Assessing the biodiversity value of degraded lowland forest in Sumatra, Indonesia

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Summary: Forest degradation, forest fires, and wildlife poaching have devastated biodiversity in Indonesia. To assess the impact of forest degradation and the potential for recovery, we used birds as a proxy for biodiversity and assessed density estimates (hereafter density) in the degraded lowland forest of Harapan Rainforest Ecosystem Restoration Concession (HRF) in Sumatra. In this study, a total of 149 bird species (from 5,317 individuals) were recorded. Of the 103 species for which densities could be calculated, 45% were lowland bird specialists (i.e. species occurring below 200 m above sea level in Sumatra), including three globally threatened and 41 Near-Threatened species. Comparison with bird densities in degraded forest of Borneo revealed that there was broad similarity across taxa but three species had significantly higher density, and four had significantly lower density, in HRF. The mosaic of degraded forest habitats in different stages of regeneration in HRF appears to support more individuals of some species, especially woodpeckers, than the Bornean sites, but fewer individuals of other species. Determining bird densities is essential to establish population baselines, allowing comparisons between sites and over time. The present study fills one gap, but we urge others to conduct similar studies to provide a better understanding of the temporal and spatial variation in bird density in Southeast Asia's degraded forests.

Ringkasan: Degradasi hutan, kebakaran hutan, dan perburuan liar memberikan tekanan yang sangat besar bagi keanekaragaman hayati di Indonesia. Untuk mengkaji dampak dari degradadasi hutan dan potensi untuk pulih, kami mempergunakan burung sebagai indikator dan mengkaji perkiraan kepadatan jenis burung di hutan dataran rendah yang telah terdegradasi di konsesi *Harapan Rainforest Ecosystem Restoration* (HRF), Sumatera. Di dalam studi ini, 149 jenis burung tercatat (dengan total individu sebanyak 5317). Dari 103 jenis burung yang kepadatannya dapat dihitung, 45% merupakan jenis burung spesialis dataran rendah (jenis burung yang ditemukan pada ketinggian di bawah 200 meter dari permukaan laut di Sumatera), termasuk tiga jenis yang berstatus terancam punah dan 41 jenis yang berstatus mendekati terancam punah. Mosaik hutan yang terdegradasi dan berada dalam berbagai tahap regenerasi di HRF sepertinya mendukung dengan baik beberapa jenis burung (misalnya jenis-jenis burung pelatuk) bila dibandingkan dengan lokasi di Kalimantan, tapi tidak untuk beberapa jenis burung lainnya. Penentuan kepadatan jenis burung sangat penting untuk menetapkan dasar bagi monitoring, dan juga memberikan peluang untuk membandingkan dengan hasil dari studi-studi di tempat lainnya untuk memberikan pemahaman yang lebih baik tentang variasi yang terjadi karena perbedaan waktu maupun spasial untuk jenis-jenis burung di hutan yang terdegradasi di Asia Tenggara.

Introduction

Tropical forests may cover only 10% of the world's land surface, but they support high species density (Dirzo & Raven 2003). However, tropical forest is disappearing fast, especially in Southeast Asia (Laurence 1999; Sodhi *et al.* 2010). With about 138 million ha or 10% of the world's remaining tropical forests, Indonesia holds one of the largest areas of tropical forest, but also the highest deforestation rate in the world (Margono *et al.* 2014). On Sumatra, the sixth largest island in the world, degraded forest has replaced much of its primary tropical rainforest, particularly in lowland areas (Wilcove *et al.* 2013). A recent study revealed that 70% of the island's forested areas have been cleared, mainly for the logging industry, from 1990 through 2010, leaving just 23,100 km^2 of primary forest in degraded condition (Margono *et al.* 2012). Following clearing, the degraded forest is usually converted to plantations or agricultural land.

Besides forest habitat degradation, the illegal wildlife trade is a major threat to biodiversity, being worth an estimated US$ 2.5 billion per year in East Asia and the Pacific, and perhaps up to USD$1 billion/year in Indonesia alone (UNODC 2013). The bird trade is a familiar phenomenon in Indonesia where thousands of birds are sold for use as pets, household ornaments, food, religious release, and traditional medicine (Jepson & Ladle 2009; Shepherd 2012). The demand for bird trade, combined with habitat loss, threatens numerous bird species in Indonesia with extinction. For example, the highly prized Straw-headed Bulbul *Pycnonotus zeylanicus* is now extinct from Javan forests, and might follow the same fate in Sumatra and Borneo (BirdLife International 2015a). Another classic example is the Bali Starling *Leucopsar rothscildi,* whose wild population was driven to extinction by poachers, then reintroduced from captive bred stock, but still suffers from poaching. Many of the wild birds sold in Java now come from Sumatra, possibly because of population declines due to trapping in Java (Jepson & Ladle 2009; Shepherd 2012). Due to severe hunting pressure, the status of the Helmeted Hornbill *Rhinoplax vigil* has recently been changed from Near Threatened to Critically Endangered (Birdlife International 2015b). Under the current pressure, many species that are considered Near Threatened might become threatened in the near future, particularly those that are being captured to fulfil bird market demand (Jepson & Ladle 2009; Harris *et al.* 2015).

The importance of degraded forest (i.e. selectively logged primary forest) for tropical biodiversity conservation has been increasingly acknowledged (Johns 1989; Sodhi *et al.* 2005; Sekercioglu *et al.* 2007; Edwards *et al.* 2010, 2011; Wilcove *et al.* 2013). In Southeast Asia, logged forests are now the dominant forest habitat remaining for forest-dependent birds. Unfortunately, the value of logged forest is largely unappreciated or ignored (Waltert *et al.* 2004; Edwards *et al.* 2010, 2011), leading to widespread destruction by forest fires in Indonesia (Marlier *et al.* 2015; Spracklen *et al.* 2015).

