Southeast Asian biodiversity: an impending disaster

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Southeast Asia has the highest relative rate of deforestation of any major tropical region, and could lose three quarters of its original forests by 2100 and up to 42% of its biodiversity. Here, we report on the current state of its biota and highlight the primary drivers of the threat of extinction now faced by much of the unique and rich fauna and flora of the region. Furthermore, the known impacts on the biodiversity of Southeast Asia are likely to be just the tip of the iceberg, owing to the paucity of research data. The looming Southeast Asian biodiversity disaster demands immediate and definitive actions, yet such measures continue to be constrained by socioeconomic factors, including poverty and lack of infrastructure. Any realistic solution will need to involve a multidisciplinary strategy, including political, socioeconomic and scientific input, in which all major stakeholders (government, non-government, national and international organizations) must participate.

Tropical ecosystems are exceptionally rich and exclusive reservoirs of much of the biodiversity on Earth. However, the rapid and extensive destruction of tropical habitats has become a serious threat to their native biota [1]. Deforestation is particularly severe in Southeast Asia, where natural habitats, such as lowland rain forests, are being destroyed at relative rates that are higher than those of other tropical regions [2]. If present levels of deforestation were to continue unabated, Southeast Asia will lose almost three-quarters of its original forest cover by the turn of the next century [2], resulting in massive species declines and extinctions [3]. More importantly, this biodiversity crisis is likely to develop into a full-fledged disaster, as the region is home to one of the highest concentrations of endemic species [4].

Here, we discuss the contribution of the unique geological history of Southeast Asia to its high species richness and endemism. We report on the current state of its terrestrial biota and highlight the primary drivers, such as forest conversion, that are responsible for the threat to the unique and rich biodiversity of the region. Finally, we discuss the major conservation challenges faced by this region.

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The unique geological history and biodiversity of Southeast Asia

In a study reported in 2000, Myers *et al.* identified 25 'biodiversity hotspots' in the world as those areas containing high concentrations of endemic species and undergoing immense habitat loss (Figure 1) [4]. Southeast Asia overlaps with four of these hotspots, each of which has a unique geological history that has contributed to its rich and often unique biota [5]. During the Pleistocene glacial episodes, some temperate species from northern Asia expanded their ranges southwards into Indo-Burma and retained their presence thereafter [6]. Fluctuating sea levels periodically converted mountains into geographically isolated islands, creating conditions that were ideal for speciation. The episodic sea-level changes also repeatedly connected the islands of Sundaland (covering the western half of the Indo-Malayan archipelago) to the Asian mainland, enabling biotic migrations from the mainland to the archipelago [7]. As the sea level rose, the isolation of these islands also facilitated speciation. The presence of rain forest refugia in parts of Sundaland during the Pleistocene also enabled the persistence of its forest biota [8]. Although it was never connected to the Asian mainland, Wallacea (covering the central islands of Indonesia to the east of Java, Bali and Borneo, and west of the province of Papua on the island of New Guinea) is one of the most geologically complex regions in the world, because its islands originated from land fragments that rifted from Gondwanaland at different geological time periods [9]. This unique geological history, together with its stable tropical climate and numerous insular biotas, enabled Wallacea to evolve highly endemic biotas of its own. The other geologically unique region of Southeast Asia, the Philippines, consists of ∼7000 islands, containing multiple centres of endemism [5]. The colonization of newly formed oceanic islands, followed by genetic differentiation and long-term persistence, has resulted in the extraordinarily high species richness and endemism of the Philippines [10]. As a result of the unique geological history Southeast Asia, the region ranks as one of the highest in the world in terms of species richness and endemism [5]. Furthermore, it features unique ecological processes, such as the strong synchrony of fruiting of trees (mast events) from the Dipterocarpaceae [11], which have major implications for forest ecology and conservation.

