E-1 Optimizing the Sustainable Management of Tropical Forests

Contact Person Toshinori Okuda
Global Environment Division
National Institute for Environmental Studies, Environment Agency
16-2 Onogawa, Tsukuba 305-0053 Japan
Tel: +81-298-50-2426 Fax: +81-298-50-2483
E-mail: okuda@nies.go.jp

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Introduction

One of the most famous features of tropical rain forests is their extreme species richness. Tropical rain forest contains more than 50% of the terrestrial organisms on the earth. However, designless human impacts have rapidly decreased the area of tropical rain forest. For example, it is estimated that the loss rate of all natural tropical forests over the decade 1981-90 was 15.4 million ha. As well, since quality of tropical rain forest including high species richness and habitats of various organisms has been elicited in last few decades, utilization of forest management system are also required in the countries of tropical regions. Understanding of the pattern of deforestation, its effects on biodiversity and other forest function, and suitable treatment for conservation of rich biodiversity are important to utilize secondly forest as the refuge of various organisms. Therefore, the present study aims to provide the sustainable management plan which optimize the ecosystem service value of the tropical forest ecosystem. We centered the following six subtopics conducted in Pasoh forest reserve and its vicinity area in the Peninsular Malaysia (Fig. 1).

(1) Since tropical forests have huge carbon storage in forest biomass (40% of the global terrestrial biomass), tropical rain forest is expected as one of the biggest carbon sink on the earth. Despite the importance of tropical forests, the area has been decreasing by converting it for agricultural or industrial land usage. To understand role and function of tropical rain forest as carbon stock and sink, we examined mechanism of carbon cycle in the focal forest stand. We studied on the spatial and temporal variations in soil respiration rates, and examined the environmental factors affecting soil respiration rate in primary and secondary forests in Pasoh Forest.

(2) A large area of tropical rain forests in the South-East Asia has been cleared by logging, fires, and many other artificial activities. Since most of lowland forest was already treated, current logging is now sifting from lowland forests to hill forests under the Selective Management System in Malaysia. Therefore, management and improvement of these disturbed hill forests is regarded as the most important future tasks for conservation of wildlife in the forests. Here, effects of forest fragmentation and selective logging on the genetic diversity and small mammal community were studied in hill and lowland dipterocarp forests in Peninsular Malaysia.

(3) As above mentioned, most lowland rain forests have been disturbed by logging operation. Therefore, secondary forests after human impacts should be focused to conserve remaining biodiversity in tropical rain forests. However, effects of deforestation on biodiversity are little known both in community and landscape levels even in lowland forests. In order to deepen the knowledge on the role of old growth rain forest in facilitating the high species diversity, the following topics had been examined: (i) difference in forest structure and forest interior microenvironment between undisturbed primary and selectively logged forests, (ii) difference in reproductive phenology of canopy tree species between the primary

and logged forests, and (iii) regeneration process and mechanism of canopy trees in the primary and logged forests.

(4) Green forest corridor between fragmented forest patches is an expectative techniques to conserve wildlife in isolated small forests. Some case-studies has been conducted in temperate regions, but no practice has been applied in tropical regions. In the study, selection of suitable tree species for corridor was conducted by a silvicultural experiment including comparison of physiological performance in some tree species in relation to light intensity and surface temperature. In addition, to develop ecosystem management system, water resource and cycle in landscape levels should be understood. Evapotranspiration in tropical rain forest is one of the most important hydrological subjects for water resources in local area as well as water cycle in global scale.

(5) Environmental impact of road construction is considered to be one major issue in logging operations. Because most of the logging roads (feeder roads) and skid trails are utilized only for a short period, these are usually constructed at low cost and bellow the road standards. To determine the extent of vegetation recovery, (i) Break the skid trails into segments using the characteristics of road, i.e., gradient, width, surface condition, degrees of recovery, (ii) record all the trees species and its height found in the segment, (iii) estimate the rate of road surface coverage, (iv) map the segment by surveying it from the existing survey reference point were conducted.

