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論文題目　Socio-ecological assessment of ecosystem services in relation to biodiversity along a gradient from forest to agricultural landscape in West Java, Indonesia
（インドネシア西ジャワの森林–農業景観における生物多様性に関連する
生態系サービスの社会生態学的評価）

Ecosystem services provided by natural resources, whether in the form of food, fiber, or fuel, or in a more abstract or psychological form such as cultural and spiritual values, are vital to the livelihoods of resource-poor rural people, particularly those living in the developing countries of the humid tropics, where, historically, people have enjoyed services derived from ecosystems for free. These various ecosystem services are strongly influenced by the level of biodiversity in regions characterized by a complex of natural and human-made ecosystems. However, the conversion of natural forests to other uses and the intensification of agricultural activities threaten both the sustainable provision of ecosystem services and biodiversity conservation. Thus, there is an urgent need to establish landscape management plans that aim to simultaneously maintain ecosystem services, satisfy increasing demands for basic economic needs, and conserve biodiversity.

In the humid tropics, forest ecosystems are still the most important source of ecosystem services and biodiversity, but agricultural ecosystems are also necessary to produce food for rural peoples. Landscapes composed of both natural and human-modified ecosystems are thus essential to provide a complete bundle of ecosystem services to local people. To cope with current threats to ecosystem services and biodiversity associated with forest conversion and intensive agriculture, both natural and human-modified ecosystems must be maintained at the landscape scale. Furthermore, before suitable landscape management plans can be implemented, it is important to understand the roles of local people, who are key stakeholders that actively use, manage, and modify the landscape.

There is a growing demand for the incorporation of social dimensions into assessments of ecosystem services, which at present usually focus on the effects of ecosystems and biodiversity on human well-being. The incorporation of social dimensions will improve our understanding of the ways in which various ecosystems benefit society and, as well, of the many ways in which societies perceive and appreciate ecosystem services. It

is crucial to integrate social and ecological aspects at the landscape scale between, on the one hand, the perception of ecosystem services by local people, who are key stakeholders, the actual ecosystem managers, and the victims of degradation of ecosystem services, and, on the other hand, biodiversity, which underlies the ecosystem functioning that provides ecosystem services. Nevertheless, such assessments are not yet being performed, although they are necessary to provide the basis on which to establish the actual landscape management plans that will both accommodate sustainable utilization of the multiple services provided by ecosystems and, at the same time, maintain biodiversity.

In this dissertation, I assess socio-ecological aspects of ecosystem services with special reference to biodiversity in a forest–agricultural landscape in West Java, Indonesia, with the aim of identifying suitable landscape management practices for ensuring the delivery of multiple ecosystem services and the resultant enhancement of human well-being. I use a socio-ecological approach that takes into account the preferences of the local people as represented by their perceptions of ecosystem services and associated landscape elements as sources of those services, as well as the species richness of the avian and insect pollinator communities that, through their contributions to ecosystem functioning, also contribute to the ecosystem services. For this study, I chose to focus on birds and insect pollinators because they are sensitive to landscape conditions and because, as pollinators, predators, seed dispersers, and ecosystem engineers, they are key players in ecosystem functioning. I used total species richness and that of each functional group to quantify potential ecosystem services, because many studies have indicated that species richness is strongly and positively correlated with ecosystem services, and because functional diversity is also a proven predictor of ecosystem services. The specific objectives of my study were to (a) assess perceptional differences in the landscape elements used and perceived as sources of ecosystem services (Chapter 2); (b) assess the bird community and its functional diversity (Chapter 3); (c) assess the diversity of insect pollinators (Chapter 4); and (d) integrate the findings presented in chapters 2 to 4 with regard to their implications for the spatial arrangement of landscape elements to establish a conceptual plan for sustainable management of a human-dominated landscape that both enhances the provision of multiple ecosystem services and maintains biodiversity (Chapter 5).

The study site is located from 600 to 1300 m above sea level in Neogene hills in Cianjur District, West Java, Indonesia. The landscape gradient extends from remnant forest, to broad- and needle-leaved tree plantations, to mixed-tree and bamboo-dominated agroforests, and thence to upland fields, paddy fields, and village settlements. The majority of the local population is engaged in agricultural activities.

I collected data on the local people's perception of ecosystem services and which landscape elements they regard as the source of those services by using structured interview techniques. I sampled 138 households out of the total of 293 households engaged in agriculture that occupied the study site. To identify which socioeconomic factors affected their perceptions of ecosystem services, I analyzed the survey data with generalized linear models (GLMs) with a logit link function that followed a binomial distribution. Next, I evaluated how accessibility to the remnant forest in two categories, less than or greater than 1.5 km from the remnant forest, affected how the people perceived each landscape element as a source of each ecosystem service.

I collected data on the birds and insect pollinator communities at sampling points chosen to represent all environmental variations at the study site. Bird surveys were performed in accordance with a standardized observation method using point counts. I defined 112 plots and aimed to sample all landscape elements in proportion to their actual occurrence in the forest–agricultural landscape. Insect pollinators were collected by a commonly used passive sampling method using pan traps. I set up 316 plastic soup bowls painted with UV-

bright yellow, white, blue, and red colors in 79 plots. For birds and insect pollinators, I calculated abundance, species richness, and Simpson's diversity index of all species in each plot, and compared their differences among landscape elements. I performed a non-metric multidimensional scaling (NMDS) analysis to investigate general species composition patterns among the different landscape elements. To quantify the effects of three environmental factors (landscape element types, vegetation covers and structures, and proximity to the remnant forest) on total species richness and that of each functional group, I used GLMs with a logarithmic link function that followed a Poisson distribution.