Considering the rapid loss of tropical forest, particularly in the lowlands, and the pressure on biodiversity from the wildlife trade, baseline density information is urgently required to monitor rates of decline, and assess the effectiveness of any conservation measures. Measurements of avian density that incorporate information about detectability can provide more accurate assessments of habitat quality than those that do not, and can be compared over time or space with less risk of bias (Karanth & Nichols 1998; Fancy & Sauer 2000; Norvell *et al.* 2003). They allow comparisons of density between primary and secondary or logged forests (e.g. Mead, 2008), and assessments of the impact of trapping for the bird trade (Jepson & Ladle 2009; Harris *et al.* 2015). Density estimates are also the basis for monitoring populations, and assessing the success or failure of conservation management (Gale & Thongaree 2006). Unfortunately, there are few published quantitative studies of bird species density in Indonesia (e.g. Marsden *et al.* 1997; Marsden 1999). In Sumatra there have been three such studies, one of which concerns hornbills (Anggraini *et al.* 2000), and the other two, the Argus Pheasant *Argusianus argus* (O'Brien *et al.* 2003; Winarni *et al.* 2009).

The aims of this paper were to: (1) provide baseline bird densities in degraded forest; and (2) compare the derived bird densities to those from other studies conducted in Southeast Asia to assess general patterns across different forest conditions. We also examined potential differences of bird density between different types of forest degradation within the study area, but these results are presented elsewhere (Marthy *et al.*, in press).

Study area

The Harapan Rainforest Ecosystem Restoration Concession (HRF) is the first ecosystem restoration concession in Indonesia, covering 984.5 km^2, straddling the provinces of Jambi (491.8 km^2) and South Sumatra (492.7 km^2), Sumatra (Fig. 1; Harrison & Swinfield 2015). It comprises a large area of lowland (30-120 m above sea level) dipterocarp forest that was extensively logged between 1970 and 2007, both legally under the former concessionaires, and illegally. Commercial logging ceased in 2006, and left a mosaic of degraded forest habitats in different stages of regeneration (Harrison & Swinfield 2015). The HRF is The concession's overall aim is to conserve and restore the forest to its former primary condition for biodiversity ecosystem services. The current study was conducted in the Jambi Province section.

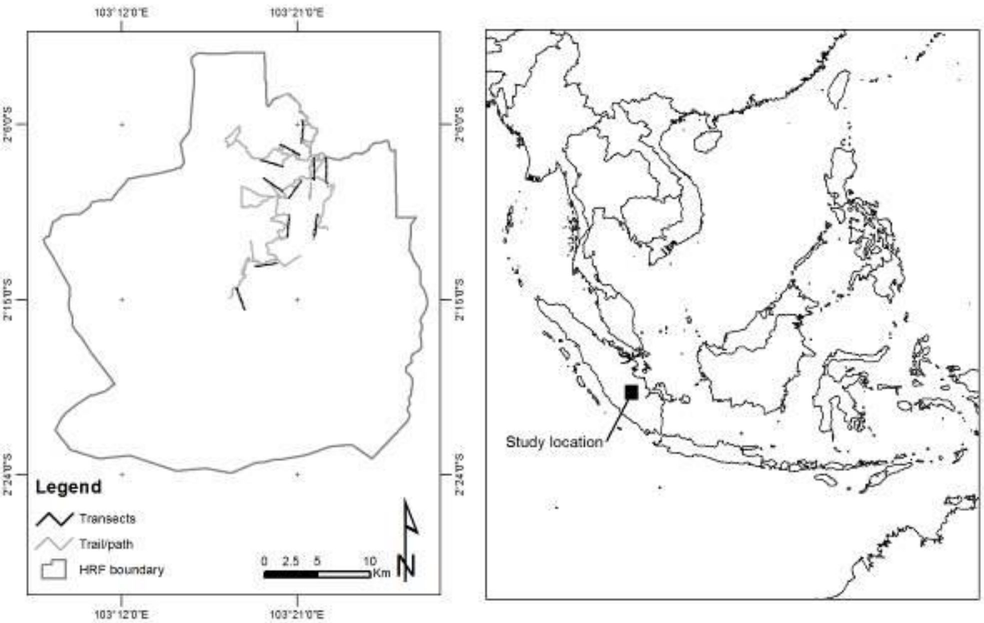

Figure 1. Map of the study area in the Harapan Rainforest Ecosystem Restoration Concession in Sumatra Island-Indonesia.

The study site is a former logging concession which started harvesting operations in 1970, using the Tebang Pilih Tanam Indonesia (TPTI) selective logging system (Armitage & Kuswanda 1989; Sist *et al.* 1998). Commercial trees with a diameter of >50m were allowed to be removed within a felling cycle of 35 years. Logging activities left a mosaic of degraded forest habitats in different stages of regeneration (Harrison & Swinfield 2015), which is typical for ex-logged forest (Putz *et al.* 2001). However, information on logging intensity was not available, lost in a fire at the logging company headquarters (Harrison & Swienfield 2015). Nevertheless, based on logging schedule maps, it was concluded that forest which was highly degraded had been logged twice (two rotations) with the first rotation in 1972, and the second rotation in 2007. The less degraded forests had only been logged once in 1992. Approximately 20% of the concession area was illegally converted to small-scale oil palm plantations, mainly when there was no active management (2004-2009). Most (70%) of the concession area is now covered by early successional plants, such as *Macaranga* spp. (Euphorbiaceae), and an invasive pioneer species from South America, *Bellucia pentamera* (Melastomataceae), which is especially abundant.

Methods

We conducted bird point-transect surveys between April and June 2011, during the breeding season of most forest species in Sumatra (van Marle & Voous 1988). The point transect method is a preferred method for conducting multi-species surveys in tropical forests (Bibby *et al.* 1992; Lee & Marsden 2008). We used 11 transects that were each 2 km long with 11 observation points that were spaced at 200 m intervals (Reynolds *et al.* 1980; Hutto *et al.* 1986). Transects were placed to cover different stages of degraded forest in the study area. Five transects were located in moderately degraded forest, with a well-stratified structure from seedlings to trees, relatively high canopy cover (71-100%) and an average tree diameter of >20cm, while six were in highly degraded forest, dominated by shrub layer plants, with a relatively low canopy cover (<40%) and an estimated average tree diameter of <20 cm. Surveys were conducted in the morning (06:30 to 10:00 hrs, 10 min per survey point) to coincide with the peak period of bird activity (Lee & Marsden 2008), and were conducted by a single observer (the first author, who was experienced in bird surveys in Sumatra) and one scribe for the whole survey, thereby reducing observer bias. Surveys were conducted immediately after the observer arrived at each point (i.e. without settling down period) and any birds detected moving away from around the survey point on the observer's arrival was counted as being present during the count period (Lee & Marsden 2008).