(6) Utilization of tropical forests as timber production is a essential resource for developing countries to earn foreign exchanges. On the other hand, tropical forests has an important role for stabilization of environmental change in global scale. There appears some conflictions between the development and protection of tropical forests. In this situation, recognition of social units would be important to decide future management system. In the study, in order to evaluate socio-economic value of tropical forest, we conducted the conjoint analysis in which questionnaires regarding the best profile of land use were given to respondents.

Research Objectives

(1)To evaluate the carbon budget, flow and future aspect of tropical rain forest, we studied on the spatial and temporal variations in soil respiration rates, and examine the environmental factors affecting soil respiration rate in primary and secondary forests in Pasoh Forest Reserve

(2) To manage and improve these disturbed forests, effects of forest fragmentation and selective logging on the genetic diversity and small mammal community were studied in hill and lowland dipterocarp forests in Peninsular Malaysia.

(3) To understand the role of old growth rain forest in facilitating the high species diversity, difference in forest structure, forest interior microenvironment, reproductive phenology of canopy tree species and regeneration process and mechanism of canopy trees between the primary and logged forests were examined.

(4) To develop rehabilitation method of tropical ecosystem, seasonal changes in soil-water relationship was studied in an primary forest, we explored the possibility of establishing corridor which enables the wildlife to migrate between the fragmented vegetation patches in a mixed landscape unit consisting of virgin forest, regenerating forest after logging, and plantation regime.

(5) To develop harvesting systems for reducing forest impact, we collected base data of the logging impacts. Concerning soil erosions, we're surveying the alignments of logging roads, the total area and the amount of earthwork for road constructions in Bukit Tarek Research Site.

(6) In order to evaluate socio-economic value of tropical forest, we conducted the conjoint

analysis in which questionnaires regarding the best profile of land use were given to respondents.

Results and Discussion

(1) Tree growth and mortality, decomposition rate of fine (leaves and fruits) and coarse (woody) litters and CO_2 emission from mineral soils and that from leaf litter were measured in both old-growth and logged over forest. The amount of carbon sequestration was evaluated by net ecosystem productivity (NEP). NEP was −1.29 and 1.34 $MgC \cdot ha^{-1} \cdot yr^{-1}$ in primary and regenerating forests, respectively, suggesting, to a small degree, a carbon source of atmospheric CO_2 in primary forest and a carbon sink in regenerating forest. Remarkable differences in the carbon cycling were the larger carbon loss as living biomass in the primary forest and the larger carbon gain through growth in regenerating forest. As a result, NPP in the primary forest (8.85 $MgC \cdot ha^{-1} \cdot yr^{-1}$) was 75% of that in regenerating forest. Several features were common in both forests; CO_2 emissions from surface litters are much smaller than the emission from SOM (≈3.5 vs. 6.6 $MgC \cdot ha^{-1} \cdot yr^{-1}$). The remaining fraction of the decomposed litters played a substantial contribution (34-88% of NPP) as the carbon pool during decomposition in both ecosystems. In summary, in the present status, primary stand of Pasoh Forest Reserve may function as a carbon source, while regenerating forest as a carbon sink, but their effects appeared trivial.

(2) The average distance of pollen flow was distinctly longer in the logged forest than in the primary forest. Although mean distance of pollen flow was large in the logged plot, its breeding unit (4.8 ha)was smaller than that of primary plot (6.3 ha). As well, pollen flow of another canopy forming species (*Neobalanocarpus heimii*) was studied in the lowland dipterocarp forest. This species had a larger breeding unit (86.3 ha) than *S. curtisii* in the hill dipterocarp forest. The arboreal squirrel community in a logged forest was found to be quite different from that of primary forest. The species composition of the regenerating trees in lowland dipterocarp plot was largely altered from the original composition before cutting. Primary forest tree species having dormant seeds. Thus, our findings revealed that logging affect genetic structure of dipterocarp species through the decrease of mother tree density and limited pollen flow. Selective logging also reduced the density and species richness of arboreal small mammals that are important seed dispersal agent in the tropical rain forest. This is outcome of changing canopy structure in logged forest.

