Integrated Assessment of Biodiversity and Multi-functionality of *Satoyama* Landscapes

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Abstract

We devised indicators to assess the biodiversity of *satoyama* environments and developed models to assess their regulating services at a nationwide scale using a common database. Because of a lack of information on species distribution and farming systems in Japan, we used indirect habitat information such as land use/cover and assessed biodiversity by calculating JOIN values, which can be used as indicators of mixtures of two land uses (*e.g.*, paddy-forest, paddy-built-up area) calculated by land-use grid data. We also developed assessment models of regulating services by collecting grid data such as "digital national land information" and modifying existing models, and measured the values of several regulating services. These values were compared among the *land classes* of the Rural Landscape Information System (RuLIS), a survey/information system developed by the National Institute for Agro-Environmental Sciences (NIAES), with the aim of monitoring, analyzing and assessing changes in biodiversity and wildlife habitats in agro-ecosystems effectively at various spatial scales. The results suggested that the spatial and temporal conditions and trends in biodiversity and regulating services could be assessed effectively by using RuLIS land class categories. Therefore, these assessment models for biodiversity and ecosystem services, both of which are assessed as functions of land use, could contribute to the creation of land-use change scenarios and estimation of environmental changes by being coupled with the spatial hierarchical framework of RuLIS.

Key words: biodiversity, land use, multi-functionality, provisioning services, regulating services

1. Introduction

"Satoyama" is a Japanese word used to refer to the mosaic of mixed coppice forests, rice paddy fields, upland fields, grasslands, streams, ponds, reservoirs for irrigation and settlements that make up the traditional rural landscape of Japan (Takeuchi *et al*., 2003). *Satoyama* areas have traditionally been maintained according to distinctive local management and farming methods that have been passed down over the generations, and they have contributed to the rich biodiversity and the provision of various ecosystem services which support people's livelihoods (Duraiappah *et al*., 2012).

Although social, political and economic changes since the 1960s, such as agricultural innovations, the fuel revolution, the shortage of young farmers and increasing globalization, have caused declines in ecosystem services and biodiversity in the *satoyama*, recent socio-economic and environmental situations have raised people's awareness of energy and food securities and the potential values of the *satoyama*. In other words, increasingly serious environmental issues are, in effect, creating opportunities for promoting the re-evaluation and use of domestic biological resources (Takeuchi, 1996; Okuro, 2008).

In accordance with these movements, new land use models based on traditional systems of local resource utilization and management have recently been attracting increasing attention throughout the world as models to support the creation of sustainable societies (Jiao *et al*., 2012). The Japanese government has also proposed creating national strategies for conservation and restoration of societies in harmony with nature and developing global strategies with the aim of rebuilding a sound human-nature relationship typified by the *satoyama* (Japanese Government, 2007). In the Millennium Ecosystem Assessment (MA) too, the *satoyama* and *satoumi* (local coastal waters) were chosen as a target for sub-global assessment (SGA) and their future was analyzed in line with several scenarios based on the MA assessment framework (Duraiappah *et al*., 2012).

It is vital to the establishment of a new societal model to come up with a new land use system which enables sustainable resource use without reducing natural values, based on integrated assessment of biodiversity and ecosystem services. Development of research and technology related to ecosystem conservation and resource use in the *satoyama* such as biodiversity conservation, maintenance and improvement of multi-functionality in agricultural lands and promotion of the utilization of woody biomass as materials and for energy, have so far been conducted separately (*e.g*., Iiyama, 2003; Takahashi, 2012). However, little is known about the conditions and trends in biodiversity and ecosystem services or their inter-linkage, which could contribute to an integrated quantitative assessment and development of land use models at both the nationwide and local scales.

In this paper we first summarize the features of biodiversity and ecosystem services, specifically focusing on the regulating services in *satoyama* environments in terms of land use/management systems, because many other studies have mainly focused on their provisioning and cultural services (Takeuchi *et al*., 2003) but few have focused on their regulating services in spite of strong interlinkages with other ecosystem services (Kato *et al*., 1997; Okuro *et al*., 2012). We then introduce a new integrated assessment model for biodiversity and regulating services, both of which are assessed as functions of land use, to show how these models could contribute to building land-use change scenarios and supporting sound decision-making about future land use in the *satoyama*.

