Open Journal of Forestry
2013. Vol.3, No.2, 62-65
Published Online April 2013 in SciRes (http://www.scirp.org/journal/ojf)

http://dx.doi.org/10.4236/ojf.2013.32010

Evaluation of Broadleaf Tree Diversity at the Basin Scale—In Case of Artificial *Chamaecyparis obtusa* Forests

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Received November 22nd, 2012; revised February 4th, 2013; accepted February 26th, 2013

In recent years, the various functions required of forests, especially the conservation of biodiversity, have been attracting increasing attention in Japan and worldwide. In Japan, 67% of national land is covered by forest, 41% of which is artificial forest (i.e., plantations). Therefore, forest biodiversity conservation efforts should also target artificial forests. In this paper, we seek to promote sustainable forest management that considers biodiversity conservation by examining indices that can be used by forest managers to evaluate the diversity of broadleaf trees. The result was that evaluation of broadleaf tree diversity in artificial forests at a basin scale was possible by combining several types of indicators.

Keywords: Artificial Forest; Forestry Management; Basin Scale; Species Diversity Index; Land Use Diversity Index

Introduction

In recent years, various functions have been required of forest ecosystems; these include not only the production of wood, but also the conservation of biodiversity, landslide prevention, cultivation of water sources, overall ecosystem health, and prevention of global warming. In particular, the conservation of biodiversity is considered a necessary function to promote sustainable land use and to conserve biodiversity of surrounding land-use types at a basin scale.

In Japan, approximately 67% of national land is covered by forest, approximately 41% of which is artificial forest (The Forest Agency, 2012). Therefore, in addition to natural ecosystems, conserving biodiversity within artificial forests is also crucial. To this end, management efforts within plantations must include thinning of the planted conifers and the maintenance of naturally regenerated broadleaf trees and understory vegetation. Forest managers must have a deep understanding of the unique species diversity of the broadleaf trees within their forests so as to promote forest management that considers tree conservation. However, clear guidelines or management approaches have not yet been established. Furthermore, appropriate studies are rare, both in Japan and worldwide, and tend to examine forests only at a small scale.

In this paper, we seek to promote sustainable forest management that considers biodiversity conservation by examining indices that can be used by forest managers to evaluate the diversity of broadleaf trees. We used several indices for evaluation, and we focused on the basin scale, which corresponds to the whole-forest level.

Survey Location and Methods

Survey Location

The survey was conducted at Hayami Forest located in Kihokucyou Kita, Mie Prefecture, Japan. Plots were established in Ootaga Forest (93 ha; 10 - 380 m above sea level; angle of inclination, 3 - 45 degrees) within Hayami Forest. Average annual temperature is 16.1˚C, and annual precipitation is 4200 mm (Meteorological Agency of Japan, 2012). Forest compartments vary in age and form a mosaic landscape.

Hayami Forest is currently managed using an intensive nurturing system aimed at the production of good wood over long-term cutting periods. *Chamaecyparis obtusa*, which is well suited to regional conditions, is the main production wood. Hayami Forest was the first forest to obtain forest certification from the Forest Stewardship Council A.C. (FSC) of Japan in February 2002.

Methods

Our research was conducted within five compartments that varied in age. We established 10 × 10 m plots within areas representative of the compartment, i.e., those lacking gaps, edge effects, and mountain streams. We examined all broadleaf and planted trees that were taller than 1 m. Broadleaf trees were chosen because they are affected by management efforts and they can be managed and investigated easily. For all broadleaf trees, we determined the number of species and the population size. We also measured tree height and diameter at a height of 50 cm from the ground, as we were unable to measure many individuals at heights of 1 - 1.3 m. For planted trees, we also measured height and diameter and counted the number of planted trees in 20 × 20 m areas to calculate stand density.

Analysis at the Compartment Scale

We analyzed the current conditions of compartments using stand density, which is an important measure of forest maintenance. For the analysis of broadleaf tree diversity within compartments, we used the number of species, population size, proportion of basal area (BA), and several species diversity indices. A 50-cm aboveground cross section was used to calculate BA as follows: BA = sum of 50 cm aboveground cross sections of a specific layer in the plot/sum of 50 cm aboveground cross sections of all trees in a plot. The proportion of BA of the natural forest was not calculated because no conifers exist within the natural areas of Hayami Forest, and thus the calculation result would be 100%. We used the Shannon-Wiener index (1), the inverse Simpson index (4), and the inverse logarithm Simpson index (5) as indices of species diversity (Yoshiaki & Kazunori, 2002):

Shannon-Wiener index (H')

$$H' = -\sum pi \log_2 pi \tag{1}$$

where $pi = \frac{Ni}{N}$ is the relative frequency of i; Ni is the population size of I; N is population size.