We recorded all birds detected as well as the estimated vertical height and horizontal distance from the survey point to the bird's initial position, or to the centre of a single-species group (estimated using digital Rangefinder). Flying birds, raptors and nocturnal species that were observed during the point count were recorded, but omitted from the data analysis as their inclusion violates assumptions of the method (Marsden 1998; Buckland *et al.* 2001). We made sound recordings for all birds recorded within each point to aid species identification. Each transect was surveyed three times to increase the likelihood of encountering rare species (Buckland *et al.* 2001; Rosenstock *et al.* 2002). The survey was conducted, if there was no rain or strong winds, on three consecutive days, but if not, the survey was conducted on the next possible day. Birds are more active in the morning thus can be easily detected (Lee & Marsden, 2008), thus repeating point transects in the opposite direction on different days helps minimize the influence of variation in bird activity, and hence detection potential (Jones 1998). So, whenever possible we rotated the daily order in which transects was visited.

Distance v.6.0 (Thomas *et al.* 2010) software was used to calculate bird densities. A transect was taken as the sampling unit. All bird records from the three surveys per transect were pooled, hence the total survey effort for each transect was 33 points (11 points x one survey and then repeated two more times). Densities were calculated only for species that were recorded ≥10 times, with the exception of threatened or Near-threatened species that were recorded <10 times. We did not calculate density for large raptors. As in similar studies (e.g. Marsden 1999; Gale & Thongaree 2006; Gale *et al.* 2009), aural and visual observations were combined to achieve sufficient sample sizes (Anderson *et al.* 2015). In the analysis, we right-truncated the data, trying several different truncation distances, testing with several different key functions (uniform, half normal, and hazard rate functions with adjustment), and selected the model with the lowest Akaike's Information Criterion (AIC; Akaike 1974) as the best model that fit the data (Buckland *et al.* 2001). We also looked at Chi-square test for grouped distance data or Kolmogorov-Smirnov goodness-of-fit and Cramér-von Mises goodness-of-fit statistics for distance data that were not grouped to assess the model fit (Buckland *et al.* 2001). For a limited number of species we also conducted analyses to assess the difference in bird densities between different forest degradation types, and these results are presented elsewhere (Marthy *et al.*, in press).

To infer densities of rare species (i.e. species recorded < 10 times) we applied the multiple-species modeling framework as proposed by Alldredge *et al.* (2007). This framework was applied by "borrowing" data on detection characteristics from commoner surrogate species that belong to the same genus or family and are similar in size and calls (Table 1). For example, the Vulnerable Sunda Blue Flycatcher *Cyornis caerulatus* was observed only twice, and only two individuals were captured during an intensive mist-netting study (n=454 total bird captures) in HRF (Hua *et al.* 2011). To calculate density for this species using the multiple-species modeling framework, we combined the two records of the Sunda Blue Flycatcher with those for the Pale Blue Flycatcher *C. unicolor* to achieve a sufficient sample size. These species belong to the same genus, have similar body size (<20 g), and high-pitched calls. However, there are two exceptions in our surrogate species selection. For the Short-toed Coucal *Centropus rectunguis* (c.160 g; Cuculidae), we chose the Common Emerald Dove *Chalcophaps indica* (90-170 g; Columbidae) as both species are medium-sized, mostly active near the ground and have a deep voice. For the Garnett Pitta *Erythropitta granatina* (53-70g; Pittidae) we chose the Rail Babbler *Eupetes macrocerus* (66-72 g; Eupetidae), as both species forage for invertebrates on the ground, and their calls have a similar rhythm.

In this multiple-species analysis, species identity was entered as an observation-level variable which calculated density for each species within a group through post-stratification by species (Marques *et al.* 2001; Rosenstock *et al.* 2002). The model selection process was as explained above for single species, with the addition of the aforementioned procedure: i.e. trying several different truncation distances and testing with several different key functions to find the best model fit.

Table 1. Surrogate species for infrequently recorded (<10 times) Vulnerable (V) and Near-threatened (NT) bird species, for which multiple-species approach was used to estimate density.

Rare species (n)	Surrogate species	Shared characteristics
Olive-backed Woodpecker (NT)	Buff-rumped Woodpecker	Medium-large (70-150 g) woodpeckers
Rufous-collared Kingfisher (NT)	Banded Kingfisher	Understory kingfisher, 40-70g
Short-toed Coucal (V)	Common Emerald Dove	Ground-dwelling non-passerines, >100g
Black-bellied Malkoha (NT)	Raffles's Malkoha	Arboreal malkoha, <70g
Large Wren-babbler (NT)	Black-capped Babbler	Terrestrial babblers of forest interior.
Striped Wren-babbler (NT)	Black-capped Babbler	Terrestrial babblers of forest interior.
White-necked Babbler (NT)	Grey-headed Babbler	Arboreal foliage-gleaning babblers, <25g .
Sunda Blue Flycatcher (V)	Pale Blue Flycatcher	Understory blue flycatchers, <22g
Malaysian Blue Flycatcher (NT)	Pale Blue Flycatcher	Understory blue flycatchers, <22g
Garnet Pitta (NT)	Rail Babbler	Terrestrial insectivore, forest interior, c. 50g
Scarlet-breasted Flowerpecker (NT)	Orange-bellied Flowerpecker	Same family
Puff-backed Bulbul (NT)	Cream-vented Bulbul	Same genus, 25-36 g.

