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When People and Environment Collide in the Tropics

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3. The Future of Southeast Asian Forests and their Species

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Introduction
Southeast Asia faces a widely recognized biodiversity crisis. The crisis has two principal causes. The first is habitat loss caused by land use change and, in particular, by the conversion of forested lands to agriculture (Myers et al. 2000, Brooks et al. 2002). Land use conversion affects all species that depend on forest habitats. The second principal cause of the Southeast Asian biodiversity crisis concerns the direct persecution of animals for meat, for the pet trade, and for their mystical value in several cultures (Corlett 2007). Habitat loss and direct persecution threaten many Southeast Asian forest species with local, regional and even global extinction (Sodhi et al. 2004). The Southeast Asian biodiversity crisis has been exacerbated by the spectacular collapse of a number of forest reserves (e.g., Smith et al. 2003, Curran et al. 2004). The conspicuous failure of nature reserves heightens the sense of crisis against the backdrop of high rates of deforestation and unsustainable rates of harvest of many game species.

The potential loss of species through their global extinction is nowhere greater than in Southeast Asia due to the high levels of endemism in the region (Sodhi et al. 2004). Myers et al. (2000) identify 25 global hotspots of endemism. Each hotspot contains at least 0.5% or 1,500 of the world’s 300,000 plant species as endemics that are found nowhere else. The eleven countries of Southeast Asia are, with the sole exception of Indonesian New Guinea, entirely included inside four of the hotspots. The hotspot of Sundaland includes Brunei, Malaysia, Singapore and the large Indonesian islands of Sumatra, Java and Borneo. The hotspot of Wallacea includes Timor-Leste and the other large Indonesian islands. The hotspot of the Philippines includes the country with the same name. And, the hotspot of IndoBurma includes all of Viet Nam, Laos, Cambodia, Thailand, and Myanmar with small extensions into tropical southern China, Indian Assam and along the foothills of the Himalayas to Nepal Altogether 29,332 plant species or 9.7% of the global total and 2,276 terrestrial vertebrate species or 8.3% of the global total are endemic to just one of these four hotspots (Myers et al. 2000). A conservation crisis that extends across these four Southeast Asian hotspots has serious implications for the preservation of global biodiversity.

Here, we will examine the first and most pervasive cause of the present-day biodiversity crisis in Southeast Asia — habitat loss — and estimate the proportion of forest endemic species threatened with extinction as a consequence. To accomplish this, we will first review past levels of forest loss in Southeast Asia, examine characteristics of the forest that remains in Southeast Asia today, and explore three possible scenarios for future changes in forest cover. We will also consider alternative assumptions about the habitat requirements of species that influence their vulnerability to extinction in light of ongoing forest loss and the characteristics of the forests that remain in Southeast Asia today and are expected to remain in the future. The different scenarios and assumptions lead to very different — albeit all tragically high — estimates of the proportion of species threatened with extinction today and in 2030. The uncertainty in these estimates highlights the critical need to resolve certain unknowns to help ensure that scarce conservation resources are deployed most effectively. Our country-specific analyses of remaining total and primary forest area, the rate of

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change of total and primary forest area, and the area and effectiveness of nature reserves also lead us to specific suggestions for where conservation investments are most urgently needed today.

A tool to quantify species extinctions caused by land use change

Conservation biologists use a nearly universal relationship between the area (A) of a habitat and the number of species (S) found there to predict numbers of endemic species threatened with extinction when land use change reduces habitat area (Pimm et al. 1995; Brooks et al. 2002). This relationship is well described by a power function, \( S = cA^z, \) where \( c \) and \( z \) are empirically determined constants. When land use change occurs, species dependent on the diminished habitat face a reduction in \( A \) from its original value, \( A_{\text{original}} \), to a new and lower value, \( A_e \). Thus, the original species area relationship, \( S_{\text{original}} = c A_{\text{original}}^z, \) is replaced with a new altered species area relationship, \( S_e = c A_e^z \), which implies a new lower number of species. Dividing the new relationship by the original relationship, we can predict the proportion of endemic species expected to survive in the newly reduced area of habitat as follows:

\[
S_e/S_{\text{original}} = (A_e/A_{\text{original}})^z
\]  

(1)

We will use Equation 1 as a heuristic tool to predict the proportion of Southeast Asian endemic species that will survive given different future values of \( A_e \). We will calculate the original, pre-agricultural area of forest, \( A_{\text{original}} \), from a 5-minute resolution global vegetation cover map derived from the 1-km resolution DISCover landcover data set supplemented, where crops dominate landcover, by the BIOME3 vegetation cover model (Haxeltine and Prentice 1996; Loveland and Belward 1997; Ramankutty and Foley 1999). The value of \( z \) falls between 0.25 and 0.35 in many studies, with values close to 0.25 being typical for fragmented landscapes created by land use change.

