wells 1999).

Although few existing protected areas will be large enough to support entire assemblages of lowland forest birds in the Sundaic region, this does not mean that species will necessarily become extinct. Even the most intolerant species may perhaps be able to persist in one or two of the larger remaining patches (albeit not the same ones). In particular, Taman Negara in Peninsular Malaysia may be large enough to safeguard much if not all of the original lowland avifauna of the Peninsula, and indeed all but four of the Peninsular Malaysian species listed in the Appendix occur within its borders (but see the preceding paragraph). On the other hand, even at this huge and well-protected site the possibility of long-term losses through species/area relaxation effects (see Brooks *et al.* 1997) must remain a source of great concern, especially with Storm's Stork, whose optimal habitat may be 'floodplain forest' (see above), and Masked Finfoot, which is perhaps only seasonal there and therefore exposed to danger in other parts of its annual range. Moreover, Borneo represents a particular challenge, since it possesses a suite of endemic threatened and Near Threatened species that are very closely associated with and possibly dependent—at least for part of their life cycle—on lowland dryland forest (Wattled Pheasant *Lobiophasis bulweri*, Bornean Peacock Pheasant, Blue-headed Pitta and Bornean Wren Babbler are the threatened species: BirdLife International 2001).

Whilst many species can be shown to be intolerant of logging or fragmentation, the balance of evidence until very recently suggested that, provided existing protected areas in the Sunda region are fully secured, it is unlikely that any species would become extinct in the medium term as a consequence of logging or fragmentation alone. However, recent acceleration in timber extraction and the inability of local authorities to assert control over clearance both inside and outside protected areas (the reasons for which are outlined in Robertson and van Schaik 2001) combine to tip the balance against this view. Moreover, if global warming is associated with the increasing incidence of droughts, fire will pose an extremely serious threat to the long-term survival of forests within protected areas. Even without global warming, 'natural' fires are still likely to pose a major threat in years of unusual drought. This threat is compounded by the persistent use of fire as a means to clear land in Indonesia and the inability of the government to deal with the issue.

There is therefore no room for either optimism or complacency over the survival of the Sundaic forest avifauna. There are pressing needs (1) to ensure that what are now the largest natural primary and logged forest blocks are all secured in their current condition, (2) to address the ever-present threat of fire and the unsustainable logging and land clearance that are occurring in the Sunda region, (3) to maintain maximum connectivity between forest fragments wherever feasible, and (4) to reduce ignorance about the value to biodiversity conservation of preserving the largest forest patches, and to promote the wisdom of the precautionary approach in forest conservation (even forest fragments of 10,000–20,000 ha that today support a diverse avifauna are likely to lose bird species during the present century, and landscape approaches to conservation will only succeed in conserving lowland forest birds if sufficiently large areas are protected).

Perhaps what emerges most strongly from this review is that the time for mere study is now over. This is not to say that further research on the processes of forest and species loss would not be welcome and valuable, but it cannot be allowed to become an excuse to delay the implementation of measures to address and contain the phenomena already clearly identified here. We know enough from recent studies to insist that, if the entire forest avifauna—and by extension the entire spectrum of biological diversity—of the Sundaic region is to stand any chance of long-term survival, only very major, immediate and sustained investment and intervention will now suffice.

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## REFERENCES

Achard, F., Eva, H., Glinni, A., Mayaux, P., Richards, T. and Stibig, H. J. (1997) Identification of deforestation hot spot areas in the humid tropics. *Tropical Ecostystem Environment Observations by Satellite Publ*. Series B, Report 4. ECSC-EC-EAEC, Brussels.

Anon. (1997) *Annual Report 1997*. Kuching, Sarawak: Forest Department.

Anon. (1998) *Annual Report 1998*. Kuala Lumpur, Peninsular Malaysia: Forestry Department.

Anderson, I. P. (1999) The detection and monitoring of vegetation fires in Sumatra using NOAA satellite data. *Forest Liaison Bureau Newsletter* (European Union Forest Liaison Bureau, Jakarta) 2: 4-5.

Anggraini, K., Kinnaird, M. and O'Brien, T. (2000) The effects of fruit availability and habitat disturbance on an assemblage of Sumatran hornbills. *Bird Conserv. Internatn.* 10: 189-202.

Appanah, S. and Weinland, G. (1991) Will the management systems for hill dipterocarp forests stand up? *J. Trop. For. Sci*. 3: 140-158.

Baber, C. V. and Schweithelm, J. (2000) *Trial by fire: forest fires and forest policy in Indonesia's era of crisis and reform*. Washington, D.C.: World Resources Institute.

van Balen, S. (1999a) Differential extinction patterns in Javan forest birds. Pp.39-57 in *Birds on fragmented islands: persistence in the forests of Java and Bali*. Wageningen University and Research Centre, the Netherlands: Doctoral thesis and Tropical Resource Management Papers No. 30.

van Balen, S. (1999b) Synthesis: survival on overpopulated islands. Pp.131-146 in *Birds on fragmented islands: persistence in the forests of Java and Bali*. Wageningen University and Research Centre, the Netherlands: Doctoral thesis and Tropical Resource Management Papers No. 30.

Beaman, R. S., Beaman, J. H., Marsh, C. J. and Woods, P. W. (1985) Drought and forest fires in Sabah in 1983. *Sabah Soc. J.* 8: 10-30.

Bennett, E. L. and Dahaban, Z. (1995) Wildlife responses to disturbances in Sarawak and their implications for forest management. Pp.66-85 in R. B. Primack and T. E. Lovejoy, eds. *Ecology, conservation and management of Southeast Asian rain forests*. New Haven: Yale University Press.

Bennett, E. L. and Gumal, M. T. (2001) The interrelationships of commercial logging, hunting, and wildlife in Sarawak: recommendations for forest management. Pp. 359-374 in R. A. Fimbel, A. Grajal and J. G. Robinson, eds. *Conserving wildlife in managed tropical forests.* New York: Columbia University Press.

