CHAPTER 6

CHALLENGES FACED WHEN CREATING AN EVALUATION METHOD OF BIODIVERSITY ON AN ECOSYSTEM LEVEL

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Abstract. In order to create an accurate evaluation method that properly reflects the value of biodiversity on an ecosystem level, the current and past studies of such methods must be analysed. Biodiversity evaluation models published in journals from 1995 to 2005 were studied and was concluded that in order to create an accurate model, the following four elements need to be included: the first, species from different guilds that maximize the phylogenetic diversity, as surrogates of the ecosystem should be included. Secondly, assess the extinction probability of the selected species by Population Viability Analysis. Thirdly, identify the potential habitat area of selected species by Potential Habitat Analysis. Fifthly, estimate the survival probability of the selected species in the potential habitat area.

1. INTRODUCTION

There are three types of values in ecosystem goods and services, which are provided by ecosystem functions; i.e., regulation functions, habitat functions, production functions, and information functions (Figure 1). Biodiversity is one of the ecosystem services supported by ecosystem structures and processes that provide habitat for wild plant and animal species (DeGroot et al., 2002). Moreover, biodiversity is the basis for most ecosystem functions, which means, it contributes directly or indirectly to all ecosystem goods and services.

As figure 1 shows, the value of biodiversity is a total value of ecological value, socio-cultural value, and economic value. Farber et al. (2002) and Wilson and Howarth (2002) discuss in detail each concept of these three values. Ecological sustainability, i.e., physical, chemical, and biological capacity of the environment,

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controls humans' socio-cultural and economic activity. Therefore, "ecological value" must be evaluated accurately and objectively because it should be the basis for the other values, i.e., "socio-cultural value" and "economic value". Then, how has the ecological value of biodiversity, the pivot of ecosystem goods and services, in other words, been evaluated?

Many evaluation models for biodiversity have been proposed, especially since CBD (The Convention on Biological Diversity) went into effect in 1993. Evaluation of biodiversity is carried out on all kinds of aspects such as assessing developmental impact on wildlife habitat, prioritizing reserve selection, and assessing mitigation effect. Corresponding to the request from these needs, many researchers are trying to evaluate regional biodiversity in unique ways suitable for their own purposes or local ecosystems.

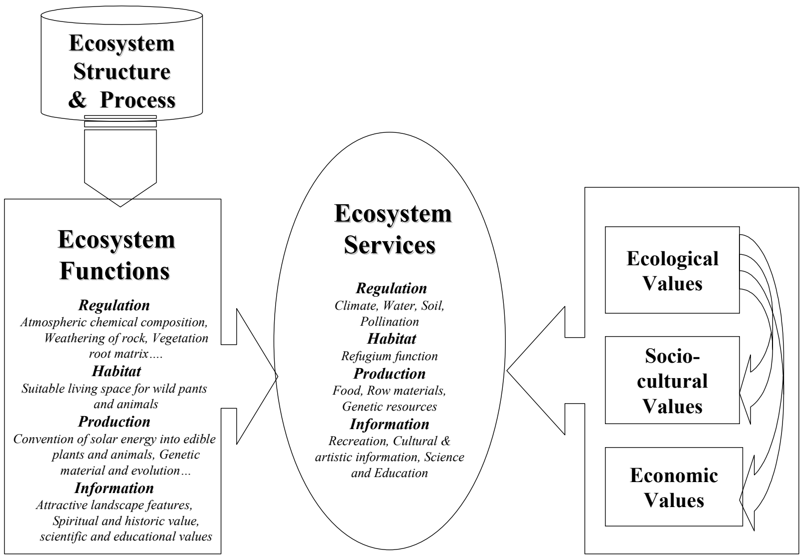

Figure 1. Framework for integrated assessment and evaluation of ecosystem functions, goods and services. (Adapted from DeGroot et al., 2002).

I examined these latest studies published in major scientific journals and delineated subjects to be included especially in an evaluation model for biodiversity at the ecosystem level. A method to measure biodiversity at the ecosystem level has not been developed enough compared to that at species level. I examined the precise direction for establishing an evaluation method of biodiversity at the ecosystem level by analysing the latest studies.

