Forest destruction in tropical Asia

William F. Laurance

Smithsonian Tropical Research Institute, Apartado 0843–03092, Balboa, Ancón, Panama, USA

I evaluate trends in forest loss, population size, economic growth, and corruption within 12 nations that contain the large bulk of Asian tropical forests, and contrast these with trends occurring elsewhere in the tropics. Half of the Asian nations have already experienced severe (>70%) forest loss, and forest-rich countries, such as Indonesia and Malaysia, are experiencing rapid forest destruction. Both expanding human populations and industrial drivers of deforestation, such as logging and exotic-tree plantations, are important drivers of forest loss. Countries with rapid population growth and little surviving forest are also plagued by endemic corruption and low average living standards.

Keywords: Asian tropical forests, biodiversity, deforestation, logging, population growth.

FOR biologists, the forests of tropical Asia are, by nearly any measure, among the highest of all global conservation priorities. Tropical Asia (defined here as Southeast Asia, South Asia, and the island of New Guinea) has some of the highest levels of biological diversity and species endemism found anywhere in the world[1]. This extreme biological richness evidently results from the insular nature of the region, from its high habitat diversity, from a complex geological history that combines distinctive biota from tropical Laurasia and Gondwana, and from fluctuating Pleistocene sea levels that facilitated colonization and possibly some speciation events across the region[2,3].

The forests of tropical Asia are also among the most threatened on earth. By 1990, only 18% of all tropical moist forests (rainforest and seasonal forest) in the world occurred in tropical Asia, whereas 58% and 25% occurred in the Americas and Africa, respectively[4]. Moreover, relative rates of tropical deforestation have been about twice as high in Asia (0.8–0.9% per year) than in either Latin America or Africa (0.4–0.5% per year)[5]. Southeast Asia has also suffered higher rates of industrial logging than the other major tropical regions[4] and could lose the bulk of its original forest cover by the end of this century[2]. Because of intense forest conversion and its great biological diversity and uniqueness, the Asian tropical region contains more recognized biodiversity hotspots than any other region on earth[6]. Forest destruction in the region is also a major source of greenhouse gases, emitting an estimated 43.5 billion metric tons of atmospheric carbon emissions by 1995 (ref. 7), and further threatens many natural products and lands on which traditional Asian cultures rely[8].

Here I evaluate trends in deforestation in the tropical Asian region, focusing on closed-canopy forests. I compare surviving forest cover and rates of forest loss among the major forested countries in the region, and contrast these trends with those in other tropical nations in the Americas and Equatorial Africa. I also assess the potential influence of some demographic and economic variables on Asian tropical forests, and highlight some important threats to these forests and their biota.

Datasets

I evaluated changes in forest cover and potentially related demographic and economic variables for 12 countries (Bangladesh, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Papua New Guinea, Sri Lanka, Thailand and Vietnam) that contain the large bulk of all closed-canopy forests in tropical Asia. Small countries (<10,000 km^2 in area) and those that are predominantly non-tropical (e.g. China, Australia) were excluded from the analysis. I also contrasted some trends in the 12 Asian countries with those from 21 tropical nations in the Americas (South and Central America and the Caribbean) and 12 tropical nations in Equatorial Africa (central and western Africa) that were also at least 10,000 km^2 in area and dominated by closed-canopy forests. Several of the datasets I used were initially compiled by Wright and Muller-Landau[9] in a pantropical study of forest-cover trends. Some of the demographic and economic variables described below were not available for all 45 countries used in this analysis, and the analyses were therefore based on available data.

The percentage of original forest cover remaining in each nation was derived by Wright and Muller-Landau[9]. To accomplish this they estimated for each nation the current forest cover, using data from the *Forest Resources Assessment 2000* (ref. 10), and then divided this value by the estimated area of original forest cover, which was generated using satellite imagery and ecosystem-modeling data[11]. Their analysis applies only to closed-canopy forests (with >40% canopy cover and no grass layer). It has two major caveats: (1) the forest inventories used in the analysis were mostly conducted between 1995 and 1999 (and sometimes as early as 1986), and (2) the inventories include all forest cover, including forest that has been logged or fragmented, secondary forest, and exotic tree plantations.

e-mail: laurancew@si.edu

Thus, these values overestimate current forest cover and include forest types other than undisturbed, old-growth forests.