(3) Our studies indicate that co-existence mechanism of light-demanding and shade-tolerant tree seedlings may be influenced due to changes in the dynamics of canopy gaps. This study confirmed significant genetic structure of two canopy tree species in the primary forest plot, and suggests that genetic structure is determined by pollination and seed dispersal. Reproductive phenology of main canopy tree species (Dipterocarpaceae) were observed in primary and selectively logged forests. These observations suggest that flowering density of small trees in the selectively logged forest do not compensate for loss of tree harvesting. We also suggested that inbreeding depression may reduce survivorship of seed and seedlings during the early stage of regeneration. Thus, there are direct and indirect effects of logging on forest ecosystem. Indirect effects of logging may be important on forest regeneration and genetic diversity. Reduction in complexity of canopy structure and gap formation resulted in declination of seedling survivorship on some tree species which require canopy gap for regeneration. Thus, further ecological and genetic studies are needed to understand the indirect effects of logging and to propose a sustainable management method for conservation of biodiversity in lowland tropical rain forests.

(4) Open planting potentiality was examined by using chlorophyll fluorescence measurements. It became clear that *Shorea platyclados*, *Dipterocarpus oblongifolius*, and *Ficus* spp. (local name:Ara) had high temperature and high strong-light tolerance. The stress factors of plant growth were found, and an afforestation technique was devised in each of the sand soil, the acid soil, and the peat-swamp soil in tropic lowland area. It became clear that the effect of even 20 m width buffer zone that prevented soil erosion after tree cutting was high. The function as "green dam" of the forest was high in tropical low land forest. The evapo-transpiration rate in Pasoh Forest Reserve was estimated approximately 1,550 mm/yr that of about 89% of the rainfall.

(5) From the relationship of the longer the length of contributing slope, the larger the volume of surface erosion, it can be assumed that the water flow running on long slope surface prevent vegetation from recovering on the road surface. The results suggest that water flow on the road surface plays an important role in vegetation recovery. Bulldozers are commonly used for the construction, and because of its earth-working feature, i.e. powerful in cutting, but poor in carrying; large amounts of unstable cut soil are left as side-casting on the fill slope after construction. This unbounded or remolded soil can be easily eroded by rain drop impact, carried by groundwater flow and transported quickly into streams during flash floods. Road surfaces are compacted by passage of vehicles, and have limited infiltration capacity. This results in the formation of rills and gullies on the forest roads that wears surface soil, and creates pathways for eroded sediment to get delivered to the stream system.

(6) Three types of land-use (protective forest, production forest and agricultural land) were chosen for the questionnaires. The value of each land use type to which respondents were willing to pay (WTP) as tax was RM27.0 ha^{-1} for protective forest, RM22.7 ha^{-1} for agricultural land use. In contrast, the value of production forest was RM-5.6 ha^{-1}. These results suggest, for example, if a protective forest is maintained as it is, the nations would pay this amount money as a tax, while if the forest is converted into other land use, the nations would request the refund of tax or request welfare whose value is equivalent to this amount of money. The interpretation for the case of agricultural land use is same as the case of protective forest. As for the production forest, the result suggests that the nations would accept expense of tax with this amount, if the production forest is changed to the other land use. Second, we also conducted the same research at the suburb near the forest Pasoh in order to estimate the WTP of the people who may have more relationship with the forest than the residents in urban area. The results showed that they might think highly of protective forest more than those who live in urban area. In addition, performing a cluster analysis, we classified all respondents into several groups using their preference data. The cluster analysis was conducted according to various questions other than conjoint questions.

