An overview of techniques for the rehabilitation of degraded tropical forests and biodiversity conservation

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This paper focuses on four topics related to biodiversity conservation through the rehabilitation of degraded tropical forests at the landscape level: (1) development of rehabilitation technology for biodiversity enhancement using secondary succession, (2) site management method for the rehabilitation of degraded land and monoculture plantations using secondary succession, (3) involving local communities in rehabilitation technologies thereby increasing their socio-economic options, (4) overall synthesis of rehabilitation technology. A compartment model has been constructed for the development of response options using rehabilitation technology and socio-economic parameters. Controlling factors consisting of landscape level trade-off and a cyclic term drive the direction and assess the adaptive set of rehabilitation techniques.

Keywords: Degraded tropical forest, forest value, rehabilitation, secondary succession, response option.

Where and why are tropical forests being degraded?

TROPICAL forests are decreasing at the rate of 12.5 million hectares every year, mainly due to land use changes. Moreover, timber harvesting has converted more than five million hectares of tropical forests to logged-over forests every year without any adequate silvicultural treatments[1]. The decrease and degradation of the tropical forests affect not only the production of timber but also the global environment. Natural disasters such as flooding, erosion, landslides and desertification are increasing due in part to the degradation or loss of tropical forest[2]. Many environmental changes are being initiated by forest harvesting including site degradation, reduced water supply, soil loss and greenhouse gas emissions. Logging and burning are major causes of forest degradation and forest harvesting initiates other forms of land utilization. In the Asia–Pacific region, population growth and rapid economic expansion have escalated demand for wood products. Increased wood production from plantation forests has the potential to reduce pressure on natural forest resources as well as contributing to environment conservation and economic advancement for landholders in the tropics.

The ecological and socio-economic correlates of tropical forest degradation are closely connected with a series of international treaties discussed in COP6 (Kyoto Protocol), the Montreal Process (Criteria and Indicators), ITTO 2000 (sustainable forest management), etc. Sustainably managed forests can mitigate global warming and conserve biodiversity as recognized by the U.N. Forest Forum (UNFF), which has set up criteria and indicators for the monitoring and assessment of forests.

In this paper, forest degradation refers to the decrease or loss of cultural, ecological and socio-economic values. Cultural value refers to long-term forest culture and reverence. Socio-economic value is the value of forest resources, and ecological value includes ecosystem services such as mitigation of global warming, carbon sequestration, biodiversity conservation, water storage and balance, landslide, erosion, mitigation of climate, fire protection, amenity, fertility of soil, sustainable primary production condition, etc.[3]. Therefore, the rehabilitation of degraded forest ecosystems means to recover and/or enrich these values.

The purpose of this study is to assess the impacts of forest harvest and synthesize the rehabilitation techniques such as: (1) development of rehabilitation technology for logged-over forest, secondary forest and degraded shrub forest, (2) rehabilitation of degraded land and monoculture plantation and development of site management methods, (3) land resources management and local community participation for forest rehabilitation management with socio-economic adaptation, (4) synthesis of the rehabilitation technology for environmental conservation and forest resources management. These techniques must not only be technically feasible and economically viable but also socially acceptable.

Changes in forest ecosystems due to harvesting

The harvesting impacts on forest ecosystems vary with time, logging methods (such as the earmarking of species logged), soil characteristics, topography, local rainfall patterns and mode of timber transportation[4,5]. Long-term monitoring can lead to better understanding of the impact of these practices.

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Harvesting impacts on soils in plantations and natural forests

Many studies have examined forest harvesting impacts on soil physical properties[6,7]. The impacts of forest harvesting on soil physical properties include reduced saturated hydraulic conductivity[8–10], coarse porosity and total porosity, and increased bulk density[5] due to compaction[6] and accelerated organic matter decomposition[5] in the plantations, logged-over forests and natural forests. While the studies of saturated hydraulic conductivity, bulk density and porosity composition are valuable indicators of harvesting effects on the forest soils and useful in predicting the deterioration of soil, they may be insensitive to change in soil water conditions. Soil chemical properties have also been changed with decreasing total carbon, total nitrogen and exchangeable cations caused by organic matter decomposition and run-off from ecosystems[3,4]. These soil changes can result from both direct and indirect harvesting effects. Changes both in chemical and physical properties of soil reduce the soil productivity.