In order to compare the densities from our study with those from elsewhere, we searched the literature for studies conducted in the Greater Sundas (Sumatra, Java, Borneo, Peninsular Malaysia, and Palawan in the Philippines) that provided bird density data for species that were recorded in the present study. Comparisons of densities were only conducted if the studies included coefficients of variation. There were only two comparable studies in Southeast Asia, one for understory birds in Bornean logged forest (Mead 2008) and another for hornbills in lowland evergreen forest in Thailand (Gale & Thongaree 2006). Comparisons were made for 20 species, using Z-tests (Plumptre 2000), and to avoid the possibility of obtaining false-positive results (Type I errors), we applied a Bonferroni correction for multiple comparisons (α /a total number of comparisons, where α =0.05).to decide if P value were significant P. In addition, we collated available data on densities from many other studies in Southeast Asia to gain an overview of density variation across different habitats and islands. Scientific names in this study follow IOC World Bird List Version 6.1 (Gill & Donsker 2016).

Results

A total of 4,353 individuals belonging to 148 bird species were recorded during the point-transect surveys. These included the Critically Endangered Helmeted Hornbill, two Vulnerable species (Sunda Blue Flycatcher and Short-toed Coucal) and 41 Near-threatened species. Overall, we were able to produce reasonably precise density estimates, as demonstrated by the coefficient of variation being < 50% for 103 bird species (Appendices 1, 2). Of 16 species that were shared between the study in logged Bornean forest and the current study, only five showed significant differences in density after applying Bonferroni corrections for multiple comparisons (Table 2). Bird species that had higher densities in our study area than in Borneo were the Buff-rumped Woodpecker *Meiglyptes grammithorax* and Scarlet-rumped Trogon *Harpactes duvaucelii*. Birds with lower densities in our study area were the Garnet Pitta *Erythropitta granatina*, Brown Fulvetta *Alcippe brunneicauda* and Little Spiderhunter *Arachnothera longirostra*. Of the four species of hornbills shared between our study area and Thailand, only the Helmeted Hornbill *Rhinoplax vigil* showed a significantly lower density in our study area, after applying the Bonferroni correction for multiple comparisons (Table 2).

Table 2. Densities (birds km^{-2}) and Coefficients of variation (%, in brackets) of birds found in Harapan Rainforest compared with densities of hornbills from lowland evergreen forest in Thailand (Gale & Thongaree 2006) and other species from logged forest in Borneo (Mead 2008). Asterisks indicate significant differences at $p<0.05$ while bold underlined Z test values indicate significance after applying Bonferroni corrections (i.e. Z value > 3.0 or < -3.0). Negative signs of P (Z test) indicate higher density in the study area while positive signs indicate higher density in other studies.

Species	Other study	Present study	P (Z test)
Scarlet-rumped Trogon	1.1(53.0)	4.5(3.8)	**<u>-5.6</u>***
Rhinoceros Hornbill	2.7(14.0)	1.2(28.0)	2.9*
Helmeted Hornbill	1.2(19.0)	0.4(24.6)	**<u>3.2</u>***
Bushy-crested Hornbill	0.67(36.0)	4.6(48.7)	-1.8
Wrinkled Hornbill	0.08(26.0)	0.7(37.3)	-2.4*
Maroon Woodpecker	3.0(56.5)	5.2(34.6)	-0.9
Buff-rumped Woodpecker	2.2(47.8)	11.6(16.2)	**<u>-4.4</u>***
Buff-necked Woodpecker	6.8(54.8)	8.0(18.0)	-0.3
Asian Green Broadbill	3.0(37.1)	4.0(26.8)	-0.6
Banded Broadbill	3.4(45.8)	3.0(10.4)	0.2
Garnet Pitta	11.2(17.6)	1.9(23.8)	**<u>4.6</u>***
Rufous winged Flycatcher	12.2(41.1)	17.3(18.3)	-0.9
Greater Racket-tailed Drongo	10.6(27.5)	21.5(14.9)	-2.5*
Grey-cheeked Bulbul	14.5(23.0)	9.7(6.4)	1.4
Yellow-bellied Bulbul	28.6(22.0)	25.6(13.5)	0.4
Hairy-backed Bulbul	238.5(22.5)	73.8(9.8)	3.0*
Brown Fulvetta	57.8(15.9)	9.4(5.9)	**<u>5.3</u>***
Grey-chested Jungle-flycatcher	6.1(26.3)	6.7(5.5)	-0.4
Purple-naped Sunbird	49.8(47.9)	25.2(12.1)	1.0
Little Spiderhunter	413.7(18.1)	164.7(8.9)	**<u>3.3</u>***

Discussion

We present densities for 103 lowland bird species in Sumatra, which covers approximately 45% of the 228 lowland bird specialists (Wells 1985) in Sumatra, thereby improving our understanding of the abundance of Sundaic birds, but especially for Sumatra where densities were previously only available for a few species (Anggraini *et al*. 2000; O'Brien *et al*. 2003; Winarni *et al*. 2009). Our results include densities for three threatened species (Sunda Blue Flycatcher, Helmeted Hornbill and Short-toed Coucal), and 41 Near-threatened species. Density information is still limited for many of these species, which is one reason why their global population sizes have not been quantified to date (BirdLife International 2015c). In addition, the densities presented here resulted from collecting data using sampling methods that utilise detection probabilities. This approach will assure that our results can be compared statistically with densities from future studies.

The multi-species modeling framework can be used to produce densities for rare species by "borrowing" information from more abundant congeners selected on the basis of similarity in phylogeny, body size, and calls (Alldredge *et al.* 2007). For rare species that are recorded on too few occasions, density can be estimated by combining data from two or more surrogate species to create detection templates. For example Marsden *et al.* (1997) combined records of Tawny-backed Fantail *Rhipidura superflua* with those of the similar but commoner Northern Fantail *R. rufiventris* to model the detection function and calculate the density of the former. Similarly, scant records of the Dark-grey Flycatcher *Myiagra galeata* were combined with those of two commoner *Monarcha* species to create a "monarch detection function" (Marsden *et al.* 1997). We used this approach to calculate densities for twelve species of global conservation concern, as the global population size for ten of these species has not yet been estimated. However, it should be noted that selecting inappropriate surrogate species could produce bias in model estimates of such rare species (Alldredge *et al.* 2007).