2. Features of Biodiversity and Ecosystem Services in the *Satoyama* in Terms of Land Use Systems

2.1 Features of biodiversity in the *satoyama*

The most important feature of *satoyama* ecosystems from the perspective of their biota is the dynamic system of relationships sustained by human activity or disturbance. Natural disturbance is known to play an important role in renewing biota, but in *satoyama* ecosystems where humans have eliminated natural disturbance, human disturbance through agriculture has tended to assume the same role (Moriyama, 1997). Another major feature of *satoyama* ecosystems is the way that their many different land use components (habitats), such as paddy fields, dry crop fields, woodlands, coppices around homesteads, water channels, reservoirs for irrigation, and secondary grasslands, are distributed in a patchwork mosaic to create the typical *satoyama* landscape (Duraiappah *et al*., 2012). Even if local populations have disappeared within a patch as a result of disturbance, those populations will recover if the same species are able to invade from surrounding patches. There are also some species called multi-habitat users that utilize a combination of different habitats within the patchwork such as the gray-faced buzzard (*Butastur indicus*; Takeuchi *et al*., 2003). The biodiversity of the *satoyama* is thus characterized by factors related to land use and landscape structure, such as the diversity of land use, the diversity of habitats created by human disturbance, and the balance between recovery from disturbance and the movement and supply of species.

Changes in agriculture and rural communities since the 1960s have dramatically transformed the nature of human impacts on *satoyama* areas and their biodiversity. There are two opposing aspects to this transformation, abandonment and intensification (Okuro, 2008). These changes have in turn led to an increasing homogenization and fragmentation of the formerly highly diversified habitats of *satoyama* ecosystems. Species closely associated with environments at an early or intermediate stage of succession are particularly vulnerable to the impacts of homogenization of habitats, while species with low mobility are easily affected by fragmentation of habitat. This homogenization, decrease, and fragmentation of habitat is also leading to a decrease in ecotones, transition areas between adjacent but different plant communities, which are very valuable habitats from the biodiversity perspective (Kusumoto *et al*., 2006).

2.2 Features of regulating services in the *satoyama*

As described above, biodiversity in the *satoyama* is the result of rational modification of the ecosystem through agriculture and forestry, or in other words, the result of the sustainable use of ecosystem services. Ecosystem services can be defined as the benefits that people obtain from ecosystems, and include provisioning services, regulating services, cultural services and supporting services (Millennium Ecosystem Assessment, 2005). In this paper we focus on regulating services which in the *satoyama* in many cases are integrally inter-linked with the provisioning services they provide through agriculture, forestry and fishery industries. Although many previous *satoyama* studies have treated provisioning services, little is known about regulating services.

Generally, agricultural activities that cause drastic transformation of nature, provide enhanced, short-time provisioning services, while negatively affecting regulating services. Conversely, in the case of the *satoyama*, where human interventions in the natural environment and agricultural, forestry and fishery businesses have been continuously conducted in the proper manner, regulating services may have been provided so as to supplement provisioning ones. For example, the surface collapse prevention function of terrace paddy fields and their levees is a function that may be exerted by discovering collapse at the initial stage and repairing it. The soil erosion prevention function of paddy fields is also very high because of the reduced impact of rainfall on the soil surface under an irrigated state. However, when cultivation ceases, rapid permeation of rainfall into groundwater sources occurs following heavy rains, subsequently leading to erosion and surface collapse (Okuro *et al*., 2001; Arita *et al*., 2003).

Maintenance of the regulating services of erosion prevention provided by forests in the *satoyama* is influenced by forest management, such as cutting, tree planting and thinning of planted forests. Even in the case of a planted forest, if the forest is soundly managed, then the services it provides can be almost the same as those from a natural forest. However, negligent management and changes in forest physiognomy have impaired these services.

2.3 Necessity of integrated assessment of biodiversity and ecosystem services in the *satoyama*

From the above-mentioned results, it is clear that land abandonment may be a major driver of reduction of both biodiversity and ecosystem services as well as intensification, because biodiversity and these services are maintained through the land management associated with agricultural production (Okuro and Takeuchi, 2010). Given the current status of agriculture and rural communities, it would of course be hardly feasible to manage 40% of Japan's land area as it has been managed to date just in order to conserve biodiversity (Takeuchi *et al*., 2003).

