E-4 Studies on ecosystem management approach in tropical landscapes

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1. Introduction

Ongoing deforestation and degradation of tropical rainforests continues to be a serious global problem. The deforestation rate of these forests has remained at about 11 million hectare year^{-1} since 1990[1)]. Although tropical forest ecosystems ought to be protected as a global heritage for their outstanding biodiversity, few strategies to slow this trend down have been effective.

Given this situation, it is suggested that a comprehensive network of core protected areas be established within tropical countries, especially those with high numbers of endemic plants and animals. In combination with this network, an ecosystem approach to forest management within designated zones surrounding these core areas could be invoked to stimulate more sustainable resource usage and protection of biodiversity. By this approach, ecosystems as well as local communities and economies are secured simultaneously. As a practical implementation of these measures, forest certification programs (e.g. FSC, ISO program) have evolved as a means of reviewing forestry operations so that landscape planning is more in keeping with the full suite of ecosystem values.

In the tropics socio-economic dependency on natural resources, apart from timber, is still relatively high. In such regions, "easy-going management schemes or poorly designed land use policies or guidelines" could cause further conflicts among the stakeholders. Hence, forehand knowledge about ecosystem service values and goods of the forest is essential for local participation in the land use planning and land use changes. The same ideas apply to misunderstanding associated with stringently protected forest. There needs to be a clear understanding about the value of these areas with emphasis on how the local people may seek economic benefits from parks or protected areas.

The goal of ecosystem management is to formulate land use and natural resource plans that maintain a healthy ecosystem and balance the needs of society, the economy, and the environment. A key feature of ecosystem management systems in tropical forests is the incorporation of intensive and scientifically rigorous information on ecosystem services and goods provided by various types of landscapes. These studies serve to reveal conflicting and compatible demands of stakeholders (e.g., biodiversity, carbon sequestration, and timber production). Such information helps researchers predict the environmental risks of land use changes and logging activities and ultimately provides the underpinnings for management strategies that facilitate many other ecosystem services derived from the forest beyond the use of timber products alone.

The ecosystem management approach requires development of a risk assessment program to clarify decisions related to land use, land use change, and forestry processes. This serves to support the development of a landscape zoning plan and prevent undesirable or unnecessary changes in land use that would eventually diminish service values (e.g., clearing forest and converting it into plantations).

In order to predict the environmental risks attributed to land use development, a database with information from an ecosystem services survey could provide a source of information about costs of other ecosystem service values through land use development. This would help planners and managers get beyond a single view point and consider other ecosystem services such those for carbon stocks and changes.

In addition to regional valuation of ecosystem services, the technology must be scaled upward so that ecological data can be projected to a wider area (e.g., national level). Along these lines, we conducted research on the possibility of monitoring ecosystems by using airborne laser profiling or aerial photography, both of which permit the measurement of canopy and forest structure and an evaluation of wildlife habitat conditions with relatively minor investment of time and money.

2. Research Objectives

1) To provide ecological assessment tools and indicators to promote a forest certification program.
2) To provide new tools and indicators to strengthen the forest certification scheme.
3) To develop a local participation program for ecosystem management.

3. Research Methods and Outline

Three subtopics were addressed with work conducted mainly in the Pasoh forest reserve and vicinity (Fig. 1) in Peninsular Malaysia based on the stepwise procedure showing in Fig. 2.