2. METHODS

Twenty three of papers that include words of biodiversity, species or ecosystem, and evaluation in their abstracts were found in 25 major scientific journals including

Ecological Applications, Biological Conservation, Landscape and Urban Planning, and Ecology, published from 1995 to 2005. Biodiversity is a comprehensive concept that has compositional, structural, and functional concepts in each hierarchy of gene, species, ecosystem, and landscape (Noss, 1990). Biodiversity evaluation models at ecosystem levels were categorized into four groups based on the concept of biodiversity: (1) models that put values on composition, (2) models that put values on structure, (3) models that put values on composition and structure, and (4) models that put values on functions.

3. OVERVIEW OF CURRENT STUDIES ON EVALUATION OF BIODIVERSITY IN ECOSYSTEMS

3.1 Models that put values on composition

Most models were categorized in this group, which puts values on the compositional aspect of biodiversity, i.e., number of species, species assemblage, and the number of ecotope types. They used definite values, indexes, or rankings for evaluation.

Oliver et al. (1996) investigated the richness and turnover of the species of ants, beetles, and spiders, which were abundant and belonged to the species-rich taxa of the forest floor. They compared the turnover of this assemblage among four forest types and proposed cost-effective methods for evaluating epifaunal invertebrate biodiversity.

Schwab et al. (2002) evaluated biodiversity of 18 meadows with different intensiveness of use by an overall index of biodiversity, i.e., the sum of the eight rankings. Rankings reflect three different types of criteria for evaluation of the sites. The first criterion was species number of angiosperms (a), spiders (s), and beetles (b). The second criterion was Simpson's Diversity Index. The third criterion was conservation index, which used the angiosperm species characteristic to nutrient-poor grassland and special spiders in terms of rarity and specificity.

$$R = Rsp + Rsd + Rci \tag{1}$$

$$Rsp = Rsp(a) + Rsp(s) + Rsp(b) \tag{2}$$

$$Rsd = Rsd(a) + Rsd(s) + Rsd(b) \tag{3}$$

$$Rci = Rci(a) + Rci(s) \tag{4}$$

Where R: Indicators of biodiversity, Rsp: Ranking of species, Rsd: Ranking of Simpson's Index, Rci: Ranking of Conservation Index

Lenders et al. (2001) evaluated floodplain ecosystems in the Netherlands using "target species" for Dutch nature conservation policy and "protected/special attention species" in a variety of national and international policy plans, laws, trends, and directives. "Target species" were required to meet the "itr-criteria" (criteria concerning the international importance of the Netherlands for the species involved (i-criterion), population development trend (t-criterion) and species rarity (r-criterion) in the Netherlands (Bal. et al., 1995) and the Red Data List criteria of the World Conservation Union (IUCN, 1993). "Protected species" approach yielded the additional species that were not particularly threatened or endangered in the Netherlands but equally important from a political and legal point of view as Red Data List species.

$$TBSindex = 100 \cdot ATB / PTB \tag{5}$$

$$ATB = \sum_{i=1}^{n} Si \tag{6}$$

$$PTB = \sum_{i=1}^{N} Si \tag{7}$$

where, TBS index: Taxonomic group biodiversity index, ABT: Actual taxonomic group biodiversity score, PTB: Potential taxonomic group biodiversity score, n: Real species number, N: Selected important species, Si: Score of species i.

Evaluation by ranking is not applicable to other regions because it puts relative values on a target area. While, evaluation by absolute value and index have an advantage at the point of applicability to other regions and cases, so that those values can be compared between them. In turn, absolute value and index have the meaning for the first time when they are compared. In addition to this, selection of representative species and weighting on the specific species need scientific grounds because they directly relate to interpretations of biodiversity.

