Review

Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia

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In 2004, Navjot Sodhi and colleagues warned that logging and agricultural conversion of Southeast Asia's forests were leading to a biodiversity disaster. We evaluate this prediction against subsequent research and conclude that most of the fauna of the region can persist in logged forests. Conversely, conversion of primary or logged forests to plantation crops, such as oil palm, causes tremendous biodiversity loss. This loss is exacerbated by increased fire frequency. Therefore, we conclude that preventing agricultural conversion of logged forests is essential to conserving the biodiversity of this region. Our analysis also suggests that, because Southeast Asian forests are tightly tied to global commodity markets, conservation payments commensurate with combined returns from logging and subsequent agricultural production may be required to secure long-term forest protection.

Revisiting Navjot's nightmare

In an influential paper published in *TREE* in 2004, Navjot Sodhi and colleagues described an impending biodiversity disaster in Southeast Asia [1]. The disaster, they argued, stemmed from several factors, including deforestation, overexploitation of wildlife, commercial logging, and anthropogenic fire, all of which were happening in a region of high species richness and endemism. Sodhi and colleagues flagged deforestation and logging as the most urgent threats, noting that Southeast Asia had the highest relative rate of lowland forest loss of any tropical region. However, they could not partition the forest loss among various sectors of the economy, due to a lack of landcover, biodiversity, and socioeconomic data. This limited their ability to develop recommendations for saving the biodiversity of the region, beyond highlighting the need for additional forest reserves and the importance of involving multiple stakeholders.

In the years since Sodhi and colleagues published their paper, there has been a flurry of studies examining the drivers of forest loss in Southeast Asia, the impact of various land-use practices on biodiversity, and the economics of conserving forests in the region. We now know much more about these issues, thereby enabling us to develop a more nuanced and practical set of conservation recommendations. Thus, the time is ripe to revisit 'Navjot's nightmare' and to explore how the conservation community can prevent the biodiversity disaster that Sodhi *et al.* warned was imminent.

In this paper, we focus on the biodiversity impacts of agricultural conversion (Box 1), logging [including reduced impact logging (RIL), Box 2], anthropogenic fire (Box 3), and the growing yet underappreciated threat of overexploitation

Glossary

Deforestation: an activity whereby intact forest is clearcut and not allowed or able to regenerate as forest, or is replaced with a nonforest landcover, such as agriculture.
Forest conversion: an activity whereby native forest is cleared and replaced with a nonforest landcover (e.g., agriculture including oil palm and rubber, timber plantations, urban land, open land, etc.).
Intact forest: (as defined in Box 1 and Figure 1) this landcover class includes primary forest, mature secondary forest, and selectively logged forest that exhibits the structural characteristics of primary forest.
Mature secondary forest: secondary forest that exhibits the structural characteristics of primary forest.
Primary forest: forests that have never been logged.
Secondary forest: forests whose canopy is dominated by secondary regrowth from previously forested land that was clearcut or from abandoned agricultural land.
Selectively logged forest: forests in which only some trees are logged (usually following a prescribed diameter threshold, which varies according to country and region). Forest may be selectively logged once or more than once. Forest selectively logged more than once is commonly known as repeatedly selectively logged forest.
Timber plantation: an industrial-scale plantation whereby trees are planted and then clearcut when mature for sawlogs, veneer logs, and pulpwood. In Southeast Asia, most timber plantations are *Acacia mangium* and *Acacia crassicarpa* monocultures grown for pulpwood.
Young secondary forest: secondary forest dominated by young secondary regrowth and usually marked by an open canopy.

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Box 1. Predicting species losses due to plantations and urbanization

Sodhi *et al.* used a conventional power-law species–area model to predict that 13–42% of species in Southeast Asia would become regionally extinct by 2100 [1]. Based on an improved species–area model [62] parameterized with recently available data on landcover [5] and species responses to forest conversion [63], we generated extinction projections under two plausible landcover change scenarios for lowland forest birds and mammals, and compared our results to those obtained by Sodhi *et al.* [1] (see the supplementary material online).

The first business-as-usual (BAU) scenario assumed that Southeast Asian forests are converted at the current (2000–2010) rate of 1.6% y^{-1} observed in Sundaland. The second conservation scenario (CONS) assumed that forest conversion rates are halved. In both scenarios, forests are converted to agricultural and urban lands, and we assumed that the proportion of these two converted lands in 2100 remains the same as that of 2010 [20]. In our model, 7–52% of lowland forest bird species (median 29%) and 9–36% (median 24%) of lowland forest mammals go extinct under the BAU scenario (range indicates 95% confidence interval of Monte-Carlo simulations) (Figure I). If forest conversion rates are halved, the numbers are lower for both birds (4–30%; median 16%) and mammals (5–20%; median 13%). Despite using updated higher forest conversion rates as well as limiting our analyses to forest-adapted species, our projections are close to (for birds) and lower than those (for mammals) made by Sodhi *et al.* because our model incorporates the present, although limited, biodiversity values of agricultural and urban lands. The wide confidence limits are contributed by the variation in the magnitude of biodiversity responses to agriculture [57,63] and the uncertainty in the slope of the power-law species-area model.