We will use several different values of \( A_e \) to complete Equation 1. The values of \( A_e \) will reflect three future scenarios for the extent of forest loss and a range of assumptions concerning the dependence of endemic species on different forest types. The three future scenarios for the extent of forest loss will be described later (see Scenarios for future changes in forest cover). The two forest types will contrast the original, undisturbed primary forest and human-altered forests. We will allow the proportion (P) of endemic species dependent on primary forest to vary continuously from 0 to 1. We will assume that the remaining endemic species (a proportion equal to 1-P) are also able to tolerate human-altered forests but not croplands. Land use change will never threaten species able to tolerate croplands and towns. To incorporate this habitat dependence, we will partition \( A_e \) into undisturbed, primary forest \( (A_{\text{primary}}) \) versus disturbed, logged forests plus naturally regenerating secondary forests \( (A_{\text{secondary}}) \) so that \( A_e = A_{\text{primary}} + A_{\text{secondary}} \). The proportion of endemic species expected to survive in the new mixture of habitats follows:

\[
S_e/S_{\text{original}} = P \times (A_{\text{primary}}/A_{\text{original}})^z + (1-P) \times (A_{\text{secondary}}/A_{\text{original}})^z
\]  

(2)

The complements of Equations 1 and 2 are the proportions of endemic species threatened with global extinction due to land use change and habitat loss.

Three caveats qualify the application of Equations 1 and 2 to predict species loss. First, the threat to Southeast Asian species will be underestimated because habitat loss is just one, albeit the most important, of several drivers contributing to the Southeast Asian biodiversity crisis (Sodhi et al. 2004). Second, the threat will be overestimated because an unknown proportion of endemic species are able to tolerate croplands and towns and will not be threatened by land use change. Finally, complications are introduced when land use change divides the remaining habitat into many small fragments. Small fragments of habitat spread widely over the original forested area will include the ranges of more species than will a single block of habitat of the same total area; however, a single, large block of habitat has greater potential to maintain species with large territories or large minimum viable population sizes. Our and other regional applications of Equation 1 to predict species loss ignore these complications (e.g., Pimm et al. 1995; Brooks et al.)

2002] These caveats emphasise our intent to use Equations 1 and 2 as heuristic tools to compare conservation outcomes under different scenarios and thereby to isolate critical areas where additional knowledge is required to invest conservation resources effectively.

Present day forest loss and the threat of extinction in Southeast Asia

1. Total forest cover today – a first prediction

Over the past 300 years, the development of cropland in Southeast Asia has come almost exclusively from the conversion of formerly forested lands to become cropland (Figure 1). There was a very low level of conversion between 1700 and 1850; however, since 1850 forest conversion to cropland has increased at an exponential rate. If we had no other information than that provided in Figure 1, Equation 1 would predict that 10.5% = \( 1 - (A_{\text{2000}}/A_{\text{1850}})^{0.273} \) of the endemic species of Southeast Asia would eventually become extinct due to past reductions in forest area. Of course, the total forest area graphed in Figure 1 includes not only primary forest but also secondary forest and plantations, and thus would lead to underestimates of extinction rates for species that require the original primary forest cover. The exponential increase in land use conversion since 1850 is also cause for serious concern should it continue into the future. We now address these issues.

2. Primary forest cover today – a refined prediction

The United Nations Food and Agriculture Organization (FAO) characterizes present-day forest resources as being primary forest, modified natural forest, semi-natural forest, or plantations for 203 countries and protectorates including the 11 Southeast Asian countries (Table 1). Primary forest includes forests of native trees * where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed * The endnotes to Table 1 provide the FAO definitions of each forest category with examples.