3.2 Models that put values on structure

Geneletii (2003) presented an approach to contribute to Biodiversity Impact assessment of road project that focused on the direct loss of ecosystems. He assessed the impact of 20 km of road development on the surrounding forest environment by the rarity of ecosystems. Indicator to express ecosystem's rarity was Potential Area

Remaining (PAR), whose value (V) was provided by dividing the target area in a potential vegetation map into the corresponding area in a present vegetation map. Then, ecosystem-loss impact score of alternative i (ELi) was calculated as follows,

$$ELi=\sum_{j=1}^{N}\left(AjVj\right) \tag{8}$$

where, Aj: predicted area loss for ecosystem type j, Vj: assessed value of ecosystem type j; N: number of ecosystem types

The method of valuing area as presented above is also used by Morimoto et al. (2003). They valued the watershed biodiversity in Maryland, USA by Biodiversity Probability Index (BPI) using land cover map. BPI for each watershed represented the sum total HU (Habitat Unit) for forest species, grassland species, wetland species, edge species, and multihabitat species per unit area. Habitat Unit is estimated by the habitat value (V), land area within a watershed (A) and contagion index (Q).

$$BPI=\sum HUj\big/A \tag{9}$$

$$HUj=\sum\left(Qi\cdot Ai\cdot Vij\right) \tag{10}$$

$$Qi=Ni,i\big/Ni \tag{11}$$

where i : Land cover type (Water, Developed land, Edge of developed land, Forest, Edge of forest, Grasslands, Edge of grasslands, Wetlands, Edge of wetlands, Barren land, and Edge of barren land), j : Species category (Forest, Grassland, Wetland, Edge, and Multihabitat species), HUj: Habitat unit of species category j , Qi : Contagion index of i, Ai : Land area of land cover type i, Vij: Habitat value of land cover type i for species category j , Ni,i : Number of cells of i adjacent to i, Ni : Total number of i.

Geneletti (2004) proposed an approach to assess the fragmentation of natural ecosystems caused by linear infrastructures, one of the greatest threats to biodiversity world-wide. Three patch indicators, the core area, the average distance from the surrounding settlements and infrastructures (disturbance), and the average edge-to-edge distance from the surrounding ecosystem patches (isolation), were selected to predict the viability of each ecosystem patch as follows,

$$Vi = \sum_{j=1}^{3} \left(Wj \cdot Aj \right) \tag{12}$$

where Vi : the viability value of patch i, Wj : the weight of the indicator j, Aj : the value score of the indicator j, calculated using the relevant value function.

Venema et al. (2005) presented a deforestation simulation model based on the idea that deforestation and forest fragmentation are underlying drivers of global biodiversity losses. They found that MNN (mean nearest neighbour distance) and MPI (mean proximity index) were the best response signal from the landscape ecology metrics to the deforestation process using the principle component analysis.

$$MNN = 1/n \sum_{j=1}^{n} \min Dij \, , i \neq j \tag{13}$$

$$MPI(D) = 1/n \sum_{j=1}^{n} \sum^{i \in Mj} Aij / D^2 ij \tag{14}$$

where n : the total number of patches in the landscape and for each patch j, Aij : the area of the ith patch of the set Mj, Mj : the set of patches within the threshold distance, D of the jth patch (Dij ≤ D). If all patches have no neighbours within the threshold distance, D, then MPI. = 0.

Then the genetic algorithm approach for forest structure optimization was illustrated with the several objective function formulations including MNN minimization, MNN constrained by MSI, MPI maximization with varying threshold distance, constrained edge habitat maximization, and PCA-based optimization.

Putting values on structural aspect of biodiversity is relatively easy once the database that can be analysed on GIS is available. However, the real meaning of the evaluation on the structure is unknown until the relationship between the structural characteristics and the compositional or functional property of biodiversity is cleared, i.e., “what kind of animals are sensitive to the forest fragmentation?” or, “how the fitness changes in response to the habitat reduction?”.

3.3 Models that put values on composition and structure

Hermy and Cornelis (2000) and Duelli (1997) advocated the model that evaluates the compositional and structural aspect of biodiversity.