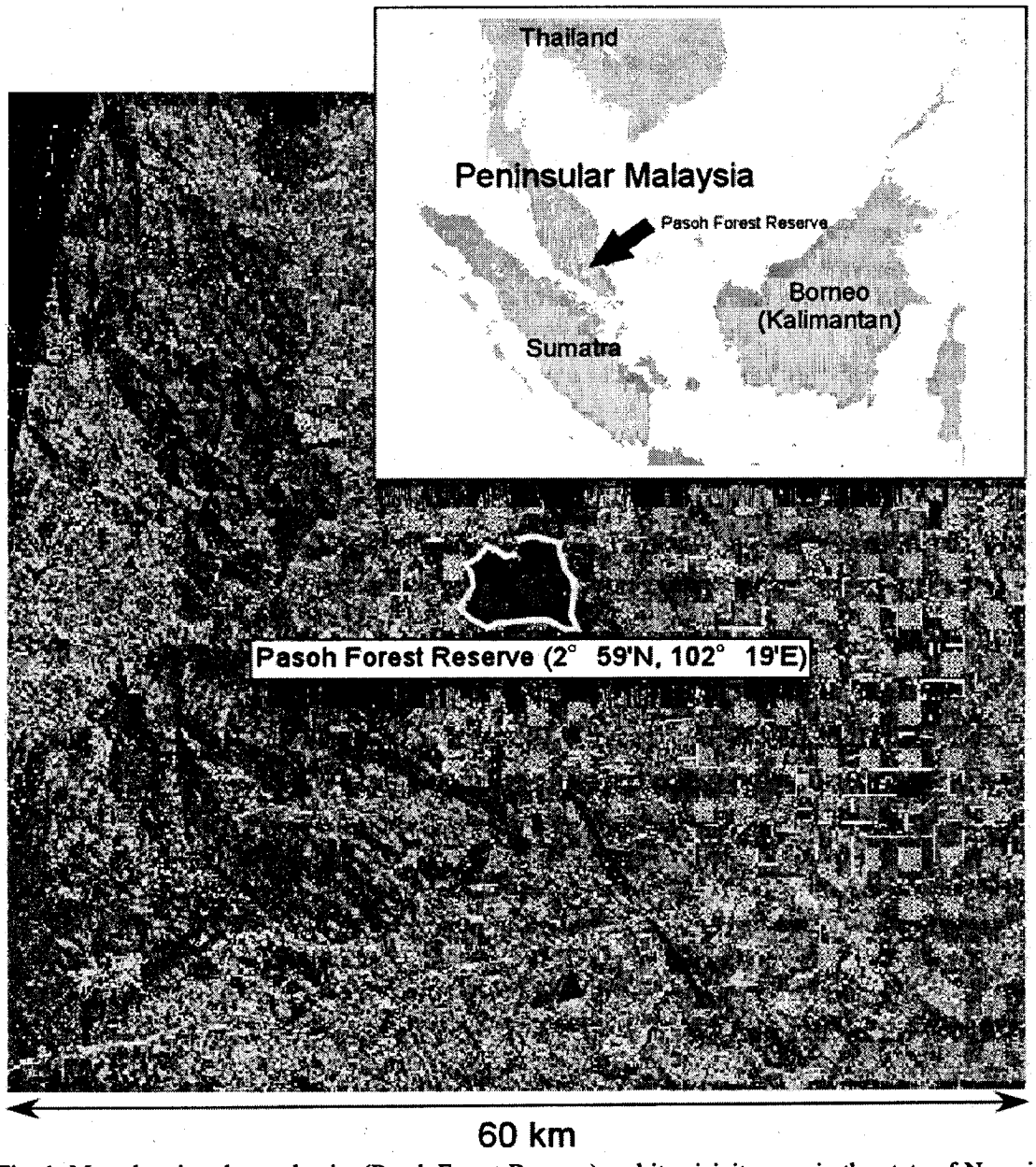

Fig. 1. Map showing the study site (Pasoh Forest Reserve) and its vicinity area in the state of Negeri Sembilan, Malaysia.