However, the *satoyama* has not always remained exactly the same for very long (Yokohari and Kurita, 2003). This suggests that rather than simply reconstructing the past and attracting the flora and fauna that once populated a particular *satoyama* area, efforts to restore *satoyama* ecosystems should focus on examining those ecosystems in the light of local history to develop mechanisms for new sustainable uses of their biological resources that preserve their rich biodiversity. Creating sound resource-circulating, low-carbon and nature-harmonious societies will require recognizing the societal value of *satoyama* ecosystem services tailored to new needs, and will require the building of local land use systems for benefiting from those services over the long term. A vital aspect of ecosystem restoration based on the above viewpoint is for stakeholders to draw up a vision for their future and share it as their own societal goal. They then need to assess the biodiversity and ecosystems from the perspective of how well ecosystem services corresponding to those societal goals are being expressed, and then implement an adaptive management of the ecosystem according to their findings. Therefore, developing integrated assessment tools, as shown below, may contribute to supporting scientific decision making when selecting the best goal from among multiple land use scenarios (Goldstein *et al*., 2012).

3. Identifying Biodiversity Indicators and Developing Assessment Methods

In Western countries, where there has long been much interest in biodiversity, and where there has been much discussion on the relationship between agriculture and biodiversity, the approach deemed effective for assessing biodiversity in agricultural ecosystems is one which integrates three types of information: (1) habitat information based primarily on land cover, (2) information on species distribution, and (3) farming system information (EEA/UNEP, 2004; Samoy *et al*., 2007; Okuro *et al*., 2008). Regarding information on species distribution in Japan, government agencies are individually databasing biodiversity-related information, an example being the Japan Integrated Biodiversity Information System (J-IBIS) provided by the Ministry of the Environment, but there are problems such as limitations on the species and regions covered and the continuity of data collection. Also, there is not enough farming system information pertaining to nationwide-level agricultural biodiversity. Under current circumstances it seems that it would be appropriate to perform assessments based on habitat information, mainly land cover. We therefore began by collecting land cover data. Keeping in mind considerations such as future general use and integration with data from other institutions, as a habitat information database on biodiversity we prepared land-use gridded data with different periods, assembled on a standard grid square system as digital national land information.

We then devised indicators to assess biodiversity of *satoyama* environments. Various methods of assessing biodiversity on the basis of land use and land cover have been devised (Yamamoto and Kusumoto, 2008), but no consideration has been given to land use patterns, which are especially important to the *satoyama,* as mentioned above. At the same time, a number of assessment methods that use spatial heterogeneity and mosaic structures as indicators have been proposed, but there have been few instances of these being applied on a nationwide scale (Kadoya and Washitani, 2011). In this study, therefore, we tried applying JOIN statistics, which are indicators of the degree to which two land uses mix; their units are sets of grid squares, and they are calculated from the degree of agglomeration and contiguity of the grid squares in the sets. Here we focused on the "paddy–forest JOIN value," which is thought to indicate the mosaic structure of the *satoyama*, and on the "paddy–built-up area JOIN value," which is thought to indicate the extent of land transformation and urbanization. In other words, using units of the third grid, we focused on the three land uses of rice paddies, forests, and built-up areas within the land use data subdivided into land-use grid squares of approx. 100 m × 100 m. We then totaled the percentage of lines where two different land uses (paddy and forest, or paddy and built-up area) adjoined, and calculated, respectively, the "paddy–forest JOIN value" and "paddy–built-up area JOIN value" (Figs.1 and 2).

To reveal their regional characteristics and patterns of change, we used the "land class" system in the Rural Landscape Information System (RuLIS), a survey/information system developed by the National Institute for Agro-Environmental Sciences (NIAES) with the aim of monitoring, analyzing and assessing changes in biodiversity and wildlife habitats in agro-ecosystems effectively at various spatial scales (Ide *et al*., 2005).