Changes in forest cover in each nation were derived from the *Forest Resources Assessment 2000* (ref. 10). These data were generated by comparing estimated forest cover in the years 1990 and 2000, and are expressed as a percentage. These data suffer from some important limitations, mostly caused by inconsistencies among countries in how and when forest cover was evaluated (see refs 12 and 13 for critiques), but are generally considered the most reliable cross-national estimates available[13].

Population densities (individuals km^{-2}) for each nation were derived for the year 1999, whereas population-growth estimates were for the period 1995–2000, using datasets from the United Nations (UN) Population Division[14]. Data on projected population sizes for tropical nations were taken from the median projection of the UN Population Division (http://esa.un.org/unpp/) for the years 2030 and 2050. To estimate the current population size of Asian nations in 2007, I interpolated between the 1999 data and the median population projection for 2030.

Data on per-capita gross national product (GNP) provide an estimate of typical incomes in each nation, and were taken from the CIA World Factbook (http://www.cia.gov/cia/publications/factbook/geos). Values are standardized to US dollars in 2002. The Corruption Perceptions Index (CPI) provides an index of corruption at a national level, and is generated by the nongovernmental organization Transparency International (http://www.globalcorruptionreport.com) based on questionnaires completed by international business people working in those countries. For the CPI, lower values indicate increasingly pervasive corruption, and higher values indicate less corruption. I used CPI values recorded in 2002.

Changes in forest cover

Total forest cover is already low in a number of tropical Asian nations, even when logged, secondary, and plantation forests are included. Bangladesh has just a tenth (10.2%) of its estimated original cover, whereas the Philippines (19.4%) and India (21.6%) each have just two-tenths. Thailand (28.9%), Sri Lanka (30.0%), and Vietnam (30.2%) each have about three-tenths of their original cover. Forest cover is higher in Myanmar (52.3%), Cambodia (52.9%), Laos (54.4%), Indonesia (58.0%), Malaysia (58.7%), and Papua New Guinea (67.6%).

There is some tendency for the most forest-rich nations to experience the highest relative rates of forest loss, and vice-versa. Forest-poor Bangladesh, India, and Vietnam, with net annual changes of +1.3%, +0.1%, and +0.5%, respectively, are either gaining forest cover or remaining roughly stable. Forest cover is declining in all other Asian tropical nations. Forest-rich Indonesia and Malaysia are rapidly losing their forests (both –1.2% $year^{-1}$), as is Sri Lanka (–1.6% $year^{-1}$) and Myanmar (–1.4% $year^{-1}$). The situation is especially alarming in the Philippines, a forest-poor country with rapid forest loss (–1.4% $year^{-1}$). Forest loss is intermediate in Thailand (–0.7% $year^{-1}$) and Cambodia (–0.6% $year^{-1}$), and lowest in Laos and Papua New Guinea (both –0.4% $year^{-1}$). Overall, the correlation between total forest cover and relative forest loss for the 12 Asian tropical nations is negative but nonsignificant ($r = –0.420$, $P = 0.17$; Pearson correlation).

Population trends and forests

Population densities differ markedly among nations in Asia, Africa and the Americas ($F_{2,42} = 4.21$, $P = 0.022$; One-way ANOVA), being significantly higher on average in Asia ($P < 0.05$; Tukey's test) than in the other two regions. Mean population densities in Asia ($X \pm SD = 213.0 \pm 263.6$ individuals km^{-2}) are roughly 3–5 times higher on average than those in Africa (39.8 ± 27.5 individuals km^{-2}) and the Americas (78.3 ± 92.8 individuals km^{-2}).

These averages, however, disguise great variation among different nations. For example, among Asian tropical nations the population density of Papua New Guinea (10.4 people km^{-2}) is only a tiny fraction of that in Bangladesh (974.2 people km^{-2}) or India (335.7 people km^{-2}). Major forested nations such as Indonesia (115.5 people km^{-2}) and Malaysia (66.4 people km^{-2}) have intermediate densities.

Such differences in population density are probably important, because there is a strong, negative relationship between population density and forest cover among the tropical nations in Asia, Africa, and the Americas (Figure 1). This relationship is highly significant in an analysis of covariance, using log-transformed population densities as a covariate ($F_{1,41} = 174.3$, $P < 0.0001$). The slope term for Africa was somewhat higher than that for Asia ($P = 0.049$) and the Americas ($P = 0.052$), indicating that African populations had a somewhat larger per-capita impact on forests, but there was no significant difference in the Y-intercepts among the three regions ($F_{2,39} = 1.94$, $P = 0.16$).

