An Ecosystem-management Approach for CDM Afforestation and Reforestation Activities: The Need for an Integrated Ecosystem Assessment Based on the Valuation of Ecosystem Services for Forested Land

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Abstract

To properly encourage and implement afforestation and reforestation (AR) within the Kyoto Protocol's Clean Development Mechanism (CDM), we suggest the introduction of an ecosystem-management approach that emphasizes the value of the ecosystem services and goods provided by forested land. Local communities and governments in developing countries tend to be influenced by the driving forces behind land-use conversion from forest to agricultural crops, which provides immediate income. However, unless proper valuations and interpretations of the ecosystem values and goods derived from forests are obtained, deforested areas may easily be converted to other uses or left as bare land rather than directed into CDM-AR uses. CDM-AR uses impose additional costs beyond those of conventional silviculture. To account for ecosystem and biodiversity conservation under CDM-AR, we require scientific tools that can rapidly but accurately monitor and predict the biological (ecological) and socioeconomic impacts (risks) of land-use changes. It remains controversial who will be responsible for the extra costs for the necessary baseline studies (scientific inputs). Given these facts and the background of deforestation in the tropics, we suggest the necessity for comprehensive, integrated ecosystem assessments. These include: (1) rapid assessments to monitor carbon stocks and changes in these stocks, and the use of ecological indicators representing the biodiversity of the forest, (2) landscape zoning assessments based on the values of an ecosystem's services and goods, and (3) risk assessments that predict the impacts of land-use changes. These fundamental intellectual approaches are useful not only for CDM activities, but also for management of a nation's natural resources, and the analyses can begin with the assembly of national-level data in geographical information systems.

Key Words

landscape zoning assessment, rapid assessment, risk assessment, tropical forest

1. Introduction

Tropical forest ecosystems, where most afforestation and reforestation (AR) activities under the Kyoto Protocol's Clean Development Mechanism (CDM) will be implemented, are being greatly affected by illegal logging and other activities that involve an array of actors. Unsustainable and destructive timber-production practices and large-scale land-use shifts from forestry to croplands (plantations), mostly led by the government sector, are driven by socioeconomic problems and poverty in local communities. Although voluntary implementation of sustainable forest management has occasionally been accomplished, it remains a challenging task and has rarely been done properly in the tropics. Considering the potential of CDM-AR to initiate forest-based businesses, to provide the benefits of vegetation reclamation, and to increase global carbon stocks, more CDM activities are needed and these activities should be encouraged in the tropics. However, the costs of the activities associated with sustainable forest management remain high. The Certified Emission Right (CER), which is based only on carbon sequestration in the forest, does not take into account the significant ecosystem services of biodiversity, nutrient cycling, catchment management, and human use provided by sustainably managed forests. The values of these ecosystem services must also be considered in any assessment. Moreover, land-use conversion from forest to croplands creates more immediate monetary benefits to local communities than maintaining the production forests, so incentives must be provided to compensate these communities for their role in protecting the value of the ecosystem services and goods derived from the forest. This compensation can be provided by local governments, communities, or donors in developed countries.

Given this background, we propose the introduction of an ecosystem-management approach that protects and provides security to ecosystems as well as to local communities and economies. The development of sound management practices in tropical forest ecosystems requires intensive studies of the value of the ecosystem services and goods provided by various types of tropical landscape. Studies should begin with a review of the functional aspects of the forest, of agriculture, of nearby urban areas, and of catchments in the study area. A database of ecosystem services constructed from these data would provide a more appropriate means for the valuation of these resources and a source of basic information for planning CDM-AR activities and attaining the potential CER. This would let planners and managers go beyond simplistic valuations of carbon stocks and changes in these stocks throughout the forest establishment in the context of the CDM framework. The approach would also allow the development of a risk assessment program to clarify decisions related to land use, land-use change, and forestry processes, and to support the development of a landscape zoning plan that would prevent undesirable changes in land use (e.g., clearing forest and converting it into plantations). We also propose the monitoring of ecosystems by using airborne laser profiling or aerial photography, both of which would permit the measurement of tree growth and an evaluation of wildlife habitat conditions with comparatively small investments of time and money.

These research topics should be implemented as part of a fundamental study that is conducted prior to or simultaneously with CDM-AR activities. In this paper, we pose the question of how and what scientific research contributes to the goal of facilitating the sustainable use of natural resources. Our goal is to provide scientific tools for proper and suitable implementation of CDM-AR projects in an area by means of integrated ecosystem assessments that comprise the assembly of a series of values for ecosystem services and goods, the establishment of databases to help manage this data, and risk assessments to predict the costs and benefits of land-use changes. Moreover, we recommend the use of rapid assessments to identify ecological indicators and monitor biomass changes in the area, as well as landscape zoning assessments to help optimize the use of an area’s natural resources.