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Figure 1: Changes in Southeast Asian land cover since 1700. Crops have increased at the expense of forest. Data from the FAO (2005) for forest cover in 2000

Before the total aggregate numbers in Table 1 can be used to evaluate the Southeast Asian biodiversity crisis, a correction must be made for the Indonesian portion of New Guinea. New Guinea is biogeographically linked to Australia, was connected to Australia repeatedly during Pliocene glaciations, and is separated by deep oceanic waters from Wallacea and the rest of Southeast Asia. Indonesian New Guinea supports 415,000 km² of forest cover. The FAO reports no modified natural forest for Indonesia (Table 1). The intense management that characterizes semi-natural forest and plantations (see footnotes to Table 1) is unlikely in Indonesian New Guinea where human population density is just 6.2 people km². We will therefore assume that the entire forest cover of Indonesian New Guinea is primary forest. This assumption is conservative with respect to the Southeast Asian biodiversity crisis because it removes the entire forest cover of Indonesian New Guinea from the primary forest cover for Southeast Asia. Just 204,790 km² of primary forest cover remains in Southeast Asia after making this correction.
We can now use Equation 2 and the total aggregate figures in Table 1 corrected by removing Indonesian New Guinea to predict the loss of endemic species from Southeast Asian forest caused by land use conversion. The potential forest cover (or $A_{\text{potential}}$) for the region after removing Indonesian New Guinea is 3,619,110 km$^2$ (Table 1). Thus, Equation 2 predicts that past forest loss threatens the eventual extinction of 51% of the Southeast Asian endemic species that require primary forest to survive. The situation is less dire for endemic species able to tolerate human altered forests. We include modified natural and semi-natural forest cover as suitable habitat for these more tolerant species and exclude plantations because most plantations consist of single introduced tree species. Henceforth, we will use secondary forest to refer collectively to modified natural and semi-natural forests. The percentage of species threatened with extinction decreases from 51% to 45%, 39%, 32%, 26% and 19% as the percentage of species tolerant of secondary forests increases from 0% to 20%, 40%, 60%, 80% and 100%, respectively.

<table>
<thead>
<tr>
<th>Country</th>
<th>Potential Forest Cover (km$^2$)</th>
<th>Forest cover in 2005</th>
<th>Total Forest (km$^2$)</th>
<th>Primary Forest (km$^2$)</th>
<th>Modified Natural Forest (km$^2$)</th>
<th>Semi-Natural Forest (km$^2$)</th>
<th>Plantations (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brunei</td>
<td>5,270</td>
<td>104,470</td>
<td>104,660</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cambodia</td>
<td>164,000</td>
<td>104,470</td>
<td>104,660</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1,708,000</td>
<td>884,960</td>
<td>884,960</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Laos (Lao PDR)</td>
<td>221,000</td>
<td>164,420</td>
<td>164,420</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Malaysia</td>
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<td>208,900</td>
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<td>Philippines</td>
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<td>71,620</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Singapore</td>
<td>510</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thailand</td>
<td>469,000</td>
<td>145,200</td>
<td>145,200</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Timor-Leste</td>
<td>14,870</td>
<td>7,980</td>
<td>7,980</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Viet Nam</td>
<td>249,000</td>
<td>129,310</td>
<td>129,310</td>
<td>850</td>
<td>101,510</td>
<td>0</td>
<td>26,850</td>
</tr>
<tr>
<td>Total</td>
<td>4,039,650</td>
<td>2,033,870</td>
<td>2,033,870</td>
<td>713,560</td>
<td>518,910</td>
<td>518,910</td>
<td>125,610</td>
</tr>
</tbody>
</table>

The percentage of endemic species predicted to become extinct varies by nearly three-fold from 19% to 51% depending upon the percentage of those species able to tolerate human altered forests. This last difference highlights the need to understand species responses to habitat degradation and to move beyond the simplistic assumption that all species require undisturbed, primary forest. Of course, forest cover is not static, which leads to future scenarios for forest cover change.

**Future forest loss and the threat of extinction in Southeast Asia**

1. Scenarios for future changes in forest cover

   We will use three different scenarios to project forest cover forward from 2005 to 2030. The first scenario is the "business as usual" scenario proposed by N. Sodhi, B. Brook and their colleagues (Sodhi et al. 2004; Brook et al. 2006). They assume "the annual percentage rate of forest loss (l) remains constant" to project future Southeast Asian forest loss. Thus, with $l$ expressed as a proportion, the area of forest remaining in 2030 ($A_{2030}$) equals $A_{2005} \times (1 - l)$. Brook et al. (2006) use a Southeast Asian wide annual percentage rate of forest loss of 1.4%. Thus, the "business as usual" scenario predicts a further decline in forest area of nearly 30% [$= 1 - (1 - l)^{25}$] by 2030.