Hermy and Cornelis (2000) developed a method for the general monitoring of biodiversity in urban and suburban parks. They put values on the compositional aspect of biodiversity, i.e., Shannon index of vascular plants and species richness of animals, and structural aspect of biodiversity, i.e., Shannon-Wiener diversity index of planar, linear, and punctual elements in parks. However these evaluation values were not integrated.

Duelli (1997) evaluated biodiversity in agricultural areas by species diversity in arthropods and by landscape parameters such as habitat diversity and landscape heterogeneity. These compositional and structural aspects of biodiversity are not integrated either, which remains to be a future challenge.

3.4 Models that put values on functions

Conroy and Barry (1996) used the source-sink dynamics model to evaluate biodiversity of a hypothetical landscape. They assumed a simple landscape (R) that had "forest (R (F))" and "unforested (R (O))" habitat and four species that had different habitat requirements.

$$R = R(F) \cup R(O) \tag{15}$$

$$A = A(F) + A(O) \tag{16}$$

where, A: area of a landscape, A (F): area of forest, A (O): area of unforested, open spaces.

They estimated total species richness based on the source-sink model.

$$\overline{S}(A, f) = \sum_{s=1}^{S} Sp(S = s) \tag{17}$$

where, p(S=s): probability of occurrence of species s, f: proportion of forested habitat.

Here each species has a different habitat requirement. For example, the forest species have the following annual rates of population change (λ):

$$\lambda i(F) = \lambda i(1) \,\phi\, 1 \tag{18}$$

$$\lambda i(O) = \lambda i(2); 0 \leq \lambda i(O) \,\pi\, 1 \tag{19}$$

where, λ(F): annual rates of population change in forested habitat,λ (O): annual rates of population change in unforested habitat,λ (1): annual rates of population change in source habitat,λ (2): annual rates of population change in sink habitat.
Equally, species k reside in open space has its annual rates of population change (λk).

$$\lambda i(F) = \lambda i(2); 0 \leq \lambda i(O) \ \pi \ 1 \tag{20}$$

$$\lambda i(O) = \lambda i(1) \ \phi \ 1 \tag{21}$$

$$\hat{N}i(2) = \hat{N}i(1) \cdot \{\lambda i(1) - 1\} / \{1 - \lambda i(2)\} \tag{22}$$

Based on the equilibrium theory of source-sink model about abundance for species i in its source habitat ($\hat{N}i(1), \hat{N}i(2)$), the total number of species appears in a landscape ($\hat{S}$) is estimated. None of evaluation models focused on the functional aspect of biodiversity in the real landscape was found this time. It suggests the difficulty of quantifying the interactions between species and ecosystem processes.

4. SUBJECTS TO BE INCLUDED IN AN EVALUATION MODEL

4.1 Identification of representative species group of ecosystems

Some of the evaluation models aiming at compositional aspects of biodiversity identified representative species of ecosystems in some way. Attributions of all creatures cannot be investigated due to cost and time restrictions.

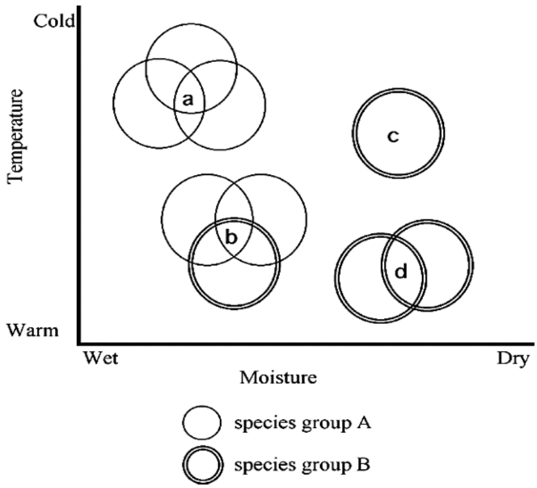

Figure 2. Hypothetical species distributions (circles) in a simple environmental space. (Adapted from Faith et al., 2002).