Natural forest ecosystems are nutrient rich but, in comparison, the nutrient stock of degraded forest is reduced. However, forest recovery contributes to the accumulation of nutrients again. At present, sustainable forest management is an important strategy for protecting natural forests and rotation of plantations will contribute to the sustainable management of natural resources in the future (Figure 1). By contrast, arable land has been severely degraded globally[11]. Forest harvesting has measurable impacts on the soil physical and chemical properties. Soil fertility is one of the key factors for plantation rotation, tree regeneration, establishment and growth of forests[10]. Forest harvesting triggers nutrients loss from the soil[12,13], into groundwater[14] and stream water[15] by runoff. These nutrient losses are accelerated due to climate in tropical plantations[15]. If the soil nutrient reserves do not recover before the next harvest, it would result in low tree production and cumulative degraded soil with poor fertility, coupled

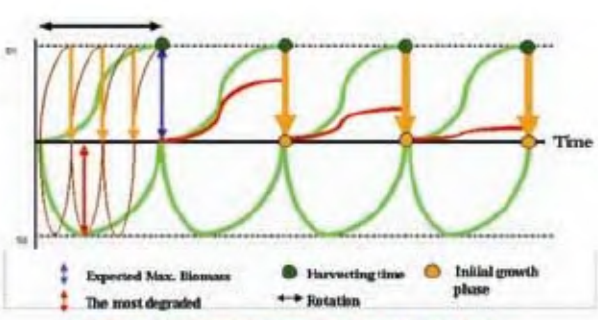

Figure 1. One of the control factors as the cyclic term for the response option compartment model. Brown line: agricultural cropping, Red line: declining tree production, Green line: sustainable forest management, Bi: Biomass, Sd: soil condition (ref. 37).

with low water permeability and aeration, thereby affecting tree growth[6]. Recovery of nutrient reserves and soil physical properties prior to the next rotation must be considered for sustainable plantation management[12,16]. Undergrowth and litter play a significant role as cation stores in the plantation and these compartments must be conserved in the plantation ecosystem. Sustainable forest management must take into account the recovery of soil properties until the next rotation and conservation of undergrowth and litter accumulation. Guidelines for reducing harvesting impacts on the plantation must incorporate these considerations, unlike the RIL guidelines[17]. Adequate silvicultural treatments must be followed for the rehabilitation of logged over forest or afforestation of degraded land.

Carbon mass loss

The decomposition rates of the slash resulting from harvest and the organic matter in the topsoil accelerate and the total carbon content decreases, because the soil moisture condition fluctuates greatly and the organic matter mineralizes into the inorganic matter and is lost from the forest ecosystem after harvesting[12]. Therefore, accelerated decomposition decreases overall soil carbon stock after harvest. However, plantations of fast-growing species were estimated to sequestrate between 100 and 200 carbon t ha^{-1} (ref. 18) as biomass of trees. In different forest types and with different harvesting methods, it was estimated that carbon mass lost from topsoil after harvesting decreased the carbon stock by 19.2 carbon t ha^{-1} in a tropical moist forest in Brunei, 9.3 carbon t ha^{-1} in a temperate forest in Japan and 5.1 carbon t ha^{-1} in a cool temperate forest in the USA[12] . Similarly after shelterwood logging in mixed broad-leaved secondary forest in temperate Japan, the total carbon decreases 14.5 carbon t ha^{-1} (ref. 19). This loss of carbon mass affects global warming, and in addition there is a loss of nutrients. However, the undergrowth and litter accumulation will play an important role in restoring the carbon and nutrient content in top soil for the regenerated forests and process of secondary succession[20]. It is a clear difference between carbon and nutrient accumulations as biomass growth and carbon and nutrient loss in the soil according to forest regeneration process.