Index of Simpson (D)

$$D = \sum pi^2 \tag{2}$$

An unbiased estimator (D')

$$D' = \sum \frac{Ni(Ni-1)}{N(N-1)} \tag{3}$$

An inverse Simpson index (L)

$$L = 1/D' \tag{4}$$

An inverse logarithm Simpson index (L')

$$L' = \log \frac{1}{D'} \tag{5}$$

Analysis at the Basin Scale

The land use diversity index (LUDI) was used for the analysis of forests at the basin scale. The LUDI is commonly used in landscape studies to improve the measurement of diversity at the landscape scale. This index enables the evaluation of all types of landscapes using mathematically weighted functions based on landscape structure and composition. The formula for the LUDI is as follows (6):

$$M' = \frac{2m\sum_{j=1}^{m}\left(j \cdot Wcj \cdot \left[kj - (kj-1)\frac{2\sqrt{\pi aj}}{pj}\right] \cdot aj\right)}{A(1+m)} \tag{6}$$

where M' is the weighted land-use diversity index; m is the number of patch types present in a landscape unit

j is $1,\cdots,m$ is patch type;

Wcj is the compositional weight of patch type j;

kj is the upper limit of the structural weight of patch type j;

pj is the sum of the perimeter of patch type j;

aj is the sum of the area of patch type j;

A is the sum of patch areas in a landscape unit.

Here, we divided all compartments in Ootaga Forest into five groups based on stand density. Thus, a value of 5 was used for m, and Pj, aj, and A were calculated using a geographic information system (GIS). In addition, evaluation results for compartments were used for Wcj, after correcting each value so that the maximum was 1. To determine the maximum value of the LUDI, we considered the maximum as M1max and compared these results with M'.

Results and Inquiry

Analysis of Compartments

Stand density exhibited a decreasing trend as the age of forest compartments within Hayami Forest increased (**Figure 1**).

Stand density within Hayami Forest was lower than forestry association of Kashimo and prefectural forest of Aichi, indicating that the management of Hayami Forest maintains low stand density in accordance with its forest management plan.

Number of Species

The total number of species peaked at a forest age of 49. After this age, species number declined with forest age (**Figure 2**). However, the total number of species did not largely differ among forest ages. On the other hand, when considering layer structure, the number of trees located lower in the canopy decreased with age, whereas the number of trees at intermediate levels increased with age. After age 67, an upper layer began to form, indicating that layer composition becomes more complex as the forest matures. In particular, layer composition within forests at age 99 approaches that of natural forests.

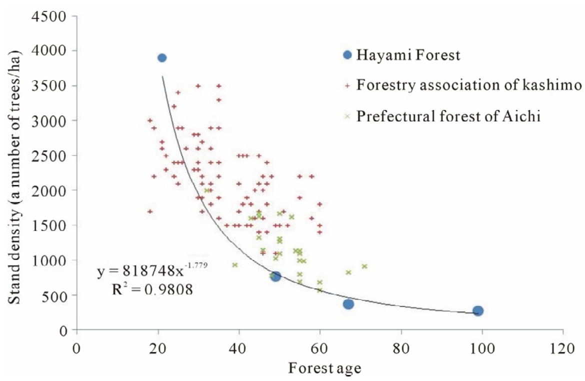

Figure 1.
Forest age and stand density.

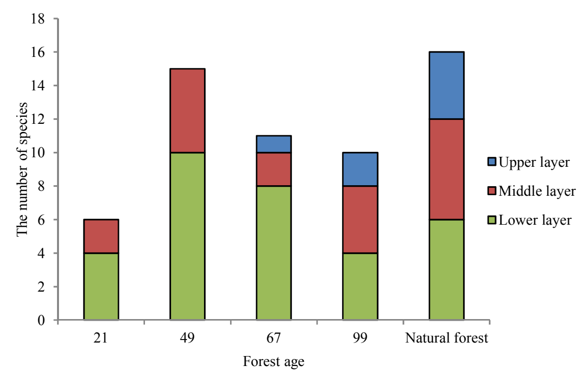

Figure 2.
Forest age and number of species.

The number of species is an effective index for forest management, as species richness is a good indicator of current forest conditions. However, the evenness of species must also be considered. Furthermore, the number of species tends to increase as plot size increases.

Population Size

Although population size exhibited a pattern similar to the number of species, the overall trend was different (**Figure 3**).