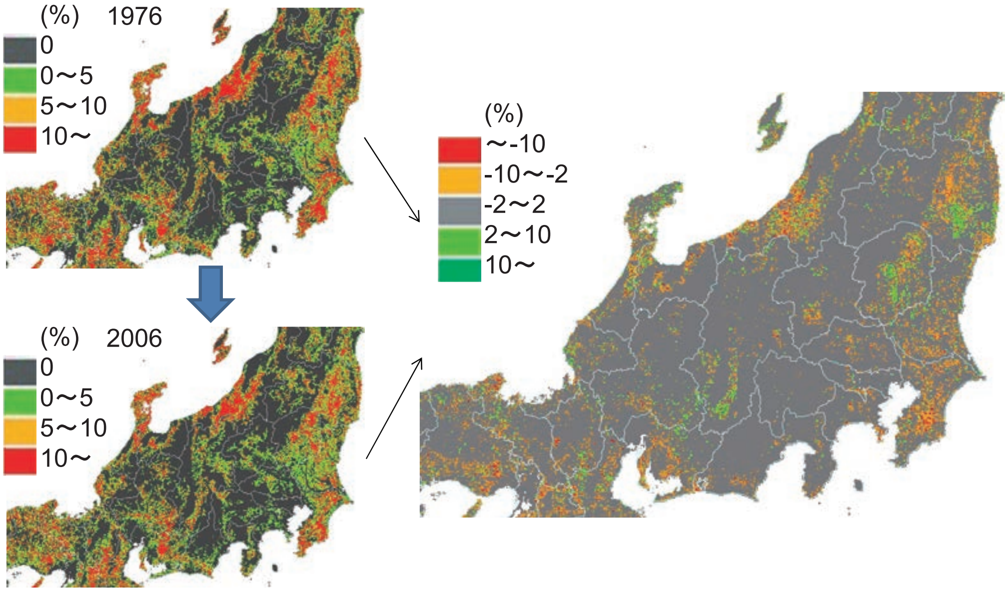

Fig. 1 Distribution and changes in paddy-forest JOIN value (%). Upper left: in 1976, lower left: in 2006, right: change rate (%) between 1976 and 2006.

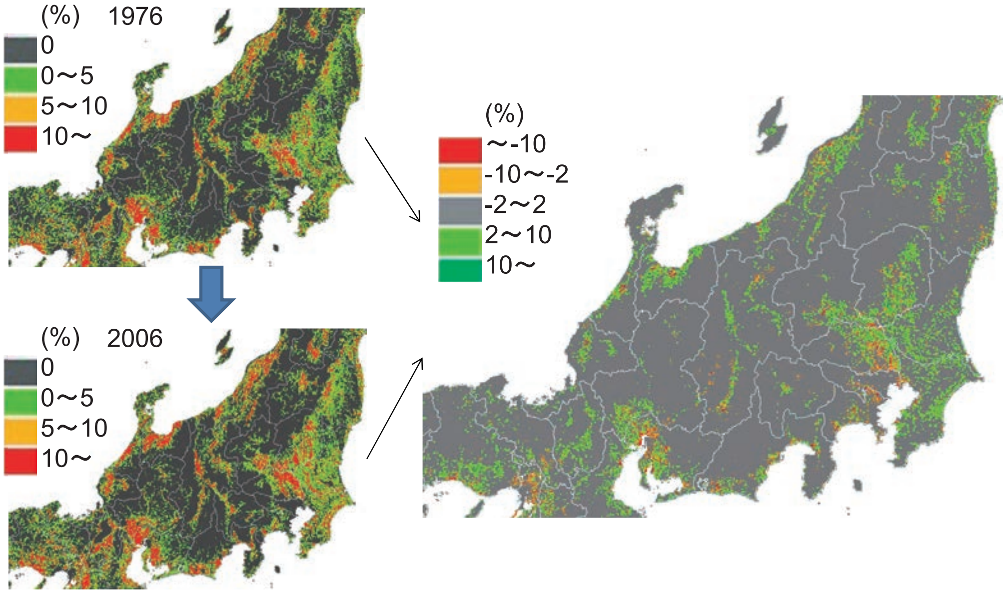

Fig. 2 Distribution and changes of paddy-built-up area JOIN value(%). Upper left: in 1976, lower left: in 2006, right: change rate (%) between 1976 and 2006.

RuLIS is composed of standardized survey methods and rural landscape types called land classes, which are classified by means of a statistical method using factors that characterize agro-ecosystems (weather, soil, geology, topography, vegetation and location convenience, all of which are available as digital national land information). These categories also have a spatial hierarchy, making it possible to change the classification levels in accordance with the spatial scale being used. Monitoring/assessment based on those environmental stratifications is thus expected to detect spatial and temporal patterns of changes more precisely.