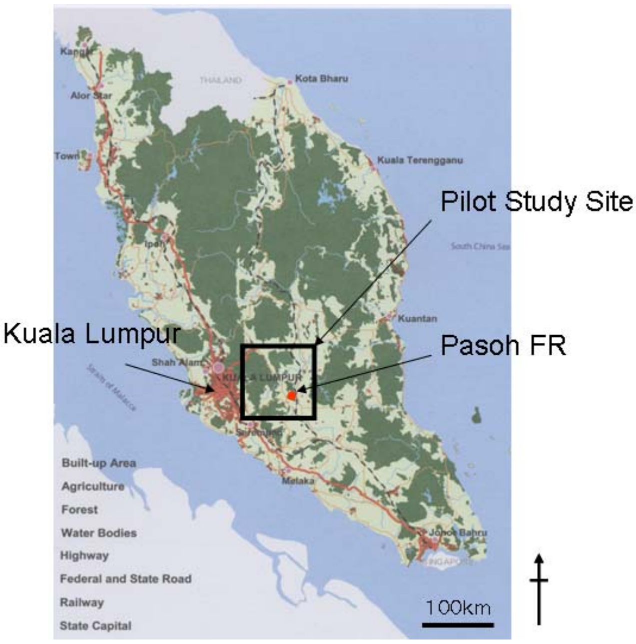

Figure 1. Pilot site located in Negeri Sembilan and Pahang states in Peninsular Malaysia, (60 km × 60 km in size, later enlarged into 100 × 100 km), for the data acquisition of ecosystem services and development of a risk assessment tool “Ecological GIS”. The pilot site includes primary and regenerating forests, rivers, plantations, residential areas and other land use types.

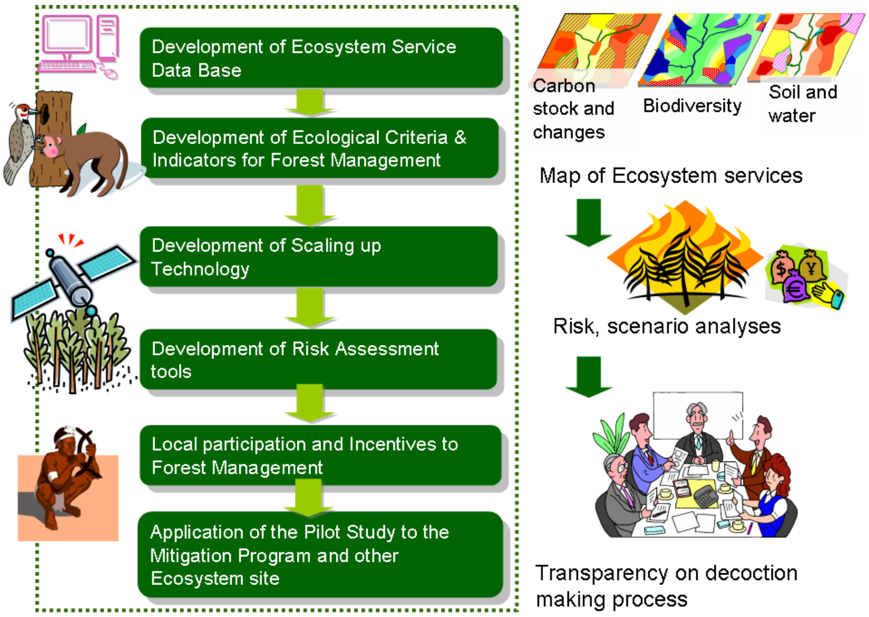

Figure 2. Stepwise procedure being taken for undertaking the present study towards the ecosystem management. The ecosystem service map will be developed as one of the products.

1) Effects of land use changes and commercial timber logging on the ecosystem service values and goods and ecosystem service mapping (GIS tools)

All available information related to the ecosystem services of rainforests has been collected and incorporated into the database to facilitate the sharing of data among scientists, as well as to develop further management programs. Based on this information, long-term effects of human impacts upon ecosystem service values and goods were studied. Tree flora and standing biomass has also been monitored in logged and unlogged sites to clarify the effect of timber extraction and accompanied effects upon the carbon budget. Tree physiology, fruit production and frugivore activity has been studied in these two sites and in fragmented forest.

2) Studies on ecological indicators as scaling up tools for rapid assessment

We studied the habitat range and ecology (e.g., behavior and food habits) of selected wildlife groups in relation to forest structure and small patches outside the reserve forest. Pollen flow was assessed in major canopy-forming species (Dipterocarpaceae) notably in relation to the density and abundance of mature trees and inbreeding depression associated with reduction of mature tree density. A PC-based system for risk assessment was upgraded to improve versatility and accessibility of the database. For this, we included a web-based GIS into the system.

3) Local participation program for ecosystem management.

In order to promote incentives for local participation in forest management, we investigated the sociological and ethnic values of forests by indigenous people. We conducted household surveys to investigate how traditional knowledge and culture has been inherited between the different generations. The livelihoods of the local aborigines (Orang Asli) have been changed in the last few decades, shifting primarily to farming in plantations from hunting activities in the forest. In large measure, the Orang Asli have taken over the labor intensive work which had formerly been undertaken by the local Malay people, who have in turn moved to the urban areas.

