GIS APPROACH TO LANDSCAPE EVALUATION BASED ON SMALL WATERSHED UNITS

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ABSTRACT:

 This research was implemented in Miyagi Prefecture, northeastern Japan. In recent years, the rich biodiversity of this prefecture has been decreasing rapidly due to loss of forest and traditional countryside landscape habitat. On the other hand, Japan has recently strengthened regulations for preservation of biodiversity and implementation of environmental impact assessments, with a strong emphasis on ecosystems. To help preserve biodiversity, a simple but effective method for environmental evaluation is required. In this research, GIS based landscape evaluation methods were applied to landscape evaluation in northeastern Japan. The study area was divided into 828 small watershed units, and four GIS indices; Natural Vegetation Cover, Extent of Forest Cover, Road Density and Land Modification Rate, were used to evaluate each watershed unit. The scores on these four categories were then used to calculate and overall score, called the Degree of Natural Symbiosis, for each unit.
 In addition, Interspersion and Juxtaposition spatial indices were analyzed for watershed units and also for polygons. The results of the evaluation were compared against known data on biodiversity and plant communities for the watershed units. The results of this comparison showed that the evaluation techniques adopted here provide an easily implemented but reliable tool for spatial environmental evaluation, and is suitable for application to various environmental planning efforts, such as regional development master plans, project- specific environmental impact assessment, species management plans and biodiversity conservation plans.

1. BACKGROUND

 In recent years, land use in Japan has been affected by intensive development, and concern with ecological preservation is increasing. At the national level, the Natural Strategy for Biodiversity is under review, and a new law governing environmental impact assessment was promulgated in June of 1997.

 Under the new law, environmental criteria are evaluated at not only the national level, but also the prefectural, county and municipal levels. The law calls for environmental disruption to be avoided whenever possible, and to be reduced or compensated for in cases when avoidance is impossible or impractical. In addition, the previous system did not focus on ecosystems, but under the new system, the concept of ecosystem has become a major focal point. The Natural Strategy for Biodiversity was based on the Convention on Biological Diversity, to which Japan became the 18th contracting country in October 1995. Under this strategy, which was revised in 2002, species of fauna and flora, as well as vital habitats, are protected. Nevertheless, as of January, 2002, about 20% of about Japan's 240 species of mammal, 13% of about 700 species of birds, and 19% of about 8800 species of vascular plants are listed as being in danger of extinction in the nation's Red Data Book.

2. AIMS

 Under these conditions, Japan requires a fast and reliable system for evaluation of ecosystems at the macro level. This research focuses on small watersheds as a unit of evaluation, and utilizes four indicators to evaluate the value of these units as natural habitats for plants and animals. In addition, spatial analyses using both the watershed units and polygons are employed to measure connectivity.

 Inclusion of connectivity is of great importance to the

research. Masuyama et al. (2003) have identified several problems involved in small watershed evaluation implemented simply by superimposing indices rather than actually comparing the watersheds. In addition, this sort of evaluation does not consider boundaries between abutting small watersheds. Evaluation of connectivity between the small watersheds is thus considered essential for meeting the goals of this research.

3. METHODS

3.1 Study Area

 Miyagi Prefecture faces the Pacific Ocean, in the Tohoku district of northern Honshu. The prefecture has an area of approximately 7300km^2, and is endowed with a great variety of rich natural habitats, including mountain ranges, such as Mt. Zao (1,841m) and Mt. Kurikoma (1,628m), hilly areas such as Mt. Tokura, lakes and marshes such as Izunuma and Uchinuma, and abundant beaches and indented rocky coasts. In addition, there are numerous biodiverse countryside habitats centering on irrigated rice paddies, which function ecologically as seasonal wetlands. However, in recent years this rich natural heritage is facing a severe crisis in biodiversity. According to the March, 2001 issue of the "Prefectural Red Data Book, 20 species of formerly present plants and animals are now extinct, 551 species are endangered, and 233 species are threatened.

3.2 Ecosystem Analysis

 To begin with, the entire prefecture was divided into small watershed units. Each unit was then evaluated using four indices derived from geographic information system (GIS) data. The scores on these indices were then summed and employed to rate each unit into four levels in terms of degree of natural

symbiosis. The indices are described below, followed by the nu umerical criteria for evaluations in Table 1.

Index 1: Vegetation Naturalness Index (VN): All plant communities within each unit were assigned a quantitative natural value. The average naturalness was then calculated by measuring the area within the unit occupied by each plant communities.