2. Why Forests Have Been Converted into Agricultural Areas: A History of Land-Use Changes at a Representative Study Site

We established a representative site for our pilot study in the states of Negeri Sembilan and Pahan in Peninsular Malaysia, and analyzed the land-use change at this site from 1976 to 1996 (Fig. 1; Okuda et al. 2003a, b). Each map covers a 3600-km^2 area, 60 km on each side

(3°15′N to 2°42′N lat., 102°03′E to 102°35′E long.). Over this period, the total forested area, including regenerating logged forest, decreased from 2362 km^2 (65.6% of the total area) to 1057 km^2 (29.4% of the total) (Fig. 2). The deforestation rate during this period thus averaged about 2.8% yr^{-1}, which was higher than the annual deforestation rate for rain forests in Peninsular Malaysia and continental southeast Asia (1.2% to 1.5% yr^{-1}) from 1981 to 1990 (FAO 1993). In contrast, the area covered by oil palm plantations increased from 176 to 741 km^2 during this period, and the area of rubber plantations increased from 889 to 1215 km^2 (Fig. 2). These

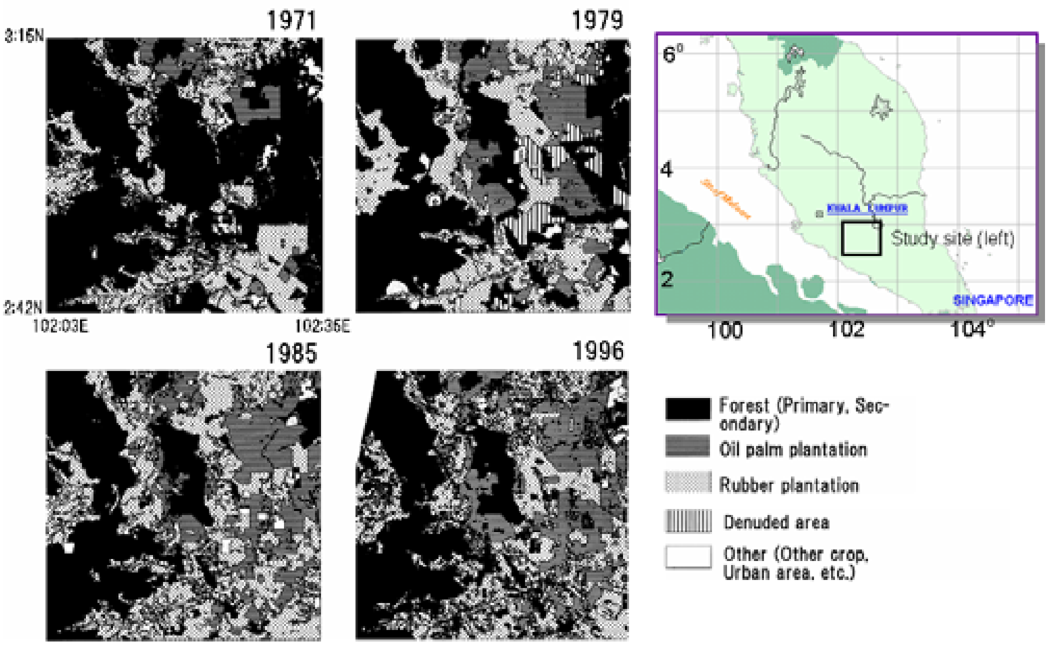

Fig. 1. Locations of the pilot study site in the state of Negeri Sembilan, Malaysia, and land-use changes in the vicinity of the Pasoh Forest Reserve from 1979 to 1996. The 1971 and 1985 maps were based on a topographic map created by researchers in the forest, whereas the 1979 and 1996 maps were created from analyses of Landsat MSS and TM data (respectively). The upper-left corner of the 1996 map was trimmed off because of a lack of Landsat image data(adopted and modified from a figure presented by Okuda et al. (2003b)).

landscape changes followed the general trend in land use throughout Malaysia, where oil palm plantations increased in area from 5690 km^2 in 1975 to 21 980 km^2 in 1992 (Department of Statistics in Malaysia). Many of the lowland forests in Malaysia were converted into oil palm plantations. Most of the large denuded area in the middle-right parts of the 1979 map in Figure 1 had become either oil palm or rubber plantations by the time of the surveys that led to the 1985 map.

Why has such an extensive area of forested land has been converted into agricultural cropland within 20 years? This change was partly caused by changes in national policy that created a national strategy aimed at improving the economies of rural areas and communities and at taking steps to obtain foreign currency by establishing agricultural products, notably palm oil, capable of competing in international markets. From another viewpoint, however, we compared the costs and benefits of oil palm plantations and forests (K. Yoshida et al., National Institute for Environmental Studies, Tsukuba, Japan, unpublished data). Surprisingly, even when the values of several ecosystem services (carbon stocks, protection against soil erosion, timber values) and the costs of maintaining the plantations (chemicals, roads, etc.) were