4. Results and discussion

4.1. Effects of land use on ecosystem services in the pilot study site

4.1.1. Land use changes

Land use and land use changes have been studied in the pilot site. As mentioned in the previous report in 2004 of this study site, forest land was reduced by 50% from 1971 to late 1996 (Fig. 3)[2]. At the same time, the area of oil palm plantations tripled and rubber plantations nearly doubled. Much of the remaining forest has been logged to various extent so as to yield a different structure from the original climax forest. These altered forest formations differ in many respects as habitat for wildlife and hence do not support all the faunal assemblages. For example, the fragmented forest in riparian areas is no longer favored by arboreal animals.

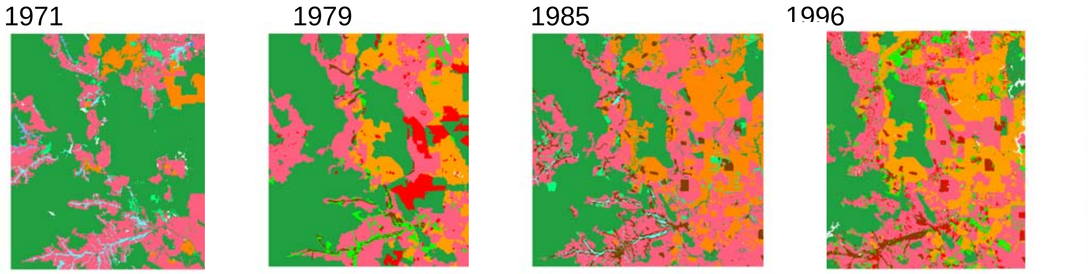

Figure 3. Land-use changes in a 60 × 60-km area around the Pasoh Forest Reserve. The 1971 and 1985 maps were based on topographic maps, whereas the 1979 and 1996 maps were created from image analyses of Landsat MSS and TM data (respectively). Green color: forests (inclusive secondary forests), pink color: rubber plantation, yellow brown color: oil palm plantation, red: denuded area.

4.1.2. Effects of landuse change on the overall ecosystem services

The ecosystem services gauged by carbon stocks, biodiversity (herbivore fauna), watershed protection (soil erosion), and traditional culture were greatly affected; many of these were degraded (Table 1). The number of mammals recorded in the previous literature for Pasoh Forest Reserve and vicinity was 111 species. According to our field surveys using a camera trapping system and citing other research references published after 1995 we counted 68 species. Tigers and elephants were extirpated from the Pasoh FR.

Table 1. Changes in ecosystem services in pilot study site

Ecological services	Changes from 1970s to late 1990s
Biodiversity	Reduction of number animal species (e.g. 111 sp. → 68 sp. in mammal sp.)
Carbon stocks/Biomass	Reduction by 38% in carbon stocks in total area of the pilot site
Watershed protection	Soil erosion increased to 2.2 times previous values
Socio economy	Utilization of non-timber products was reduced from 270 items to 70 items

4.2.3. Soil and nutrient losses and evapotranspiration in relation to landuse changes

We surveyed the effects of logging upon soil erosion from a viewing point within the pilot study site. Soil and nutrient losses from a 1987 km^2 watershed draining from the Pasoh region were estimated by the Universal Soil Loss Equation (USLE) model. The land-use compositions were derived from satellite images captured in 2003. Forest comprised about 62% of the catchment area, of which 95% was in pristine condition. This was followed by rubber (22.4%), oil palm (10.7%) and sundry crops (3.1%). Total estimated soil loss from the entire watershed was 7.15 mil t/yr (or 35.9 t/ha/yr). The highest rate of soil loss was obtained for non-tree sundry cultivation (477 t/ha/yr) and the least for undisturbed forest (12.1 t/ha/yr). Consequently, primary forest contributed only 19.7% of the total soil loss despite occupying about 59% of the land area. Estimated losses of C, N, P and K from the top soil were 184 928, 12 607, 3739 and 3963 t/yr, respectively wherein primary forest contributed the least nutrient losses and non-tree sundry cultivation the highest.

Evapotranspiration (ET) was estimated for the entire watershed. It was 3.11 mm/day or equivalent to 1135 mm/year. Based on normal annual rainfall of 2294 mm for 1995 and 1443 mm in dry year of 2002, the expected annual water yields are and 1159 mm/yr and 308 mm/yr, respectively. Averages ET from forest, oil palm and rubber were very similar, 3.112, 3.111 and 3.109 mm/day. On an annual basis the ET rate is considerably lower than the reported values calculated from water balance approach.