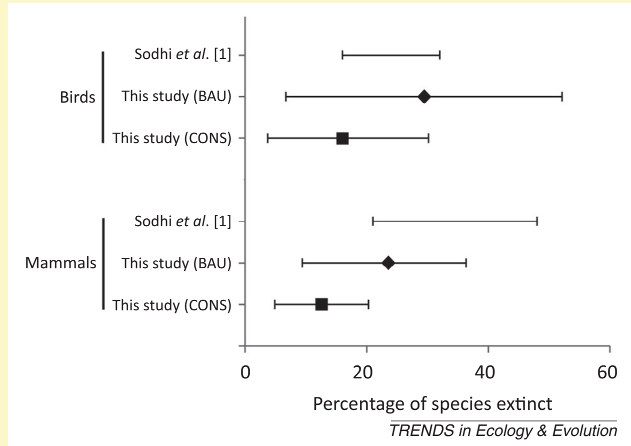

Figure I. Percentage of lowland forest bird and mammal species projected to go extinct by 2100. For the results obtained by Sodhi *et al.* [1], the ticks represent the likely range of percent extinctions. For the results obtained in this study, the ticks represent the 95% bootstrap confidence intervals and the diamonds [business-as-usual (BAU) scenario] and squares [conservation (CONS) scenario] represent the median value derived from 10 000 Monte Carlo resamples.

of the wildlife of the region (Box 4). Other threats to biodiversity, including invasive alien species [2] and climate change [3], were cited by Sodhi *et al.*; by excluding them from this analysis, we do not mean to suggest that they are unimportant. Rather, we have chosen to focus on what we consider to be the most widespread and serious threats to the biodiversity of the region today.

Deforestation in Southeast Asia

Deforestation remains a serious problem in Southeast Asia. The Forest Resources Assessment 2010 of the Food and Agriculture Organization revealed that primary forest (see Glossary) in the ten Southeast Asian countries decreased from approximately 663 000 km^2 in 2000 to approximately 640 000 km^2 in 2010 (–0.35% $year^{-1}$; Table S1 in the supplementary material online) [4]. The decline of secondary and selectively logged forests (i.e., 'naturally regenerating forests' *sensu* the FAO) was even more pronounced, from 1 442 000 km^2 to 1 348 000 km^2 in the same period (–0.67% $year^{-1}$).

Within Southeast Asia, we focus on Sundaland, which encompasses the Malay Peninsula, Borneo, Sumatra, Java, and the surrounding smaller islands (Figure 1), because it is the most severely threatened subregion ([5] and references therein). By 2010, deforestation had claimed approximately 70% (approximately 773 000 km^2) of the original lowland forests of Sundaland, and 65% (approximately 96 000 km^2) of its peat swamp forests (Figure 1; see the supplementary material online). Between 2000 and 2010, peat swamp forests experienced a much higher rate of deforestation (–3.7% $year^{-1}$) than did lowland forests (–1.6% $year^{-1}$) or montane forests (–0.1% $year^{-1}$), and are being lost most quickly in Sumatra (–5.2% $year^{-1}$) followed by Borneo (–2.8% $year^{-1}$).

Oil palm agriculture is often blamed for deforestation in Southeast Asia [6], a reasonable conjecture given that the area under oil palm cultivation has increased 87% over the past 10 years alone [7]. Within the Kalimantan provinces of Indonesia, 90% of oil palm expansion from 1990 to 2010 came at the expense of some type of forest (47% intact forest, 22% logged forest, and 21% agroforest) [8]. However, oil palm is not the only driver of land-use change in Southeast Asia. The region is also experiencing rapid development of its pulp and paper industry. In 2010, Indonesia had 4.9 million ha of timber plantations that produced 7 million tons of pulp and 10.5 million tons of paper [9,10]. The National Government is planning to triple the area under timber plantations to 14.7 million ha by 2030 [11]. Rubber (*Hevea brasiliensis*) is also replacing forests in parts of Southeast Asia; the total area of rubber plantations in the region grew by 32% [7] over the past decade, although we do not know precisely how much of this growth came at the expense of intact, selectively logged, or secondary forests.

Impacts of forest conversion on biodiversity

Several studies, both recent and older, have examined how various taxa are affected by different types of forest conversion. Approximately 75% of forest-dwelling bird species [12,13] and approximately 80% of forest-dwelling butterflies [6,14,15] are lost when forests are converted to oil palm plantations. There is also a dramatic shift in the community composition of bees [16]. Furthermore, most International Union for the Conservation of Nature (IUCN) Red-listed bird species do not persist within oil palm plantations [12,17], although some imperiled mammals, including tiger (*Panthera tigris*), can use oil palm plantations if hunting is controlled [18]. Aquatic

Box 2. Reduced impact logging

The destructive logging techniques commonly used in Southeast Asia have led to calls for more careful management of timber concessions [64,65] via RIL [66,67]. RIL involves a suite of activities designed to diminish damage to forest structure, reduce the release of carbon, and improve the viability of timber harvesting over longer time frames [67,68]. RIL is now a prerequisite for timber certification under the Forest Stewardship Council (FSC), which yields a market premium of 5–77% above the price of uncertified Malaysian timber [69]. In some regions of Southeast Asia, all logging must now be via RIL [70].