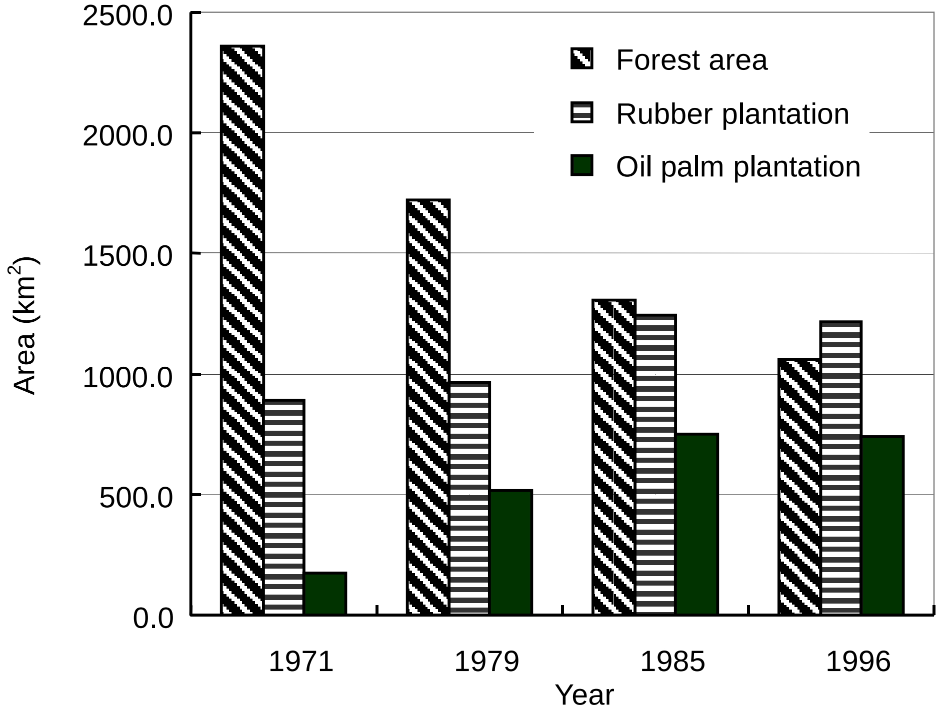

Fig. 2 Changes in the areas of forest and plantation from 1971 to 1996 for the study area shown in Fig. 1(adopted and modified from a figure presented by Okuda et al. (2003b)).

considered, oil palm plantations produced a much higher cash value than the total value of the ecosystem services derived from the forests in flat alluvial areas. In fact, the areas converted into oil palm plantations consisted mainly of flat alluvial topography that had originally been covered by lowland dipterocarp forest, which today remains only in the protected forest reserve. In contrast, most of the forest that remained in 1996 was found in the hilly parts of the region, where the development and management of oil palm plantations was considered to be overly difficult.

This brief description provides the historical background for land use and land-use change at the study site. We now believe that the surprising results of the aforementioned study by Yoshida et al. resulted from the preliminary nature of our understanding of the true values of ecosystem services and goods. Unless the values of the ecosystem services provided by forests are fully and properly evaluated and accounted for on the basis of our improved understanding, these forests will eventually be converted into cropland or deforested areas and will not be reforested. In terms of the additional costs of managing forested areas under CDM, the AR activities described under CDM must appear sufficiently attractive to investors that it encourages them to enhance various kinds of ecosystem services that go beyond simply increasing carbon stocks.

3. The Need for Integrated Ecosystem Assessments

3.1. A database for the values of ecosystem services provided by tropical forests

Considering the unique background and history of deforestation in the tropics, planners and managers must pay careful attention to the value of ecosystem services and goods produced from the forest in proposing any kind of activities related to land-use changes. In recent years, the necessity for integrated ecosystem assessments has been recognized to provide a useful indication of the values of ecosystem services and of the goods provided by forests (e.g., Myers 1996; Costanza et al. 1997). These assessments are increasingly being recommended because the value of the ecosystem service provided by forests has usually been neglected, whereas the value of commercial crops and farmland has been overemphasized; this inappropriate emphasis has overwhelmed perceptions of the existing and potential values provided by forests. In addition, the value of natural forests has not been objectively assessed. This has led to destructive exploitation of forests and landscape conversion from forests to farmland without assessment of the impacts of these changes prior to clearing the forests.