Change in biodiversity following secondary succession

Microclimate changes occur in open sites subject to selective logging and clear cutting[8]. Open sites are exposed to sunlight which results in greater fluctuations in ambient air temperature compared to the forest understorey, and more mesic conditions due to lower interception of rainfall and evapo-transpiration. Microclimatic conditions in the open site are similar to those of the natural gap in a mixed dipterocarp forest[10,21]. The patterns of tree dominance and

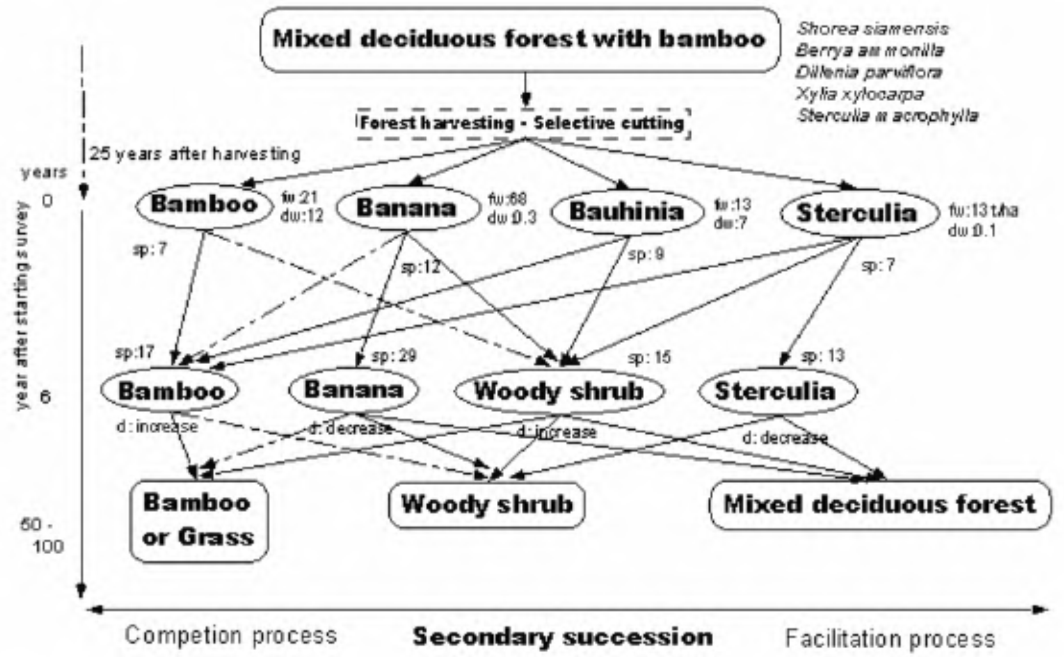

Figure 2. Facilitation and competition processes during secondary succession in Mae Klong watershed research site. Bamboo: *Cephalostacyum pergracile,* banana: *Musa acuminata,* Bauhinia: *Bauhinia virdencens,* Sterculia: *Sterculia machrophylla.* Species compositon consists of *Xylia, Schleichera, Dillenia, Dipterocapus* from Banana and woody shrub and Croton, Colona, Xylia from Sterculia and Bauhinia to woody shrub. fw: fresh weight (ton/ha), dw: dry weight, sp: species number, d: density

species composition change, thereby altering successional processes. For example in logged-over seasonal tropical forest in Thom Pha Phoon, Thailand (Figure 2), the pioneer plant species such as wild banana (*Musa acuminata*), *Bauhinia viridescens* and *Sterculia macrophylla* with large populations of bamboo suppressed the seedling establishment of dominant tree species. Community structure was altered due to higher fire frequencies, desiccation, human disturbance and the dynamics of the pioneer species. Pioneer species such as the wild banana, which are widespread in different types of natural forests, although at lower densities, played a key role in the population dynamics of logged-over forest. This succession process depends on the magnitude of disturbances and site conditions[12]. It has been estimated that the growth and regeneration rate of trees has decreased in the tropics due to multiple factors, such as forest degradation, soil erosion, landslides and greenhouse gas effects that are directly or indirectly linked to forest harvesting[22]. However, while forest harvesting leads to changes in the ecosystem, subsequent land utilization may cause more severe impacts on natural ecosystems. Nevertheless, the effects of forest harvesting have not been fully understood, especially in tropical rainforests[23]. Information on the long-term impacts of tree harvesting on forest ecosystems, especially with regard to changes in biodiversity, soil and productivity, is lacking.