Bennett, E. L., Nyaoi, A. J and Sompud, J. (1997) Hornbills *Buceros* spp. and culture in northern Borneo: can they continue to co-exist? *Biol. Conserv.* 82: 41-46.

Bennett, E. L. and Robinson, J. G. (2000) Hunting for sustainability: the start of a synthesis. Pp.499-519 in J. G. Robinson and E. L. Bennett, eds. *Hunting for sustainability in tropical forests*. New York: Columbia University Press.

BirdLife International (2001) *Threatened birds of Asia: the BirdLife International Red Data Book*. Cambridge, U.K.: BirdLife International.

Brooks, T. M., Pimm, S. L. and Collar, N. J. (1997) The extent of deforestation predicts the number of threatened birds in insular South-East Asia. *Conserv. Biol.* 11: 382-394.

Brooks, T. M., Pimm, S. L. and Oyugi, J. O. (1999) Time lag between deforestation and bird extinction in tropical forest fragments. *Conserv. Biol.* 13: 1140-1150.

Bucher, E. H. (1992) The causes of extinction of the Passenger Pigeon. Pp.1-36 in D. M. Power, ed. *Current Ornithology* 9. New York: Plenum Press.

Burgess, N. D. and Mlingwa, C. O. F. (1993) Forest birds of coastal forests in East Africa. *Proc. VIII Pan-Afr Orn. Congr.* 295-301.

Castelletta, M., Sodhi, N. S. and Subaraj, R. (2000) Heavy extinctions of forest avifauna in Singapore: lessons for biodiversity conservation in Southeast Asia. *Conserv. Biol*. 14: 1870-1880.

Chin, S. C., Corlett, R. T., Wee, Y. C. and Geh, S. Y. (1995) *Rain forest in the city: Bukit Timah Nature Reserve, Singapore*. Singapore: National Parks Board (*Gardens' Bull. Singapore*, Suppl. 3).

Connell, J. H. (1978) Diversity in tropical rain forests and coral reefs: high diversity of trees and corals is maintained only in a non-equilibrium state. *Science* 19: 1302-1310.

Corlett, R. T. and Turner, I. M. (1997) Long-term survival in tropical forest remnants in Singapore and Hong Kong. Pp.333-345 in W. F. Laurance and R. O. Bierregaard, eds. *Tropical forest remnants: ecology, management and conservation of fragmented communities.* Chicago: University of Chicago Press.

Counsell, S., ed. (1999) *Life after logging: the impacts of commercial timber extraction in tropical rainforests*. London: Friends of the Earth Trust/The Rainforest Foundation.

Curran, L. M. and Leighton, M. (2000) Vertebrate responses to spatiotemporal variation in seed production of mast-fruiting Dipterocarpaceae. *Ecol. Monogr.* 70: 101-128.

Curran, L. M., Caniago, I, Paoli, G. D., Astianti, D., Kusneti, M., Leighton, M., Nirarita, C. E. and Haeruman, H. (1999) Impact of El Niño and logging on canopy tree recruitment in Borneo. *Science* 286: 2184-2188.

Cutler, A. (1991) Nested faunas and extinction in fragmented habitats. *Conserv. Biol.* 5: 496-505.

Dennis, R. (2000) The recent outbreak of fires in Indonesia. CIFOR Website, 28 March 2000.

Danielsen, F. (1997) Stable environments and fragile communities: does history determine the resilience of avian rain-forest communities to habitat degradation? *Biodiv. and Conserv.* 6: 426-466.

Danielsen, F. and Heegaard, M. (1994) The impact of logging and forest conversion on lowland forest birds and other wildlife in Seberida, Riau Province, Sumatra. Pp.59-60 in Ø. Sandbukt and H. Wiriadinata, eds. *Rain forest and resource management*. Jakarta: Indonesian Institute of Sciences.

Danielsen, F. and Heegaard, M. (1995) Impact of logging and plantation development on species diversity: a case study from Sumatra. Pp.73-92 in Ø. Sandbukt, ed. *Management of tropical forests: towards an integrated perspective*. Oslo: Center for Development and the Environment, University of Oslo.

DFID (1999) Indonesia: towards sustainable forest management. Final report of the Senior Management Advisory Team and the Provincial Level Forest Management Project. Indonesia–U.K. Tropical Forest Management Programme. Jakarta: Department for International Development (U.K.).

Douglas, I., Spencer, T., Greer, A. G., Bidin, K., Sinun, W., and Meng, W. W. (1992) The impact of selective commercial logging on stream hydrology, chemistry and sediment loads in Ulu Segama rain forest. *Phil. Trans. Roy. Soc. London* B 335: 397-406.

Douglas, I., Bidin, K., Balamurugan, G., Chappell, N. A., Walsh, R. P. D., Greer, T. and Sinun, W. (1999) The role of extreme events in the impacts of selective tropical forestry on erosion during harvesting and recovery phases at Danum Valley, Sabah. *Phil. Trans. Roy. Soc. London* B 354: 1749-1761.

Dranzoa, C. (1995) Populations of unlogged and logged forests in Kibale National Park, Uganda. PhD Thesis, Makarere University, Kampala.

Duckworth, J. W., Wilkinson, R. J., Tizard, R. J., Kelsh, R. N., Irvin, S. A., Evans, M. I. and Orrell, T. D. (1996) Bird records from Similajau National Park, Sarawak. *Forktail* 12: 117-154.

Elagupillay, S., Laidlaw, R. K. and bin Wan Noordin, W. S. (in press) Tiger conservation and the Department of Wildlife and National Parks, Peninsular Malaysia. *J. Wildlife and Parks* 13.

Fox, J. E. D. (1973) *A handbook to Kabili-Sepilok Forest Reserve*. Kuching: Borneo Literature Bureau (Sabah Forest Record No. 9).