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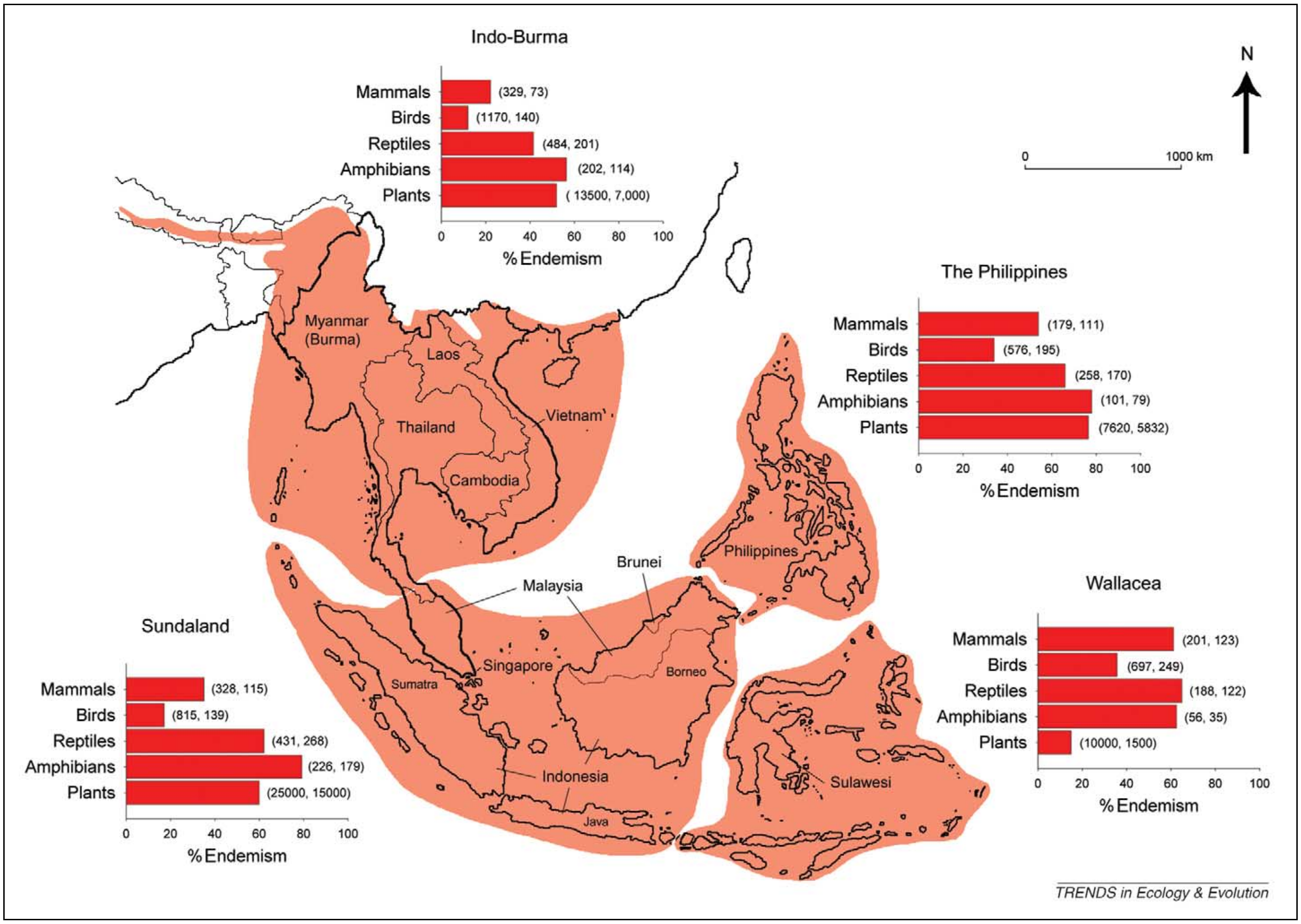

Figure 1. Species richness and endemism in Southeast Asia. The four biodiversity hotspots overlapping Southeast Asia are highlighted in red. Bars represent the percentage of species endemic to the respective hotspot. Numbers in parentheses represent total and endemic species known to science, respectively. The island of Borneo includes the political divisions of Brunei, Malaysia and Indonesia. The Indo-Burma hotspot includes part of Bhutan, Nepal, eastern India, southern China, as well as islands such as Hainan and the Andamans. Details of biodiversity hotspot boundaries, and numbers of total and endemic species within each hotspot were taken from Conservation International [74].