Not only do tropical nations with dense populations tend to have little forest cover, but those with high population-growth rates also tend to suffer the highest rates of forest loss (Figure 2). This is illustrated by a negative relationship between the population-growth rate and rate of change in forest cover among tropical nations ($r_s = 0.316$, $n = 41$, $P = 0.044$; Spearman rank correlation).

Populations are expected to continue growing markedly in tropical Asia. For the 12 nations used in this analysis, the current total population size of 1.87 billion is expected to rise to about 2.4 billion in the year 2030, and to about 2.6 billion in 2050 (based on the UN median projections). Nations with relatively low population densities, such as

Cambodia, Laos, Malaysia and Papua New Guinea, are currently growing the fastest (Figure 3). Although densely populated, the Philippines is also growing rapidly, and even hyper-populous nations such as India and Bangladesh have quite high growth rates.

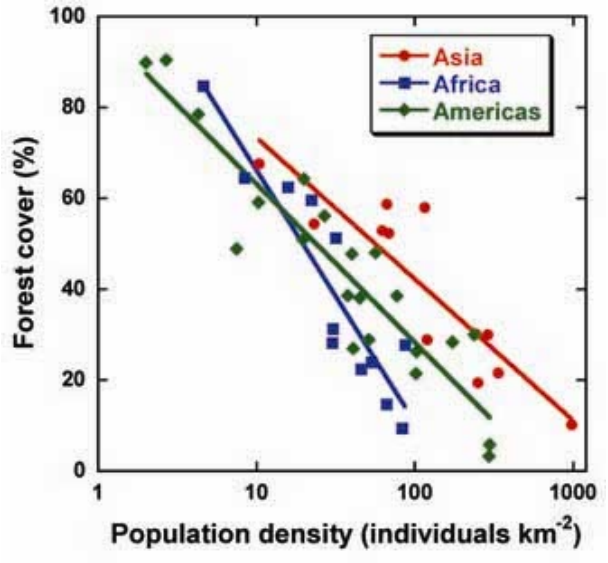

Figure 1. Relationship between human population density and remaining forest cover (including logged or regenerating forests and plantations) for 45 tropical nations in Asia, Africa and the Americas (including the Caribbean). Forest-cover data were derived by Wright and Muller–Landau[9].

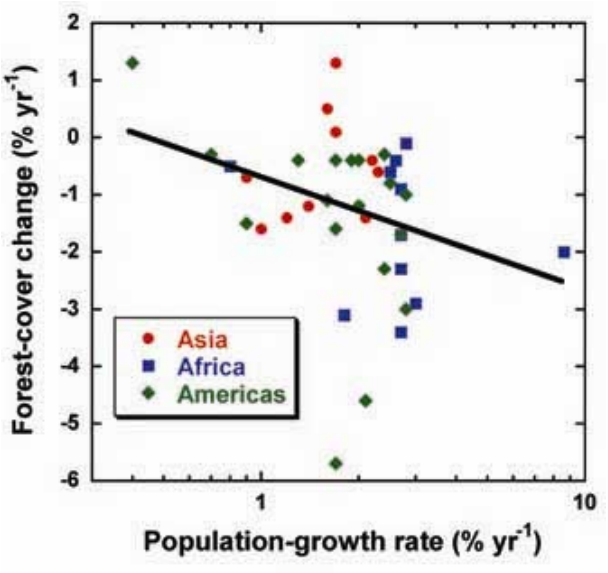

Figure 2. Relationship between annual population-growth rate (1995–2000) and annual change in forest cover (1990–2000) for 45 tropical-forest nations.

Economics and corruption

Tropical countries with the fastest-growing populations tend to be the most corrupt (Figure 4). The relationship between the Corruption Perceptions Index (CPI) and population growth rates (1990–2000) was nearly significant (r = 0.339, P = 0.062; Pearson correlation using 31 countries for which CPI data were available). Notably, with