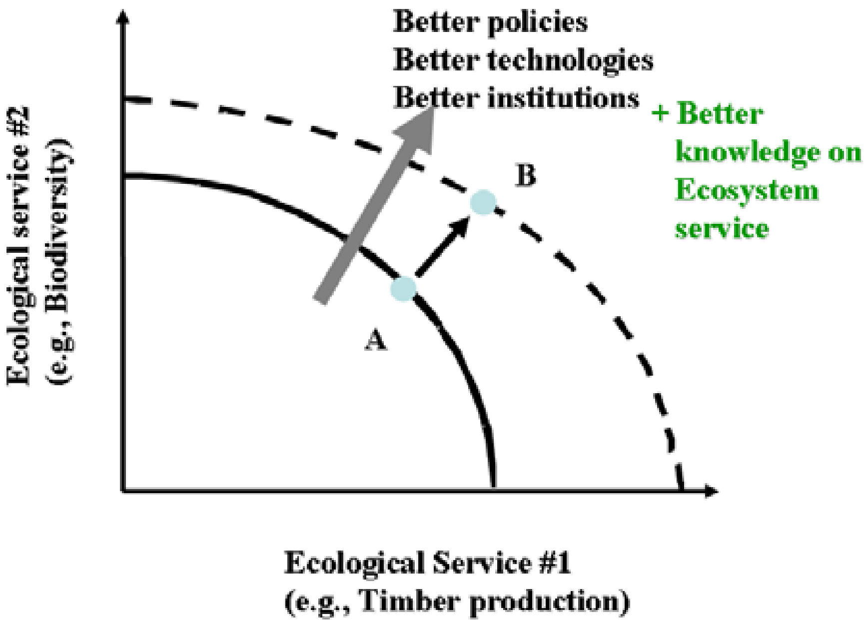

Fig. 3 The trade-offs between two conflicting ecosystem services. Each line represents the combined value of two ecosystem services. Given existing policies and technologies, every point on the line maximizes the combined value of different proportions of the two ecosystem services. The value could increase from “A” to “B” if new technologies (e.g., irrigation systems, reduced-impact logging systems), new policies (e.g., price controls for wood, forest management certification), or new institutions (e.g., for monitoring ecosystem productivity, scientific research) are introduced. Adopted and partly modified from a figure presented by the Millennium Ecosystem Assessment Committee (1998).

Purely economic assessments are unable to evaluate all potential services and goods provided by an ecosystem; instead, the primary objective of our proposed alternative assessment is to offer an objective basis for examining the variables that influence the costs and benefits of proposed land-use changes and to provide alternative options for land-use and management systems. In this regard, of course, a one-time assessment is insufficient, and the methodology for assessing and reassessing service values should be revised repeatedly, highlighting changes in the volumes, conditions, and market prices of natural resources and reviewing the conservation policies responsible for these factors. Such well-revised total economic assessments immediately attract public interest because the proposed activities have clear social impacts; therefore, access to such assessments facilitates investment decisions and encourages best-practice AR activities and forest management.

Furthermore, we believe that one-dimensional analyses of the values of ecosystem services will not solve the problems of deforestation and ecosystem degradation. In fact, trade-off relationships are apparent among the various economic goods and ecosystem services; for example, timber production can conflict with the protection of catchments and biodiversity. However, an improved recognition of the functional aspects of ecosystems and of the ecosystem services they provide, combined with the introduction of new and improved technology, better policies, and enhanced institutional involvement (e.g., measurement of the necessary ecosystem service data), can increase the total value of ecosystem services determined by balancing conflicting goods and services (Fig. 3). When such trade-offs among services were considered unimportant, a sectoral approach made some sense, but today, nations expect that ecosystem management must be capable of reconciling conflicting goals (Millennium Ecosystem Assessment Committee 1998).

In this regard, afforestation or reforestation through CDM-AR could potentially provide several different kinds of ecosystem service in addition to carbon sequestration (e.g., biodiversity protection, catchment protection). Nevertheless, assessment of the values of ecosystem services and goods should be improved by incorporating new criteria or guidelines for assessing the ecosystem services provided by an ecosystem. As well, ecologists should continue to search for new criteria, guidelines, and technologies capable of minimizing the trade-offs among conflicting services. At the same time, ecologists and economists should

Table 1 Summary of major ecosystem services and goods required for establishment of the database.

Ecosystem service	Factor encompassed by the ecosystem services	Items that must be surveyed
Catchment protection	Soil erosion Water quality	Vegetation type, structure, volume, slope aspects, soil type, precipitation
Carbon sequestration	Biomass Soil respiration Edaphic condition	Canopy height, canopy structure
Biodiversity conservation	Habitat heterogeneity Food resources Fragmentation Spatial distribution of vegetation	Canopy height, forest structure, species composition, gap dynamics, topographic data
Socioeconomic services	Option value Existing value	Socioeconomic data (racial, employment, etc.), LULUCF*, natural resource availability (NPP, biomass)

*LULUCF: Landuse and Landuse Changes and Forestry

cooperate to find tools capable of establishing a linkage between dynamic changes in ecosystem services and socioeconomic factors at local or global scales.

To meet these goals, we propose the establishment of database tools for managing the ecosystem services and goods provided by rain forests and their constituent vegetation and landscapes. However, as mentioned earlier, such a database should not be prepared merely to accumulate data and create archives of different data sources, since each ecosystem service or good is tightly related to all others and since managing one service sometimes leads to trade-offs in the management of others. Instead, the database should be relational; that is, it should let us analyze the relationships in the data to provide insights that would help planners, managers, and ecologists to understand how the value of an ecosystem service varies as a function of changes in other services (Table 1). By combining this information with decision-support tools, ecosystem services such as the protection of biodiversity that are difficult to evaluate quantitatively can be indirectly evaluated.