The current state of biodiversity

Three plant and eight animal species have been listed as 'extinct' in Southeast Asia by the International Union for the Conservation of Nature and Natural Resources (IUCN) [12]. Because Southeast Asia has a fairly recent history of large-scale deforestation (i.e. over the past two centuries), many of the native species of the region, such as rare long-lived trees, might be persisting as 'living dead' and are doomed to extinction owing to isolation caused by the fragmentation of habitats [3]. Therefore, although the actual number of extinct species in the region is not presently alarming, the level of endangerment of extant species reveals the seriousness of threats, such as deforestation, that are faced by the regional biota. The number of threatened species in Southeast Asia, including those in the IUCN categories of 'critically endangered' (CE), 'endangered' (EN) and 'vulnerable' (VU) ranges from 20 (CE) to 686 (VU) species for vascular plants, six to 91 species for fish, zero to 23 species for amphibians, four to 28 species for reptiles, seven to 116 species for birds, and five to 147 species for mammals (see Online Supplementary Material) [12]. The loss of many of these regional populations is likely to result in global extinctions because of the high proportion of endemic species (Figure 1; see Online Supplementary Material) [13]. For example, 59.6% of the 29 375 vascular plant species in Indonesia do not occur anywhere else (see Online Supplementary Material) [13].

Drivers of biodiversity threat

Here, we discuss the drivers of biodiversity loss and endangerment in Southeast Asia, which might act either alone or in concert.

Forest conversion

The conversion of natural habitat to other land uses is the major driving force behind worldwide biodiversity loss [14–17]. Most of Southeast Asia was under forest cover 8000 years ago (see Online Supplementary Material) [18], but large-scale deforestation in the region began during the 1800s as a result of agricultural expansion that was needed to meet the increasing local and global demand for rice *Oryza sativa* [19]. The planting of perennial export crops, including rubber *Hevea brasiliensis*, oil palm *Elaeis guineensis* and coconut *Cocos nucifera*, also accounted for 20–30% of the total cultivated area of the region [19]. After

1950, increasing demand for Asian timber led to the proliferation of commercial logging activities [19]. Southeast Asian rain forests are particularly valuable to the logging industry for domestic consumption and export because its diverse dipterocarp species can be grouped for sale into just a few end-use classes [20]. Between 1880 and 1980, Southeast Asia experienced an average annual forest loss of 0.3% [19]. During the past decade, the loss of 'natural forest' in the region has continued at a rate of 1.4% y^{-1} (see Online Supplementary Material) [13,21], which was higher than the deforestation rates of other speciose tropical regions, such as Central America and the Caribbean (1.2%), and South America (0.5%) [13]. Currently, less than half (41.3–44.2%) of the original forests of Southeast Asia remain (see Online Supplementary Material) [21,22].

Deforestation in Southeast Asia has resulted in collateral impacts on its rich and unique biodiversity, with Singapore being the most heavily affected country to date (Box 1; see Online Supplementary Material). The most immediate impact of logging activities is the alteration of the unique multilayered and closed tropical forest canopy [20]. Reductions in canopy height, surface area and the crown size of selectively logged Malaysian forests are still evident after four decades of regeneration [23]. In Borneo, the species richness of trees was shown to be negatively associated with the intensity of logging activities [24]. Seedlings and saplings in these logged sites were also species poor [24], suggesting that logged forests require long periods of time to recover their original plant richness.

Conversion of land to agricultural use has even more detrimental impacts, owing to the depletion of soil nutrients and erosion following intense agricultural activities [25]. Even after a century of succession, the plant richness of abandoned agricultural areas in Singapore was only 60% of that of primary forests [26]. The selective logging of dipterocarps is also likely to decrease their reproductive success by reducing the extent and intensity of interspecific mast fruiting, which has been suggested to be a reproductive strategy that has evolved to satiate seed predators [11]. Logging has led to recruitment failure of dipterocarps within a national park in Borneo, which is now surrounded by logged forest, and logging has also exacerbated local El Niño events [11]. Recent studies reveal a trend of declining species richness and population density with increasing forest disturbance through logging activities, agriculture or urbanization across a range of Southeast Asian taxa, including termites [27], dung beetles [28], ants [29], bees [30], butterflies [31], moths [32], birds [33,34] and mammals [35–40]. Furthermore, the loss of animals that produce ecological services, such as seed dispersal, nutrient recycling and pollination, might further impede forest regeneration in the disturbed areas.