The two remaining scenarios project future forest cover from predicted changes in human population density and present-day relationships between forest cover and human population density (Wright and Muller-Landau 2006a). Figure 2 presents the relationship between potential forest cover remaining in 2000 and rural population density in 2000 for Southeast Asian and neighboring tropical countries. The neighboring countries extend the observed range of population density, and their inclusion improves the proportion of variation explained by the relationship without altering the form of the relationship. We will use this relationship and also the similar relationship with total (urban + rural) population density to project forest cover forward from 2005 to 2030. We emphasise that we repeat these projections for both rural and total (urban + rural) population densities (Wright and Muller-Landau 2006a). The argument for using rural population density is that rural people clear forests, and, perhaps even more importantly, rural people maintain open landscapes by preventing natural secondary succession that would quickly re-establish forest cover in humid Southeast Asia. The argument for projecting future forest cover using total (urban + rural) population density is that it is ultimately demand for food and other products that drives deforestation, and that this demand arises from the total population. The percentage of Southeast Asian living in urban settings was 15% in 1990 and 39% in 2000 and is predicted to rise to 61% in 2030 (Census 3; United Nations 2004). This increase in urbanisation raises the possibility that urban demand for food and other products could contribute more to deforestation at sites remote from urban centers in the future as the ratio of urban to rural population densities increases. Thus, we repeat our projections of future forest cover using both the predicted increase in rural population density and the predicted increase in total (urban + rural) population density. The United Nations Population Division has predicted both rural and total urban population change for every member country forward to 2030 (United Nations 2004). To project future forest cover for Southeast Asia, we will first use the population changes predicted for 2030 for each country to project future forest cover from the present-day relationships between forest cover and both rural and total (urban + rural) population density and then sum the country-level values (Wright and Muller-Landau 2006a). A crucial question remains, which is how to project changes in primary as well as total forest cover into the future.

2. Changes in primary forest cover from 1990-2005

   Past changes in primary forest cover might suggest how to project future changes in primary forest cover. The FAO (2006) reports the area of primary forest present in each Southeast Asian country in 1990, 2000 and 2005 (Table 2). The value reported for Singapore is an order of magnitude higher than the value normally accepted for primary forest in Singapore (Corlett 1992). This suggests that all secondary forest has been included. It is widely believed that prehistoric human activities altered most tropical forests (reviewed by Wright and Muller-Landau 2006a), and it is reasonable to assume that the FAO data for primary forests include all secondary forests as well as pristine primary forests for most countries. Henceforth, we will use primary forest as defined by the FAO
The primary forest cover remaining and its loss between 1990 and 2005 varied widely among the eleven Southeast Asian countries (Table 2). Myanmar, Singapore and Timor-Leste lacked or virtually lacked primary forest in 1990. Cambodia and Viet Nam are on track to join these countries. Primary forest covered 4.7% of its pre-agricultural area in Cambodia in 1990 and 58% of this was lost by 2005. Primary forest covered just 1.5% of its pre-agricultural area in Viet Nam in 1990 and a stunning 78% of this was lost by 2005. Indonesia has the largest intact forest resource base in Southeast Asia, and an intermediate rate of loss. Primary forest covered 41% of its pre-agricultural area in 1990 and declined by 31% by 2005. Indonesian primary forest is largely in New Guinea, and we are unable to separate Indonesian New Guinea from the 15-year record of primary forest cover change in Table 2. This period saw large forest losses in Borneo and Sumatra, however (Smith et al. 2003, Curran et al. 2004), so much of this change fell within Southeast Asia. The five remaining countries offer more reason for hope. Primary forest covered 59% of its pre-agricultural area in Brunei in 1990 and 11% of this was lost by 2005. Finally, the Lao People’s Democratic Republic, Malaysia, the Philippines and Thailand reported modest amounts of primary forest in 1990, which ranged from 3% to 14% of pre-agricultural forest area and no loss of primary forest over the next 15 years (Table 2). Primary forest will take centuries to regenerate, and its ongoing loss is a conservation tragedy in Indonesia and Brunei and particularly in Cambodia and Viet Nam.

These recent observed changes in primary forest area suggest country-specific projections of future primary forest area. This approach will be difficult to implement, however, because Indonesian New Guinea, which contributes more than half of the primary forest cover of the 11 Southeast Asian countries, cannot be isolated from the Indonesian data (Table 2). We will therefore consider the role played by forest reserves in each country.