Estimates of the global population sizes of two species of global conservation concern detected in our study area were available, and thus the proportion of this global population within our study area could be defined. The global population size for the Short-toed Coucal is estimated as 15,000 to 30,000 individuals, and for the Sunda Blue Flycatcher, 6,000 to 15,000 individuals (BirdLife International 2012de). Extrapolating our results to cover the part of HRF where the study was conducted (i.e. 492 km^2 concession area in Jambi) suggests that this area had approximately 1–2% and 2.5% of the global population of the Short-toed Coucal and Sunda Blue Flycatcher, respectively. Nevertheless, BirdLife global population sizes are rough estimates, requiring additional data estimates of population densities from other regions, and greater information on their ecology.

There are only a few bird studies from Southeast Asia that determined detection probabilities from which to calculate density (Jones *et al.* 1995; Marsden *et al.* 1997; Gale & Thongaree 2006; Mallari *et al.* 2011), and only three for Sumatran birds (Anggraini *et al.* 2000; O'Brien *et al.* 2003; Winarni *et al.* 2009). Comparisons of densities between different areas (e.g. islands) should consider habitat characteristics, which affect species detection probabilities, but the comparison made here is intended to show potential differences. Nevertheless, based on available data from two studies, the densities of several species in HRF were significantly higher than in logged forest. For example, Scarlet-rumped Trogon was apparently four times more abundant in our study than in logged forest in Borneo (Table 2). This species is found in lowland primary forests, and intolerant of disturbance to canopy cover (BirdLife International, 2015c). This difference in density might possibly due to different disturbance regimes between Borneo and our study area. Putz *et al.* (2001) conclude that variable logging intensities in the tropics are creating great challenges for evaluating the effect of logging. Comparing densities of hornbills between HRF and Thailand (Gale & Thonggaree 2006) indicated that two species had higher densities in Thailand, whereas one, the Wrinkled Hornbill, apparently had a higher density in HRF, albeit not significantly so after the Bonferroni correction was applied. Gale & Thonggaree (2006) found that hornbill densities are generally lower in Thailand compared to other parts of Southeast Asia, possibly due to the scarcity and isolation of lowland forests, and spatial and temporal variation in fruit availability.

The densities of hornbills in the present study tended to be lower than those from primary forest in Bukit Barisan Selatan National Park (BBSNP), south-western Sumatra, particularly for Helmeted Hornbill (4 times lower), but not for Bushy-crested Hornbill *Anorrhinus galeritus* (Anggraini *et al.* 2000; Table 3). For Helmeted Hornbill this is not surprising, as this species is forest-dependent (BirdLife International 2015b), indicating that degraded forest is likely less suitable for this species. However, considering the unsustainably high levels of bird trade in this species, whose status has recently been upgraded to Critically Endangered, the Harapan population assumes some importance. The Bushy-crested Hornbill prefers closed canopy forest and has been shown to strongly avoid disturbed areas (Anggraini *et al.* 2000). Despite this, our density estimates for this species were slightly higher than those from BBSNP and North Sumatra, and much higher than that from Thailand (Tables 2, 3). This may reflect differences in hunting intensity and sampling time between study sites, but it is also possible that the mosaic of degraded forest patches available at the study site provides more food (e.g. Wich *et al.* 2011) and nest trees for this species.

Woodpeckers in the Sundaic region have been well studied in Peninsular Malaysia (Short 1978; Styring & Ickes 2001a, b; Styring & Hussin 2004a, b) and Kalimantan (Lammertink 2004). In our study, densities of woodpeckers were apparently higher than those from logged forest in Kalimantan and Peninsular Malaysia, with few exceptions (Table 3). Based on perch diameters and microhabitats used, Styring & Hussin (2004b) divide the woodpeckers into two large groups: conventional foragers, which excavate frequently, using relatively larger perches and foraging on snags (dead limbs and trees), contrasting with novel foragers, which use smaller perches and microhabitats that are always available year round in the tropical forest such as arboreal ant and termite nests. The mosaic of degraded forest patches in our study area might provide resources that are suitable for both groups of woodpeckers.

Styring & Ickes (2001a) suggest that the low abundance of Buff-rumped Woodpeckers in logged forest in Peninsular Malaysia is due to the logging scheme in Malaysia, whereby large non-commercial trees, lianas and snags are removed to provide more light and space for the growth of commercial trees. This has resulted in even-aged stands with fewer snags, treefall gaps, and smaller lianas, which are important for timber management. Lammertink (2004) showed that the 85% density reduction of Checker-throated Woodpecker *Picus mentalis* in Kalimantan logged forest was better predicted by the quantity of timber removed than area remaining as unlogged patches. This may indicate that the habitat condition in HRF is slightly better for this species than in logged forest in Kalimantan (2.0 birds km^{-2} vs 1.2 birds km^{-2}). The density of Argus Pheasants (2.5 birds km^{-2}) in HRF was similar to that in BBSNP (0.9-3.7 birds km^{-2}; Winarni *et al.* 2009). This species prefers undisturbed forest (Winarni *et al.* 2009) and is sensitive to hunting, but seems to be relatively tolerant of some types of logging (Sözer *et al.* 1999). Compared with logged forest in Borneo (Mead 2008; Table 2), three species in our study had lower densities (e.g. Garnet Pitta), and two had higher densities (e.g. Buff-rumped Woodpecker). These again highlight variations in density that are possibly due to different disturbance regimes (e.g. Putz *et al.* 2001), food resources (e.g. Styring & Hussin 2004b), nest sites or predator densities (Côté & Sutherland 1997).

Table 3. Densities (birds km^{-2}) for birds found in Harapan Rainforest compared with studies elsewhere in Greater Sundas, including Peninsular Malaysia. A: logged lowland forest, Pasoh, Peninsular Malaysia (Short 1978); B: logged lowland forest, Gunung Palung, West Kalimantan (Lammertink 2004); C: logged forest outside Danum Valley, Sabah (Mead 2008); D: primary forest, Danum Valley, Sabah (Mead 2008); E: primary lowland dipterocarp forest, Central Kalimantan (McConkey & Chivers 2004); F: primary lowland forest, Bukit Barisan Selatan NP, Sumatra (Anggraini *et al.* 2000).