So what does RIL accomplish in terms of forest structure, carbon retention, and biodiversity? By reducing residual damage, RIL retains larger stocks of trees for future harvest and spares the release of carbon dioxide [71,72]. In Sabah, conventional logging (CL) resulted in 41% of nonharvest trees being crushed by tractors and falling timber, but residual damage was reduced to 17% with RIL [72]. The area of land covered with roads and skid trails was also reduced from 17% under CL to 6% with RIL, accompanied by higher rates of woody vegetation recovery on skid trails ([68], but see [73]). Lower residual damage, often combined with lower initial harvests [71,72], might offer longer-term economic benefits via higher future timber yields [74] and the sale of spared carbon under Reducing Emissions from Deforestation and Forest Degradation + (REDD+) [66].

In a comparison of RIL versus CL after a first logging rotation in Sabah, RIL resulted in improved species richness and diversity for dung beetles [75], but not for tree species [76]. After a first rotation under CL and a second logging rotation under RIL, there was minimal to no benefit for birds, dung beetles, and ants compared with sites logged twice using CL [70]. At least in the short term, therefore, there is little evidence to suggest that RIL has significant benefits for biodiversity, although this cannot be ruled out over longer timescales. However, RIL might provide tremendous benefits for biodiversity indirectly if the resulting carbon payments, higher long-term timber yields, and certification premiums prevent logged forests from being converted to agricultural plantations.

biodiversity is also harmed by forest conversion. When a patch of peat swamp forest was converted to banana and oil palm plantations in Peninsular Malaysia, 67% of fish species restricted to peat swamp forests were lost [19]. If current rates of peat swamp forest conversion in Sundaland continue to 2050, 16% of the fish species restricted to peat swamp forests are projected to become extinct [20].

Forest conversion to rubber also causes serious losses of Sundaland biodiversity. Most species of forest-dwelling birds [12,21], including all but one of 16 IUCN Red-listed species, disappear, being replaced by widespread, smaller species. Additionally, plant [21] and bat [22] species richness declines dramatically in rubber plantations. There is some evidence, however, that 'jungle rubber', in which a secondary forest understory is allowed to regrow as the rubber trees mature, is more beneficial to biodiversity [21,23], with higher levels of plant and bird species richness compared with rubber plantations.

The conversion of forest to *Eucalyptus, Albizia*, and *Acacia* paper-pulp plantations results in a less dramatic loss of Sundaland bird biodiversity than is the case with oil palm [24,25]. However, bird communities in young tree plantations are dominated by widespread, open-country species, whereas, even in mature plantations, some important bird groups, such as muscicapine flycatchers, large woodpeckers, canopy frugivores, and kingfishers, are absent [24,25]. Nevertheless, approximately 50% of bird species found in primary forest persist within mature tree plantations when a complex secondary forest layer is allowed to grow beneath the plantation canopy [24,25].

Given the loss of biodiversity associated with converting forests to certain types of plantation, the question naturally arises whether there might be ways to make those plantations more hospitable to biodiversity. As noted above, in the case of tree plantations, the retention of a secondary forest layer beneath the plantation canopy helps to retain forest-dwelling birds. Unfortunately, with respect to oil palm, the available evidence suggests that little can be done. Studies have shown that steps taken by oil palm producers to retain biodiversity, such as allowing understory plants to grow within plantations, planting flowering plants to attract beneficial insects, and leaving patches of forest inside plantations, yield minor benefits in terms of attracting or sustaining forest-dwelling species [17,26]. (Whether more radical steps to retain biodiversity in oil palm plantations would yield better results is unknown, because plantations have thus far not been designed with biodiversity conservation as a priority.)

With updated deforestation rates, the development of more accurate species–area models, and a better understanding of how biodiversity responds to forest conversion, we are able to provide revised estimates of regional bird and mammal extinctions in Sundaland and compare them with previous estimates [1] (Box 1).

Impacts of logging on biodiversity

Throughout Southeast Asia, forests that are not being converted to food crops, oil palm, or pulp-and-paper plantations are being logged to various degrees. Even parks and preserves that are nominally off limits to loggers are nonetheless susceptible to illegal logging [27]. Fortunately, we now have a better understanding of the impacts of large-scale commercial logging, as well as RIL (Box 2), on biodiversity than was the case in 2004. A first round of selective logging, for example, the removal of all commercially valuable trees >60 cm diameter at breast height (dbh), appears to have relatively limited impact on Sundaland biodiversity. In an analysis of all known studies from Sabah, Malaysian Borneo, Berry *et al.* found that, for most taxonomic groups, the species richness in primary forest was retained in selectively logged forest, and that all mammal species persisted, although sometimes in reduced abundances [28]. Studies conducted elsewhere in Borneo [29–32], Sumatra [30], and the Malay Peninsula [33] also found that most forest-dwelling species in most taxa are able to persist in forests that have been selectively logged once, although again sometimes at reduced abundances.

In Indo-Burma, a first rotation of logging had limited impacts on butterflies [34], although more intensive logging marginally reduced species richness. Pileated gibbons (*Hylobates pileatus*) persisted in the face of logging, but at reduced abundances [35]. In Sulawesi, the species richness of dung beetles [36] and birds [37] declined slightly after one logging rotation, whereas that of bryophytes [38] increased slightly. Here, too, most species in each taxon persisted after logging [36–38]. Curiously, to the best of

Box 3. Fire and forest conversion in Southeast Asia

Forest fires are a major concern in Southeast Asia because they result in biodiversity losses [77], have negative impacts on human health [78], and may facilitate climate change by releasing large amounts of carbon dioxide into the atmosphere [79]. Therefore, understanding where and when they occur is important.