Forest fires

Although forest fires have always occurred in Southeast Asia, a combination of factors, such as poor land conversion practices, logging and more-intense El Niño events, act in concert to increase the chances of catastrophic fires in the region [39,40]. For example, logging can increase the vulnerability of forests to fire by opening up the canopy, creating piles of flammable wooden debris and facilitating access to forests for people. In 1997–1998, up to 5 million ha of forests in Indonesia (Sumatra and Kalimantan) were consumed by forest fires [41]. It was estimated that 4.6% of the canopy trees, as well as 70–100% of seedlings and 25–70% of saplings, were destroyed in Sumatra (Barisan Selatan National Park). Owing to the loss of fruiting trees, many avian frugivores, such as the helmeted hornbill *Buceros vigil*, experienced population declines of up to 50% [42]. Immediately following the fires, other animals, such as the siamang *Holobates syndactylus*, the largest of the gibbons, disappeared completely from the burnt areas [39]. Siamang groups whose territory included forest that was either burned or adjacent to burned areas were significantly smaller and experienced higher infant and juvenile mortality than did groups not affected by fire [43].

Hunting for bushmeat

Humans have been hunting wildlife in Southeast Asia for at least 40 000 years [44,45]. However, hunting pressure has increased immensely with increasing human densities and declining forest areas in the region. The situation is further exacerbated by factors such as logging, creation of roads, better hunting equipment and ineffective wildlife protection [46–48]. Wildlife is currently being extracted from tropical forests at more than six times the sustainable rate [49]. In Sarawak, Malaysia, an estimated 2.6 million animals were shot and 23 500 tons of wildlife meat are consumed on annual basis [49,50]. A similar trend is reported from Sabah, Malaysia, where an estimated 108 million animals are hunted for bushmeat each year [50]. Such figures are alarming, especially given that intense hunting can depress animal densities [50].

Wildlife trade

Southeast Asia is a major hub of wildlife trade (see Online Supplementary Material) [51]. In 2000, the net legal export of lizard and snakeskins from Indonesia was 29.4% and 28.2% of global exports, respectively. Even a highly urbanized country, such as Singapore, was an active trader of wildlife and wildlife products, with a total net import of 7093 live animals and a total net export of 301 905 animal skins in 2000 alone (see Online Supplementary Material). The alarming numbers of wildlife resources that are legally traded in Southeast Asia are, in all likelihood, a gross underestimation of the actual volume of wildlife traded in the region. Trade unaccounted for includes illegal and unrecorded wildlife traffic, as well as many animals that died before reaching their intended destination or were sold in local markets. The lucrative pet trade in Southeast Asia is the major driving force behind its wildlife trade [52,53]. For example, rampant trapping for the pet trade, coupled with habitat conversion, has driven the endemic Bali starling *Leucopsar rothschildi* to the verge of extinction over the past three decades [54]. Currently, there are <20 wild individuals of this species, which are restricted to the Bali Barat National Park [54]. In spite of being listed on Appendix 1

Box 1. Singapore case study: a recipe for disaster

From both a scientific and management perspective, it would be informative if we could excise hypothetically a representative Southeast Asian site, allow it to fulfil its economic potential, and document the consequent losses of natural habitats and biodiversity, all within a greatly accelerated time frame. Perhaps it is both depressing and fortunate that Singapore is one such ecological 'worst case scenario'.

Singapore has experienced exponential population growth, from ~150 subsistence-economy villagers in the early 1800s to four million people in 2002 [13,72]. In particular, Singapore has transformed itself from a developing country of squatters and slums to a developed metropolis of economic prosperity within the past few decades and, thus, has been widely regarded by the leaders of regional developing countries as the ideal economic model.

However, the success of Singapore came with a hefty price, paid for by its biodiversity. The island has suffered massive deforestation (>95%), initially from the cultivation of short-term cash crops (e.g. gambier *Uncaria gambir* and rubber *Hevea brasiliensis*) and subsequently from urbanization and industrialization [72]. A recent study by Brook *et al.* [3] showed substantial rates of documented (observed) and inferred (based on what could have occurred in Singapore before habitat loss) extinctions, with most extinct taxa (34–87%) being species of butterflies, fish, birds and mammals (Figure I). Similar environmental scenarios are already unfolding on a much larger scale in other Southeast Asian countries, such as Indonesia [73]. Extrapolations based on the species–area model calibrated to the biodiversity losses in Singapore indicate that the current rate of habitat destruction in Southeast Asia will result in the loss of 13–42% of regional populations of all species by 2100, at least half of which could represent global species extinctions (Figure I) [3].