Species	Present study	A	B	C	D	E	F
Scarlet-rumped Trogon	4.5			1.0	4.0		
Rhinoceros Hornbill	1.2					3.7	2.6
Helmeted Hornbill	0.4					0.7	1.9
Black Hornbill	2.9					3.4	
Bushy-crested Hornbill	4.6					5.5	3.1
Wrinkled Hornbill	0.7					0.3	
Rufous Piculet	12.4	3.9	4.9				
White-bellied Woodpecker	2.5	1.5	0.5				
Chequer-throated Woodpecker	2.0	2.3	1.2				
Crimson-winged Woodpecker	3.6	2.3	1.2				
Maroon Woodpecker	5.2	3.9	1.7	3.0	22.0		
Orange-backed Woodpecker	5.8	1.5	4.3				
Buff-rumped Woodpecker	11.6	1.5	0.9	2.0	9.0		
Buff-necked Woodpecker	8.0	5.4	5.3	7.0	27.0		
Banded Broadbill	3.0			3.0	11.0		
Garnet Pitta	1.9			11.0	10.0		
Rufous-winged flycatcher	17.3			12.0	73.0		
Greater racket-tailed Drongo	21.5			11.0	14.0		
Black-naped Monarch	25.6						
Grey-cheeked Bulbul	9.7			15.0	23.0		
Hairy-backed Bulbul	73.8			239.0	212.0		
Grey-headed Babbler	5.4			49.0	21.0		
Chestnut-winged Babbler	31.5			50.0	164.0		
Fluffy-backed Tit-babbler	9.8			41.0	63.0		
Brown Fulvetta	9.4			58.0	224.0		
Short-tailed Babbler	20.4			73.0	115.0		
Black-capped Babbler	13.5			8.0	72.0		
Grey-chested Jungle Flycatcher	6.7			6.0	22.0		
Purple naped Sunbird	25.2			90.0	22.0		
Little Spiderhunter	164.7			414.0	255.0		

Our study provides densities of almost a half of the lowland forest specialist bird species in Sumatra, and as it incorporates detection probabilities, allows comparisons over time and between sites. Yet, as comparable data are still very limited, our density comparisons between HRF and other sites should be taken only as a preliminary indication of the possible impacts of logging and/or habitat degradation. Nevertheless, the comparison shows that 30 species are able to persist, or even thrive, in degraded forest, highlighting its biodiversity conservation value (see also Edwards *et al.* 2011). In Indonesia, which is still losing vast swathes of lower elevation forest every year, our study presents a strong argument for protecting degraded forest, rather than clearing it and converting to oil palm or other plantations particularly for our study site, which is one of the few remaining examples of lowland dipterocarp forest in Sumatra.

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Appendix 1. Bird species (n=103) recorded 10 or more times (or if not, species threatened) and threatened or near threatened species recorded less than 10 times in degraded forest of Harapan Rainforest Ecosystem Restoration Concession during April-June 2011, arranged in order of decreasing density. All species are Near-threatened except for Short-toed Coucal and Sunda Blue Flycatcher which are Vulnerable, and Helmeted Hornbill which is Critically Endangered. CI indicates the 95% confidence interval around the density, % CV is the coefficient of variation of the density, D is the density estimate (birds km^{-2}), and n is the number of observation.

Common name	Scientific name	IUCN	n	D	%CV	95% CI	
Little Spiderhunter	*Arachnothera longirostra*		236	164.7	8.9	137.4	197.5
Spectacled Bulbul	*Pycnonotus erythropthalmos*		227	97.5	10.0	80.0	119.0
Orange-bellied Flowerpecker	*Dicaeum minullum*		81	96.1	12.6	74.9	123.4
Hairy-backed Bulbul	*Tricholestes criniger*		113	73.8	9.8	60.9	89.5
Cream-vented Bulbul	*Pycnonotus simplex*		87	64.7	17.0	46.3	90.5
Green Iora	*Aegithina viridissima*	NT	126	44.0	10.4	35.9	53.9
Buff-vented Bulbul	*Iole olivacea*	NT	83	44.0	13.6	33.7	57.6
Plain Flowerpecker	*Dicaeum concolor*		44	43.2	14.0	32.6	57.2
Ferruginous Babbler	*Trichastoma bicolor*		142	35.8	10.3	29.3	43.8
Sooty-capped Babbler	*Malacopteron affine*		87	34.5	13.6	26.4	45.0
Chestnut-winged Babbler	*Stachyris erythroptera*		89	31.5	13.0	24.4	40.7
Dark-necked Tailorbird	*Orthotomus atrogularis*		84	30.9	10.5	25.1	38.0
Chestnut-rumped Babbler	*Stachyris maculata*	NT	104	30.6	19.6	20.8	45.0
Black-headed Bulbul	*Pycnonotus atriceps*		82	26.5	9.4	22.0	32.0
Yellow-bellied Bulbul	*Alophoixus phaeocephalus*		70	25.6	13.5	19.6	33.4
Black-naped Monarch	*Hypothymis azurea*		80	25.6	4.4	23.5	27.9
Malay Sooty Barbet	*Caloramphus hayii*	NT	43	25.4	20.6	16.8	38.5
Purple-naped Sunbird	*Hypogma hypogmicum*		43	25.2	12.1	19.7	32.1
Greater Racket-tailed Drongo	*Dicrurus paradiseus*		122	21.5	14.9	16.0	28.8
Olive-winged Bulbul	*Pycnonotus plumosus*		47	21.3	4.5	19.4	23.3
Asian Fairy-bluebird	*Irena puella*		43	20.6	10.5	16.7	25.4
Short-tailed Babbler	*Malacocincla malaccensis*	NT	69	20.4	13.5	15.6	26.6
Scaly-crowned Babbler	*Malacopteron cinereum*		59	20.3	15.2	15.0	27.5