Ford, H. A. and Davison, G. W. H. (1995) Forest avifauna of Universiti Kebangsaan Malaysia and some other forest remnants in Selangor, Peninsular Malaysia. *Malayan Nature J.* 49: 117-138.

Gro-Nielsen, L. (1997) A survey of the avifauna in primary forest compared with the avifauna in different types of secondary forest. Danish Ornithological Society – Khao Nor Chuchi Lowland Forest Project. Unpublished.

Haila, Y., Hanski, I. K., Niemela, J., Puntilla, P., Raivio, S. and Tukkia, H. (1994) Forestry and boreal fauna: matching management with natural forest dynamics. *Ann. Zool. Fennici* 31: 187-202.

Hails, C. and Jarvis, F. (1987) *Birds of Singapore*. Singapore: Times.

Holmes, D. (2000) *Deforestation in Indonesia: a review of the situation in Sumatra, Kalimantan and Sulawesi*. Jakarta, Indonesia: World Bank.

Holmes, D. and Rombang, W. M. (2001) *Daerah penting bagi burung Sumatera*. Bogor: PKA/BirdLife International–Indonesia Programme.

Holmes, D., Rombang, W. M. and Octaviani, D. (2001) *Daerah penting bagi burung Kalimantan*. Bogor: PKA/BirdLife International–Indonesia Programme.

Jepson, P., Jarvie, J. K., MacKinnon, K. and Monk, K. A. (2001) The end for Indonesia's lowland forests? *Science* 292: 859.

Johns, A. D. (1986) Effects of selective logging on the ecological organisation of a peninsular Malaysian rain forest avifauna. *Forktail* 1: 65-79.

Johns, A. D. (1988a) Effects of 'selective' timber extraction on rain forest structure and composition and some consequences for frugivores and folivores. *Biotropica* 20: 31-37.

Johns, A. D. (1988b) Long-term effects of selective logging operations on Malaysian wildlife. II Case studies in the Ulu Segama Forest Reserve, Danum Valley and Tabin Conservation Areas, Sabah, East Malaysia. Unpublished report, Institute of Tropical Biology, University of Aberdeen, U.K.

Johns, A. D. (1989a) Timber, the environment and wildlife in Malaysian rain forests. Unpublished report, Institute of Tropical Biology, University of Aberdeen, U.K.

Johns, A. D. (1989b) Recovery of a peninsular Malaysian rainforest avifauna following selective timber logging: the first twelve years. *Forktail* 4: 89-105.

Johns, A. G. (1996) Bird population persistence in Sabahan logging concessions. *Biol. Conserv.* 75: 3-10.

Johns, A. G. (1997) *Timber production and biodiversity conservation in tropical rain forests*. Cambridge: Cambridge University Press.

Johnson, N. and Cabarle, B. (1993) *Surviving the cut: natural forest management in the humid tropics.* Washington, D.C.: World Resources Institute.

Kang, N. and Hails, C. J. (1995) The birds of the Bukit Timah nature reserve and central catchment area. Pp. 121-143 in S. C. Chin, R. T. Corlett, Y. C. Wee and S. Y. Geh, eds. *Rain forest in the city: Bukit Timah Nature Reserve, Singapore*. Singapore: National Parks Board (*Gardens' Bull. Singapore*, Suppl. 3).

Kemp, A. (1995) *Bird families of the world: the hornbills, Bucerotiformes*. Oxford: Oxford University Press.

Kinnaird, M. F. and O'Brien, T. G. (1998) Ecological effects of wildfire on lowland rainforest in Sumatra. *Conserv. Biol*. 12: 954-956.

Lambert, F. R. (1989) Little known Oriental birds: Large Green Pigeon *Treron capellei*. *Oriental Bird Club Bull.* 9: 22-24.

Lambert, F. R. (1990) Avifaunal changes following selective logging of a north Bornean rain forest. Report to the Danum Valley Management Committee, Sabah Foundation and the Socio-economic Research Unit of the Prime Minister's Department. University of Aberdeen, Aberdeen.

Lambert, F. R. (1991a) The conservation of fig-eating birds in Malaysia. *Biol. Conserv*. 58: 31-40.

Lambert, F. R. (1991b) Fruit eating by Purple-naped Sunbirds *Hypogramma hypogrammicum* in Borneo. *Ibis* 133: 425-426.

Lambert, F. R. (1992) The consequences of selective logging for Bornean lowland forest birds. *Phil. Trans. Roy. Soc. London* B 335: 443-457.

Lambert, F. R. and Marshall, A. G. (1991) Keystone characteristics of bird-dispersed figs in a Malaysian lowland forest. *J. Ecol.* 79: 793-809.

Lambert, F. R. and Woodcock, M. (1996) *Pittas, broadbills and asities*. Mountfield, Sussex, U.K.: Pica Press.

Lammertink, M. (1999) Responses of woodpeckers to forest disturbance after selective logging in Kalimantan – preliminary data. Paper presented at 'The balance between biodiversity conservation and sustainable use of tropical rain forest'; Ministry of Forestry and Estate Crops/TROPENBOS/NOW workshop, Balikpapan, Indonesia, 6–8 December 1999.

Lenton, G. M. (1984) The feeding and breeding ecology of Barn Owls *Tyto alba* in Peninsular Malaysia. *Ibis* 126: 551-575.

Lim, K. S. (1997 [published 1999]) Bird biodiversity in the nature reserves of Singapore. Proceedings of the Nature Reserves Survey Seminar. *Garden's Bull. Singapore* 49: 225-244.

Lim, K. S. and Gardner, D. (1997) *Birds: an illustrated field guide to the birds of Singapore*. Singapore: Sun Tree Publishing.

Long, A. J. and Collar, N. J. (2002) Distribution, status and natural history of the Bornean Ground Cuckoo *Carpococcyx radiatus*. *Forktail* 18: 110-119.