We accordingly used the land classes (Classes 1 through 8) of the upper classification level (Level 3) suitable for the nationwide scale. Results indicated that paddy–forest JOIN values were high for some mountainous and hilly landscape regions (Class 4) and for the upland and lowland regions (Classes 5 through 8), while the paddy–built-up area JOIN values were high for the upland and lowland regions (Classes 5 through 8). Overall the paddy–forest JOIN value tended to decrease, while the paddy–built-up area JOIN value tended to increase,

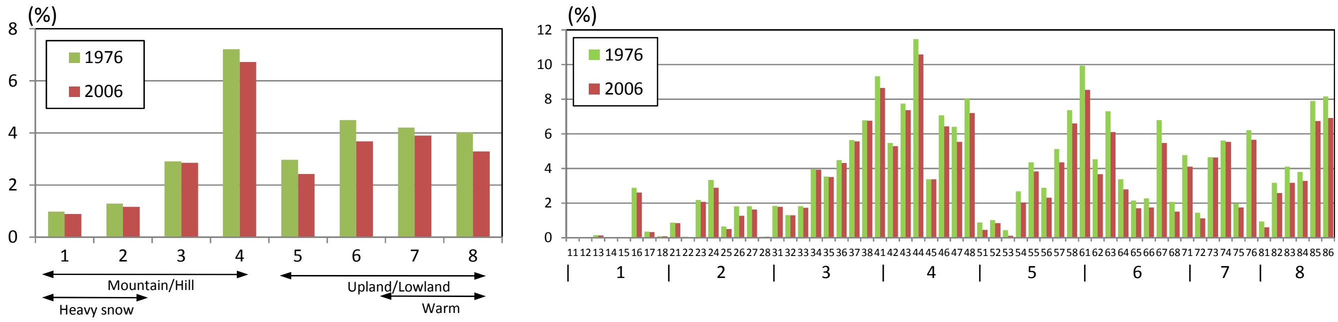

Fig. 3 Changes in paddy-forest JOIN values in different land classes of RuLIS. Left: upper level (8 classes), right: lower level (64 classes). Numerical values from 1 to 8, and from 11 to 86 indicate land class categories at upper and lower levels, respectively. Topographic and climatic factors relevant to each land class are shown along the horizontal axis.

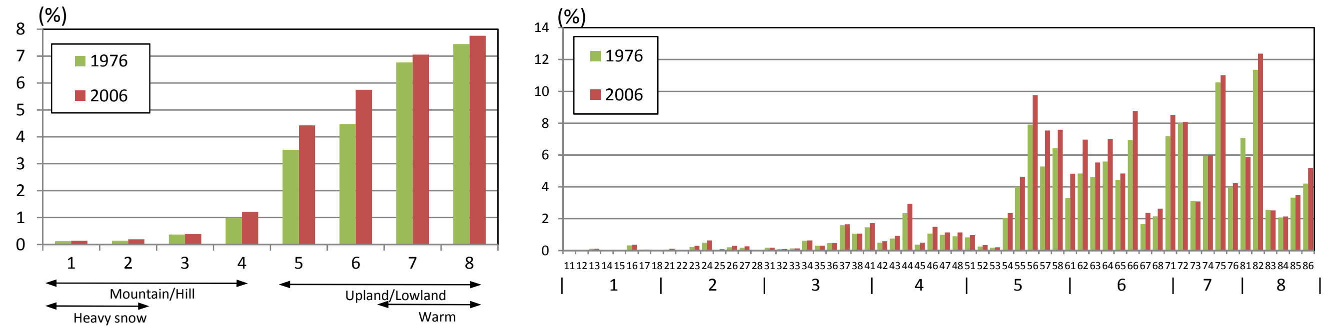

Fig. 4 Changes in paddy-built-up area JOIN values in different land classes of RuLIS. Left: upper level (8 classes), right: lower level (64 classes). For the legend, see Fig. 3.

but we found that both rates of change were greatest in Classes 5 and 6, corresponding to suburban areas (Figs. 3 and 4). Analyzing JOIN statistics for each land class in this way showed that it is possible to assess the regional characteristics of biodiversity and its changes seen in terms of spatial structures.

We then ascertained the relationship between nationwide and regional scales using RuLIS agricultural ecosystem categories, and investigated the validity of multiscale assessment using that method. We compiled paddy–forest JOIN values and paddy–built-up area JOIN values, as calculated above for the RuLIS upper classification level (8 classes), which corresponds to the nationwide scale, and the lower classification level (64 classes), which corresponds to the local scale. We found with respect to paddy–forest JOIN values that for the classes which had high JOIN values in the upper level, the classes in the lower level generally also had high JOIN values. However, there were also classes in the lower level with markedly high JOIN values regardless of the JOIN values in the upper level (such as paddy-centered landscapes in lowlands and hilly areas, and upland valley paddy landscapes in downstream areas) (Fig. 3). These classes closely coincide with landscape areas found by past studies to have high habitat potential (Kusumoto *et al.*, 2006). We also discerned the same tendency in paddy–built-up area JOIN values (Fig. 4). Judging by the foregoing, it seems that using the hierarchical nature of RuLIS agricultural ecosystem categories enables multiscale assessments of biodiversity in the *satoyama* on the nationwide and regional levels.