Accordingly, the database should be based on the functional aspects of individual ecosystem services (e.g., watershed protection, carbon sequestration, biodiversity protection) and on the parameters that affect the services, as well as on the relations and linkages between services.

3.2. Monitoring ecosystem services by means of rapid assessments and upscaling technology

For planners and managers to be able to monitor ecosystem services, they must develop tools that permit rapid assessments that can be applied at different scales. Two key applications for these tools would be for monitoring carbon stocks and biodiversity.

3.2.1. Carbon stocks and changes (carbon sequestration)

Major interest has arisen in promoting CDM-AR activities, owing to changes in carbon stocks, which are expected to provide monetary benefits in the future. The carbon stocks of forests can be estimated by means of aerial photography or satellite images that have been calibrated against ground-truthed data and spectral data. For this purpose, vegetation indices such as the Normalized Difference Vegetation Index (NDVI) have been used. Several previous studies have reported good linear relationships between NDVI and the leaf area index (LAI) of forests (Spanner et al. 1984, Running et al. 1986); in turn, LAI has a strong functional relationship with the biomass of stem wood biomass and with net primary productivity (Gholz 1982, Waring 1983). However, NDVI values derived from Landsat images and stand structure variables or total aboveground biomass were poorly correlated in tropical Puerto Rican and Costa Rican forests (Sader et al., 1989). Thus, the validity of the indices varies both locally and at larger geographical scales. Nevertheless, vegetation indices may be a valid tool for distinguishing the volume and distribution of vegetation at continental or global scales.

With aerial photography, the vertical canopy structure of a forest can be characterized, and the height of the forest canopy can be measured by means of triangulation. This conventional method has been used to construct topographic maps and to assess the 3-D structural morphology of the ground beneath forests. The reliability and accuracy of this method for mapping tree heights are expected to be very high. However, aerial triangulation only measures the height of the canopy surface; thus, fine-scale ground surveys (e.g., at 5-m intervals) must be conducted to measure the actual ground level, and such surveys require considerable labor and time. Thus, it is not appropriate to use this method to survey canopy heights over extensive areas (more than 1 km^2 area). Laser profiling, a recently introduced technique, is now beginning to be used commercially for topographic mapping and other applications because it solves the problem of high labor and time costs that occurs with aerial photography. This is because laser profiling can measure the difference between ground level and the canopy surface simultaneously by using ground control points (GCPs). Some studies have been conducted to measure canopy heights and structures in temperate and boreal coniferous forests. However, the accuracy of this methodology must still be examined to confirm how broadly the technique can be applied.

3.2.2. Biodiversity

Forest ecosystems are highly heterogeneous in terms of their structure, their biological components, and the interactions among these components. Ideally speaking, any evaluation of ecosystem services should account for the spatial and structural heterogeneities of these ecosystems. Otherwise, it is easy to set a simple economic and ecological value for the vegetation and treat this value as being uniform for an entire landscape, even though factors such as biomass, carbon sequestration, and species composition all vary greatly in response to changes in the topography, soil, and other microenvironmental conditions (Okuda et al. 2004). The value of an ecosystem service related to biodiversity is more difficult to quantify than is the case for other ecosystem services because of estimation uncertainties, the heterogeneities of the plants and animals involved, and their complex biological interactions within the forest.

For these reasons, a new tool must be developed that will let managers and planners rapidly evaluate both the heterogeneous internal forest conditions (e.g., biodiversity, carbon stocks) and the external conditions of the forest structure. This tool will probably be based on remote-sensing technology. This tool could be named “rapid assessment”. However, such evaluations of biodiversity are urgently needed, and effective, convenient, user-friendly tools and indicators must be developed so that impacts on biological events can be evaluated rapidly but accurately. Such tools and indicators should also be applicable to different landscapes. It