Rehabilitation of degraded forest ecosystems with response option

Development of the rehabilitation technology

Until now effective rehabilitation technology has not been applied to a logged-over forest and degraded land. Instead wild seedlings that are considered useful have been cultivated and distributed using particular processing methods. If wild seedlings are not distributed, enrichment planting technology is applied (seed preservation, young tree production, selection of tree species, mixed planting, gap planting, etc.). The recovery of biodiversity and forest function are then evaluated[24,25].

I have studied the secondary succession of logged over and burnt forest in East Kalimantan, Indonesia (Figure 3). I classified six vegetation types in the undergrowth of burnt logged-over tropical lowland mixed dipterocarp forest in order to evaluate the influence and role of vegetation types in secondary succession[26]. This kind of information could be used to identify vegetation that can facilitate or retard the succession process[27,28] in relation to species interactions[29]. The facilitation vegetation type accelerates natural regeneration whereas the competitive vegetation types retard natural regeneration and can only be applied to enrichment planting, mixed plantation and catalytic plantation.

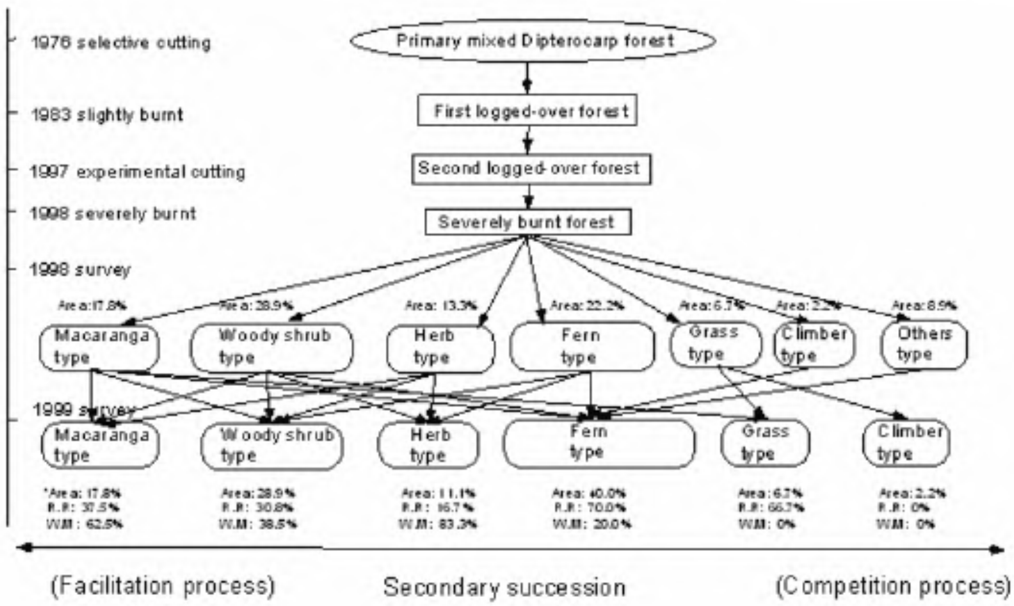

Figure 3. Vegetation recovery process after forest harvesting and fire at Bukit Soeharto Education forest in East Kalimantan, Indonesia (*Area: quadrat no. total quadrat x 100, R.R.: remaining rate of quadrat. WM: recruit to woody shrub and *Macaranga* type) (modified from ref. 26).