I found that rural people living along the entire gradient from forest to agricultural lands were acutely aware of many ecosystem services, although they were more aware of direct services such as food and fuelwood than of indirect services. Place of origin, residential location, area of agricultural lands and agroforests, and number of livestock were the most influential socioeconomic factors determining the number of ecosystem services perceived by an individual respondent. People living closer to the remnant forest perceived more ecosystem services than those living further away. Among the landscape elements, agroforests provided the highest number of ecosystem services, followed by remnant forest, and they were highly appreciated by people living far from the remnant forest. However, the remnant forest and timber plantations were highly appreciated as sources of cultural services by people living across the landscape, regardless of the accessibility of the forest. Extractive activity in conflict with forest conservation, such as capturing birds to be sold as pets, still occurs, not because the people engaging in this activity do not perceive the importance of biodiversity conservation but rather because it provides them with a direct economic benefit. Therefore, I inferred that people living close to the forest will promote prospective ecosystem services and biodiversity conservation only if their economic needs are accommodated. I also found that agroforests were perceived as providing the largest number of direct and indirect ecosystem services, regardless of whether the respondents lived close to or far from the remnant forest. This result implies that agroforests are an important supplement to the remnant forest in the provision of some ecosystem services.

The bird community assessment results showed that bird species richness, diversity, and abundance differed significantly between the remnant forest (where values were highest) and village settlements (lowest). Species richness in broad- and needle-leaved tree plantations and mixed-tree agroforests was high-intermediate, and that of bamboo-dominated agroforests and upland and paddy fields was low-intermediate, between the species richness values in the remnant forest and in village settlements. The NMDS analysis results revealed that the avian species compositions in human-made ecosystems differed dramatically from the composition in the remnant forest, mainly because of a decline in the abundance of forest specialists (including IUCN red-listed species) in the former, and their replacement by open-habitat generalists. Among environmental factors, landscape element differences tended to be more important than other factors in explaining species richness values in each ecological group, as well as in all species combined, although forest specialists were affected not by landscape element type but by proximity to forest canopy cover. These findings imply that the forest remnant plays an important role in the maintenance of bird diversity, particularly of forest-dependent species, because 55% of forest specialist species were found only in the remnant forest. Nevertheless, the needle- and broad-leaved tree plantations harbored 26% and 36% of forest specialist species, respectively. The mixed-tree agroforests also supported 26% of forest specialists and forest-edge species. Moreover, among the human-modified ecosystems, mixed-tree agroforests exhibited the highest species richness of species endemic to

Indonesia, and they also contained a high proportion of various functional groups that play key roles as pest controllers, pollinators, and seed dispersers.

The insect pollinator community assessment results showed that species richness, diversity, and abundance were highest in the remnant forest and the mixed-tree agroforests, and lowest in upland fields and village settlements. Species compositions did not differ among landscape elements. However, there was a dramatic difference between the forest and village settlements, mainly because of a decline in the species richness and abundance of efficient pollinators such as bees and wasps in the latter, and their replacement by less efficient pollinators such as moths, butterflies, flies, and beetles. Vegetation cover, particularly that of top canopy, tended to be more important than other factors in explaining the species richness of insect pollinators, even in fields where annual crops were cultivated. However, species richness of efficient pollinators (bees and wasps) was moderately affected by proximity to the forest. Even though landscape element differences were not a main factor influencing species richness of total insect pollinators, the remnant forest was likely the source of efficient pollinators, especially of bees. Among human-modified ecosystems, mixed-tree agroforests maintained the highest number of species of insect pollinators.

The results presented in Chapters 2 to 4 show that both local people's perceptions of ecosystem services and the functional biodiversity of birds and insect pollinators generally decreased from the remnant forest to human-modified ecosystems. Therefore, to conserve the diversity of forest birds and efficient pollinators (bees and wasps) as well as to preserve services related to the regulation of water, soils, and the atmosphere that many of the local people perceive, protection of forests should be a priority. In addition, to reduce extractive activities that conflict with forest conservation, such as the capturing of birds to be sold as pets, the economic needs of people must be accommodated. Then, if people have access to the remnant forest, biodiversity conservation and the maintenance of various ecosystem services will be promoted.

To prevent extractive utilization of forest resources, alternative ways for rural people to earn income must be provided. For example, the expansion of agroforests in buffer zones around the forest combined with economic utilization of the planted trees and shrubs can reduce human pressure on the remnant forest. In fact, my study shows that mixed-tree agroforests play pronounced sociological and ecological roles that could be further enhanced by establishing them close to the remnant forest and by creating ecological corridors to the remnant forest through both broad- and needle-leaved tree plantations. Greater functional diversity of birds in the agroforests could be sustained by increasing tree density and by introducing tree species that attract bark-gleaning insectivores. The bamboo-dominated agroforests, which produce economically important materials for value-added crafts (e.g., woven-bamboo walls, locally called bilik) used by the local people, as well as construction materials sold mainly to city markets, should be located far from the remnant forests, because these agroforests are clearly not favored by many efficient pollinators or functional groups of birds. Also, the addition of trees to provide canopy cover in paddy and upland fields would attract insect pollinators to those ecosystem elements.

Additional studies are needed that fully cover the landscape gradient from intact forest to intensively exploited agricultural lands and densely populated urban areas, and that directly evaluate the role of biodiversity in all landscape elements, in order to quantify the extent to which species diversity improves the delivery of ecosystem services. In combination with such additional results, the outcomes of the present study will contribute to the development of a generalized ecosystem-service-based landscape management plan that is adaptable to conditions in developing countries in the humid tropics.