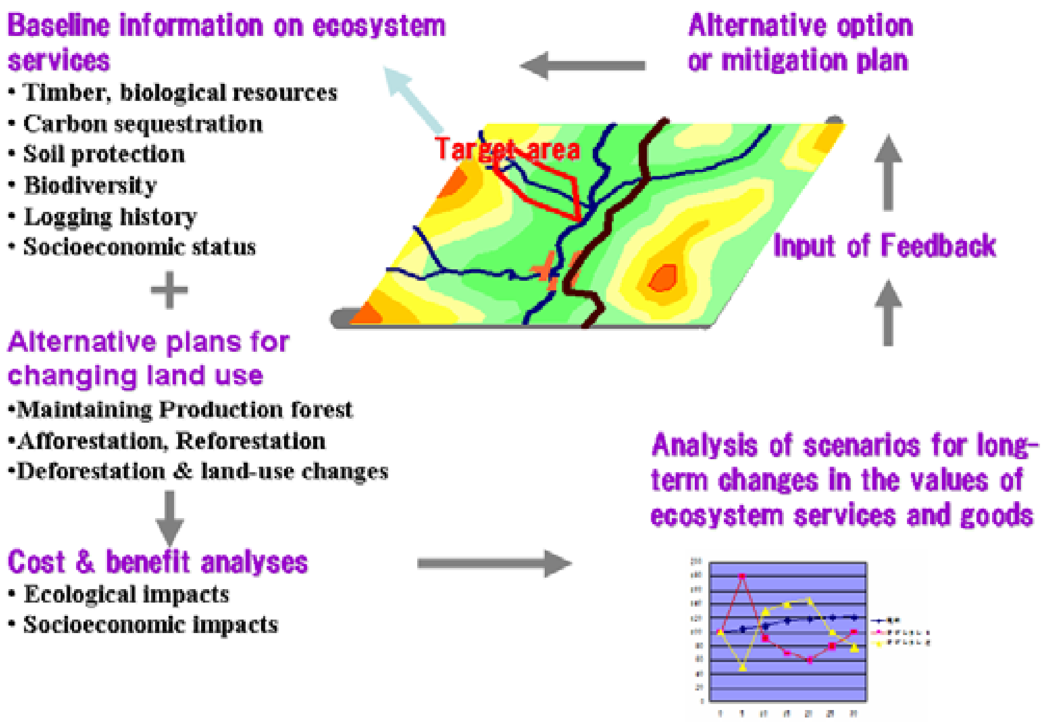

Fig. 4 Risk assessment based on an evaluation of ecosystem services and goods produced by a managed area

should be possible to "scale up" their predictions to larger areas by extrapolating the findings at smaller (fine) scales. Before we can establish a database of ecosystem services related to biodiversity, these sorts of tools and indicators are urgently needed.

3.3. Risk assessment using geographical information systems

Despite the mountains of data that have been generated by research on tropical forests, and the publication of numerous scholarly articles, the loss of tropical forests has not slowed appreciably. Yet decision-makers continue to give researchers and technical experts the continuing and still only partially resolved mission of elucidating the mystery of how tropical forests work. This understanding is certainly a prerequisite for long-term conservation of these forests, but with current rates of loss, little time is left to ensure the survival of the remaining tropical forests, and even existing research sites are in jeopardy. This raises serious doubts about whether the usual approach—cataloguing data from isolated research themes and the running of projects according to each researcher's individual agenda—can truly contribute to the conservation goals defined in research proposals. That is, there is a very real problem: there is currently no means to connect the voluminous data and research achievements on forest ecosystems with regional environmental management initiatives, including those responsible for the well-being of tropical forests. As a way of addressing this problem, we propose an assessment of the value of the ecosystem services provided by tropical forests as a means to take advantage of and integrate basic research, applied research, and the formulation of management plans and policy.

Even this objective makes no sense if each of these activities is conducted independently, in different places, and on differing scales. In view of the diverse social factors that exist in tropical regions and the special nature of the environments in which tropical forests exist, it also makes no sense to do nothing but present general and theoretical solutions. It is therefore crucial that the research community choose specific areas as test sites, generate some ideas for the sustainable development and conservation of the resources of these areas from the perspective of academic research, use these areas to demonstrate how ecosystem functions can be assessed, and simultaneously conduct practical research aimed at providing sustainable benefits to the area by managing its forests sustainably.

Through the establishment of a database of ecosystem services, we have developed "Ecological GIS", a risk-assessment tool that relies on GIS technology running on personal computers. With this system, clients can be rapidly provided with a summary of the environmental risks associated with a proposed development (e.g., logging, clearing forest for plantation development). As well, the present status of the forest (the original form of the landscape) and the results of a long-term scenario analysis of the values of its ecosystem service can be presented (Fig. 4).

3.4. Landscape zoning assessment

With the database of ecosystem services and the two assessment tools described above, a cost and benefit analysis can be based on the proposed direction of a zoning framework; that is, the master zoning plan can be established so as to emphasize biodiversity, watershed ecosystems, carbon sequestration and stocks, or comprehensive value of the ecosystem services provided by an area.

To meet this objective, a test site can be chosen, including, for example, production forest, a forest reserve to protect biological and genetic resources, residential areas, other farming areas, or non-timber plantations (oil palms, rubber plantations). Within the test site, managers and planners can use a simulation model to evaluate and predict the optimal use of the landscape so as to continue providing ecosystem services and protecting biodiversity. Such models may not be practical where the demarcation of individual landscape units is inflexible (e.g., where such units have already been defined by current land ownership or legislation), but such tools would be very useful for future planning of landscape management to protect biodiversity. Furthermore, a consideration of forest management as it should be practiced in the future indicates that it is essential to research and understand the history of and social factors behind the decline of forests in the areas being managed.