The fern type indicated competition because ferns became dominant (70% of plants), and the site had the lowest species richness and recruitment of woody shrubs, while 13 months after burning the soil remained dry. The grass type was similar to the fern type in dynamics. The herb type represented the facilitation process because species richness and recruitment of woody shrubs increased, light levels and soil moisture increased, thereby supporting the diversity-productivity hypothesis[30], but not the hypothesis that species-rich sites were more resistant to invasion[31]. Woody shrub and fern types will be given lower rating for rehabilitation of ecosystems, based on the further monitoring.

Rehabilitation of the degraded land

Rehabilitation of degraded land and monoculture plantation should focus on the improvement of soil fertility and reconstruction of the species composition of a reference natural forest. Indigenous fast-growing species should be introduced into the site, after screening tree species for rehabilitating abandoned sites. The methodology has not been properly established.

Therefore we have studied thinning effects and coppice regeneration in a 25-year-old teak (*Tectona grandis*) plantation for management of tropical long-rotation plantation in Thom Pha Phun, Thailand. The area under monoculture plantations has expanded in the tropical regions recently[32], but plantation for timber production and long-rotation tree plantation has not received adequate attention. It is necessary to establish silvicultural techniques, including nursing, planting, weeding, thinning, branching, density control, and regeneration for long-rotation tree plantation[33]. The growth trajectories and thinning intensities of the remaining trees and coppice re-growth were assessed. We studied the multi-storey teak plantation and natural seedling establishment at the plantation site in order to establish a manual for teak plantation management. Thong Pha Phum has a monsoonal climate with summer, wet and dry seasons, an average temperature of 26.5°C, and an average annual rainfall of 1764 mm. The experimental treatments carried out were 1 : 1 mechanical thinning, 2:2 mechanical thinning, low thinning, and clear cutting in 1997. We have measured DBH and height of remaining trees, coppices and natural teak seedlings. Elephant yarding was applied and one coppice was retained at each stem. We had the following results. Growth of remaining trees was higher for low thinning, 1:1 thinning, 2:2 and control (height and DBH). Growth of coppices was higher for clear cutting, 2:2, 1:1, and low thinning (height and DBH). Number and height of seedlings was higher for clear cutting, 2:2, 1:1, low thinning. To restore a degraded forest to multi-storied forest and for higher biomass, 2:2 thinning is the best method coupled with elephant yarding. Teak plantations can be managed through coppice regeneration and the introduction of multistoried forest by thinning (Figure 4). Thinned trees can be marketed but coppiced trees must be checked for quality. Restored multistoried teak forest prevents surface erosion and results in the continuous production of teak timber.