4.2.4. Carbon flux and N_20 emission

In order to make a more precise estimation of the carbon budget (carbon stocking and sequestration) in forest ecosystems, measurement of soil respiration is indispensable. However, the soil respiration is known to be spatially heterogeneous in accordance with above ground biomass. Thus the environmental factors affecting the spatial pattern of soil respiration require further elucidation. Based on the field survey in Pasoh and its vicinity, we found that soil water content was a relevant parameter for estimating soil respiration. Based on this fact, we estimated the annual carbon flux from the soil using three regression equations which included soil water content and soil respiration rate. The annual carbon flux from soil was 16.9~19.2 t C ha^{-1} in the primary forest, 17.5~18.5 t C ha^{-1} in the secondary forest, 14.3~14.5 t C ha^{-1} in the oil palm plantation and 9.0~11.2 t C ha^{-1} in the rubber plantation. These values can be quoted for estimation of carbon sequestration at the broader scale.

We measured the N_2O flux in three different land uses—primary forest, oil palm plantation, and rubber plantation. In addition, we measured and compared the N_2O flux in logged sites and un-logged sites in selective logging forest for about one year and half. The N_2O emission rate in the primary forest was significantly higher than those in the plantations throughout the experimental period. This result suggests that primary forest soil is a greater source of N_2O than oil palm and rubber plantations, and that conversion from forest to plantation decreases N_2O emission from soil. The rate of N_2O emission in the primary forest showed a clear seasonal change, with higher values in wet soils and lower values in dry soils. The rates in the plantations showed no seasonal change. The proportions of soil surface carbon and nitrogen in primary forest were three times those in the plantations. And the soil bulk densities in primary forest were higher than in the plantations. The difference in soil C, N contents and soil bulk densities between the primary forest and the plantations may affect the rate of N_2O emission from the soil.

The soil N_2O emission rates in the logged sites were about 3-100 times higher significantly than those in the un-logged sites throughout the experimental period. These results showed that the logging practice had increased N_2O fluxes remarkably, and suggested that the logging practice might accelerate global warming at least for one year after logging in point of N_2O fluxes. It could be caused by the increase of soil N availability, especially NO_3^-, and soil compaction by machine disturbance in logged sites.

The present study showed that the conversion from tropical forest to plantation remarkably increased the N_2O emission from soil at initial period and then decreased with time. The result suggests that plantation managements for long time decrease the emission of N_2O in a given area. More studies are needed to evaluate quantitatively and accurately the effect of land use change on N_2O flux in the future.

4.1.3. Biodiversity loss

Among a total of 500 terrestrial species of birds (including inland species that occupy riparian habitats) found in Peninsula Malaysia, 156 are endemic to the Sundaland (Peninsular Malaysia, Sumatra, Java, Bali, Borneo and smaller islands west of the Wallace Line) of which 82 (53%) are now red-listed by IUCN. Lowland forests, primarily the dipterocarp rainforests (as represented by the Pasoh Reserve Forest) have undergone the most extensive shrinkage of their former area; hence they carry the highest risk of extinction of biota. Similar threats to the other major groups of land vertebrates are rooted in a large number of endemic species for this region and the disproportionate removal of lowland forests. Continued expropriation of timber and conversion to plantation agroforestry will further fragment these forests and reduce the likelihood that fully functioning ecosystems can regenerate. Thus, a comprehensive strategy is needed to identify what remains of primary lowland forests in Peninsular Malaysia, especially patches of forest with adequate area to support viable populations of species as a functional community and to overcome the likelihood of loss through stochastic events. Stimulation of a competitive industry with the oil palm industry that relies upon maintenance of intact natural forest would bolster the security of the rainforest from an economic perspective.

4.1.4. Changes on the primate distribution

We surveyed primate distributions and their habitat range in Pasoh Forest Reserve and its vicinity. Two species of macaque were found both inside and in fragmented patches outside the reserve (Fig. 4). In contrast, leaf monkeys (*Presbytis femoralis* and *Semnopithecus obscurus*) and white-handed gibbons were more restricted to the forest reserve. A small troop of gibbons was regularly found in fragmented stands just outside primary forest. Generally speaking, gibbon troops seldom forayed far from large areas of primary or mature forest. Species such as the gibbon may not be imminently threatened with extirpation because they can occupy both lowland and montane forest, hence their populations and gene flow may be distributed over a wider area. Ultimately primate conservation will depend to a great extent upon the size and connectivity of primary and mature rainforest patches, where forest structure and trees species composition (fruiting trees) are critical factors for their reproductive success and survival.