3. Forest reserves and primary forest cover

Effective forest reserves will prevent the loss of primary forests within their boundaries. This raises two questions relevant to projections of future primary forest cover in Southeast Asia: First, do the forest reserves of Southeast Asia support primary forest? And, second, are they effective?

Several Southeast Asian countries have impressive systems of nationally and internationally recognised forest reserves (Table 3). The World Conservation Union and the United Nations Environment Program synthesize information on all protected natural areas in the World Data Base on Protected Areas (WDPA Consortium 2004). The WDPA is incomplete, but is the best globally comprehensive data available on protected areas. Wright et al. (in review) used Geographic Information Software to superimpose the global distribution of 14 biomes (Olson et al. 2001) onto the boundaries of every reserve included in the WDPA. Table 3 includes all Southeast Asian reserves whose boundaries are defined in the WDPA and that include tropical or subtropical coniferous, dry broadleaf or moist broadleaf forest biomes. Myanmar has another 31 reserves whose boundaries are not yet included in the WDPA. Indonesia, the Philippines, Thailand and Viet Nam are among the top ten tropical countries for numbers of forest reserves, and Indonesia and Thailand are among the top ten for the area of forest protected. Although the WDPA is incomplete, these top rankings are unlikely to change. Cambodia, Indonesia, the Lao People’s Democratic Republic, the Philippines and Thailand have all protected more than 10% of their potential, pre-agricultural forest area, and Viet Nam has protected more than 8% (Table 3). This represents a remarkable commitment to conservation.
Table 3: The forest reserves of Southeast Asia. Number of Reserves refers to reserves that include tropical coniferous, dry broadleaf or moist broadleaf forest whose boundaries are listed in the World Data Base on Protected Areas. Number Rank is the ranked value of Number of Reserves among 70 countries with reserves that meet these criteria. Area is the summed area of forest in those reserves. Area Rank is the ranked value of Area among the same 70 countries. Percentage of Potential Forest Area equals Area divided by Potential Forest Cover (Table 1). Ratio of Reserve Area to Primary Forest Area equals Area divided by Primary Forest Cover in 2005 (Table 1).

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Reserves</th>
<th>Number Rank (of 70)</th>
<th>Area of Reserves (km²)</th>
<th>Area Rank (of 70)</th>
<th>Percentage of Potential Forest Area</th>
<th>Ratio of Reserve Area to Primary Forest Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brunei</td>
<td>7</td>
<td>39</td>
<td>81</td>
<td>65</td>
<td>1.54</td>
<td>0.029</td>
</tr>
<tr>
<td>Cambodia</td>
<td>30</td>
<td>19</td>
<td>45,045</td>
<td>11</td>
<td>27.5</td>
<td>14.0</td>
</tr>
<tr>
<td>Indonesia</td>
<td>204</td>
<td>1</td>
<td>181,414</td>
<td>2</td>
<td>10.6</td>
<td>0.372</td>
</tr>
<tr>
<td>Lao PDR</td>
<td>21</td>
<td>21.5</td>
<td>36,873</td>
<td>12</td>
<td>16.7</td>
<td>2.47</td>
</tr>
<tr>
<td>Malaysia</td>
<td>23</td>
<td>20</td>
<td>11,377</td>
<td>25</td>
<td>3.51</td>
<td>0.298</td>
</tr>
<tr>
<td>Myanmar</td>
<td>3</td>
<td>52.5</td>
<td>2,080</td>
<td>44</td>
<td>0.344</td>
<td>-</td>
</tr>
<tr>
<td>Philippines</td>
<td>155</td>
<td>2</td>
<td>33,512</td>
<td>14</td>
<td>12.0</td>
<td>4.04</td>
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<tr>
<td>Thailand</td>
<td>102</td>
<td>5</td>
<td>66,784</td>
<td>6</td>
<td>14.2</td>
<td>1.04</td>
</tr>
<tr>
<td>Viet Nam</td>
<td>78</td>
<td>9</td>
<td>20,103</td>
<td>19</td>
<td>8.07</td>
<td>2.37</td>
</tr>
</tbody>
</table>

What type of forest is found inside these reserves? The final column of Table 3 presents the ratio of the summed areas of reserves that overlap forest biomes to the area of primary forest in 2005 for each country. The forest reserves of Cambodia and Viet Nam are 14-fold and 23-fold larger than the area of primary forest in 2005, respectively. The forest reserves of the Lao People’s Democratic Republic and the Philippines are 2.5-fold and 4-fold larger than the area of primary forest in 2005, respectively. Reserves in these four countries include mostly human-altered forests. On the other hand, the forest reserves of Brunei, Indonesia, Malaysia and Thailand might protect largely primary forests.