4. Use of a Database of Tree Demographic Information for Afforestation and Reforestation

Reforestation and afforestation programs for the rehabilitation of degraded areas must be carefully considered from various angles, such as from the perspectives of biodiversity and the socioeconomic impacts of management decisions on local communities. These issues should particularly be considered when the project will be implemented on a commercial basis, as is the case in CDM, because fast-growing species (often non-native species) tend to be chosen for these activities. As a minimum prerequisite for meeting the problems posed by the

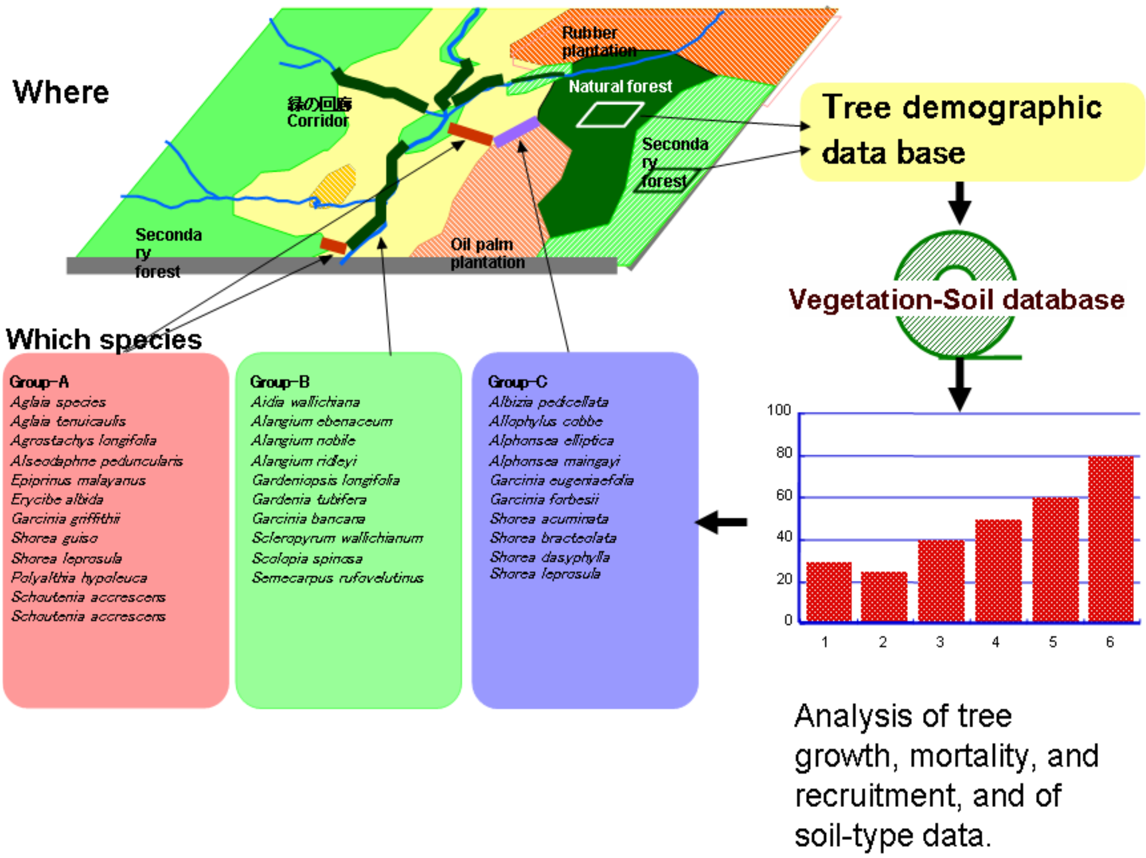

Fig. 5 The use of a tree demographic database to support afforestation and reforestation (AR) activities

biological impacts of AR, many researchers have suggested the use of local or indigenous tree species instead of exotic fast-growing species. However, owing to the high complexity of the tree-environment relationship and the high species richness of tropical rain forests, screening procedures intended to identify tree species suitable for silvicultural purposes are not always successful. Fast-growing species are not always superior to slow-growing species when the longevity and physiological performance of a species are considered in the context of pest or herbivore damage. Vulnerability to such problems tends to be more significant with exotic plant species. Moreover, there is always a trade-off between the shade tolerance of a species and its growth rate. When CDM-AR is considered in the form of mixed-species forests rather than monocultures, such considerations become important, as tree species vary in their growth rate and growth habit. To be safe, planners should take a pessimistic (or at least conservative) view of the selection of tree species for AR activities; we have the ability to choose the desired species from vast number of tropical tree species, some of which are fast-growing exotics (e.g., *Acacia* or *Eucalyptus* spp. in southeast Asia) that are also tolerant of pests and other biological impacts (e.g., herbivore damage).

Considerable effort and many trials will be necessary to adequately test the physiological responses of planted seedlings in different environments. In order to facilitate this time-consuming procedure and provide insight into the physiological performance of selected tree species, we propose the use of a tree demographic database that is available for regions near the project area (Fig. 5). By analyzing the distribution, mortality, and recruitment of trees in relation to the edaphic and light environments of the natural forest, it should be possible to determine the adaptive potential of a tree species in relation to a given environment or project area. If such a database is not available, it should be possible to choose a demographic database for other sites in the same region. It is controversial whether creating and monitoring new demographic plots is economically feasible, but in the long run, the positive impacts of such plots can provide essential basic inputs for planning the implementation of AR activities. Thus, such ecological studies should always be included as part of an AR project, and monitoring of tree demographic data in the plot should be conducted simultaneously so as to create a demographic database where none exists or to refine an existing database.