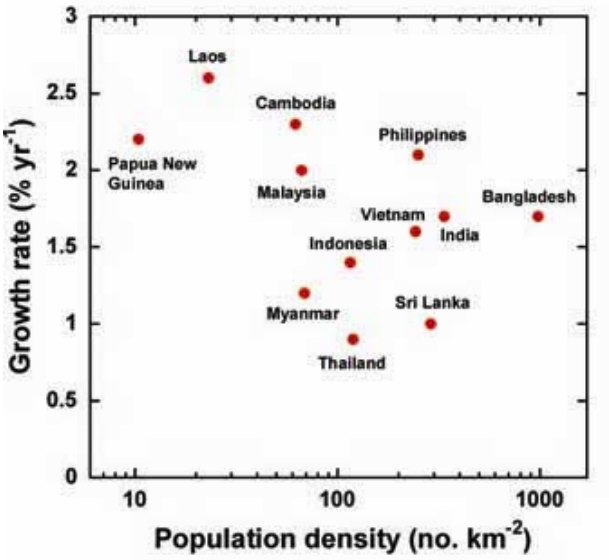

Figure 3. Relationship between human population density (in 1999) and the population-growth rate (1995–2000) for 12 Asian tropical nations. The relationship approaches statistical significance (r_s = 0.501, P = 0.097; Spearman rank correlation).

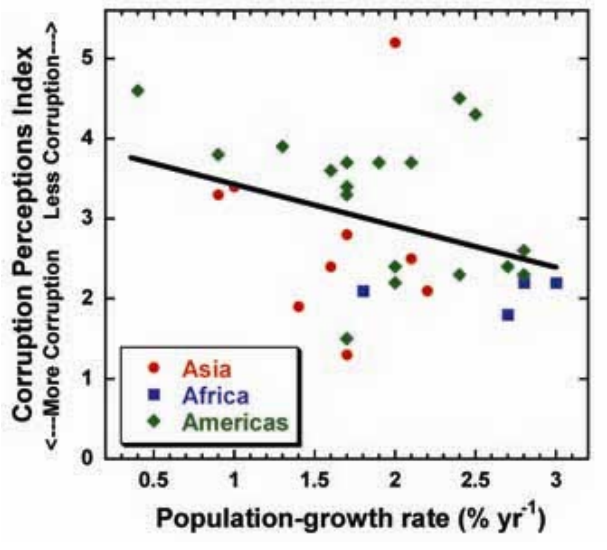

Figure 4. Relationship between the Corruption Perceptions Index (CPI) and the population-growth rate (1995–2000), based on 30 tropical nations for which data were available. Lower values for the CPI indicate greater corruption.

the sole exception of Malaysia (which has a moderate CPI value of 5.2), CPI values were very low (<3.5) for Asian tropical countries for which data were available (Bangladesh, India, Indonesia, Myanmar, the Philippines, Papua New Guinea, Sri Lanka, Thailand and Vietnam), indicating that corruption is considered severe in these nations. In addition, corruption is highest in the poorest countries[15], as demonstrated by a very strong relationship between per-capita GNP and the CPI ($F_{1,28} = 33.29$, $R^2 = 54.3\%$, $P < 0.0001$; linear regression) for tropical nations.

Not surprisingly, tropical countries with the fastest-growing populations tend to be the poorest. This is demonstrated by a significant, negative correlation between per-capita GNP and population growth rate ($r_s = –0.318$, $n = 41$, $P = 0.043$; Spearman rank correlation). For example, the four fastest-growing countries in tropical Asia, Cambodia, Laos, the Philippines and Papua New Guinea have per-capita GNPs of just US$300–1200 per year.

Finally, poor nations tend to have less surviving forest cover than do less-deprived ones (Figure 5), as illustrated by a significant relationship between forest cover and per-capita GNP for 41 nations for which data were available ($F_{1,39} = 4.18$, $R^2 = 9.7\%$, $P = 0.048$; linear regression). This relationship is worrisome because, with the exception of Malaysia and Thailand, Asian tropical nations have low living standards, with per-capita GNP averaging less than US$1200 per year.

Threats to forests in tropical Asia

My study highlights several important patterns and trends that are relevant to forest conservation in tropical Asia. On average, Asian tropical nations have population densities that are 3–5 times higher than those in Equatorial Africa and the tropical Americas. In tropical Asia, as elsewhere in the tropics, population density is strongly and negatively correlated with net forest cover, and positively correlated with current rates of forest loss. Half of the 12 Asian tropical nations I examined have already experienced severe (>70%) deforestation, and several of the remaining countries, such as Indonesia, Malaysia and Myanmar, are losing forests at an alarming pace. The Philippines is unique among Asian nations in having both severe forest loss and continued high rates of forest destruction. Many Asian tropical nations still have rapid population growth, and these nations tend to be poorer, more severely plagued by corruption, and have less surviving forest, than do nations that are growing less rapidly. Overall, the population of tropical Asia is expected to expand from less than 1.9 billion today to perhaps 2.6 billion by the year 2050, and this increase will clearly place severe stresses on surviving forests.