Lovejoy, T. E. (1985) *Rehabilitation of degraded tropical rainforest lands*. Gland, Switzerland: IUCN (Commission on Ecology Occas. Paper 5).

MacKinnon, J. and Phillipps, K. (1993) *A field guide to the birds of Borneo, Sumatra, Java and Bali.* Oxford: Oxford University Press.

van Marle, J. G. and Voous, K. H. (1988) *The birds of Sumatra: an annotated check-list.* Tring, UK: British Ornithologists' Union Check-list 10.

Marsh, C. and Greer, A. G. (1992) Forest land use in Sabah. *Phil. Trans. Roy. Soc. London* B 335: 331-339.

McCarthy, J. F. (2000) 'Wild logging': the rise and fall of logging networks and biodiversity conservation projects on Sumatra's rainforest frontier. *CIFOR Occas. Pap.* 31.

McClure, H. E. and Hussein B. O. (1965) Avian bionomics of Malaya 2. The effect of forest destruction upon a local population. *Bird Banding* 36: 242-269.

Mitra, S. S. and Sheldon, F. H. (1993) Use of an exotic tree plantation by Bornean lowland forest birds. *Auk* 110: 529-540.

Nijman, V. (1998) Habitat preferences of Great Argus Pheasant (*Argusianus argus*) in Kayan Mentarang National Park, East Kalimantan, Indonesia. *J. Orn*. 139: 313-323.

Oyugi, O. J. (1998) Tropical forest fragmentation and avian population changes in Kakamega forest, Kenya. M. Phil. thesis, Moi University, Eldoret, Kenya.

Parrott, S. and Andrew, P. (1996) An annotated checklist of the birds of Way Kambas National Park, Sumatra. *Kukila* 8: 57-85.

Pattanavibool, A. and Edge, W. D. (1996) Single-tree selection silviculture affects cavity resources in mixed deciduous forests in Thailand. *J. Wildl. Mgmt*. 60: 67-73.

Patterson, B. D. (1987) The principle of nested subsets and its implications for biological conservation. *Conserv. Biol.* 1: 323-334.

Poore, D., Burgess, P., Palmer, J., Rietbergen, S. and Synnott, T. (1989) *No timber without trees: sustainability in the tropical forests*. London: Earthscan.

Prentice, C. and Aikanathan, S. (1989) *A preliminary faunal survey of the North Selangor peat swamp forest*. Kuala Lumpur: WWF Malaysia and Asian Wetland Bureau.

Putz, F. E., Redford, K. H., Robinson, J. G., Fimbel, R. and Blate, G. M. (2000) *Biodiversity conservation in the context of tropical forest management*. Washington, D.C.: World Bank Environment Department.

Redford, K. H. (1992) The empty forest. *BioScience* 42: 412-422.

Robertson, J. M. Y. and van Schaik, C. P. (2001) Causal factors underlying the dramatic decline of the Sumatran orang-utan. *Oryx* 35: 26-38.

Robinson, J. G. (1996) Hunting wildlife in forest patches: an ephemeral resource. Pp.111-130 in J. Schelhas and R. Greenberg, eds. *Forest patches in tropical landscapes.* Washington, D.C.: Island Press.

Round, P. D. and Brockelman, W. Y. (1998) Bird communities of disturbed lowland forest habitats of southern Thailand. *Nat. Hist. Bull. Siam Soc*. 46: 171-196.

Schweithelm, J. (1998) The fire this time: an overview of Indonesia's forest fires in 1997-98. Discussion paper, WWF Indonesia.

Scotland, N., Fraser, A. and Jewell, N. (1999) Roundwood supply and demand in the forest sector in Indonesia. Jakarta: Department for International Development (U.K.) (Indonesia-U.K. Tropical Forest Management Programme: Report no. PFM/EC/99/08).

Short, L. L. (1978) Sympatry in woodpeckers in lowland Malayan forest. *Biotropica* 10: 122-133.

Styring, A. R. and Ickes, K. (2001) Woodpecker abundance in a logged (40 years ago) vs. unlogged lowland dipterocarp forest in Peninsular Malaysia. *J. Trop. Ecol*. 17: 261-268.

Thiollay, J.-M. (1995) The role of traditional agroforests in the conservation of rain forest bird diversity in Sumatra. *Conserv. Biol.* 9: 335-353.

Thiollay, J.-M. (1998) Current status and conservation of Falconiformes in tropical Asia. *J. Raptor Res*. 32(1): 40-55.

Turner, I. M. and Corlett, R. T. (1996) The conservation value of small, isolated fragments of lowland tropical rain forest. *Trends in Ecol. and Evolution* 11: 330-333.

Uhl, C., Jordan, C., Clark, K., Clark, H. and Herrera, R. (1982) Ecosystem recovery in Amazon caatinga forest after cutting and burning, and bulldozer clearing treatments. *Oikos* 38: 313-320.

Wells, D. R. (1985) The forest avifauna of western Malesia and its conservation. Pp.213-232 in A. W. Diamond and T. E. Lovejoy, eds. *Conservation of tropical forest birds*. Cambridge, U.K.: International Council for Bird Preservation.

Wells, D. R. (1999) *The birds of the Thai-Malay Peninsula*. London: Academic Press.

Whitmore, T. C. (1984) *Tropical rain forests of the far east*. Oxford: Clarendon Press.

Whitmore, T. C. (1990) *An introduction to tropical rainforests.* Oxford: Oxford University Press.

Whitmore, T. C. (1997) Tropical forest disturbance, disappearance and species loss. Pp.3-12 in W. F. Laurance and R. O. Bierregaard, eds. *Tropical forest remnants: ecology, management and conservation of fragmented communities.* Chicago: University of Chicago Press.

Whitten, T., Holmes, D. and MacKinnon, K. (2001) Conservation biology: a displacement behaviour for academia? *Conserv. Biol.* 15: 1-3.