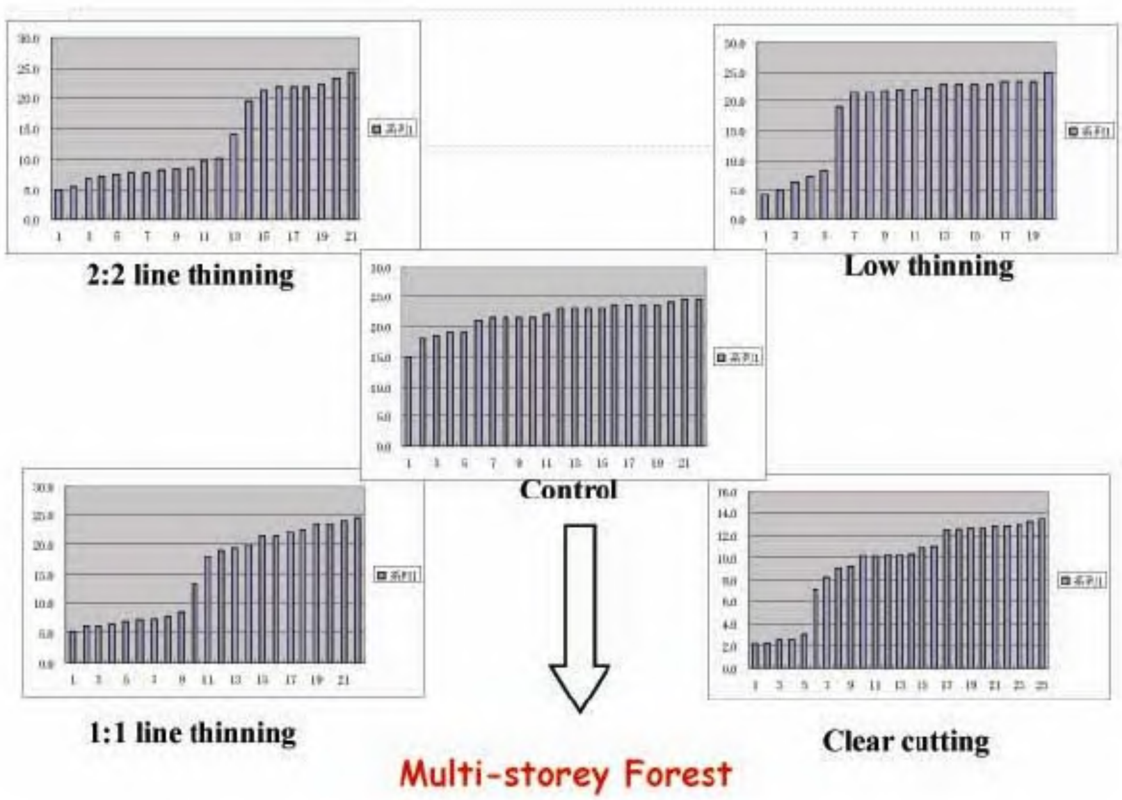

Figure 4. Teak multi-storey forest created by thinning and coppices.

Land resources management

Preliminary investigation of the characteristics of the local community and environmental resource management was conducted. A survey of the attitudes of the local community was carried out so that the trends can be used for designing the programme. The socioeconomic effects which the rehabilitation technology brings to a community were evaluated. The integration of the participatory rehabilitation technology to the local policy body was examined. A local community incentive was incorporated into rehabilitation technology[34].

Forest degradation caused by the impact of local communities living adjacent to tropical forests has threatened the livelihoods of these communities. Urban communities also recognize the environmental problems caused by forest loss and degradation. Therefore, using a questionnaire, we attempted to look at the differences in attitudes towards tropical degraded forests among Thais, Japanese, and Indonesians, and between local communities and urban citizens. The objective of this study was to find out methods to increase participation of local communities in the rehabilitation of forests, to change socio-economic conditions and land resource management practices. We had carried out the interviews in Bangkok, Kanchanaburi and Thong Pha Phun, in Thailand, Luwlian, in Indonesia, and Iida city, Takao, Tsukuba, Mishima city and Tokyo in Japan. The perceptions of the Thais and Japanese on forests differed: Thai people recognized more forest types, such as man-made forest, temperate forest, windbreak forest, environment forest and urban shrub forest, than Japanese people. Japanese people looked upon forests as important in themselves, whereas the Thais looked upon forests as sources of water and non-timber forest products. Japanese people gave importance to forests for their carbon sequestration function, whereas the Thais regarded forests as a source of food and employment. Indonesians and the Thais regarded forests as a source of forest products and timber, and for aesthetic pleasure, whereas both categories are of low significance in Japan. A Principal Components Analysis shows that the eigen value is more than 2 for 4 principal components and the cumulative contribution is about 72%. Therefore, principal components 1, 2, 3 and 4 are significant in this analysis. Using principal component 1 (pc1) for the *X*-axis and principal component 2 (pc2) for the *Y*-axis, the score scatter diagram for the attitudes towards the forest is given in Figure 5. The positive nature/environment', 'human/life', and 'plantation/direction of the *X*-axis represents 'CO2/carbon', 'afforestation' by loading factors. The minus direction of the *X*-axis means