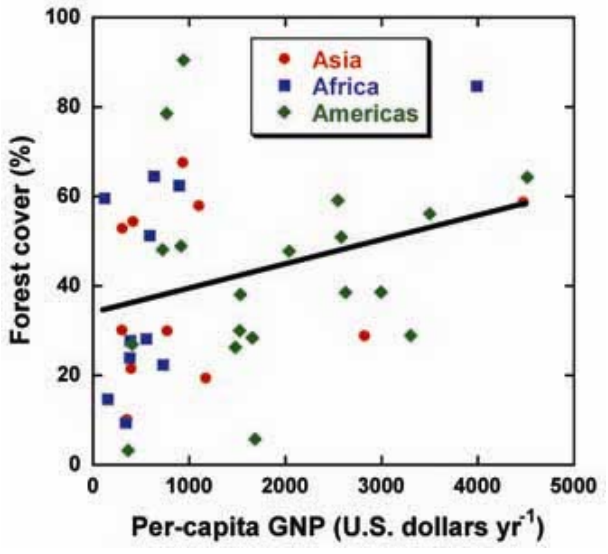

Figure 5. Relationship between per-capita Gross National Product (GNP), an index of economic development, and remaining forest cover, for 41 nations for which data were available.

I detected a strong correlation between human population density and forest cover in tropical nations (Figure 1), as has been demonstrated in other recent studies[9]. This relationship could arise in part because nations with dense populations have many rural residents, who reduce forest cover via slash-and-burn farming[9], and also because the many residents of populous nations place heavy demands on agricultural land, timber, fuel-wood, and other forest products[16]. It is important to emphasize, however, that industrial drivers have clearly increased in importance in recent decades as a proximate cause of tropical forest conversion[17]. In tropical Asia, among the most important of such industrial drivers are selective logging, large-scale plantations of oil-palm and rubber trees and mineral exploitation[2,17,18]. Such activities not only directly destroy or degrade forests, but they also provide a key economic impetus for road-building in forested areas[19,20]. Such roads greatly increase physical accessibility to forests for colonists, hunters and swidden farmers[21,22].

In addition to industrial drivers, economic globalization is also becoming an increasingly important cause of forest conversion[17]. For example, the enormous increase in Chinese demand for timber, palm oil, minerals and other natural resources over the past decade has had a major impact on tropical Asian forests, in part by exacerbating large-scale illegal logging activities in countries such as Myanmar, Indonesia and Papua New Guinea[23]. As industrialization and globalization further increase in tropical Asia, the strong relationship between local population density and forest cover (Figure 1) may begin to weaken, because even sparsely populated countries can be intensively exploited in a globalized world[16].

An important caveat of this study is that the forest-cover estimates I generated for Asian nations include not just old-growth forests but also logged and regenerating forests, as well as exotic-tree plantations. In much of tropi-

cal Asia, old-growth forests are being rapidly replaced by other forest types. According to a recent analysis[24], old-growth forests have nearly vanished in Cambodia, Laos, Myanmar, the Philippines, Singapore and Vietnam, comprising just 0–6.7% of their original forest area (Figure 6). The ecological impacts of logging are particularly severe in tropical Asia because of the large volume of marketable timber in the dominant dipterocarp trees, which promotes high logging intensities[2,3]. Because of chronic overexploitation, major log-exporting countries such as Malaysia and Indonesia are now experiencing timber shortages[25], and their logging corporations are aggressively moving into other developing nations in the tropics[26].

Another caveat is that the great cultural, political and historical diversity of tropical Asia also influences nature conservation, above and beyond the factors examined in this study. In parts of India and Sri Lanka, for example, the survival of some large wildlife species in relatively densely populated areas[21,27] is aided by good environmental laws and traditional societal taboos on hunting[28]. This contrasts with rampant forest and wildlife exploitation in areas of Indonesian Borneo, Sumatra, and New Guinea that are being colonized via transmigration programs[29]. Hence, the environmental impacts of local populations can differ between older, more stable cultures and those in new frontiers; the former may retain some traditional prohibitions against overexploitation of nature whereas the latter are sometimes chaotic and lawless[17].