Williams, R. S. R. (2002) The rediscovery and doubtful validity of the Blue-wattled Bulbul *Pycnonotus nieuwenhuisii*. *Forktail* 18: 107-109.

Woods, P. (1989) Effects of logging, drought and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica* 21: 290-298.

Wong, M. (1985) Understory birds as indicators of regeneration in a patch of selectively logged West Malaysian rainforest. Pp.249-263 in A. W. Diamond and T. E. Lovejoy, eds. *Conservation of tropical forest birds*. Cambridge, U.K.: International Council for Bird Preservation.

Wong, M. (1986) Trophic organisation of understory birds in a Malaysian dipterocarp forest. *Auk* 103: 100-116.

World Bank (2001) *Indonesia: environment and natural resource management in a time of transition*. Washington, D.C: The World Bank.

World Wide Fund for Nature (WWF) Malaysia (1998) Assessment of wildlife and its management in relation to forestry in the KPKKT Concession Area, Terengganu. Report for Gesellschaft für Technische Zusammenarbeit (GTZ). Kuala Lumpur: WWF Malaysia.

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## APPENDIX

### Sundaic forest bird species for which evidence to date exists of endangerment from selective logging and forest fragmentation.

All species are included in the table where existing data suggest either fragmentation ('Frag') or selective logging ('Log') causes their population decline or loss at least one site. For those species for which data are considered to be unambiguous in indicating a strong negative response, bold is used in the 'Affected by' column; assignation of bold to species provides the basis for the numerical analysis in this paper, but it is, inevitably, subjective to some degree, and should be understood as a guideline determination based on the available evidence. 'Frag?' and 'Log?' indicate that data are inconclusive but suggestive of decline for the species in at least some parts of its range. Feeding guilds are based on Lambert (1990).

| Species | Range & type | RDB status | Size | Nest | Affected by | Source for fragmentation | Source for logging |
|---|---|---|---|---|---|---|---|
| **Arboreal frugivores/predators** | | | | | | | |
| Hornbills All lowland canopy species | | | L | Hn | Frag,Log? | FD | WF |
| Bushy-crested Hornbill *Anorrhinus galeritus* | SE | | L | Hn | Frag | Se | |
| Rhinoceros Hornbill *Buceros rhinoceros* | SE | NT | L | Hn | **Frag** | S,vB,WK | |
| Great Hornbill *Buceros bicornis* | | NT | L | Hn | Frag?Log? | RB | J |
| Helmeted Hornbill *Rhinoplax vigil* | SE | NT | L | Hn | **Frag** | S,Se,WK | |
| White-crowned Hornbill *Aceros comatus* | SE | | L | Hn | Log? | | RB |
| Gold-whiskered Barbet *Megalaima chrysopogon* | SE | | L | He | Log? | | L,RB |
| **Arboreal frugivores** | | | | | | | |
| Large Green Pigeon *Treron capellei* | SE,L | VU | L | C | **Frag** | FD,vB,Se,(S) | |
| Thick-billed Green Pigeon *Treron curvirostra* | | | M-ML | C | **Frag** | S | |
| Little Green Pigeon *Treron olax* | SE,L | | M | C | Frag?Log? | S | PA |
| Green Imperial Pigeon *Ducula aenea* | L | | L | C | Frag | vB,S | |
| Jambu Fruit Dove *Ptilinopus jambu* | SE | NT | ML | C | Frag,Log | (FD),S | RB,G |
| Yellow-crowned Barbet *Megalaima henricii* | SE | NT | M | He | **Frag**,Log? | FD,S | G |
| Red-crowned Barbet *Megalaima rafflesii* | SE,L | NT | ML | He | Log | | RB |
| Blue-eared Barbet *Megalaima australis* | | | M | He | **Frag** | S | |
| Green Broadbill *Calyptomena viridis* | SE | NT | ML | Sf | **Frag,Log** | (FD),S | L,W,RB,DN,WF,PA |
| Asian Fairy Bluebird *Irena puella* | | | M-ML | C | **Frag**,Log? | vB | RB |
| **Nocturnal predators/insectivores** | | | | | | | |
| Oriental Bay Owl *Phodilus badius* | | | L | Hn | **Frag** | (FD),S | |
| Reddish Scops Owl *Otus rufescens* | SE | NT | ML | Hn | Frag,Log? | (FD),vB | J |
| Barred Eagle Owl *Bubo sumatranus* | SE | | L | Hn | Frag,Log? | S | G |
| Malaysian Eared Nightjar *Eurostopodus temminckii* | SE | | ML | Gs | Log | | W |
| Frogmouths *Batrachostomus* spp. | | | M-ML | C | Frag | (FD) | |
| Gould's Frogmouth *Batrachostomus stellatus* | SE | NT | M | C | **Frag** | S | |
| **Sallying substrate-gleaning insectivores** | | | | | | | |
| Diard's Trogon *Harpactes diardii* | SE | NT | ML | Ds | **Frag,Log** | FD,S | L,GJ,RB,G,PA |
| Scarlet-rumped Trogon *Harpactes duvaucelii* | SE | NT | M | Ds | **Frag,Log** | FD (S) | L,W,RB,G,PA |
| Cinnamon-rumped Trogon *Harpactes orrhophaeus* | SE | NT | M | Ds | **Frag,Log** | FD | L,W,G |
| Orange-breasted Trogon *Harpactes oreskios* | | | M | Ds | Log? | | L |
| Red-naped Trogon *Harpactes kasumba* | SE | NT | ML | Ds | **Frag**,Log | (FD),S | L,J |
| Dusky Broadbill *Corydon sumatranus* | | | ML | Sf | **Frag**,Log | S | RB,G |
| Banded Broadbill *Eurylaimus javanicus* | | | ML | Sf | **Frag**,Log | S | RB,L,G |
| Black-and-yellow Broadbill *Eurylaimus ochromalus* | SE | NT | M | Sf | **Frag**,Log | S | L,(DN) |
| Black-and-red Broadbill *Cymbirhynchus macrorhynchos* | | | M-ML | Sf | **Frag** | S | |
| White-throated Jungle Flycatcher *Rhinomyias umbratilis* | SE | NT | S | Hn/C | **Log** | | L,GJ |
| Brown-chested Jungle Flycatcher *Rhinomyias brunneata*[1] | | VU | S | Hn/C | Log | | W |
| Fulvous-chested Jungle Flycatcher *Rhinomyias olivacea* | SE | | S | Hn/C | **Frag,Log** | vB | RB,G |