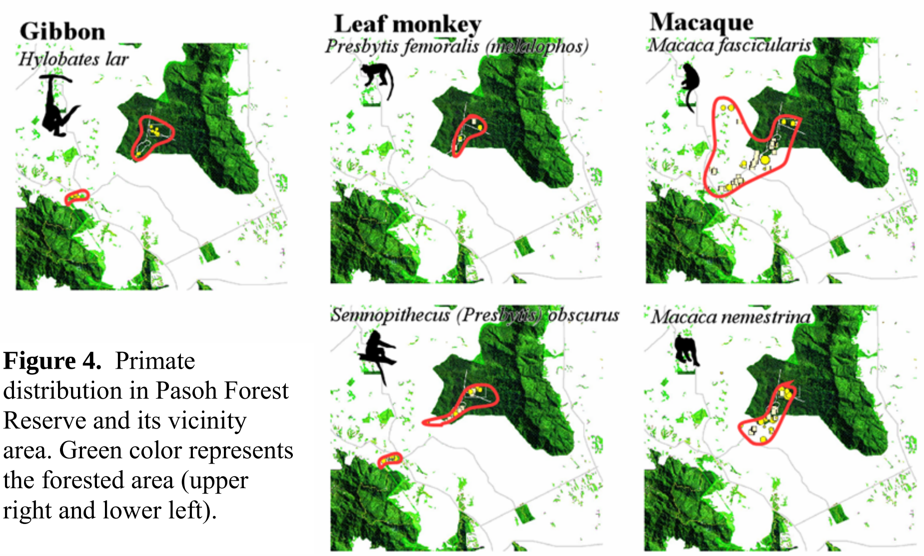

Figure 4. Primate distribution in Pasoh Forest Reserve and its vicinity area. Green color represents the forested area (upper right and lower left).

4.2 Studies on ecological indicators as scaling up tools for rapid assessment

4.2.1. Ecological indicators

- Insects, pollinators

To determine the logging impacts on pollinator insects, the bee community was surveyed among 4 different land use types (primary forest, logged forest, oil palm and rubber plantation). using honey traps. The majority of bees were large stingless bees, *Trigona fimbriata*, and Asian honey bees, *Apis cerana*. The diversity of bee species was higher in primary forest than logged areas. We also investigated the pollination system of major timber trees, *Shorea* spp., section *Mutica*. Two thrip species with different ecological traits contributed to the pollination of these tree species. A diversity of pollinator insects support forest regeneration hence these insects provide a useful indicator of forest health.

- Woodpeckers, umbrella species and Cavity users

We surveyed the distribution of cavities and natural hollows as nesting/roosting sites for woodpeckers and barbets. At a study site in the Pasoh Forest Reserve most cavities (n = 70) were found in snags (77%) compared to live trees (23%). 20% of all snags (DBH ≥ 15 cm) contained cavities. Larger diameter snags, especially dipterocarps (median DBH, 57 cm), were favored commensurate with their availability. Examination of cavity dimensions in terms of known body size of woodpeckers and barbets revealed that small or large cavities were in living trees; whereas most of the mid-sized cavities, representing the majority of cavity excavators, were in snags. By comparison, natural hollows (n = 33) were more evenly distributed between snags (55%) and live trees (45%). The mean number of hollows per snag (0.081 ± 0.021) conformed to a Poisson distribution with few snags or trees with multiple holes. The size distribution of these hollows suggests that a wide range of species, including the larger owls and hornbills, could use these holes for nesting or roosting.

Recent studies in Thailand reveal that only a select few tree species are favored by hornbills for nesting. Taken together, these findings suggest that in tropical forests the majority of birds in the cavity-requiring guild require 1) specific large-diameter trees for nesting, together with fruit-bearing trees in close proximity, or 2) older forest as a source of snags, and most importantly an abundant supply of insects for food (esp. termites and ants). The cavity-users offer a useful index of forest health and could be used to set more critical guidelines for better management of forests from a resource extraction perspective.