Overlaying the most recent long-term fire occurrence data set [80] with landcover data from Sundaland [5] reveals that yearly fire occurrences (per 1000 km^2) were highest on peatlands followed by nonpeat lowlands (see the supplementary material online). However, fewer fires occurred in intact forests versus converted landcover types (Figure IA), consistent with observations from previous studies [81,82]. Montane habitats generally experienced fewer fires than lowlands.

Fire occurrence consistently peaks from August to October (Figure IB), coinciding with the warmer and drier season. The Southern Oscillation Index (SOI) was negatively correlated with fire occurrences in the following month (i.e., low SOI, an indication of an El Niño episode, precedes high fire occurrence; linear regression model $R^2 = 0.20$; Figure IC) (see the supplementary material online). Previously, Fuller and Murphy found that SOI lagged fire occurrences using an older fire occurrence data set from 1996 to 2001 [81].

Our analyses show that continued high rates of peatland and lowland forest conversion and degradation are likely to increase the frequency of fires in Sundaland. Fire frequencies are highest in the warmest and driest months, and are further elevated during El Niño episodes. As fire frequencies increase during El Niño, aerosols from biomass fires are expected to intensify droughts and further increase fire susceptibility [83]. Given that a drop in SOI precedes an increase in fire occurrences, SOI could be used to forecast fire susceptibility. However, the predictive power of SOI is limited, in part, by the anthropogenic nature of fires in the region [82].

In Indonesia, where fire occurrence is high, myriad institutions and regulations have been put in place to curb fires. Unfortunately, they have been largely ineffective for a variety of reasons, including weak enforcement of laws, a failure to consult with local people regarding legislative processes, and a lack of incentives to promote good land-management practices [61].

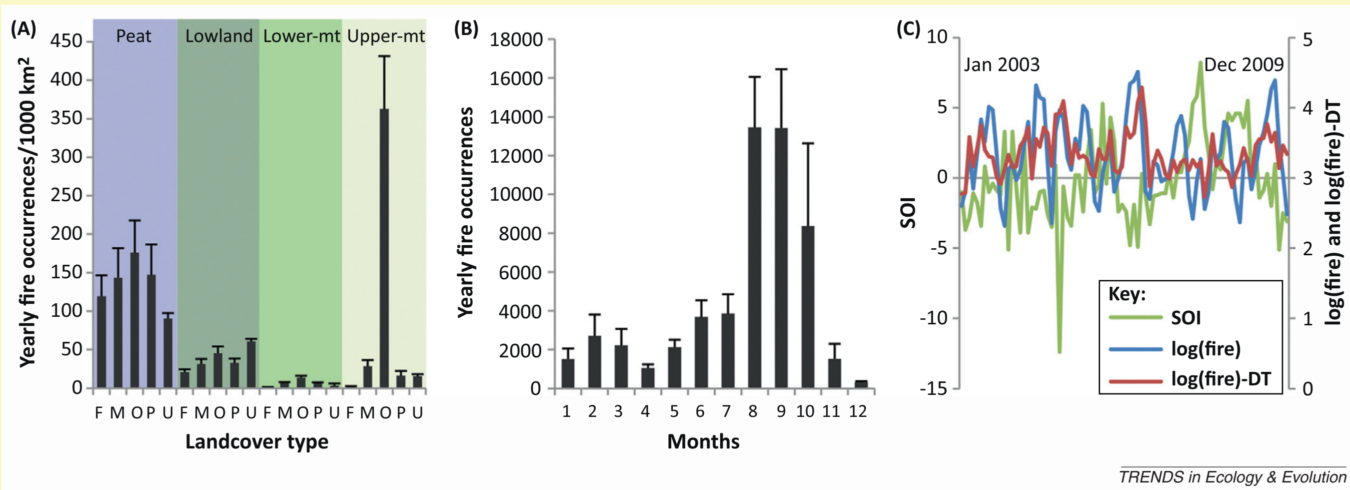

Figure I. Mean yearly fire occurrences [80] across **(A)** landcover types [3] and **(B)** months. Error bars show ± standard error (SE). **(C)** Monthly Southern Oscillation Index (SOI) [84], log_{10}-transformed [log (fire)] and log_{10}-transformed-detrended [log (fire)-DT] monthly fire occurrence from January 2003 to December 2009 [80]. High fire occurrence values in the open, upper montane areas are false detections due to hot volcano craters in Java and Sumatra [82]. Landcover types are as follows: F, forest; M, montane; O, open; P, plantation and regrowth; U, urban.

our knowledge, no study has investigated the impacts of logging in the Philippines, notwithstanding the large number of imperiled species that occur there; anecdotal evidence points to the presence of many endemic, imperiled species in logged forests (D. Edwards, personal observation).

The best information on how the number of logging rotations affects Southeast Asian biodiversity comes from studies in Sabah, Malaysian Borneo, where logging companies re-entered coupes for a second round of selective cutting <20 years after the initial off-take, targeting all commercially valuable trees with a dbh >40 cm [39,40]. Despite the highly destructive nature of this second rotation [39], there remained a surprisingly high level of biodiversity within these twice-logged forests. Birds, dung beetles [39], and leaf-litter ants [41] retained >75% of species found within the primary forest, and there were relatively minimal differences between twice-logged and once-logged forests in terms of community composition. If similar patterns hold elsewhere in Southeast Asia, then intensely logged forests may prove to be important and unappreciated reservoirs of biodiversity. That said, there are some critical unknowns about the long-term value of logged forests for biodiversity, including: (i) the successional trajectory of logged forests; (ii) whether there is an extinction debt of species to be paid over subsequent decades; and (iii) whether some of the undesirable correlates of logging, such as encroachment, burning (Box 3), and hunting (Box 4), can be kept at bay.