5. Concluding Remarks

In addition to the assessments described above, a number of other effective methods are conceivable as approaches to creating environmental management plans at test sites. Integrated environmental management plans can further include catchment management plans (headwaters, aquatic resources, preventing the loss of soil and nutrients due to logging, etc.), diversity management plans (establishment of buffer zones and wildlife corridors), and others. When these models are integrated and a certain resource management option is adopted, a model or other means should be used to concretely and visibly predict the results. Moreover, the decision-support tool should identify what options should be chosen in order to provide long-term, stable supplies of natural resources and agricultural produce in the area, and to increase the overall ecosystem service values of the land. Note that the kind of assessment tools we visualize are not merely toys for model-players; instead, they are a very effective means of eventually providing comprehensible information to the public so as to promote local participation and consensus-building for the use and development of an area’s natural resources. This approach would also prevent any one party involved in the process from hiding information or developing lopsided (one-sided) landscape management plans.

As we mentioned earlier, the collection and integration of the required baseline information and research studies will add costs to any CDM implementation. Policy-makers in host and donor countries and other interested parties, as well as the CDM project manager and local communities that will benefit from forest rehabilitation projects, may need to consider these costs as the prerequisite for a successful CDM implementation. The successful implementation of CDM-AR activities cannot be expected without this investment of time and money. Nevertheless, many of these prerequisite studies are fundamentally important and useful beyond the CDM project itself; they also benefit forest management and other sustainable uses of a country's natural resources, even though it remains controversial who should be responsible for the cost of this work. In addition, one must always account for the forces (local demands) that are driving changes in land use from forests to agricultural croplands that generate more obvious welfare and monetary benefits to local communities. The value of ecosystem services generated by maintaining forests should always considered as an additional cost that may be (or perhaps should be) compensated for by some mechanism other than CER, such as environmental taxes.

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References

Costanza, R., d'Rage, R., de Grout, R., Farber, S., Grass, M., Hannon, B., Limburger, K., Name, S., O'Neill, R.V., Paulo, J., Ruskin, R.G., Sutton, P., van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

FAO 1993. Forest Resource Assessment 1990: Tropical Countries. U.N. Food and Agric. Org., Rome.

Gholz, H.L. (1982) Environmental limits on aboveground net primary production, leaf area and biomass in vegetation zones of the Pacific Northwest. Ecology 63: 469-481

Millennium Ecosystem Assessment Committee (1998) Millennium ecosystem assessment: strengthening capacity to manage ecosystems for human development. Available at http://www.ma-secretariat.org/

Myers, N. (1996) The world's forest: problems and potentials. Environmental Conservation 23: 156-168

Okuda, T., Adachi, N., Suzuki, M., Quah, E.S., Manokaran, N. (2003a) Effect of selective logging on canopy and stand structure in a lowland dipterocarp forest in peninsular Malaysia, Forest Ecology and Management 175: 297-320

Okuda, T., Suzuki, M., Adachi, N., Yoshida, K., Niiyama, K., Nur Supardi, M. N., Manokaran, N., Mazlan, H. (2003b) Logging history and its impact on forest structure and species composition in the Pasoh Forest Reserve-implications for the sustainable management of natural resources and landscapes. In Okuda, T., Niiyama, K., Thomas, S.C., Ashton, P.S. (eds.). Pasoh: Ecology of a Rainforest in South East Asia, Springer-Verlag, Tokyo, pp.15-34

Okuda, T., Nor Azman, H., Manokaran, N., Saw, L.Q., Amir, H.M.S., Ashton, P.S. (2004) Local variation of canopy structure in relation to soils and topography and the implications for species diversity in a rain forest of Peninsular Malaysia. In: Losos, E.C., Leigh, E.G. Jr. (Eds.), Forest Diversity and Dynamism: Findings from a Network of Large-Scale Tropical Forest Plots, Univ. Chicago Press, Chicago, IL. pp. 221-239

Running, S.W., Peterson, D.L., Spanner, M.A., Teuber, K.B. (1986) Remote sensing of coniferous forest leaf area. Ecology 67: 273-276

Sader, S.A, Waide, R.B., Lawrence, W., Joyce, A.T. (1989) Tropical forest biomass and successional age class relationship to vegetation index derived from LANDSAT TM data. Remote Sens. Environ. 28: 143-156

Spanner, M.A., Acevedo, W., Teuber, K.W., Running, S.W. (1984) Remote sensing of the leaf area index of temperate coniferous forests. In: Proc. of 1984 Machine Processing of Remotely Sensed Data Symposium, 12-14 June, Purdue University, West Lafayette, IN, pp. 362-369

Waring, R.H. (1983) Estimating forest growth and efficiency in relation to canopy leaf area. In McFadyen, A., Ford, D. (Eds.) Advances in Ecological Research vol. 13. Academic, New York. pp. 327-354