- Mammals

Throughout the peninsula as a whole, many of the larger mammal species are now red-listed by IUCN most often because their populations are constrained by availability of suitable habitat. For example, there are 7 known cat species in Peninsular Malaysia ranging in size from smallest (flat-headed cat) to largest (tiger). Four of these felids are listed as vulnerable and the tiger (*Panthera tigris*) is endangered. The future security of these species against poaching and demographic factors is best met through large protected areas, such as the Taman Negara National Park or the Endau-Rompin. The same can be said for the Asian elephant (*Elephas maximus*), Malayan tapir (*Tapirus indicus*) and Sumatra rhinoceros (*Dicerorhinus sumatrensis*).

- Canopy trees and its gene flow

Canopy forming trees of the dipterocarp family were evaluated for gene flow between individual adult trees of dipterocarp species taking advantage of mass flowering events that happened in 2001, 2002 and 2005 in Pasoh Forest Reserve. In 2005, we gathered seeds from ten mother trees representing nine species. The gene flow analysis was done using samples of *Shorea leprosula* in 2001 and 2002. The average rate of out-crossing between two flowering events was similar. The out-crossing rate was higher for the seedling stage than for seeds more directly, which is considered to be an effect of inbreeding depression. The gene flow was much more frequent from outside than within the plot. In order to fully understand gene flow among trees in this region, it will be necessary to use both direct and indirect estimates (e.g., model-based method).

- Soil respiration for estimating carbon sequestration

In order to make a more precise estimate of the carbon budget in forest ecosystems, soil respiration rates were assessed in part of the study site. Since soil respiration is known to be spatially and chronologically heterogeneous, we employed an open-top chamber system placed in various microenvironments of the forest floor. Although we did not get a complete set of data for this, it appears that CO_2 flow on the forest floor was not very apparent during the night time. It has been said that such flow might be cause for underestimation of total CO_2 emissions. In order to clarify this, we will need to conduct longer-term monitoring of soil respiration in different topographical positions of the study site.

4.2.2. Tools for upscaling ecosystem services to the broader landscape scale

- Tools for the configuration of forest structure and biomass

In order to estimate standing biomass of the tropical rain forest, we utilized a laser profiling system to reconstruct the three dimensional forest structure. For this fiscal year, we analyzed the biomass variation in relation to topography and found that biomass was much greater on ridge tops than in the lower part of the hillslope. These findings match a previous study on hill dipterocarp forests. Thus, the laser profiling system can be applied not only to the lowland forest but also to the hill dipterocarp forest, both of which have sustained considerable losses to commercial timber logging.

We also checked for consistency in mapping the canopy by the laser profiling system vs.

conventional survey methods (e.g., aerial triangulation). Our results show that both approaches can be used quite effectively for long-term analysis of chronological variation of forest structure and biomass.

- Tools for estimation of forest productivity in the broader region

The map the Net Primary Productivity (NPP) was made for entire part of Peninsular Malaysia forest using NOAA AVHRR satellite data (Fig. 5). A series of NOAA satellite data for the year 2004 have been pre-processed, first to precisely co-register each image through geometric correction and secondly the radiometric corrections were performed to eliminate the radiometric distortions mainly caused by angles of incidence that differ from sun light. Meteorological parameters such as surface solar radiation, surface temperature and rainfall were obtained from the Malaysian Meteorological services as additional inputs to the model Results of the analysis indicate that the annual values of NPP are within the range of 50 to 6,000 gc/m^2/year, while the values of Normalized Differential Vegetation Index (NDVI) are within the range of 0.04 to 0.7.

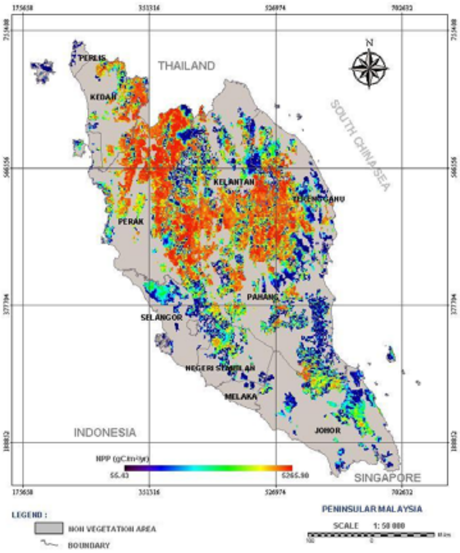

Figure 5: Mean Annual Net Primary Productivity of Peninsular Malaysia 2004 (NOAA)