Compared to the number of species, the proportion of lower-layer trees increased within compartments that harbor large population sizes. Therefore, if the diversity of broadleaf trees is evaluated using population size, lower-layer trees are relatively dominant to middle and upper-layer trees.

The population size offers the advantage of assessing evenness between species. However, when several species are co-dominant, the index will overestimate the importance of those species.

Proportion of BA

Planted trees accounted for 88% - 99% of the proportion of BA at all ages of forests, as the study was located within an artificial forest (**Figure 4**).

Broadleaf trees clearly continue to grow as the forest ages, as the dominance of broadleaf trees and the proportion of middle- and upper-layer trees increases with forest maturation. Because the proportion of BA is calculated from the sum of BA, lower-layer trees that exhibit low BA dominance will decrease even if the population size is large. In contrast, middle- and upper-layer trees that exhibit high BA dominance will be abundant even if the population size is small. Considering this, the proportion of BA serves as an index that expresses the dominance of each layer and thus differs from the number of species. In addition, the equality of species can be accessed from this index in a manner different from population size. However, high dominance does not always indicate high diversity.

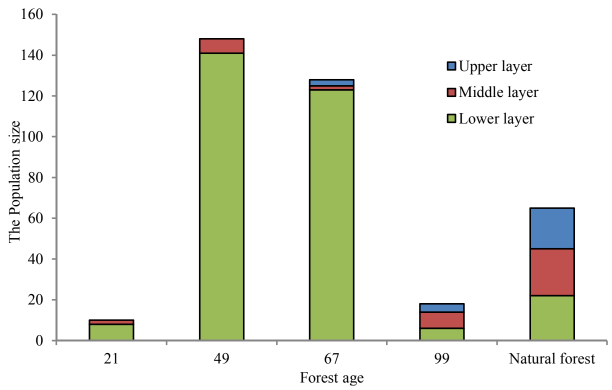

Figure 3.
Forest age and population size.

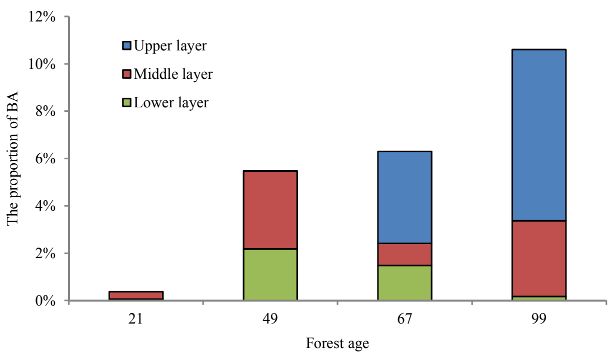

Figure 4.
Forest age and proportion of BA.

Species Diversity Index

All of the species diversity indices exhibited maximum values at a compartment age of 21, in which both the number of species and population size were lowest (**Figure 5**).

On the other hand, compartments of age 67, in which population size was largest, exhibited the lowest species diversity. These results suggest that evaluations using species diversity indices may be erroneous. In Hayami Forest, each compartment age varied little in species number, although population size varied greatly. Because species diversity indices are calculated using combinatorics, if species numbers vary little, plots with large populations will exhibit high values of species diversity.

Species diversity indices offer the advantage that results are easy to understand and to compare, as the result is just one number. However, the validity of the results must be assessed using the number of species or population size. Therefore, using species diversity indices alone is not a recommended approach.

Evaluation Using LUDI

The results of the four indices used to evaluate the diversity of broadleaf trees and the age of forests were used to evaluate the current distribution of compartments for *Wcj*. As a result, maximum *M'* was the number of species (**Table 1**) because the

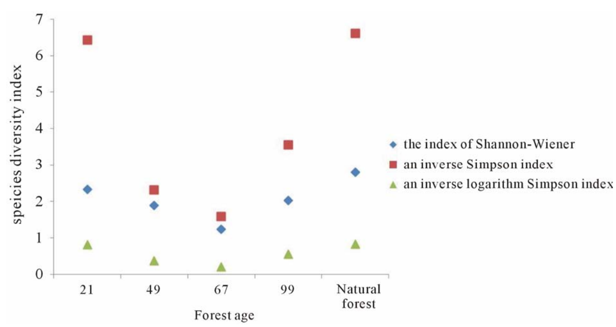

Figure 5.
Forest age and species diversity indices.

Table 1.
Results of LUDI.

Wcj	*M'*	*M'/M1max*
Forest age	3.262	0.393
Number of species	5.214	0.628
Population size	3.816	0.459
An inverse logarithm Simpson index	3.928	0.473
BA	3.577	0.431
1	6.710	0.808
M1max	0.000	-

number of species attained a high value regardless of forest age. On the other hand, other indices were almost equal in value for *M'* and were lower than that of the number of species. These indices exhibited low overall values because they were also low at the compartment level. However, the overall value of the LUDI cannot be determined by *M'* alone.