There is widespread concern that these reserves are paper parks unable to protect the forests within their boundaries. Wright et al. (in review) assessed the effectiveness of Southeast Asian forest reserves by superimposing reserve boundaries and daily satellite-based fire detections provided for the entire globe by the Moderate Resolution Imaging Spectroradiometer (Justicz et al. 2002). Many human activities increase the low background frequency of fire in tropical forests. These activities include logging, which increases fuel loads; forest fragmentation, which increases the number of fire-prone forest edges; and agriculture, which involves fire to clear and manage land. A simple visual comparison of the number of fires detected inside forest reserves and just outside those reserves provides a first indication of the level of success of those reserves. Figures 4, 5 and 6 present every fire detected in 2002, every protected area registered in the World Data Base on Protected Areas (WDPA Consortium 2004), and the distribution of biomes following Olson et al. (2001) for Cambodia, Malaysia and Indonesian Borneo and Java, respectively. The large number of fires inside several forest reserves and the general lack of any inhibitory effect of reserves on the number of fires suggest that Cambodian reserves are failing (Figure 4). There are virtually no fires inside Malaysian forest reserves, and Malaysia provides a stellar example of what should be possible in all Southeast Asian countries (Figure 5). The reserves of Indonesian Borneo are widely recognized to be in crisis (Smith et al. 2003; Curran et al. 2004) and the fire numbers confirm this (Figure 6). Two reserves in eastern Java with very large numbers of fires include active volcanoes that trigger the satellite-based fire detection algorithm repeatedly. Otherwise, Javan reserves approach the standard for success set by Malaysia (Figure 6). The very high numbers of fires in reserves in Cambodia and Borneo are also observed in Guatemala, Paraguay and Sierra Leone.

Figure 4: Fires, forest reserves and biomes of Cambodia. Fires were detected by the satellite-based Moderate Resolution Imaging Spectroradiometer during 2002. Each forest reserve registered with the World Data Base on Protected areas is presented in dark gray. Biomes are moist broadleaf tropical forest (white) and dry broadleaf tropical forest (gray). The large number of fires inside several forest reserves and the general lack of any inhibitory effect of reserves on the number of fires suggest that several Cambodian reserves are failing.

Figure 5: Fires, forest reserves and biomes of Cambodia. Fires were detected by the satellite-based Moderate Resolution Imaging Spectroradiometer during 2002. Each forest reserve registered with the World Data Base on Protected areas is presented in dark gray. Biomes are moist broadleaf tropical forest (white) and dry broadleaf tropical forest (gray). The large number of fires inside several forest reserves and the general lack of any inhibitory effect of reserves on the number of fires suggest that several Cambodian reserves are failing.

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4. Projecting future changes in primary forest cover

Having concluded that forest reserves provide little insight into future changes in primary forest cover, the country-level changes in primary forest cover observed between 1990 and 2005 (Table 2) could still guide projected changes in primary forest cover. One possible scenario might retain 2005 primary forest cover for the four countries that lost no primary forest between 1990 and 2005, reduce primary forest cover to zero for Cambodia and Viet Nam, and maintain a constant proportion or constant absolute rate of primary forest cover loss for Brunei and Indonesia. We are, however, unable to extract New Guinea from the Indonesian primary forest cover data. Because New Guinea contributes more than half of the primary forest cover of the 11 Southeast Asian countries, this presents an insurmountable problem. For this reason, we will fall back on the simplest possible assumption. We will assume that total forest cover and primary forest cover decrease in lockstep. This assumption will underestimate future primary forest cover where effective nature reserves disproportionately protect primary forest and will overestimate future primary forest where people disproportionately clear primary forest. The latter is occurring in Amazonian Brazil (Wright and Muller-Landau 2006a). With these caveats in mind, we will implement our three scenarios for future forest with proportionate losses to total and primary forest cover.