The future of nature conservation

By virtually any measure, Asian tropical forests are being lost at an alarming pace. Much of the surviving forest cover is already fragmented or degraded[30] (Figure 6). At present rates of conversion, perhaps only a tenth of the original forest will survive by the year 2100, mostly within protected areas[31].

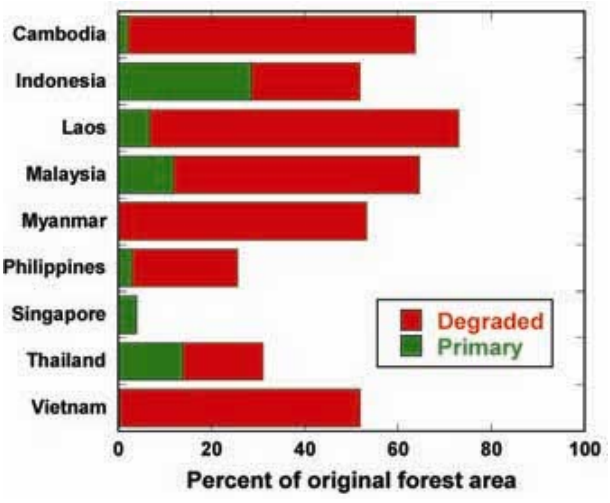

Figure 6. Estimated percentage of degraded and primary forest for selected Asian tropical nations, based on a recent analysis[24]. Degraded forests include logged and secondary forests and plantations.

Can protected areas sustain the biodiversity of tropical Asia? The situation is highly uncertain. Five nations, Cambodia, Indonesia, Laos, the Philippines and Thailand, have nominally protected at least 10% of their original forest cover[24]. However, many protected areas are being isolated[32] and degraded by illegal logging, hunting and other forms of encroachment[33,34]. Some reserves have already collapsed ecologically[33–36]. Protected areas in Peninsular Malaysia and Java are relatively stable, but many in Cambodia, Vietnam, Laos, the Philippines and Indonesian Borneo are seriously imperiled[24,33–36]. Clearly, it will be crucial to bolster and expand the current protected-area network in tropical Asia, and to manage off-park lands more sustainably. The Heart of Borneo initiative, for example, which seeks to maintain ecological connectivity among 22 protected areas across parts of Kalimantan, Sarawak, Sabah, and Brunei[37], could potentially limit the deleterious impacts of reserve isolation and overhunting on biodiversity[38–40]. Ecological restoration could also help to increase the viability of certain degraded reserves[41]. Much will depend upon the success or failure of such initiatives.

Recent debate has focused on the notion that developing nations, as their economies expand, might eventually tend to shift from deforestation to afforestation[9,16,42–45]. This could occur because exploitation of native forests becomes less important as industrialization increases, because nations expand tree plantations to help maintain timber supplies, and because pressure to improve environmental quality rises as people become more affluent[46]. Is such a 'forest transition' likely in tropical Asia, where many economies are now expanding? Several features of Asian tropical nations identified in this study – particularly high population densities and/or high population-growth rates, low per-capita GNP, and high corruption – appear to militate against a forest transition. This is because the poorest and most poorly governed nations appear far less likely to make the forest transition, even after they have depleted their forests[47]. Rather, they simply continue to exploit their last surviving forests, much as is happening in the Philippines, Sri Lanka and Thailand today. This is by no means a prophecy, but it suggests that environmental conditions in tropical Asia are likely to become considerably worse before they begin to get better.

Summary

Tropical Asia has less remaining forest, higher rates of deforestation and logging, and much higher population densities, than do other major tropical regions. In tropical Asian nations, as elsewhere in the tropics, population density is strongly and negatively correlated with net forest

cover and positively correlated with current rates of forest loss. Half (6/12) of the Asian nations I evaluated have already experienced severe (>70%) deforestation, and several of the remaining countries, such as Indonesia, Malaysia and Myanmar, are losing forests at an alarming rate. Even where forests survive they are often logged, fragmented or otherwise degraded. Many Asian tropical nations still have rapid population growth, and these countries tend to be poorer and more beset by corruption than those that are growing less rapidly. Overall, the population of tropical Asia is expected to expand from less than 1.9 billion today to perhaps 2.6 billion by the year 2050, and this will place further stresses on remaining forests. In addition to continued population growth, rapidly expanding industrialization and globalization in Asia are having increasingly important impacts on native forests. Endemic corruption, especially in the timber industry, is further complicating efforts to promote environmental sustainability. Because of its remarkably high species richness and endemism, the rapid loss and degradation of forests will likely have serious impacts on Asian biodiversity.