Therefore, to determine the maximum LUDI, we randomized the grouping of compartments, with the qualifications that the area, perimeter, and placement would not change and *Wcj* would be fixed at 1 (i.e., no weighting). We then calculated *M*1max for the maximum LUDI using 500 randomizations. The *M*1max results suggested that the ideal diversity of land use occurs at the basin scale. We also calculated *M*/*M*1max; that is, how much *M'* contributed to *M*1max. Furthermore, the ideal can easily be determined by depicting the results using GIS (**Figures 6** and **7**).

The *M'*/*M*1max of the number of species was high at 0.628,

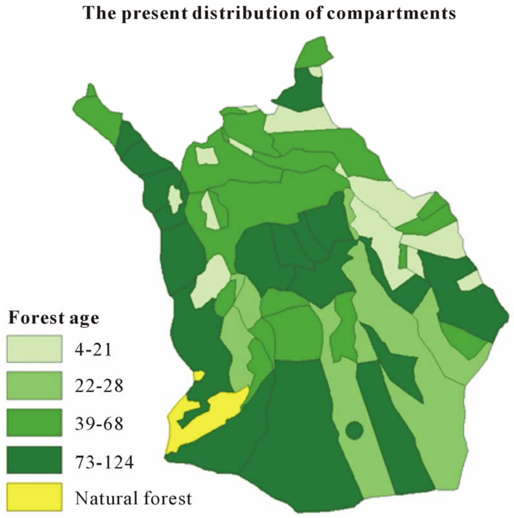

Figure 6.
The present distribution of compartments depicted using GIS.

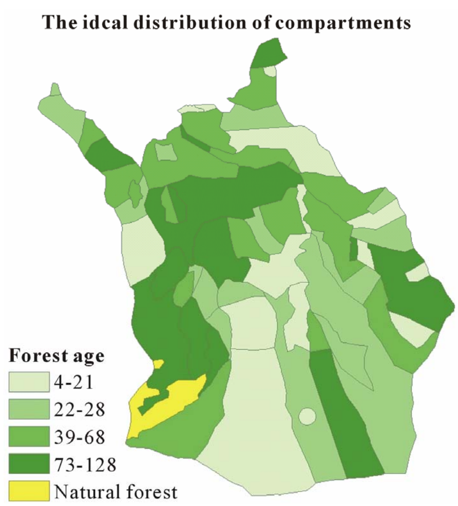

Figure 7.
Results of the LUDI depicted using GIS.

suggesting that the current diversity of species is ensured at a certain level. The value of *M'*/*M*1max when *Wcj* was 1 was 0.808. Because the value of *M'* when *Wcj* is 1 represents the distribution of compartments, this value suggests a high evaluation of the distribution of compartments. Furthermore, diversity at the basin scale will be enhanced by declines in old forests (age 39 - 99) and increases in young forests (age 22 - 38), according to this analysis.

Originally, the LUDI was used as an index to evaluate land-use diversity and not for the evaluation of broadleaf tree diversity. However, by using the results of the four indices for *Wcj*, it is possible to evaluate diversity. Furthermore, this approach allows us to determine what proportion of *M*1max was achieved by *M'* by calculating *M'*/*M*1max. Using this index, the LUDI can be used as an index to evaluate the diversity of broadleaf trees. Furthermore, the LUDI can be employed by forest managers to determine the ideal distribution of compartments. One potential issue is that the method used to calculate maximum LUDI in this paper involved several qualifications; therefore, the results of LUDI alone are not adequate for designing a sustainable forest management approach.

Conclusion

Our results demonstrated that all tested indices were similar in their effectiveness, as they each evaluate different aspects of diversity. Moreover, we determined that the diversity of broadleaf trees at the basin scale can be evaluated using the LUDI. However, results obtained using individual indices must be evaluated with caution. Another issue is that we only used data for *Chamaecyparis obtusa* in Hayami Forest. It is unknown whether similar results would be obtained if data were used for forests of *Chamaecyparis japonica* and *Larix leptolepis* or for forests with an insufficient management regime. Future research should collect data within forests other than those of *Chamaecyparis obtusa*.

Although each index offers advantages and disadvantages, we found that the diversity of broadleaf trees at the basin scale was most effectively evaluated using these indices in combination. Alternatively, a method could be developed to use all indices in one model. We hope that this topic will be further explored and clarified through interdisciplinary research.

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