Projecting the future threat of extinction due to land use change

We will now use the complement of Equation 2 to project the threat of global extinction caused by land use change for Southeast Asian endemic species in 2030. Changes in forest cover will be projected forward to 2030 beginning with the area in primary and secondary forest in 2005 for each Southeast Asian country (Table 1, excluding Indonesian New Guinea) and each of the three scenarios described previously (see Scenarios for future forest cover change). For each scenario, we will project forest cover separately for primary and secondary forest and then use the complement of Equation 2 to evaluate the sensitivity of the apparent extinction crisis to the proportion of endemic species entirely dependent upon undisturbed primary forest. Because rural populations are actually declining in Southeast Asia (Figure 3), the rural population model projects increases in total forest area. We forced all increases in forest area to be for secondary forests and did not allow primary forest area to increase above levels observed in 2005. We removed Indonesian New Guinea throughout Table 4 summarises the observed values of forest cover in 2005, projected values of forest cover for 2030 for the three scenarios, and the proportion of endemic species threatened with global extinction for these levels of land use change when every species is dependent upon primary forest and when every species is also able to tolerate secondary forests.

Table 4: Southeast Asian forest cover and the proportion of endemic species threatened with global extinction due to land use change and the proportion of species dependent upon undisturbed primary forest. Forest cover is from FAO (2006) for 2005 and is projected under three scenarios of forest cover change for 2030. The proportion of endemic species threatened with global extinction (the final two columns) is estimated from the forest cover values and the proportion of species dependent on primary forest using Equation 2.

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario</th>
<th>Forest cover (000 km²)</th>
<th>Species dependent on primary forest (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Primary</td>
</tr>
<tr>
<td>2005</td>
<td>observed</td>
<td>1,498</td>
<td>205</td>
</tr>
<tr>
<td>2030</td>
<td>business as usual</td>
<td>1,053</td>
<td>144</td>
</tr>
<tr>
<td>2030</td>
<td>total population</td>
<td>1,292</td>
<td>176</td>
</tr>
<tr>
<td>2030</td>
<td>rural population</td>
<td>1,566</td>
<td>205</td>
</tr>
</tbody>
</table>

Figure 7 shows how the proportion of endemic species threatened with global extinction varies with the proportion of species able to tolerate secondary forests.

Figure 7: The proportion of Southeast Asian endemic species threatened with global extinction depends strongly on the proportion of species that require undisturbed primary forest and is relatively insensitive to the details of the projection of future land use change and habitat loss. The "business as usual" (solid line), total population change (long dashed line) and rural population change (short dashed line) scenarios are described in the text under Scenarios for future changes in forest cover.
Implications for conservation in Southeast Asia

The projections in the final two columns of Table 4 are sobering. The most optimistic scenario considered suggests that 18% of the endemic species of Southeast Asia will be threatened with global extinction due to land use change in 2030. This represents nearly 5,300 species of plants and more than 400 species of amphibians, reptiles, birds and mammals that will be threatened with extinction if all endemic species are able to survive in secondary forest and the area of primary forest holds constant while the area of secondary forest increases as rural populations decline. This scenario is overly optimistic. The percentage of threatened species rises to 22% if increasing total (urban + rural) populations cause primary and secondary forest areas to decline and to 26% under the business as usual scenario. If endemic species are unable to tolerate secondary forest and are instead dependent on primary forest, the percentage of threatened species increases by two to threefold to 51%, 55% and 53% under the three scenarios, respectively. In addition, habitat loss is just one, albeit the most important, of the threats to Southeast Asian biodiversity (Sodhi et al. 2004). The extinction of somewhere between 20% and 60% of the endemic species of Southeast Asia is possible.

Many conservationists anticipate even worse outcomes (Dirzo and Raven 2003; Sodhi et al. 2004). The three scenarios considered here all anticipate a decline in absolute deforestation rates (Wright and Muller-Landau 2006a,b). Absolute rates of conversion of intact primary forests to human altered logged forests increased in Indonesia in the wake of the economic and political crises of the 1990s (Smith et al. 2003). Absolute rates of conversion of forest to cropland might increase if global markets created new demands for Southeast Asian agricultural products. The global market for cacao drove forest conversion to cacao plantations in West Africa through most of the 1990s (Rudel 2002), and the global market for soybeans is driving similar increases in cropland along the southern margin of the Amazon today (reviewed by Wright and Muller-Landau 2006a). Transmigration programs that move people from Java to less densely populated parts of Indonesia are perhaps the greatest threat that might increase absolute deforestation rates in Southeast Asia today. The form of the relationship in figure 2 illustrates the danger of transmigration programs. Forest cover is linearly related to the logarithm of population density. Thus, given the slope of the relationship observed in figure 2, a doubling (or halving) of population density is associated with a decrease (or increase) of just 12% in remaining forest area. The log-linear form of this relationship means that multiplicative changes in human population density cause arithmetic changes in remaining forest area. Transmigration programs can cause human population density to increase by several hundred percent at their destination but to decrease by a few tenths of a percent at their source. For this reason, transmigration programs weaken havoc on the forests of Indonesia. These examples illustrate how government programs (transmigration), global markets and political and economic crises might exacerbate forest loss and increase the threat of extinction in Southeast Asia.