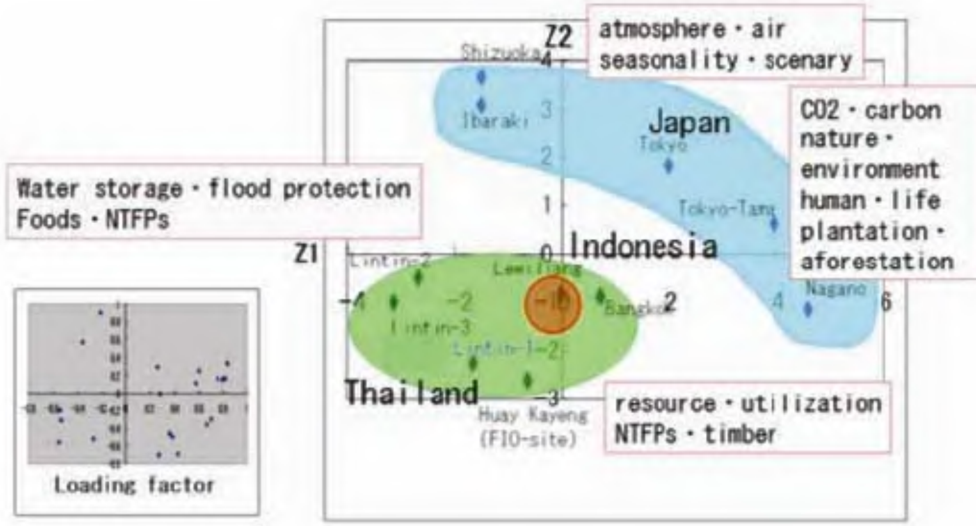

Figure 5. Score scatter diagram for the attitudes towards the forest[34].

'water storage/flood prevention' and 'non-timber forest products/foods'. The plus direction of the *Y*-axis shows 'atmosphere/air' and 'seasonality/landscape'. The minus direction of the *Y*-axis indicates 'resources/ utilization' and 'forest products/timber' by loading factors. Japanese expect the forest will play an important role in 'CO_2/carbon' sequestration, purify 'atmosphere/air' and 'environment/nature' has the relation to 'seasonality/landscape', 'human/life' and 'plantation/afforestation'. Whereas the Thais and Indonesians expect the forest to be important in 'water storage/ flood prevention', 'non-timber forest products/foods', 'forest products/timber' and 'resource/utilization'. Our conclusion is that the rehabilitation techniques must be site and situation-specific, including the natural environmental and socioeconomic conditions of the local community[35].

Rehabilitation technology – Overview

I have constructed the compartment model (Figure 6) using several kinds of parameters, such as rehabilitation techniques, site evaluation and classification, evaluation of landscape level rehabilitation, selection of planting tree species, natural forest corridor, silvicultural techniques of degraded land, mixed plantation, and socio-economic parameters such as local community participation, socio-economic adaptability to changes, land resources management, synthesis of rehabilitation techniques, and networking[36]. For driving these parameters as a compartment model, I have selected the controlling factors such as landscape level, trade-off and cyclic term[37]. These controlling factors would play a key role in adaptive management of the rehabilitation activity. Using this compartment model, I have produced the response option of rehabilitation which will be applied to the area under consideration. Response option of the management method of forest rehabilitation was performed on a landscape level based on an ecology–area relation. I tried to create the compartment model which will be controlled by three control factors and propose the rehabilitation response option to each site-specific field and central or local governments. These parameters for the rehabilitation of degraded and less valued forest ecosystems were site-specific. Therefore, we consider the issue and necessity of a response option for each site. The local government policy must be necessary for the effective rehabilitation policy instead of central government policy, through the 'ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests', published in 2002. We have proposed two response options for two different sites. However, it is first necessary to study the history of the site, in the motivation of the local community (ethnic group), marketing, local community interview resulting in the explicit extraction of parameters. The response option must be emphasized on particular parameters, and actual response option must be created.

Synthesis of rehabilitation technologies

We still have some questions to be answered on the rehabilitation activities: (1) Are there diverse types of secondary forests? (2) Can we expect newly established secondary forests to resemble the original forest? (3) Is the original forest a final goal for the rehabilitation of degraded forest ecosystems? We can discuss, clarify and answer the above questions through the rehabilitation research. Information on the natural secondary succession process has contributed to develop these techniques[22].