| Species | Range & type | RDB status | Size | Nest | Affected by | Source for fragmentation | Source for logging |
|---|---|---|---|---|---|---|---|
| Greater Racket-tailed Drongo *Dicrurus paradiseus* | L | | M | C | Log? | | RB,DN |
| Bronzed Drongo *Dicrurus aeneus* | | | M | C | **Frag** | S | |
| Crow-billed Drongo *Dicrurus annectans* | | | M | C | Log? | | RB |
| **Sallying insectivores** | | | | | | | |
| Red-bearded Bee-eater *Nyctyornis amictus* | SE | | M-ML | Tn | Frag,Log? | FD | RB |
| Rufous-chested Flycatcher *Ficedula dumetoria* | | NT | S | C/Hn | Frag?**Log** | (FD)(S?) | L,W,J |
| Understorey blue flycatchers *Cyornis* spp. | | | S | C | **Frag** | (FD),(S?),Se | |
| Large-billed Blue Flycatcher *Cyornis caerulatus* | SE,L | VU | S | C | **Log**,Frag? | Se | L |
| Bornean Blue Flycatcher *Cyornis superbus* | SE | | S | C | **Log**,Frag? | Se | L |
| Grey-headed Canary Flycatcher *Culicicapa ceylonensis* | | | S | Sr | **Frag,Log** | (FD),(S),Se | L,GJ,J,W,RB,G |
| Maroon-breasted Philentoma *Philentoma velatum* | SE | NT | M | C | **Frag,Log** | (FD),S,vB | L,GJ,DN |
| Rufous-winged Philentoma *Philentoma pyrhopterum* | SE | | S | C | **Frag** | S | |
| Asian Paradise-flycatcher *Terpsiphone paradisi* | | | S | C | **Frag** | vB | |
| Spotted Fantail *Rhipidura perlata* | SE | | S | C | **Frag,Log** | (FD)(S?) | L,GJ |
| **Bark-gleaning insectivores** | | | | | | | |
| Crimson-winged Woodpecker *Picus puniceus* | SE | | ML | He | **Frag,Log** | S,vB | Lm,G |
| Checker-throated Woodpecker *Picus mentalis* | SE | | ML | He | **Frag,Log** | S,vB | Lm |
| Banded Woodpecker *Picus miniaceus* | SE | | ML | He | **Frag** | vB | |
| Buff-necked Woodpecker *Meiglyptes tukki* | SE | NT | M | He | **Frag,Log** | S | Lm,G |
| Greater Flameback *Chrysocolaptes lucidus* | | | ML-L | He | **Frag** | (FD),S,vB | |
| Olive-backed Woodpecker *Dinopium rafflesii* | SE | NT | ML | He | **Frag** | S | |
| Maroon Woodpecker *Blythipicus rubiginosus* | SE | | ML | He | **Frag,Log** | (FD?),S | L,RB,Lm,G |
| Rufous Woodpecker *Celeus brachyurus* | | | M-ML | He | **Frag**,Log | vB | Lm |
| Orange-backed Woodpecker *Reinwardtipicus validus*[2] | SE | | L | He | **Frag**,Log? | S,vB,FD | L |
| White-bellied Woodpecker *Dryocopus javensis* | L | | L | He | **Frag**,Log? | S,vB | L,G |
| Great Slaty Woodpecker *Mulleripicus pulverulentus* | L | | L | He | **Frag** | (FD),vB,S | |
| Grey-and-buff Woodpecker *Hemicircus concretus* | SE | | M | He | **Frag** | S | G |
| Velvet-fronted Nuthatch *Sitta frontalis* | | | S | Hn | Frag?Log | (FD) | L |
| **Terrestrial insectivores of forest interior** | | | | | | | |
| pittas *Pitta* spp. | | | M-ML | Cc | Log? | | J |
| Banded Pitta *Pitta guajana* | SE | | ML | Cc | **Frag** | FD,(S) | |
| Garnet Pitta *Pitta granatina* | SE,L | NT | M | Cc | **Frag** | FD,S | |
| Chestnut-naped Forktail *Enicurus ruficapillus* | SE | NT | M | Sr | **Frag,Log** | FD | L,GJ |
| White-crowned Forktail *Enicurus leschenaulti* | | | M | Sr | **Frag**,Log | FD | T,C,J,(DN) |
| Black-capped Babbler *Pellorneum capistratum* | SE | | M | Cc | **Frag** | (FD),S | |
| Rail-babbler *Eupetes macrocerus* | SE | NT | M-ML | ? | Frag,Log | FD | DN,J |
| Large Wren Babbler *Napothera macrodactyla* | SE | NT | M | C | **Frag,Log** | FD,S | L,J,RB,DN |
| Bornean Wren Babbler *Ptilocichla leucogrammica* | SE,L | VU | M | | Log? | | J |
| Striped Wren Babbler *Kenopia striata* | SE | NT | S | C | **Frag,Log** | (FD),S,Se | L,GJ,W,RB (DN) |
| Blue Whistling Thrush *Myophonus caeruleus* | | | ML | C | Frag | vB | G |
| **Terrestrial omnivores** | | | | | | | |
| Great Argus Pheasant *Argusianus argus* | SE | NT | L | Gs | Frag,**Log** | S,FD | J,L,VN |
| Malaysian Peacock Pheasant *Polyplectron malacense* | SE | VU | L | Gs | Frag | FD,S | |
| Crested Fireback *Lophura ignita* | SE,L | NT | L | Gs | Log? | | GJ |
| Crestless Fireback *Lophura erythrophthalma* | SE,L | VU | L | Gs | Frag | S | |
| Black Partridge *Melanoperdix nigra* | SE | VU | L | Gs | Frag | S | |
| Partridges Lowland (*Arborophila*) species | | | L | Gs | Frag,Log | (S),(FD) | J,GJ |