4. Developing an Assessment Model for Regulating Services

As an aspect of the regulating services in agroecosystems, nationwide assessments of the environmental conservation functions of farmland and forestland have thus far been carried out using digital national land information and other data (Kato *et al.*, 1997). But these are relative assessments, based on results of calculations for only one period, using class values from comparisons with changes that occur in the event that farmland or forestland is abandoned. It is not possible to determine change trends or the current state. At the same time, because many of these function assessment models perform their calculations with assessment equations that have land use as a variable, using land use data for multiple time periods enables one to determine the temporal and spatial changes of each function. We therefore started by obtaining digital national land information for assessing environmental conservation functions, and databased it. We next used the content of available existing datasets to make assessment equations and category score tables (assessment score tables are included in the explanation of each environmental factor) for individual functions, and attempted to assess environmental conservation functions using the units of the third grid. The following is an example of soil erosion prevention;

$$\text{Soil Erosion Prevention (E)} = E1\times E2\times E3\times(E4+E5)/2\times 100$$

where E1: rainfall intensity, E2: slope gradient, E3: land use, E4: soil type, E5: soil texture. A model that was developed by the Soil Conservation Service of the United States Department of Agriculture (Wischmeier and Smith, 1965) was applied to this study, according to Kato *et al.* (1997). Although E itself is a dimensionless value for a relative evaluation, the amount of soil loss (t/ha/year) can also be roughly estimated by multiplying it by a factor of 2.5 in the case of Japan (National Land Agency of Japan, 1993)

Having obtained assessment values for multiple time periods using the assessment equations and units of the third grid, we next analyzed change trends using RuLIS agricultural ecosystem categories, in the same way that JOIN values were used in the biodiversity assessments, in order to find regional characteristics and changes in patterns. On a nationwide scale, the assessment value totals stayed at about the same level from 1976 to 2006, and we found no large changes in regulating services. But on a regional scale we found that distribution and change patterns were different (Fig. 5). For example, although the soil erosion prevention function was low overall in upland and lowland areas (Land Classes 5 through 8), we confirmed that the tendency was especially marked in Class 7. We also found that even within the same class in upper levels, there were regional differences in distribution and change in the lower level (Fig. 5). Assuming that most of the variables such as soil properties, topography and rainfall were nearly same between 1976 and 2006, those changes would have been caused by land use changes.

As this indicates, analyzing the above assessment values of environmental conservation functions for each land class makes it possible to perform multi-scale assessments of the regional characteristics of regulating services and their changes.

5. Integrating Assessment Models for Biodiversity and Ecosystem Services

Building on the above-mentioned results, we calculated JOIN values and regulating services indicator values (soil loss amount estimated as the soil erosion prevention function) for each of the RuLIS land classes at lower level (64 classes) and analyzed the relationship between the two. The results showed that with the decline in paddy–forest JOIN values, the soil erosion amount could be divided into two groups of classes: classes in which the soil erosion amount decreased in mountainous/hilly areas and those in which it increased in upland/lowland areas (Fig. 6). Judging by the differences in