1. Mittermeier, R. A. *et al*., *Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*, Cemex, Conservation International and Agrupacion Sierra Madre, 1999.
2. Sodhi, N. S., Koh, L. P., Brook, B. W. and Ng, P. K. L., Southeast Asian biodiversity: an impending catastrophe. *Trends Ecol. Evol*., 2004, **19**, 654–660.
3. Corlett, R. T. and Primack, R. B., Tropical rainforests and the need for cross-continental comparisons. *Trends Ecol. Evol*., 2006, **21**, 104–110.
4. Whitmore, T. C., Tropical forest disturbance, disappearance, and species loss. In *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities* (eds Laurance, W. F. and Bierregaard, R. O.), University of Chicago Press, Chicago, USA, 1997, pp. 3–12.
5. Mayaux, P. *et al*., Tropical forest cover change in the 1990s and options for future monitoring. *Philos. Trans. R. Soc. B*, 2005, **360**, 373–384.
6. Myers, N. *et al*., Biodiversity hotspots for conservation priorities. *Nature*, 2000, **403**, 853–858.
7. Zhao, S. *et al*., Land use change in Asia and the ecological consequences. *Ecol. Res*., 2006, **21**, 890–896.
8. Sodhi, N. S. *et al*., Biodiversity and human livelihood crises in the Malay Archipelago. *Conserv. Biol*., 2006, **20**, 1811–1813.
9. Wright, S. J. and Muller-Landau, H., The future of tropical forest species. *Biotropica*, 2006, **38**, 287–301.
10. FAO, Global Forest Resource Assessment 2000 – Main Report, FAO Forestry Paper 140, United Nations Food and Agricultural Organization, New York, 2000.
11. Ramankutty, N. and Foley, J. A., Estimating historical changes in global land cover: croplands from 1700 to 1992. *Glob. Biogeochem. Cycles*, 1999, **13**, 997–1027.
12. Fearnside, P. M., Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. *Clim. Change*, 2000, **46**, 115–158.
13. Matthews, E., *Understanding the FRA 2000*, World Resources Institute, Washington, DC, 2000.
14. United Nations, *World Population Prospects: The 2001 Revision*, Department of Economic and Social Affairs, Population Division, New York, 2001.
15. Laurance, W. F., The perils of payoff: corruption as a threat to global biodiversity. *Trends Ecol. Evol*., 2004, **19**, 399–401.
16. Laurance, W. F., Have we overstated the tropical biodiversity crisis? *Trends Ecol. Evol*., 2007, **22**, 65–70.
17. Rudel, T. K., *Tropical Forests: Regional Paths of Destruction and Regeneration in the Late Twentieth Century*, Columbia University Press, Chichester, UK, 2005.
18. Leimgruber, P. *et al*., Forest cover change patterns in Myanmar (Burma) 1990–2000. *Environ. Conserv*., 2005, doi:10.1017/S0376892905002493.
19. Fearnside, P. M., Protection of mahogany: a catalytic species in the destruction of rain forests in the American tropics. *Environ. Conserv*., 1997, **24**, 303–306.
20. Laurance, W. F. and Peres, C. A. (eds), *Emerging Threats to Tropical Forests*, University of Chicago Press, Chicago, USA, 2006.
21. Corlett, R. T., The impact of hunting on the mammalian fauna of tropical Asian forests. *Biotropica*, 2007, **39**, 292–303.
22. Laurance, W. F., Tropical logging and human invasions. *Conserv. Biol*., 2001, **15**, 4–5.
23. Laurance, W. F., The dragon and the rainforest. *Tropinet*, 2007, **18(1)**, 1–2.
24. Wright, S. J. *et al*., The future of Southeast Asian forests and their species. In *Prepare for Impact! When People and the Environment Collide in the Tropics* (eds Stacey, N., Campbell, B., Boggs, G., and Steffen, W.), Charles Darwin University Press, Darwin, Australia, in press.
25. Toni, A., An overview of Asian companies, in particular Malaysian companies, Greenpeace (http://archive.greenpeace.org/comms/97/forest/asian_companies_executive_summary.html)
26. Laurance, W. F., Cut and run: the dramatic rise of transnational logging in the tropics. *Trends Ecol. Evol*., 2000, **15**, 433–434.
27. Johnsingh, A. T. J. and Negi, A. S., Status of tiger and leopard in Rajiji-Corbett Conservation Unit, northern India. *Biol. Conserv*., 2003, **111**, 385–393.
28. Sekhsaria, P., Conservation in India and the need to think beyond 'tiger vs tribal'. *Biotropica*, 2007, **39**, 575–577.
29. Fearnside, P. M., Transmigration in Indonesia: lessons from its environmental and social impacts. *Environ. Manage*., 1997, **21**, 553–570.
30. Stibig, H.-J. *et al*., A land-cover map for South and Southeast Asia derived from SPOT-VEGETATION data. *J. Biogeogr*., 2007, **34**, 625–637.
31. Sodhi, N. S., Koh, L. P. and Brook, B. W., Southeast Asian birds in peril. *Auk*, 2006, **123**, 275–277.
32. DeFries, R. Hansen, A., Newton, A. C. and Hansen, M. C., Increasing isolation of protected areas in tropical forests over the past twenty years. *Ecol. Appl*., 2005, **15**, 19–26.
33. Curran, L. M. *et al*., Lowland forest loss in protected areas of Indonesian Borneo. *Science*, 2004, **303**, 1000–1003.
34. MacKinnon, K., Megadiversity in crisis: politics, policies, and governance in Indonesia's forests, In *Emerging Threats to Tropical Forests* (eds Laurance, W. F. and Peres, C. A.), University of Chicago Press, Chicago, USA, 2006, pp. 291–305.
35. Smith, J., Obidzinski, K., Subarudi, I. and Suramenggala, I., Illegal logging, collusive corruption and fragmented governments in Kalimantan, Indonesia. *Int. For. Rev*., 2003, **5**, 293–302.
36. Wright, S. J., Sanchez-Azofeifa, A., Portillo-Quintero, C. and Davies, D., Poverty and corruption compromise tropical forest reserves. *Ecol. Appl*., 2007, **17**, 1259–1266.
37. ATBC, Resolution concerning the 'Heart of Borneo' transboundary conservation initiative. Association for Tropical Biology and Conservation (www.atbio.org), Washington, DC, 2006.
38. Sodhi, N. S., Lee, T. M., Koh, L. P. and Prawiradilaga, D. M., Long-term avifaunal impoverishment in an isolated woodlot. *Conserv. Biol*., 2006, **20**, 772–779.