Economic insights

The economic drivers and consequences of land-use change in Southeast Asia are complex. There are certainly private and social costs and benefits associated with any land-use decision; however, the weight of evidence suggests that the conversion of forests in Southeast Asia is tightly tied to global commodity markets [42] and has been since at least the tropical timber boom of the 1980s [43]. The pressure of global commodity demand does not seem to be easing off, with the real prices (a proxy for demand) for pulp, rubber, palm oil, and hard logs increasing by 3–333% (Table S2 in the supplementary material online) [44] between 2000 and 2010.

Box 4. Wildlife trade

The trade of illegal wildlife products for traditional Asian medicines, luxury meat, skins, and cage birds poses a growing threat to the biodiversity of Southeast Asia [85–87]. As Asian economies have grown, particularly those in China and Vietnam, so too has the demand for wildlife products. So intensive is the pressure to supply this market that the last known Javan rhinoceros (*Rhinoceros sondaicus annamiticus*) in mainland Southeast Asia was shot for its horn in Vietnam in 2010 (Figure IA [88]).

Several other charismatic mammal species are now imperiled, including tiger (*Panthera tigris*; Figure IB,C; [89]) and the trio of Southeast Asian pangolins (*Manis javanica, Manis pentadactyla*, and *Manis culionensis*; Figure ID; [90]). Approximately 30 000 pangolins were seized by enforcement agencies between 2000 and 2007 in Southeast Asia [90], although these figures represent a small fraction of the total trade.

The illegal wildlife trade is extremely lucrative, well organized, and well funded [89,90]. Syndicates offer rural communities increasingly high prices for wildlife products, thereby ensuring that many people will hunt and sell wildlife. Over a 13-month period from 2007 to 2008, middlemen in Sabah, Malaysia, invested US$3.5 million (prices in 2008 US$) on 108 tons of pangolin and 1 ton of scales, paying local communities US$32 per kg and US$51 per kg of scales [90]. The demise of the last rhinoceros in Vietnam suggests that consumers' desires for rare wildlife products can make it financially worthwhile to seek out the last individuals of dwindling populations, driving an anthropogenic Allee effect [91] and potentially leading to species extinction [92].

Bird species that are endemic to Southeast Asia are imperiled by the legal (and illegal) trade of millions of wild-caught cage birds [93]. Beautiful songsters, such as the straw-headed bulbul (*Pycnonotus zeylanicus*), are in decline, whereas the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)-listed Bali starling (*Leucopsar rothschildi*) is nearly extinct in the wild. In addition, the legal trade in wild-caught birds for religious ('merit') release involves huge numbers of individuals. At two temples in Phnom Penh, more than 680 000 individual birds, worth US$235 000 in profit to street sellers, were released annually [94]. Most of these birds are believed to die shortly after release. Without changes to inappropriate legislation (such as laws in Vietnam that allow authorities to sell confiscated wildlife, effectively turning policemen into wildlife traders), more resources for enforcement, severer sentencing, and an improved understanding of why people use wildlife products, combined with effective media campaigns to change attitudes, the future of many traded species in Southeast Asia is bleak.

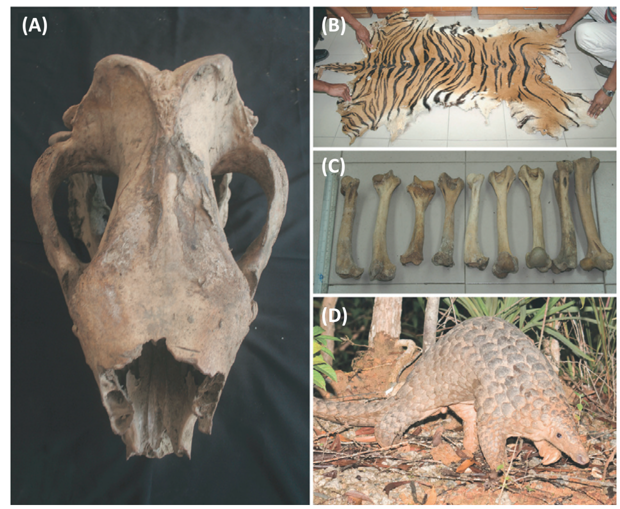

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Figure I. Victims of wildlife trade. **(A)** The skull of the last individual of Javan rhinoceros *Rhinoceros sondaicus annamiticus*, which was found shot and with its horn removed in Cat Tien National Park, Vietnam, in 2010. **(B)** Tiger pelt and **(C)** tiger bones openly on sale in Sumatra, Indonesia. **(D)** A pangolin: scales are used in traditional Asian medicine and its meat is considered a delicacy. Reproduced, with permission, from Sarah Brook/WWF (A), Julia Ng/TRAFFIC (B,C), and Norman Lim (D).