Therefore, the method used to select the representative species or species group of ecosystems is important. Faith and Walker (2002) insist that effective indicator species groups tend to be distributed over a range of habitats or environments.

Figure 2 shows hypothetical species distributions in a simple environmental space. Species group A consists of five species, and species group B consists of four species. Each group has a different habitat requirement. When we select four areas of high biodiversity, repeated samplings from sections a, b, d, which individually are the most species-rich areas for one species group or for both groups together, will not produce a set of areas that are species rich. However, selecting just four areas, one each from sections a, b, c, and d, would sample all the species from the two groups.

This suggests that the species group whose members span a wide range of habitats or environments should be an effective indicator of biodiversity. It can be concluded that different guilds, i.e., species or populations at the same level of a food pyramid and using the same resources, are appropriate as indicators of biodiversity.

In contrast, Williams and Hero (2001) and Humphries et al. (1995) insist that subsets of organisms that are most evenly spaced or distributed over the topology of the phylogenetic tree, not the geographical environment, should be the effective indicators of biodiversity. This idea comes from the theory that biodiversity can be evaluated by “option value”: a safety net of biological diversity for responding to unpredictable events or needs, and that option value can be measured by the distance between species in cladistic relationships.

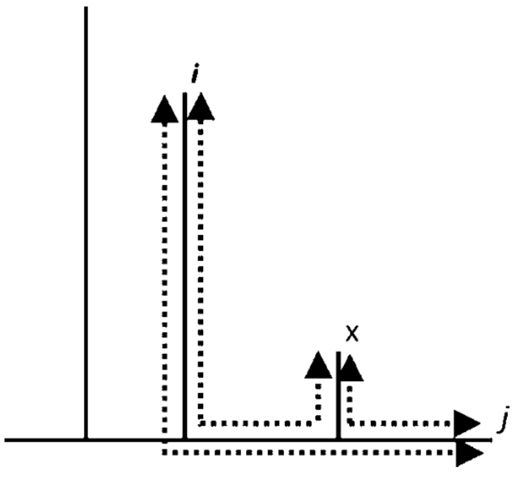

Figure 3. A hypothetical cladogram of four taxa. (Adapted from Faith, 1991). Phylogenetic diversity is measured by summing branch lengths between species i and j. *PDi,j = 0.5 (Dx,i + Dx,j - Di,j), where, Da,b: Minimum branch length between species a and b.*

Figure 3 shows a hypothetical cladogram of four taxa. Length between them is regarded as magnitude of character differences between them. Selecting species whose phylogenetic diversity is high, that is, those distances on the phylogenetic tree that are the longest, would maximize the “option value”.

Choosing species using phylogenetic trees is characterized by its longer geohistorical span of biodiversity than the selection of species using guilds. It is still difficult to carry out this identification method in practice because species that have been delineated in phylogenetic trees are limited. However, this method is advantageous to the selection of representative species groups because it considers the future of ecosystems.

To conserve today’s biodiversity in a shorter time span, and to keep its “option value” maximum, it is necessary to choose species groups from both points of view as evaluation targets of biodiversity. That means, species from different guilds that maximize the phylogenetic diversity, as surrogates of the ecosystem should be included.

4.2 Species’ suitability to environment and response regime to disturbance

It may be a serious problem to regard species that use the same resources as completely homogenous.

Lindenmayer and Lacy (1995) analysed population vulnerability of two guilds of the mountain brushtail possum, and pointed out that different species, even those within the same guild, may vary in vulnerability to disturbance and environmental perturbation. Alvarez-Buylla et al. (1996) performed population vulnerability analysis (PVA) to predict extinction times of four tropical rain forest tree species. They found that critical phases in a life cycle are different for long- and short-lived species. Moreover, long- and short-lived species had contrasting responses to different temporal and spatial regimes of perturbation. They suggest that it is important to reveal the composition of metapopulations to perform realistic vulnerability analysis. PVA based on the actually measured demographic and environment stochastic enable one to predict the extinction risk of selected species groups. Functional aspects of biodiversity such as habitat suitability and susceptibility to environmental fluctuations are the essence of biodiversity itself. It is desirable to perform PVA for quantitative evaluation of biodiversity.