39. Brook, B. W., Sodhi, N. S. and Ng, P. K. L., Catastrophic extinctions follow deforestation in Singapore. *Nature*, 2003, **424,** 420–423.
40. Laurance, W. F. *et al*., Ecosystem decay of Amazonian forest fragments: a 22-year investigation. *Conserv. Biol*., 2002, **16**, 605–618.
41. Lamb, D., Erskine P. D. and Parrotta, J. D., Restoration of degraded tropical forest landscapes. *Science*, 2005, **310**, 1628–1632.
42. Rudel, T. K., Is there a forest transition? Deforestation, reforestation, and development. *Rural Sociol*., 1998, **63**, 533–552.
43. Dinda, S., Environmental Kuznets curve hypothesis: a survey. *Ecol. Econ*., 2004, **49**, 431–455.
44. Bhattarai, M. and Hammig, M., Governance, economic policy, and the environmental Kuznets curve for natural tropical forests. *Environ. Dev. Econ*., 2004, **9**, 367–382.
45. Barbier, E. B., Agricultural expansion, resource booms and growth in Latin America: implications for long-run economic development. *World Dev*., 2004, **32**, 137–157.
46. Rudel, T. K. *et al*., Forest transitions: towards a global understanding of land use change. *Global Environ. Change*, 2005, **15**, 25–31.
47. Ewers, R. M., Interaction effects between economic development and forest cover determine deforestation rates. *Global Environ. Change*, 2006, **16**, 161–169.

ACKNOWLEDGEMENTS. I thank Richard Corlett, Navjot Sodhi, Mark Ashton, Robert Ewers, and John Withey for commenting on the manuscript, and Joseph Wright and Helene Muller-Landau for kindly providing access to their datasets.