The magnitude of the rents (profits) from the production of these commodities has been discussed and debated for well over a decade [45]. Bids for logging concessions in Peninsular Malaysia reportedly reached US$16 000 per hectare in the 1990s [46]. More recent studies in Sabah, Malaysia, show that logging of lowland forests can return a profit of US$9000–13 000 per hectare [40,42], whereas a meta-analysis of 25 logging studies across Southeast Asia, reported net returns to logging of US$1260–13 840 per hectare, with a mean value of over US$5500 [47].

Such high returns help to explain the pervasive logging in the region. Additionally, there is pressure from commodity production (e.g., oil palm) on lands after they have been logged. A suite of recent studies has shown that oil palm plantations, which reach maturity in 3–7 years, produce rents of US$4000–11 000 per hectare [42,48,49]. This is critically important with respect to biodiversity conservation because the combined returns from logging and subsequent conversion of the site to commodity production constitute a major barrier to protection; that is, the opportunity cost of conserving forests is great [50].

Along with the private financial benefits of logging and commodity production, there can be additional social benefits. For example, in addition to employing workers, some oil palm companies provide housing, schooling, and medical care for communities associated with the plantations [51]. There are also social costs associated with the conversion of forests to plantations, such as the resultant biodiversity loss, increased carbon emissions, increased smog, and, in the case of oil palm, increased low-level ozone with accompanying health and crop yield impacts [52,53].

Although we are aware of no formal cost–benefit analysis for land-use change in the remaining primary forests in Sundaland, recent studies indicate that the financial returns to logging and palm oil production in lowland Sabah are, on average, twice as large as those currently possible under conservation (incorporating payments for carbon, biodiversity, water, and ecotourism) (Figure 2 [42,47–49]). This disparity poses a major obstacle to protecting primary forests in the region.

Despite the large financial returns to logging and forest conversion, situations that favor conservation surely exist. For example, in some cases, the returns to logging and agricultural production are lower than reported above, due to slope, soil, distance to markets, and other mitigating factors. In such cases, there will be opportunities to use carbon payments and other incentive payments to stem forest conversion [54]. Additionally, western consumers have shown a willingness to pay price premiums for palm oil-derived goods that are produced in ways that are less harmful to biodiversity [18]. In theory at least, these price premiums could cover the harvest losses on plantations