| Species | Range & type | RDB status | Size | Nest | Affected by | Source for fragmentation | Source for logging |
|---|---|---|---|---|---|---|---|
| **Arboreal foliage-gleaning insectivores/understorey specialists** | | | | | | | |
| Rufous-collared Kingfisher *Actenoides concretus* | SE | NT | ML | Tn | **Frag**,Log | (FD),S | WF,J |
| Oriental Dwarf Kingfisher *Ceyx erithacus* | | | S | Tn | **Frag** | S | |
| Rufous Piculet *Sasia abnormis* | SE | | S | He | Frag,Log? | (FD)(S?) | W,J |
| Ferruginous Babbler *Trichastoma bicolor* | SE,L | | M | C | Frag? | (FD),Se? | |
| Grey-breasted Babbler *Malacopteron albogulare* | SE,L | NT | M | C | **Frag** | S | |
| Black-throated Babbler *Stachyris nigricollis* | SE,L | NT | M | Cc | **Frag** | S | |
| White-necked Babbler *Stachyris leucotis* | SE | NT | M | C | Log? | | J |
| Grey-headed Babbler *Stachyris poliocephala* | SE | | M | Cc | Log | | GJ,J |
| Fluffy-backed Tit Babbler *Macronous ptilosus* | SE | NT | S | Cc | **Frag** | S | |
| **Arboreal foliage-gleaning insectivores** | | | | | | | |
| Hodgson's Hawk Cuckoo *Hierococcyx fugax* | | | ML | Pa | Frag?Log? | (FD),Se? | RB |
| Buff-rumped Woodpecker *Meiglyptes tristis* | SE | | M | He | **Frag**,Log | S,vB,Se | RB,G |
| Chestnut-rumped Babbler *Stachyris maculata* | SE | NT | M | Cc | **Frag,Log** | (FD),S | L,GJ,W |
| Chestnut-backed Scimitar Babbler *Pomatorhinus montanus* | SE | | M | C | Frag | FD | (DN) |
| White-bellied Yuhina *Yuhina zantholeuca* | | | S | C | Frag?Log | (FD) | GJ |
| Moustached Babbler *Malacopteron magnirostre* | SE | | M | C | Log | | GJ |
| Rufous-crowned Babbler *Malacopteron magnum* | SE | NT | M | C | **Log** | | GJ,W,RB |
| Scaly-crowned Babbler *Malacopteron cinereum* | | | S | C | Frag?**Log** | (FD) | L,RB,DN |
| Crested Jay *Platylophus galericulatus* | SE | NT | ML | C | Frag? | (FD) | DN |
| Violet Cuckoo *Chrysococcyx xanthorhynchus* | | | M | Pa | Frag | vB | |
| Black-bellied Malkoha *Phaenicophaeus diardi* | SE | NT | M | C | **Frag** | S | |
| Chestnut-breasted Malkoha *Phaenicophaeus curvirostiris* | SE | | ML | C | Log? | | L |
| Raffles's Malkoha *Phaenicophaeus chlorophaeus* | SE | | M | C | **Frag**,Log? | S | RB,G |
| Red-billed Malkoha *Phaenicophaeus javanicus* | SE | NT | ML | C | **Frag**,Log? | S | L,RB |
| Rufous-tailed Shama *Copsychus (tichixos) pyrropygus* | SE | | M | Hn | Frag?**Log** | (FD) | L,W,J |
| Lesser Cuckooshrike *Coracina fimbriata* | SE | | M | C | **Frag**,Log? | S,vB | RB |
| Bar-bellied Cuckooshrike *Coracina striata* | L | | M-ML | C | **Frag**,Log? | (FD),S | RB |
| Malaysian Cuckooshrike *Coracina javensis* | SE | | ML | C | Frag | (FD),vB | |
| Large Woodshrike *Tephrodornis virgatus*[3] | | | M | C | **Frag** | S | |
| Fiery Minivet *Pericrocotus igneus* | SE | NT | S | C | **Frag** | S | |
| Green Iora *Aegithina viridissima* | SE | NT | S | C | **Frag** | S,Se? | |
| **Arboreal foliage-gleaning insectivores/frugivores** | | | | | | | |
| Dark-throated Oriole *Oriolus xanthonotus* | | NT | M | C | **Frag**,Log? | S,vB | PA |
| Red-throated Barbet *Megalaima mystacophanos* | SE | NT | ML | He | **Frag**,Log? | FD,S | RB |
| Brown Barbet *Calorhamphus fuliginosus* | SE | | M | Cn/Tn | **Frag**,Log? | S | RB |
| Black Magpie *Platysmurus leucopterus* | SE,L | NT | L | C | Log | | L,PA |
| Grey-bellied Bulbul *Pycnonotus cyaniventris* | SE | NT | M | C | **Frag** | (FD),S | G |
| Scaly-breasted Bulbul *Pycnonotus squamatus* | SE | NT | M | C | **Frag** | vB | |
| Spectacled Bulbul *Pycnonotus erythropthalmos* | SE | | S | C | **Frag** | (FD),S,Se? | |
| Puff-backed Bulbul *Pycnonotus eutilotus* | SE | NT | M | C | **Frag** | S | |
| Black-and-white Bulbul *Pycnonotus melanoleucos* | SE | NT | M | C | **Frag** | S | |
| Buff-vented Bulbul *Iole olivacea* | SE | NT | M | C | Frag? | S | |
| Yellow-bellied Bulbul *Criniger phaeocephalus* | SE | | M | C | Frag | S | |
| Brown Fulvetta *Alcippe brunneicauda* | SE | NT | S | C | Log | | L,G |
| Yellow-breasted Flowerpecker *Prionochilus maculatus* | SE | | S | Sc | **Frag** | S,Se | |