Common name	Scientific name	IUCN	n	D	%CV	95% CI	
Moustached Babbler	*Malacopteron magnirostre*		48	19.9	18.0	13.9	28.5
Raffles's Malkoha	*Rhinortha chlorophaeus*		39	18.3	12.1	14.4	23.4
Black-and-yellow Broadbill	*Eurylaimus ochromalus*	NT	85	17.6	13.9	13.4	23.2
Rufous-winged Philentoma	*Philentoma phyrrhoptera*		24	17.3	18.3	11.9	25.1
Blue-winged Leafbird	*Chloropsis cochinchinensis*		54	16.8	8.1	14.3	19.7
Blue-eared Barbet	*Psilopogon duvaucelii*		178	16.3	10.4	13.3	20.0
Crimson Sunbird	*Aethopyga siparaja*		14	14.6	35.6	6.9	30.7
Black-capped Babbler	*Pellorneum capistratum*		40	13.5	19.3	9.2	19.8
Rufous-tailed Shama	*Trichixos pyrrhopygus*	NT	82	13.5	10.6	11.0	16.7
Ruby-cheeked Sunbird	*Anthreptes singalensis*		18	13.4	14.4	9.9	18.1
Pin-striped Tit-babbler	*Macronous gularis*		84	12.6	12.8	9.8	16.3
Rufous Piculet	*Sasia abnormis*		19	12.4	17.1	8.7	17.6
Rufous-fronted Babbler	*Stachyridopsis rufifrons*		30	11.8	6.3	10.4	13.4
Buff-rumped Woodpecker	*Meiglyptes grammithorax*		33	11.6	16.2	8.4	16.1
Chestnut-backed Scimitar Babbler	*Pomatorhinus montanus*		76	11.0	7.2	9.5	12.6
Rufous-crowned Babbler	*Malacopteron magnum*	NT	38	10.1	9.3	8.3	12.2
Fluffy-backed Tit-babbler	*Macronous ptilosus*	NT	40	9.8	8.6	8.2	11.7
Grey-cheeked Bulbul	*Alophoixus bres*		36	9.7	6.4	8.6	11.1
White-crowned Forktail	*Enicurus leschenaulti*		32	9.5	9.8	7.8	11.6
Brown Fulvetta	*Alcippe brunneicauda*	NT	54	9.4	5.9	8.3	10.6
Asian Red-eyed Bulbul	*Pycnonotus brunneus*		27	8.9	14.6	6.6	12.0
Buff-necked Woodpecker	*Meiglyptes tukki*	NT	18	8.0	18.6	5.5	11.7
Rufous-tailed Tailorbird	*Orthotomus sericeus*		31	7.8	20.8	5.1	11.8
Black-winged Flycatcher-shrike	*Hemipus hirundinaceus*		23	7.1	19.3	4.8	10.5
Grey-chested Jungle Flycatcher	*Cyornis umbratilis*	NT	36	6.7	5.5	6.0	7.5
Streaked Bulbul	*Ixos malaccensis*	NT	12	6.6	40.1	2.8	15.5
Thick-billed Green Pigeon	*Treron curvirostra*		46	6.4	4.9	5.8	7.0
Pale Blue Flycatcher	*Cyornis unicolor*		10	6.0	56.9	1.8	20.4

Common name	Scientific name	IUCN	n	D	%CV	95% CI	
Scarlet Minivet	*Pericrocotus speciosus*		21	5.9	16.7	4.1	8.6
Orange-backed Woodpecker	*Reinwardtipicus validus*		11	5.8	11.1	4.5	7.4
Lesser Green Leafbird	*Chloropsis cyanopogon*	NT	15	5.5	33.0	2.8	11.0
White-chested Babbler	*Trichastoma rostratum*	NT	16	5.5	22.0	3.5	8.7
Grey-headed Babbler	*Stachyris poliocephala*		13	5.4	28.0	3.0	9.9
Maroon Woodpecker	*Blythipicus rubiginosus*		14	5.2	34.6	2.6	10.7
Black-hooded Oriole	*Oriolus xanthonotus*	NT	58	4.9	4.1	4.5	5.3
Plain Sunbird	*Anthreptes simplex*		12	4.8	44.7	1.8	12.3
Greater Green Leafbird	*Chloropsis sonnerati*		17	4.7	24.5	2.8	7.9
Common Hill Myna	*Gracula religiosa*		41	4.7	7.0	4.1	5.4
Bushy-crested Hornbill	*Anorrhinus galeritus*		13	4.6	48.7	1.7	12.2
Rail-babbler	*Eupetes macrocerus*		21	4.6	17.1	3.2	6.5
Red-naped Trogon	*Harpactes kasumba*	NT	21	4.6	14.8	3.4	6.3
Puff-backed Bulbul	*Pycnonotus eutilotus*	NT	6	4.6	16.5	3.1	6.9
Scarlet-rumped Trogon	*Harpactes duvaucelii*	NT	52	4.5	3.8	4.1	4.8
Blue-rumped Parrot	*Psittinus cyanurus*	NT	15	4.2	71.4	1.1	16.8
Asian Green Broadbill	*Calyptomena viridis*	NT	24	4.0	26.8	2.3	6.8
Yellow-crowned Barbet	*Psilopogon henricii*	NT	60	4.0	11.2	3.2	5.0
Crimson-winged Woodpecker	*Picus puniceus*		25	3.6	15.4	2.6	4.9
Brown-throated Sunbird	*Anthreptes malacensis*		14	3.2	41.6	1.3	7.6
Banded Broadbill	*Eurylaimus javanicus*		18	3.0	10.4	2.4	3.8
Black Hornbill	*Anthracoceros malayanus*	NT	28	2.9	16.7	2.1	4.1
Great Argus	*Argusianus argus*	NT	60	2.9	17.9	2.1	4.2
Common Emerald Dove	*Chalcophaps indica*		37	2.9	22.3	1.8	4.5
Banded Kingfisher	*Lacedo pulchella*		21	2.8	1.2	2.7	2.9
Golden-whiskered Barbet	*Psilopogon chrysopogon*		69	2.7	10.2	2.2	3.3
Black-throated Babbler	*Stachyris nigricollis*	NT	16	2.6	25.5	1.5	4.4
White-bellied Woodpecker	*Dryocopus javensis*		17	2.5	14.8	1.8	3.3