<u>4.2.3. Scenario analyses and risk assessment tools on landscape development using GIS approaches</u>

- Development of PC based risk assessment tool

To assess the long-term effects of logging and land use changes on the values of forest goods and services, we are developing a PC-based risk-assessment system coupled with GIS to provide information on the potential benefits and environmental risks of proposed developments. This sub-theme aims development and improvement of "Ecological Service GIS", which is an interactive PC-based system that enables evaluation of ecological risks resulted from the degradation of forests and land use changes. In the last year's study, Ecological Service GIS based on Legacy GIS (Arc View 3.0) had been reconstructed to be an independent system (Ecological Service GIS engine) for eliminating the disadvantages caused by the limitations of Legacy GIS itself and enhancing the connectivity to network such as Internet through Web-GIS in future. In this year, the improvement of Ecological Service GIS engine focused on the enhancement of usability and processing capability by GIS engine.

- Parameter extraction for the ecosystem service mapping and risk assessment

We developed three indices aimed for risk assessment of rainforests based on ecological services for the purpose of strategic and effective establishment of rainforest networks. The indices are 1) Developmental Risk Index that represents the possibility of development, or conversion from forests to other land use, 2) Ecological Service Index that represents the status of ecological services that each forest provide, and 3) Ecological Hazard Risk Index that is the result of risk assessment based on the previous two indices (Fig. 6). In the case study, it is suggested that the ecological hazard risk index can be a usable tool to develop strategic planning rainforest protection.

- Cost and benefit analysis based upon the landuse change scenario

Cost-benefit analyses were conducted based on the present and future land-use framework. With this framework, we conducted scenario analyses on ecosystem service loss through landuse changes from primary forest to oil palm plantation.

In this study, landuse changes from 1995 to 2003 (8 years) in the pilot study area were highlighted. Three types of impacts of agricultural development were examined: (i) relationship of total soil loss to changes in land use pattern, (ii) mapping trends of ecosystem services and goods for primary forests in 1995 and 2003, and (iii) risk assessment of ecosystem services and goods based on simulation of converting 339 x 10^3 ha of primary forest into mass-scale oil palm plantation.

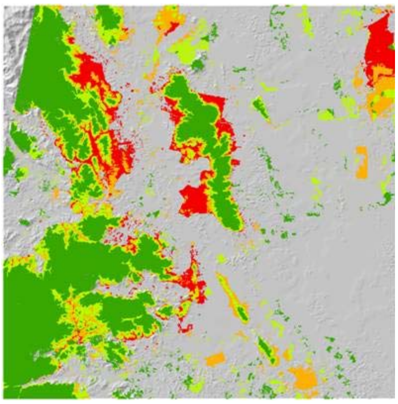

Figure 6. Hazard Map of the study site. Green color indicates the forest land, while red color indicates the area with high probabilities of deforestation.

4.3. Local participation program for ecosystem management.

The Orang Asli communities are a significant player for future management of forest ecosystems because of their economic and cultural dependency on forests and forest products.

A survey of Malay villages showed an accelerated outflow of younger generations to urban areas. Depopulation and aging over the last two decades has altered the production system in rural Malaysia. Without manpower, traditional small-holder rubber plantations have changed into more labor-efficient large-scale plantations managed by public corporations; and labor-intensive oil palm plantations are now replacing rubber plantations by small farmers.

Production and living systems of the Orang Asli have also changed. Instead of foraging for forest products such as rattans and resins as a means of livelihood, they are managing their own small-scale rubber and oil-palm plantations which somewhat resemble those of rural Malaysia in 1970. Thus they have become detached from the forest and less dependent upon forest products economically. But from a cultural and ethnic perspective, forests and activities in the forest still appear to be important to them. For example, hunting by blow pipe in surviving forest "islands" still has cultural significance. These trends were similarity observed throughout the Peninsular Malaysia.

Given their historic and lasting connection to the forest, the Orang Asli are primary contenders as stewards of the forest, i.e., for the implementation of ecosystem management, "Empowerment" on Orang Asli and their community is necessary. Towards this, their traditional knowledge and skills need to be valued and highlighted locally and globally. By doing this, inter-linkage between the local society and forest can be developed.

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