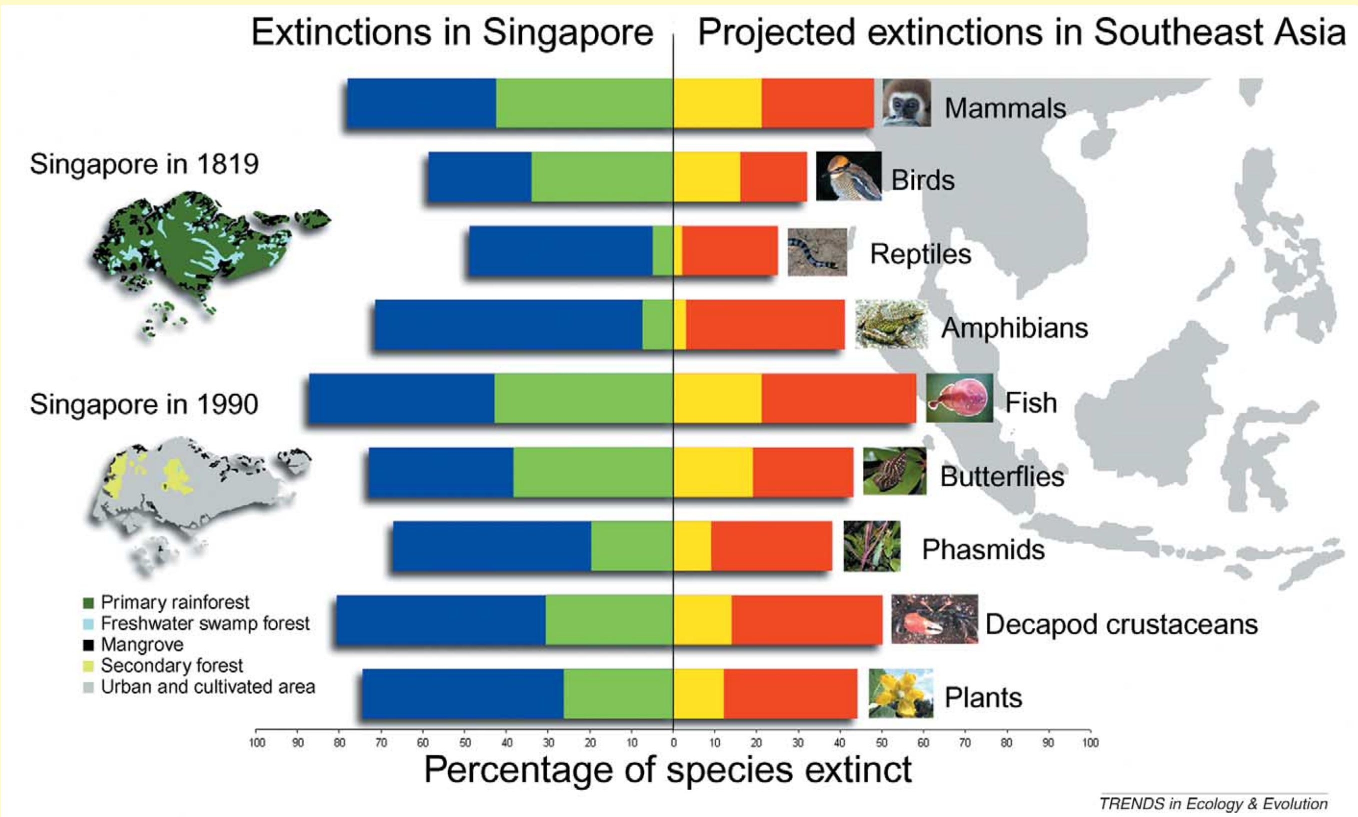

Figure I. Population extinctions in Singapore and Southeast Asia. Green and blue bars represent recorded and inferred extinctions in Singapore, respectively. Yellow and red bars represent minimum and maximum projected extinctions in Southeast Asia, respectively.

of the Convention on International Trade in Endangered Species (CITES) in 1970 and having been protected in Indonesia since 1971, 19 individuals were observed being sold illicitly in shops in Singapore in 1979 and 16 individuals were observed in cages in Denpasar (Bali, Indonesia) in 1982 [54].

