An evaluation of forest road network by α- and β-indices

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Abstract
The development of formation of forest road network over time can be expressed by α- and β-indices. The α- and the β-indices have been proposed to evaluate the degree of development of circular road networks. The indices are calculated easily from the number of nodes and the number of routes. The development of the forest road network of the University Forest in Hokkaido, the University of Tokyo, can be discussed by these indices. The Tokyo University Forest in Hokkaido has natural forest management, with mixed forest of cool-temperate broad-leaved species and sub-boreal conifers. The main research objective is to practice sustainable forestry management compatible with conservation of environment, keeping in line with natural diversity and ecosystem. The forest management was developed at almost the same time as the construction of forest road network. The road density in the forest has reached 41 m/ha since 1955. By the presence of a forest road network at a high density for natural forest management, even standing trees at a low price in the selection cutting stand can be sold. The results show that the circular road networks increase when α ≥ 0 or β ≥ 1. The relationship between α- and β-indices is simple and practical, and can ascertain the functioning of development change of the forest road network.

Keywords: α-index, β-index, forest road network, sustainable forest management, selection cutting

1. INTRODUCTION

There is a strong relationship between an α-index and a β-index, and they are related to the forest-road density and the degree of road nodal interconnection (Sakai and Naya, 1992). The developmental formation of a forest road network can be expressed by these indices. The University Forest in Hokkaido, the University of Tokyo, has an advanced extensive forest road network. The value of development of the forest road network is discussed with indices.

2. FOREST ROAD NETWORK OF THE UNIVERSITY FOREST IN HOKKAIDO, THE UNIVERSITY OF TOKYO

The natural forest management of the University Forest in Hokkaido shows a successful and good example of natural forest management. The main research objective of the University Forest management is sustainable harvesting compatible with conservation of environment, and keeping stable natural diversity and ecosystem. The high density forest road network has led to
successful implementation of management. The forest road network is well developed and functioned, and new construction has now decreased.

The University Forest in Hokkaido is situated in the central part of Hokkaido, 43°N, 142°E. The area covers 22,800 ha, altitude ranges from 200 m to 1,460 m, and the management area is 19,800 ha.

The forest is located in the mixed forest zone between the cool-temperate zone with broad-leaved species and the sub-boreal zone with conifers such as Abies, Picea, Taxus, Quercus, Betula, Fraxinus, Tilia, Acer, Salix and other trees.

The University Forest was established in 1899, and the first forest management research plan was made in 1907. About 40 tree species are treated as valuable for management. Nowadays the average stand with selection cutting system has 800 trees of which 20 species DBH > 5 cm in a 250 cubic meters stand. The percentage of conifer trees is about 55 % in volume.

The method of natural forest management of the University Forest in Hokkaido is based on stand characteristics. Forest is classified into three types of stand, “selection cutting stand”, “clear cutting stand”, and “supplemental planting stand”. The classification depends on whether natural regeneration is possible or not, and whether quality of the standing trees is high or not. For selection cutting, cutting intensity is usually 16 or 17 percent of standing volume on a cyclical basis every 10 or 20 years, respectively. For supplemental planting, natural regeneration is difficult to establish, and remaining trees are good in condition, therefore group selection cutting and planting are practiced. For clear cutting stand, natural regeneration is not possible, and trees have bad quality. After clear cutting, plantation is practiced. Planting species are almost always conifers growing in the University Forest nursery, whose parents are from the University Forest.

In 1950, felling and bucking were exclusively practiced by manual handling saw, pre-hauling by man and horse especially in winter, stacking by men, and transportation by forest railways extending 80km in the forest. From 1955 forest railways were converted to forest roads, and extended to 930km in 2004, with density at 41 m/ha. The forest management has coincided with the construction of forest road network. All forest roads have truck transportation capacity. The typical operation system is felling by chainsaw, pre-hauling by small tractors and truck transportation now. Forest road network is important to be extensive for intensive forest management. Since the forest road network has a high density in a natural forest management, even standing trees at a low price can be sold with competitive pricing (Miyamoto and Igarashi, 2004). The roads also contribute a considerable conservation value for water (Sakai et al, 2003) and biodiversity (Miyamoto and Igarashi, 2004).