What steps can be taken to avoid these outcomes? There are three obvious answers. The first is to protect the last remaining primary forest in Cambodia and Viet Nam and to reduce the loss of primary forest in Brunei and Indonesia (Table 2). The second is to raise the effectiveness of existing forest reserves in Cambodia, Indonesian Borneo and other Southeast Asian countries to the levels realised in Malaysia (Figures 4-6). The third is to increase the number of forest reserves in Brunei and Malaysia to the high levels observed in other Southeast Asian countries (Table 3). These three steps plus the ongoing protection of the remaining primary forests of the Lao People's Democratic Republic, Malaysia, the Philippines and Thailand (Table 2) could set Southeast Asia on course to realize the more optimistic outcomes in Table 4.

Yet, the most optimistic outcomes in Table 4 still anticipate the extinction of thousands of plant species and hundreds of vertebrate species. This is unacceptable, and solutions must be sought. The logic of the species-area relationship dictates a single viable solution: increase the area of forested habitat. Species threatened with extinction by habitat loss often persist for decades to centuries as small yet ultimately unsustainable populations (Pimm et al. 1995). This presents a window of opportunity to re-establish conditions that will permit their long-term survival. The intense urbanisation of Southeast Asia that is now underway (Figure 3) provides just this opportunity. The concentration of people in urban centers will allow natural secondary succession to re-establish primary forest. In either case, the pace of restoration of these lands can be enhanced through simple cost-effective means, including the addition of seeds of selected species whose seed dispersal agents might be missing (Lamb et al. 2005).

The extraordinary concentration of valuable timber poses a severe problem for the conservation of primary forest in Southeast Asia. Each protected primary forest represents an untapped economic opportunity for the timber industry, and loggers will remove timber illegally whenever political and economic conditions permit (Smith et al. 2003; Curran et al. 2004). The concentration of valuable timber in primary forests means that conservation biologists must seriously consider the conservation value of logged and secondary forest in Southeast Asia. Conservation biologists routinely assume that every endemic species is entirely dependent on undisturbed, primary forest (Myers et al. 2000; Brooks et al. 2002; Sodhi et al. 2004). Wright and Muller-Landau (2006a) made the opposite assumption to highlight the need for research to determine the habitat requirements of tropical species for primary versus human altered forests. Figure 7 illustrates the sensitivities of the extinction crises caused by habitat loss to the assumption of species absolute requirement for primary forest versus tolerance of logged and secondary forests. There are indications that many Southeast Asian species tolerate logged forests (Cannon et al. 1998; Meijaard et al. 2005) this offers hope that future increases in forest area combined with re-plant the plant species composition of old-growth forests can still prevent the loss of 80% or more of the endemic species of Southeast Asia.

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Endnotes

1 Primary forest cover includes forests of native trees where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Non-wood forest products might be collected, and some trees might have been removed.

2 Modified natural forest cover includes "but is not limited to: selectively logged-over areas, naturally regenerating areas following agricultural land use, areas recovering from human induced fires, etc; areas where it is not possible to distinguish whether the regeneration has been natural or assisted."

3 Semi-natural forest includes "areas under intensive management where native species are used and deliberate efforts are made to increase/optimize the proportion of desirable species, thus leading to changes in the structure and composition of the forest. Naturally regenerated trees from other species than those planted/seeded may be present."

4 Plantations include 'introduced species and in some cases native species, established through planting or seeding, mainly for production of wood or nonwood goods' or "for provision of services". Plantations include all stands of introduced species established purposefully and "areas of native species characterized by few species, straight tree lines and/or even-aged stands."

5 Includes Indonesian New Guinea which supports 415,000 km² of forest, which is presumably all listed as primary forest (see Primary forest cover in 2005 - a refined prediction)

6 Includes Indonesian New Guinea

7 Myanmar has 34 protected areas. The WDPA includes the boundaries of just three

8 Secondary forest area equals the sum of modified natural and semi-natural forest area from Table 1.