Many animal and plant products are used in traditional Chinese medicine, which dates back 5000 years. Trade in the raw materials of traditional Chinese medicine has a detrimental impact on many vertebrates in Southeast Asia, including tigers, bears, rhinos, turtles, snakes, tokay geckos, pangolins, monkeys and swiftlets [5]. This is exemplified by the Sumatran tiger *Panthera tigris sumatrae*, from which body parts such as bones and penises are used in traditional medicine. Between 1975 and 1992, South Korea imported 6128 kg of tiger bones (340 kg y^{-1}), of which 60% originated from Indonesia [55]. The demand for the Sumatran tiger continues to threaten the remaining wild population of an estimated 500 individuals [56].

Other potential drivers

Sala *et al.* [14] showed that, relative to the overwhelming impact of forest conversion, other drivers, such as climate change, nitrogen deposition, invasive species and atmospheric CO_2 change, are not expected to have significant effects on biodiversity in tropical terrestrial ecosystems. Climate change was shown to have the largest proportional effect on biodiversity in extreme environments, such as the arctic and boreal zones, and the least effect in the tropics, with only montane areas being substantially affected [14]. Nitrogen deposition is expected to have the largest impact on biodiversity in areas that are most nitrogen limited, such as temperate forests [57]. Invasive species are also not expected to impact tropical ecosystems greatly because various abiotic and biotic factors, such as high species diversity, minimize the probability of successful establishment by invaders in undisturbed communities in the tropics [58]. The increased atmospheric concentration of CO_2 is expected to have a large impact on biodiversity mainly in areas where plant growth is most limited by water availability and where there is a mixture of C_3 and C_4 species, such as grassland and savannas. This is because of known species differences in the effect of CO_2 on water-use efficiency [59]. Nevertheless, in spite of these findings, the relative importance and long-term implications of these drivers of biodiversity threats and, more critically, their synergistic impacts on the biodiversity of Southeast Asia, remain poorly understood.

Conservation challenges

The outlook for the biodiversity of Southeast Asia appears bleak, owing to several key social, scientific and logistical conservation challenges faced by the region. The major challenges in mitigating the imminent threats to its biodiversity are primarily socioeconomic in origin, including population growth, poverty, chronic shortage of conservation resources (both expertise and funding) and corrupt national institutions. As regional societies strive to match the living standards of developed nations, environmental issues are inevitably marginalized. Increasing human population density is a primary socioeconomic driver of forest loss in Asia [60] and, in Southeast Asia, both this and economic growth are positively associated with forest loss (Figure 2).

Research on Southeast Asian biodiversity over the past 20 years has also been neglected in comparison to other tropical regions. We compared all of the internationally peer-reviewed research articles about biodiversity from the Biological Abstracts data base (excluding exclusively marine studies) that were published between 1983 and 2003. The number of scientific publications about Southeast Asian biodiversity was fewer than was expected for its forest area compared with other tropical regions, including Central America and the Caribbean, Sub-Saharan Africa, and South America. Furthermore, the distribution of research effort in Southeast Asia was also taxonomically biased. For example, there were more research papers on mammals than would be expected if studies were distributed according to the relative species richness of taxonomic groups; however, there remains a dearth of research on other important taxa, such as vascular plants, invertebrates and fish. To remedy the paucity of biodiversity studies in Southeast Asia, particularly in poorly studied taxonomic groups, collaborative research efforts of regional and international expertise on Southeast Asian biotas are urgently needed [61].

The diversity of habitat types in Southeast Asia is another major challenge for the conservation of its biodiversity [62] and there are numerous habitats that remain poorly studied. For example, recent studies reveal that the highly acidic blackwaters of peat swamps have much higher biodiversity and productivity than was previously thought [63], and contain many hitherto unrecognized rare and endangered fish species [64]. Furthermore, recent studies of limestone formations in Southeast Asia revealed the presence of many endemic and highly specialized taxa [65]. Additionally, large tracts of rain forests and mangroves in Southeast Asia have yet to be surveyed by professional biologists [66]. The lack of biodiversity studies in such neglected habitats is a serious impediment to the conservation of Southeast Asian biodiversity because sound biological knowledge is needed to prioritize conservation areas and habitat, and to model sustainable use of resources, such as timber and bushmeat. Currently, such biological understanding in Southeast Asia lags behind those of other regions.

Protected areas (both existing and future) are the main hope for preserving the biodiversity of Southeast Asia.