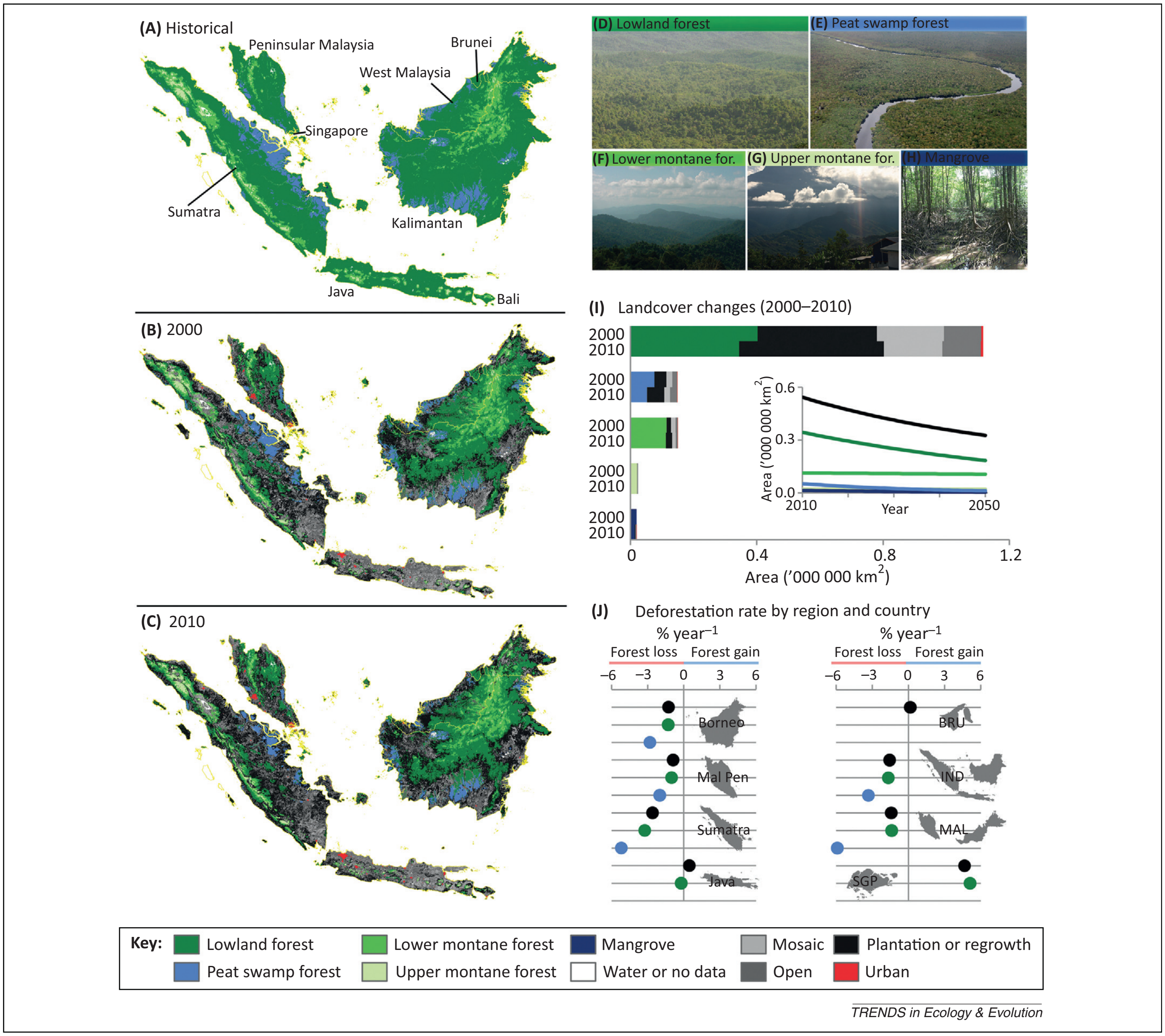

Figure 1. History of land-use change in Sundaland. **(A)** Historical (prehuman disturbance) ([5,95,96], see the supplementary material online), **(B)** Year 2000, and **(C)** Year 2010 landcover distribution [5,96]. Five major forest types in Sundaland: **(D)** lowland forest (for.), **(E)** peat swamp forest, **(F)** lower montane forest, **(G)** upper montane forest, and **(H)** mangrove. We present landcover changes in the five forest types from 2000 to 2010 **(I)**. Inset graph shows the likely trajectory of different forests assuming geometric change following yearly deforestation rates from 2000 to 2010. Given that forest loss is greatest in lowland and peat swamp forest, we show annual deforestation rates (2000–2010) for these two types of forest in addition to aggregated forest area (black dots) across regions and countries **(J)**. Regional abbreviations: Mal Pen, Malay Peninsula comprising Peninsular Malaysia and Singapore. Country abbreviations: BRU, Brunei Darussalam; IND, Indonesia; MAL, Malaysia; SGP, Singapore. We present only aggregated deforestation rates for Brunei because the unavailability of a reliable peatland map precluded the determination of peat swamp forest areas [5]. In addition, there were no peat swamp forest areas in Singapore and Java. Data for the different landcover types follow colors used in the map. Reproduced, with permission, from Reuben Clements (D,F,G), Xingli Giam (E), and Wee Foong Ang (H).

that are willing to alter their management practices to favor declining species, such as pangolins and porcupines [55], or to ensure that new plantations are not established in primary, selectively logged, or secondary forests.

Two additional factors affecting the economics of land-use change in Southeast Asia are the temporal changes in price and demand for wood and agricultural products and the regulatory aspects of land-use decisions. Voluntary schemes involving payments to landowners to reduce forest conversion could perform as well as mandatory schemes, given the appropriate accounting, revenue, and cost-sharing structures [56]. Linked to this regulatory aspect is the issue of just how much land is allowed to be converted from forest to cropland. Regulations mandating that logged forests should not be converted will affect not only biodiversity, but also the opportunity cost of conservation, because biodiversity and profit show differential responses across logging intensities (Figure 3). Whereas the value of the timber stock declines precipitously after two logging rotations, biodiversity values do not, suggesting that protecting logged forests are a cost-effective approach to conserving biodiversity in the region [40].

Fluctuating global prices and demand for the commodities that have driven land-use change in Southeast Asia

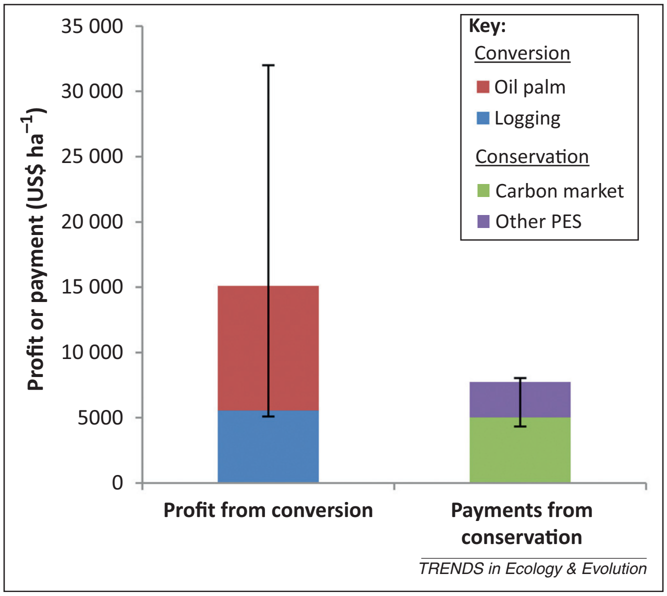

Figure 2. Potential returns to forest conversion compared with hypothetical returns to forest conservation via payments for ecosystem services (PES) in Southeast Asia. Stacked bars denote accumulative mean values from logging followed by oil palm conversion (conversion) and carbon payments followed by payments for other PES (conservation). Error bars show the minimum and maximum accumulative values. All profits and payments in 2009 US$. Data from [42,47–49].

might positively or negatively affect future biodiversity conservation efforts; so too could better elucidation of the social costs and benefits of policy decisions. Indeed, we foresee ample opportunities for social scientists to influence the outcome of future land-use decisions in Southeast Asia. Currently, most discussions about the costs and benefits of logging and forest conversion are held with little consideration of social issues beyond a presumption that the income from logging and oil palm is broadly beneficial.

Conservation recommendations

Taken together, the body of recent research in Southeast Asia points to three important conclusions about the forests of the region. First, in terms of protecting the full array of vulnerable plants and animals, there is no substitute for conserving the remaining primary forests [39,57].