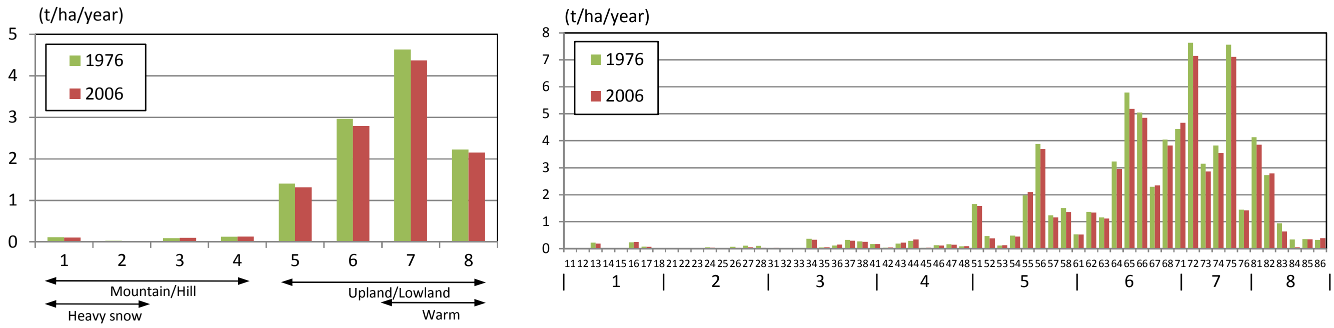

Fig. 5 Changes in soil erosion prevention service (amount of soil loss; t/ha/year) in different land classes of RuLIS. Note that lower values indicate higher prevention services. For the legend, see Fig. 3.

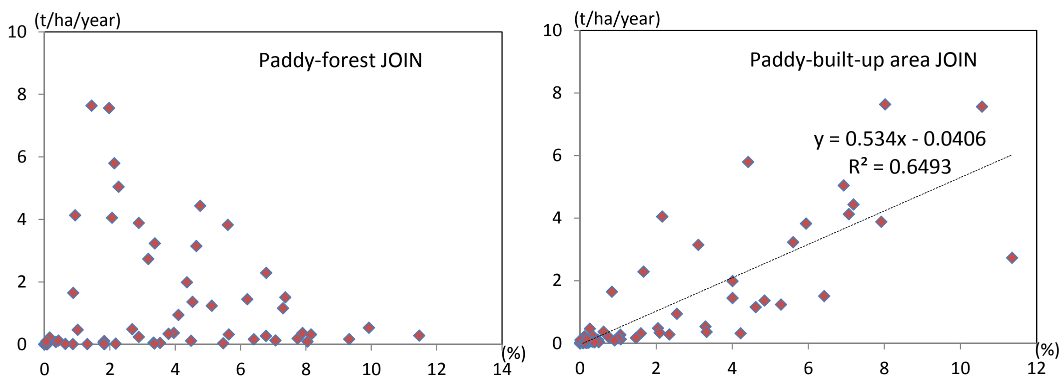

Fig. 6 Relationship between JOIN values and soil erosion prevention services at the lower level (64 classes) of RuLIS. Left: paddy-forest JOIN values, right: paddy-built-up area JOIN values.

the two groups' geographical distributions, the former was attributable to abandoned rice paddies returning to forests, while the latter was attributable to urbanization due to conversion to housing lots and other uses. However, we need further analysis of change patterns of land use for each land class to confirm drivers controlling those trends. We were able to corroborate this with the significant positive correlation between the paddy–built-up area JOIN values and the soil erosion amount. On the other hand, the soil erosion amount tended to decline uniformly as the paddy–forest JOIN value increased. This suggests that progression of the paddy–forest mosaic does not necessarily lead to a decline in regulating services (Fig. 6).

Our results indicate that integrated assessments of biodiversity and ecosystem services are made possible by using the shared variable of land use, shared datasets such as "digital national land information" as a representative example, and the shared assessment units of RuLIS land classes.

6. Conclusion

We developed a *satoyama* biodiversity assessment method which uses land use as habitat information. This is the first such instance in Japan, which as yet has no biological distribution information for agro-ecosystems, in which *satoyama* biodiversity has been assessed on a nationwide scale using integrated indicators based on spatial structural characteristics, and it has great academic significance.

We also developed a method to assess change over time in regulating services. By improving on preexisting models, which have assessed situations only as a snapshot, and by using land use data for multiple time periods it is possible to determine trends in temporal and spatial changes in regulating services. This method can also be used for scenario analyses.

Based on these results, we constructed a frame for the integrated analysis of biodiversity and ecosystem services. The use of RuLIS agricultural ecosystem categories, which have shared numerical data and a spatial hierarchy, made it possible to perform multi-scale, quantitative assessments of the linkage between biodiversity and ecosystem services, and of regional characteristics. Compared with other versatile assessment tools, the advantage of this assessment frame is that it includes the environmental stratification procedure which is needed for the assessment of *satoyama*-like landscapes, of which there are various types depending on natural and socio-economic conditions. Further, the assessment frame provided in this study could be used as an effective tool for supporting scientific decision making when selecting the best land use options from among multiple land use scenarios, and it therefore it could have great significance in practical application.

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