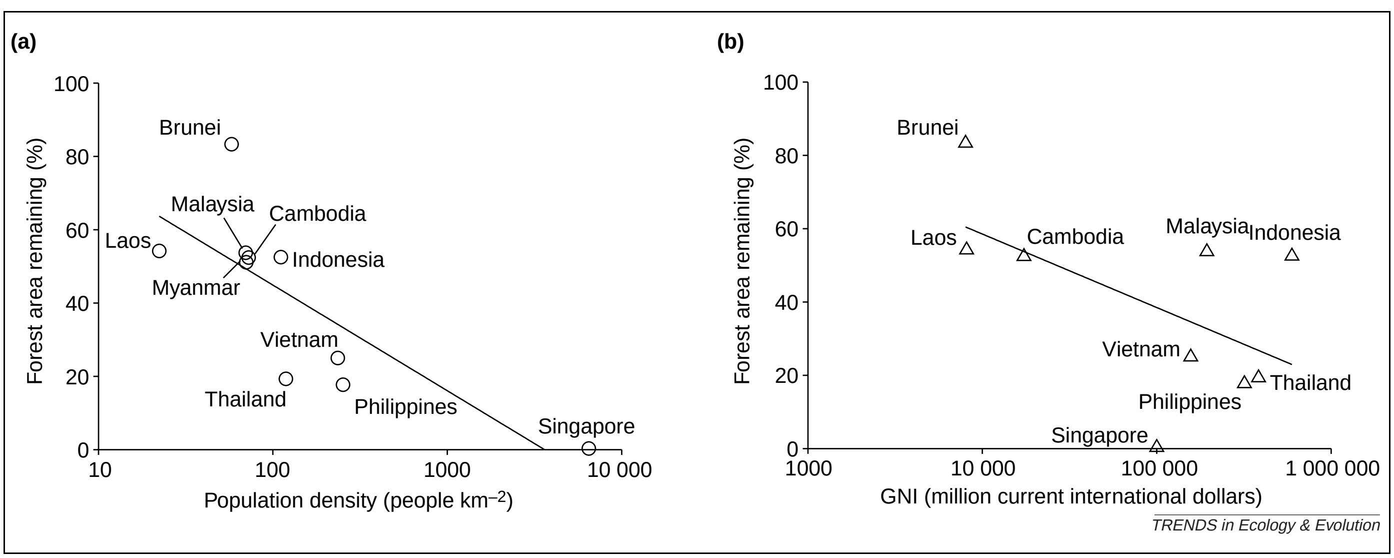

Figure 2. Socioeconomic correlates of forest loss. The proportion of forest area remaining in Southeast Asian countries correlated with **(a)** population density in 2000 ($r=-0.78$, $P=0.008$); and **(b)** Gross National Income (GNI) at current international dollars in 2000 ($r=-0.57$, $P=0.111$) [13]. GNI of Brunei was taken in 1998.

Currently, there are 2262 protected areas in the region, which cover a total land area of 58 million ha (13.4%) (see Online Supplementary Material) [13,67]. More than half of the total cover of these areas is in Indonesia (24 million ha) and Malaysia (10 million ha). Recent studies show that, in spite of their 'protected' status, some of these areas have become increasingly isolated and deforested [68]. For example, from 1985 to 2001, the forest cover of lowland protected areas in West Kalimantan, Indonesia, was reduced by 1.85 million ha (63%). In addition, of the 64 remaining forest fragments, only 16 were considered large enough (>10 000 ha) to support intact vertebrate fauna [68–70]. Protected areas also vary considerably in their degree of effectiveness [71]. Bruner *et al.* showed that the effectiveness of such areas for biodiversity conservation was correlated most strongly with the density of guards [71]. Therefore, the enforcement and management of parks is crucial to the success of protected areas in conserving the native habitats and biodiversity of Southeast Asia.

Conclusion

Massive anthropogenic habitat modifications, forest fires and the overexploitation of wildlife in Southeast Asia are clear-and-present dangers to its biodiversity. In spite of the pessimistic outlook, there are ways to conserve at least some of the regional natural resources. Given that many of the drivers of biodiversity loss (e.g. international demand for rain forest timber and elevated global CO_2 levels) are issues that transcend national boundaries, any realistic solution will need to involve a multi-national and multi-disciplinary strategy, including political, socioeconomic and scientific input, in which all major stakeholders (governmental, non-governmental, national and international organizations) must partake. Key solutions should include enhancing public environmental awareness, delineating adequately protected reserves and providing economic incentives for conservation.

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Supplementary data

Supplementary data associated with this article can be found at doi:10.1016/j.tree.2004.09.006

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