Second, the profitability of logging and oil palm agriculture makes protection of those unlogged forests exceedingly expensive, except in places where topographic conditions, distance to markets, and other factors reduce the profitability of these enterprises [39]. [Peat swamp forests may be something of an exception here, in that they typically lack high densities of large, commercially valuable trees yet retain immense amounts of soil carbon. Here, carbon payments might only need to overcome the opportunity costs of foregoing an agricultural crop (e.g. oil palm), although at the present time they are insufficient to do so in the case of oil palm.]

Third, by far the most severe losses of biodiversity occur not when forests are logged but rather when they are converted to oil palm plantations, pulp and paper plantations, or food crops. Hence, preventing logged forests from being converted to plantations or croplands should be a priority (perhaps even the top priority) of conservationists in Southeast Asia.

Fortunately, the sharp drop in the residual timber value of once- and twice-logged forests, combined with their continuing value for biodiversity, makes the protection of logged forests a potentially cost-effective way to preserve biodiversity in this region. Thus, conservationists and decision-makers should look to protecting logged forests as a way to expand or connect existing reserves or to create entirely new reserves.

An alternative approach (devising ways to make plantations and croplands more hospitable to biodiversity) holds less promise. There is little evidence that steps taken to make oil palm plantations 'greener' yield significant benefits in terms of biodiversity conservation [17,28,58] (although more research on this topic is needed). This suggests that appropriate mitigation for forest loss due to oil palm should focus on biodiversity banking and other off-site measures, rather than improving the plantations *per se*.

Compared with oil palm, timber plantations might offer more potential for improvement, because studies have shown that steps can be taken to increase significantly the biodiversity within them. The degree to which consumers will be willing to pay the premiums necessary to sustain these 'greener' operations remains an open question [59], but there is evidence that consumer pressure on major purchasers of commodities has been instrumental in increasing the demand for certified products. The strategic placement of timber plantations instead of oil palm around parks and other forested areas should be encouraged and even supported financially.

Sustained campaigns by nongovernmental organizations targeted toward major commodity producers have also led to several notable successes, including a recent announcement by Asia Pulp and Paper, an industry giant, to commit to sourcing raw materials only from timber plantations as well as to cease conversion of peatlands [60].

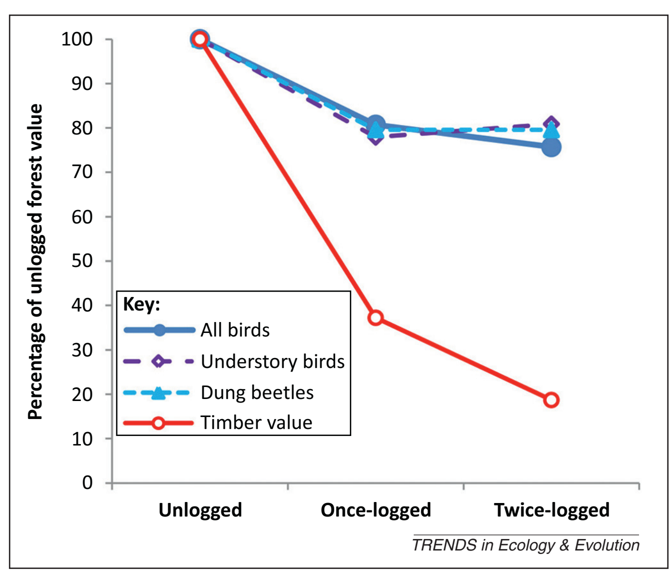

Figure 3. Percentage changes in the number of forest species from unlogged (primary) forests and standing timber values across unlogged, once-, and twice-logged forests. Values from unlogged (primary) forests are taken as the baseline (i.e., 100%). Data from [40].

Because high rates of peatland and lowland forest conversion are associated with higher frequencies of fire in Sundaland (and likely elsewhere in Southeast Asia), stricter enforcement of laws and regulations designed to reduce the risk of wildfire or the use of incentives to promote better land-management practices could go a long way to reducing this threat [61]. Given that in extreme years, wild fires can affect the health and well being of humans well beyond the country of origin, fire prevention across Southeast Asia should be seen as an international issue; multiple countries have a stake, both economic and social, in addressing the problem. International pressure might help to overcome local or national resistance to land-management reforms.

Concluding remarks

Nearly a decade after Sodhi *et al.*'s call to arms [1], we have a much deeper understanding of the myriad ecological and economic issues underlying the ongoing biodiversity crisis in Southeast Asia. It is a crisis driven largely by the conversion of forests to croplands, especially oil palm and rubber. (Selective logging poses a lesser threat, largely because most, but not all, of the species found in primary forests appear to be able to persist in logged forests.) In addition, it is a crisis made all the more difficult to address by the profitability of both logging and oil palm cultivation. Despite these challenges, however, viable policy options, based on sound science and good economics, are slowly coming into focus and, in some cases, being implemented. They include preserving logged forests as a cost-effective way to enlarge the network of protected areas in the region; identifying and targeting for protection those forests that are unsuitable for either logging or oil palm cultivation; and mobilizing public pressure to get large, multinational purchasers of palm oil, rubber, and paper products to buy their materials from companies that agree not to clear forests for new plantations. Although the outlook for the biodiversity of Southeast Asia is far from sanguine, we are cautiously optimistic that a disaster foretold need not become a reality.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tree.2013.04.005.

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