| Species | Range & type | RDB status | Size | Nest | Affected by | Source for fragmentation | Source for logging |
|---|---|---|---|---|---|---|---|
| **Miscellaneous insectivores/piscivores** | | | | | | | |
| SILVER-RUMPED SPINETAIL *Rhaphidura leucopygialis* | SE | | S? | Hn | **Frag** | S,vB | |
| BLUE-BANDED KINGFISHER *Alcedo euryzona* | SE | VU | M | Tn | **Frag,Log** | vB | GJ,(DN) |
| BANDED KINGFISHER *Lacedo pulchella* | | | M | Tn | **Frag,Log** | vB,S | L,RB,J |
| **Nectarivores/insectivores** | | | | | | | |
| RED-THROATED SUNBIRD *Anthreptes rhodolaema* | SE | NT | S | Sc | **Frag** | S | G |
| CRIMSON SUNBIRD *Aethopyga siparaja* | L | | S | Sc | Frag | vB | |
| GREY-BREASTED SPIDERHUNTER *Arachnothera affinis* | SE | | M | L | **Frag** | S,Se | G |
| LONG-BILLED SPIDERHUNTER *Arachnothera robusta* | | | M | L | **Frag**,Log? | vB | DN,G |
| THICK-BILLED SPIDERHUNTER *Arachnothera crassirostris* | SE | | M | L | **Frag** | S | G |
| YELLOW-EARED SPIDERHUNTER *Arachnothera chrysogenys* | SE | | M | L | **Frag** | vB,S | G |
| SPECTACLED SPIDERHUNTER *Arachnothera flavigaster* | SE,L | | M | L | **Frag** | S | G |
| **Nectarivores/insectivores/frugivores** | | | | | | | |
| PLAIN SUNBIRD *Anthreptes simplex* | SE | | S | Sc | Frag? | Se | |
| PURPLE-NAPED SUNBIRD *Hypogramma hypogrammicum* | | | S | Sc | **Frag** | S | |
| THICK-BILLED FLOWERPECKER *Dicaeum agile* | | | S | Sc | **Frag** | vB | |
| PLAIN FLOWERPECKER *Dicaeum concolor* | | | S | Sc | **Frag** | S | |
| YELLOW-VENTED FLOWERPECKER *Dicaeum chrysorrheum* | | | S | Sc | **Frag** | vB | |
| CRIMSON-BREASTED FLOWERPECKER *Prionochilus percussus*[4] | SE | | S | Sc | **Frag**,Log? | vB | J |

Superscript notes (column 1): [1] Brown-chested Jungle Flycatcher is a non-breeding visitor. [2] Orange-backed Woodpecker is regular in old overgrown rubber estates in Peninsular Malaysia (D. R. Wells *in litt.* 2002). [3] Large Woodshrike is regular in old overgrown rubber estates in Peninsular Malaysia (D. R. Wells *in litt.* 2002). [4] Crimson-breasted Flowerpecker reaches peak abundance in gap-phase vegetation in logged forest (D. R. Wells *in litt.* 2002).

Range and type: SE = Sundaic Endemic; L = lowland specialist, mostly <600 m. Designations derived from Wells (1985) with modifications.

RDB status: NT = Near Threatened; VU = Vulnerable (as indicated in BirdLife International 2001).

Size: S – small species (weight < 20 g); M – medium-sized (20-69 g); ML – medium-large (70-150 g); L – large (>150 g).

Nest: C – simple cup or platform; Cc – roofed cup; Ds – cavity in dead tree, usually a stump; Gs – scrape on ground; He – excavated hole; Hn – natural hole; L – woven on underside of leaf; Pa – parasitic; Sc – hanging structure, close to attachment point; Sf – hanging structure, nest far from attachment point; Sr – woven, attached to rock or tree; Tn – excavated tunnel in bank, termite mound or rotten tree.

Sources of data (from Peninsular Thailand, Malaysia, north Borneo, Sumatra, Java; note that question marks indicate uncertainty):
*Species affected by fragmentation*: vB – species most threatened on Java by lowland forest fragmentation (van Balen 1999a,b; see also Table 2, but note that there are different criteria for inclusion of species—and therefore some different species—in that table); FD – species known to have been present at a Peninsular Malaysian study site but which could no longer be found (Ford and Davison 1995); (FD) – species which would probably have been present at a Peninsular Malaysian study site prior to fragmentation but which were not found (Ford and Davison 1995); S – species extinct or now very rare in Singapore, based on Kang and Hails (1995), Lim (1997), Lim and Gardner (1997), Corlett and Turner (1997); (S) – species absent from Singapore which may have become extinct; Se – birds that have apparently declined or disappeared from Sepilok, Sabah, based on unpublished work of K. Ickes; WK – based on evidence from various observers made at Way Kambas, Sumatra.
*Species affected by selective logging*: DN – based on data supplied by F. Danielsen relating to Danielsen and Heegaard (1995) (short survey); (DN) – suggested trend/effect from DN; G – Gro-Nielsen (1997) (short study; data included only when they add weight to other studies; some declines may have been associated with fragmentation rather than logging); GJ – (Grieser-)Johns (1996); J – Johns (1986, 1989a,b); L – Lambert (1990, 1992); Lm – Lammertink (1999); PA – Prentice and Aikanathan (1989) (peatswamp forest); RB – Round and Brockelman (1998); VN – Nijman (1998); W – Wong (1986); WF – World Wide Fund for Nature (WWF) Malaysia (1998).