Common name	Scientific name	IUCN	n	D	%CV	95% CI	
Red-bearded Bee-eater	*Nyctyornis amictus*		22	2.5	33.5	1.3	5.0
Long-billed Spiderhunter	*Arachnothera robusta*		10	2.4	1.3	2.4	2.5
Crested Jay	*Platylophus galericulatus*	NT	15	2.3	43.8	0.9	5.6
Scarlet-breasted Flowerpecker	*Prionochilus thoracicus*	NT	2	2.2	5.3	2.0	2.5
Chequer-throated Woodpecker	*Chrysophlegma mentale*	NT	13	2.0	0.7	2.0	2.1
Black Magpie	*Platysmurus leucopterus*	NT	12	2.0	30.5	1.0	3.7
Garnet Pitta	*Erythropitta granatina*	NT	6	1.9	23.8	1.2	3.1
Red-crowned Barbet	*Psilopogon rafflesii*	NT	48	1.9	6.4	1.7	2.2
Diard's Trogon	*Harpactes diardii*	NT	18	1.8	8.2	1.5	2.1
Black-bellied Malkoha	*Phaenicophaeus diardi*	NT	4	1.8	8.2	1.5	2.1
Striped Wren-babbler	*Kenopia striata*	NT	6	1.4	16.4	1.0	1.9
Plaintive Cuckoo	*Cacomantis merulinus*		15	1.4	1.2	1.3	1.4
Slender-billed Crow	*Corvus enca*		16	1.4	36.5	0.7	3.0
Rhinoceros Hornbill	*Buceros rhinoceros*	NT	27	1.2	28.0	0.7	2.1
Malaysian Blue Flycatcher	*Cyornis turcosus*	NT	2	1.1	21.9	0.6	1.7
Indian Cuckoo	*Cuculus micropterus*		18	1.0	15.1	0.7	1.3
Rufous-collared Kingfisher	*Actenoides concretus*	NT	7	0.9	0.5	0.9	1.0
Sunda Blue Flycatcher	*Cyornis caerulatus*	VU	2	0.8	28.7	0.5	1.6
Wrinkled Hornbill	*Rhabdotorrhinus corrugatus*	NT	10	0.7	37.3	0.3	1.6
White-necked Babbler	*Stachyris leucotis*	NT	2	0.7	29.2	0.4	1.3
Large Wren-babbler	*Napothera macrodactyla*	NT	3	0.6	17.1	0.5	1.0
Short-toed Coucal	*Centropus rectunguis*	VU	8	0.6	26.7	0.4	1.1
Olive-backed Woodpecker	*Dinopium rafflesii*	NT	2	0.5	16.7	0.4	0.7
Helmeted Hornbill	*Rhinoplax vigil*	CR	14	0.4	24.6	0.2	0.7

Appendix 2. Bird species (n=45) that were recorded < 10 times in degraded forest of Harapan Rainforest during April-June 2011, except for threatened species included in Appendix A. List in order of decreasing frequency; n, total observations; A, observed outside the survey period; B, flying or nocturnal birds or raptors

Common name	Scientific name	n
Lesser Cuckooshrike	*Coracina fimbriata*	9
Square-tailed Drongo-Cuckoo	*Surniculus lugubris*	9
Grey-breasted Spiderhunter	*Arachnothera modesta*	8
Oriental Dwarf Kingfisher	*Ceyx erithaca*	8
Blue-eared Kingfisher	*Alcedo meninting*	7
Banded Bay Cuckoo	*Cacomanthis sonneratii*	7
Hodgson's Hawk-cuckoo	*Hierococcyx nisicolor*	7
Wreathed Hornbill	*Rhyticeros undulatus*	7
Grey-and-buff Woodpecker	*Hemicircus concretus*	6
Yellow-breasted Flowerpecker	*Prionochilus maculatus*	6
Spotted Fantail	*Rhipidura perlata*	6
Olive-backed Sunbird	*Cinnyris jugularis*	5
Oriental Magpie Robin	*Copsychus saularis*	5
Green-billed Malkoha	*Phaenicophaeus tristis*	5
White-rumped Shama	*Copsychus malabaricus*	4
Malayan Banded Pitta	*Hydrornis irena*	4
Ashy Tailorbird	*Orthotomus ruficeps*	4
Dusky Broadbill	*Corydon sumatranus*	3
Scarlet-backed Flowerpecker	*Dicaeum cruentatum*	3
Green Imperial Pigeon	*Ducula aenea*	3
Rufous Woodpecker	*Micropterus brachyurus*	3
Chestnut-breasted Malkoha	*Phaenicophaeus curvirostris*	3
Hooded Pitta	*Pitta sordida*	3
Velvet-fronted Nuthatch	*Sitta frontalis*	3
Spectacled Spiderhunter	*Arachnothera flavigaster*	2
Rusty-breasted Cuckoo	*Cacomantis sepulcralis*	2
Greater Coucal	*Centropus sinensis*	2
Grey-headed Canary-flycatcher	*Culicicapa ceylonensis*	2
Oriental Dollarbird	*Eurystomus orientalis*	2
Yellow-bellied Warbler	*Abroscopus superciliaris*	1
Violet Cuckoo	*Chrysococcyx xanthorhynchus*	1
Himalayan Cuckoo	*Cuculus saturatus*	1
Yellow-vented Flowerpecker	*Dicaeum chryssorheum*	1
Mountain Imperial Pigeon	*Ducula badia*	1
Abbott's Babbler	*Malacocincla abboti*	1
Black-thighed Falconet	*Microhierax fringillarius*	1
Crimson-breasted Flowerpecker	*Prionochilus percussus*	1
Ruby-throated Bulbul	*Pycnonotus dispar*	1
Yellow-vented Bulbul	*Pycnonotus goavier*	1
Malaysian Pied Fantail	*Rhipidura javanica*	1
White-crowned Hornbill	*Berenicornis comatus*	A

Common name	Scientific name	n
Large-tailed Nightjar	*Caprimulgus macrurus*	B
Whiskered Treeswift	*Hemiprocne comata*	B
Blue-crowned Hanging Parrot	*Loriculus galgulus*	B
Crested Serpent-eagle	*Spilornis cheela*	B