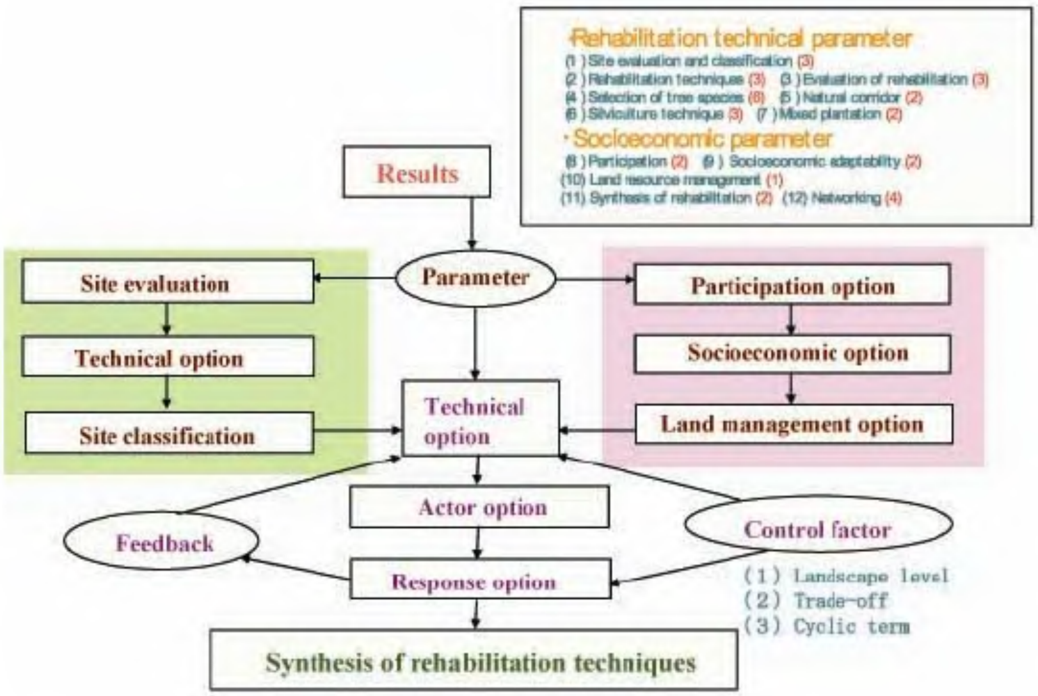

Figure 6. Compartment model for response option of regional adaptation of rehabilitation techniques[36].

Actual application of the response option on site will change depending on the circumstances and must be discussed on site. Successful and unsuccessful case studies need to be reviewed. For example, Chisan (controlling the landslide and erosion) and Ryoku-ka (afforestation) are examples of rehabilitation of degraded forest ecosystems. Planting of trees using ecological information is a basic rehabilitation technique. Augmenting the area of rehabilitated forest lands will significantly expand the area of potential sites for forests in a situation of limited land resources, contributing to the sustainable use of forest resources, and in fact will allow the conservation of primary tropical forests and bring about environmental improvement. The result of the response option is expected to promote the sustainable economic use of forest resources, conservation of gene resources and environmental conservation in tropical forests. The local government and local community will conduct annual assessments and compile reports and contribute to the feedback to select the adequate response option. The retrieval system will be a key vehicle for synthesizing the results of the research, which will be shared among collaborators and practitioners (scientists, forest managers, small forest holders and local community) and thereby contribute to long-term monitoring and rehabilitation of degraded forest ecosystems. Important findings have already emerged. We need to recover degraded land, develop local community participation, establish multipurpose forests for multiple benefits, and promote a network to share and cooperate on rehabilitation across countries and regions. Regional adaptation of the forest rehabilitation for land, policy and environmental and biodiversity conservation must be applied using the response option (compartment model) as sustainable forest management.

Increasing rehabilitated forest lands are significantly increasing the area under forest, to the sustainable use of forest resources and the conservation of primary tropical forests, ecosystem services and biodiversity.

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