4.3 Environmental factors related to species distribution

Integration of compositional aspects of biodiversity (species richness and species composition) and structural aspects of biodiversity (shape and pattern of habitat and ecotope) enables a potential habitat analysis (PHA).

Pino et al. (2000) analysed the relationships of spatial distribution of bird species richness with landscape variables such as diversity index of landscape, relative shrubland, cropland, or urban cover, and geo-coordinate. Cropland species were the most dependent on the abundance of relative area of cropland cover and on landscape diversity, whereas forest species exhibited weak correlation with landscape variables. Fairbanks et al. (2001) investigated the relationships between assemblages of bird species in South Africa and 20 environmental variables including climate, topology, and vegetation, landscape type defined by topology and climate, and land-use. He found that bird species assemblages were primarily related to climate variables such as growing season temperature and seasonality of precipitation, and water balance.

Environmental factors related to distributions of species and species groups differ among them. Quantifying the relationships of the structural aspect of biodiversity, i.e., pattern of environmental factors, and the compositional aspect of biodiversity, i.e., distribution of organisms will enable estimation of potential habitat.

Pattern-based evaluation procedure has a defect in its unrealistic assumption that species suitable to some environmental attributes distribute evenly in the environment with those attributes. However, advantageously, it permits us to predict potential biodiversity even in difficult-to-reach areas. It also enables the assessment of environmental changes effects on species and species groups.

4.4 Integration of functional and compositional aspects of biodiversity into the structural aspect of biodiversity

Integration of the functional aspect and structural aspect of biodiversity is behind that of the compositional aspect and structural aspect of biodiversity (for example, Williams and Hero, 2001; Pino et al., 2000; Fairbanks et al., 2001).

It will be possible to predict quantitatively the population vulnerability in a potential habitat once the functional aspect of biodiversity, i.e., species' habitat suitability and susceptibility to the environment changes estimated by PVA, is related to the structural aspect of biodiversity such as pattern of habitat and ecotope.

Specifically, it is desirable to investigate the demography of local populations as long as possible in the various habitats and ecotopes with many different attributes, i.e., type, shape, and pattern of environmental factors, in the potential habitat areas predicted by PHA. The investigation period is to be long enough to include yearly fluctuation of species behaviour. Quantifying the relationships between environmental attributes of habitat and ecotope, and parameters that define the population dynamics, will enable one to predict population vulnerability in the potential habitat area. Evaluation of the present and future status of biodiversity would be possible by integration of the functional and compositional aspects into the structural aspect of biodiversity.

5. SUMMARY

In order to create an accurate evaluation method that properly reflects the value of biodiversity on an ecosystem level, the current and past studies of such methods must be analyzed.

Biodiversity evaluation models published in journals from 1995 to 2005 were studied and was concluded that in order to create an accurate model, the following four elements need to be included:

i. Species from different guilds that maximize the phylogenetic diversity, as surrogates of the ecosystem should be included.

In order to maintain the current level of biodiversity in the short term, species belonging to different guilds reflect as the best indicator of biodiversity. In addition, species selected widely from the phylogenetic tree can also act as a good indicator of biodiversity maintenance in the long term.

ii. Assess the extinction probability of the selected species can by Population Viability Analysis.

The Population Viability Analysis or PVA, a type of demographic study, can estimate the vulnerability of a representative species population, quantitatively.

iii. Identify the potential habitat area of selected species by Potential Habitat Analysis.

Potential Habitat Analysis or PHA can analyze the correlation between the species distribution and environmental pattern quantitatively.

iv. Estimate the survival probability of the selected species in the potential habitat area.

Combining three aspects of biodiversity, composition, structure, and function of biodiversity will estimate quantitatively the biodiversity on an ecosystem level. In other words, relating parameters derived from PVA (function) of indicator species as described in i (composition) with the structure and pattern of ecotope delineated in PHA will evaluate properly the biodiversity on an ecosystem level.

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