3. a- AND β-INDICES

An α-index has been proposed to evaluate the degree of developmental formation of circular road networks (Ono et al, 1991). It is calculated from the following formula:

$$\alpha = \frac{(m - n + p)}{(2n - 5)}$$

(1)

where n is the number of nodes, m is the number of routes, and p is the component of the network. The value p is 2 when the network is composed of two parts, and p is 1 for no separated parts. The numerator is a number of circular road networks (v), wherein the
denominator is a number of circular road networks when all nodes are connected to each other by a route. The $\alpha$-index exceeds zero when circular road networks begin to be formed, and it approaches 0.25 as circular road networks are completed in the case of forest road network (Ono et al, 1991; Sakai and Naya, 1992).

On the contrary, the following $\beta$-index was previously used (Yeates, 1968).

$$\beta = \frac{m}{n}$$

(2)

The $\beta$-index equals 1.0 when a simple connecting graph, and it approaches 1.5 as a network greatly interconnected (Yeates, 1968). The $\alpha$- and $\beta$-indices are calculated easily by the number of nodes and routes.

From Equations (1) and (2), $p = 1$, and $1 >> 1/n$,

$$\alpha = \frac{(\beta - 1 + p/n)}{(2 - 5/n)} \approx \frac{(\beta - 1)}{2}$$

(3)

This relationship can be derived in another way from a point of convergence, that is, $\alpha = 0.25$, $\beta = 1.5$, and the values when the minimum circular road network is formed, that is, $\alpha = 0$, and $\beta = 1.0$. The $\alpha$- and $\beta$-indices have a strong linear relationship with Equation (3) (Sakai and Naya, 1992).

4. RESULTS AND DISCUSSION

Forest road network in the University Forest in Hokkaido is shown in Figure 1.

![Figure 1. Forest road network in the University Forest in Hokkaido, the University of Tokyo.](image)

Measured $\alpha$- and $\beta$-indices and the number of circular roads ($\nu$) are shown in Table 1. A forest road map of 1 to 50,000 is used for calculating the indices. During 1976 and 1986 there were no construction of circular roads, and new roads were only constructed as one-way road. This lack of circular construction is the reason for $\alpha$ and $\beta$ decrease during 1976 and 1986. As anticipated by the characteristics of the $\beta$-index, circular roads increase when $\beta >= 1$. This increase in circular road formation also applies to the $\alpha$-index when $\alpha >= 0$.

It is reported that circular roads are increasingly formed when the road density exceeds 12 m/ha (Sakai and Naya, 1992). During 1966 and 1976, road density increased after the
introduction of mechanized road construction system, whereby \( \alpha \)-index exceeded 0. The result therefore suggests that it is necessary for the road density to exceed 12 m/ha at least in order to \( \alpha \geq 0 \) or \( \beta \geq 1 \).

Stage of the road development is shown in Figure 2. Taking into consideration that the forest road network in the University Forest in Hokkaido is well developed and functional in natural forest management, the value of \( \alpha = 0.15 \) should be the index or aim of forest road location and planning.

Table 1. The change of \( \alpha \)- and \( \beta \)-indices, and circular road network of \( \nu \).

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<tbody>
<tr>
<td>( \alpha )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.121</td>
<td>0.108</td>
<td>0.146</td>
<td>0.147</td>
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<tr>
<td>( \beta )</td>
<td>0.947</td>
<td>0.5</td>
<td>0.794</td>
<td>1.215</td>
<td>1.194</td>
<td>1.277</td>
<td>1.282</td>
</tr>
<tr>
<td>( \nu )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>102</td>
<td>98</td>
<td>164</td>
<td>218</td>
</tr>
<tr>
<td>Density (m/ha)</td>
<td>4.0</td>
<td>1.0</td>
<td>3.5</td>
<td>25.9</td>
<td>30.2</td>
<td>37.3</td>
<td>41.0</td>
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Figure 2. Relationships between \( \alpha \)- and \( \beta \)-indices.

5. CONCLUSION

The relationship of Equation (3) is very simple and practical, and it is useful in converting both indices to each other. From Figure 2, the stage of development of circular road network can be assessed.
6. LITERATURE CITED

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connectivity and relationships between the development of forest-road networks and