N = Summation of [(Community Naturalness x Community Area)/ Small Watershed Area]

The data is based on Natural Environment GIS (Ministry of Environment, 1998). The average naturalness was then calculated by measuring the area within the unit occupied by each plant community, according to the following formula.

Index 2: Quantitative Index of Forest (QF): Quantitative index of the forest is defined as the proportion of forest area to the entire area of each small watershed.

BF = Forest Area/Small Watershed Area

Forest area is based on Natural Environment GIS (Ministry of Environment, 1998).

Index 3: Index of Fragmentation of Natural Environment (FN) according to Road Effect

Roads were analyzed as a major factor in fragmentation and isolation of natural environments. The fragmentation index of the natural environment' was calculated based on the total length of roads, defined as national motorways, national roads, prefectural roads and municipal roads included in the JMC Map (Japan Map Center, 1998).

FN = Total Road Length/ Small Watershed Area

Index 4: Land Development Rate (LD): To assess the magnitude of human impact on the natural environment, an index of land modification was calculated as the proportion of the total watershed areas occupied by artificial structures. .

LD = Land development Area/ Small Watershed Area

The data regarding distribution of artificial structures is based on National Land Numerical Information (Natural Land Agency, 1997).

The Total Score (Degree of Natural Symbiosis as calculated as VN+QF+FN+L D

Table 1. Evaluation of degree of natural symbiosis using four indices

Evaluation Level	VN	QF	FN	LD	Degree of Natural Symbiosis
I	(7-10)	(85-100)	(0-0.05)	(0-3)	very high
II	(3-7)	(55-85)	(0.05-0.1)	(3-10)	high
III	(1-3)	(35-55)	(0.1-0.15)	(10-30)	low
IV	(0-1)	(0-35)	(0.15-)	(30-)	very low

3.3 Spatial Diversity Analysis

The spatial diversity index was used to measure horizontal diversity between small watershed units. This technique, which uses measurements of I_S (Interspersion) and J_x (Juxtaposition) as components of spatial diversity, was described by Mead et al. (1981), and is considered to be the most effective index for quantitative and qualitative evaluation of habitats (Heinen & Cross, 1983). In this technique, calculations were originally implemented using raster (Clevenger et al., 1997, Clark et al., 1993). In this research, however, measures of interspersion and juxtaposition were also used in a mesh analysis applied to polygon units within the small watershed units. In raster-based analysis, a value of 1 or 2 is respectively assigned to diagonal edges and to vertical or horizontal edges at juxtaposition by the raster. This can result in an underestimation. In addition, when the actual connectivity is considered, the length of a boundary between small watersheds can have a powerful influence on the suitability of the region as natural habitat, especially on large mammals such as black bears. It should also be kept in mind, however, that the connectivity calculated by either raster or grid does not have an equal influence on all species. Areas of utilization may vary among species. For these reasons, we also assessed spatial diversity utilizing polygons, which represent the actual situation as seen in the natural world. Masuyama et al. (2003) have shown that when the results of small watersheds evaluation are superimposed on a map showing the distribution of critical species, the areas with high degree of spatial diversity coincide with those in which these species were identified, proving the effectiveness of this evaluation method. Interspersion and Juxtaposition as spatial analyses provide an understanding of the connectivity among adjacent small watershed units. Following are descriptions of the original calculation method using grid, and consequently, small watersheds evaluation is suitable in conservation of biodiverse habitat. These spatial analyses provided an understanding of the connectivity among adjacent small watershed units.

1) Original Calculation Method Using Grid

1-1 Interspersion (I_s)

I, II, III and IV represent the small watershed evaluation categories as described in Table 1 above. Interspersion is calculated as the total number of changes recorded between adjacent units divided by the total possible number of changes. In this case, for example, Is = 5/8 = 0.625

I	II	II
IV	I	I
I	III	III

1-2 Juxtaposition (J_x)

Diagonal edges are assigned a score of 1; and either vertical or horizontal edges a score of 2. Various edge combinations can then be assigned a relative weight factors ranging from 0 to 1. In the above case, for example, Jx = 6.6/12.0 = 0.55

Edge types	Quantity[1]	Quality[2]	Total
I/I	4	0.8	3.2
I/II	3	0.6	1.8
I/III	3	0.4	1.2
I/IV	2	0.2	0.4
	12		6.6

2) Calculation Method Using Polygons

2-1 Interspersion (Isp)

Isp is calculated as the number of different polygon evaluation levels divided by the total number of polygons. In this case, for example,

Isp=3/4=0.75

2-2 Juxtaposition (Jxp)
Quantitative: If Adjacency distance between 2 polygons is greater than the mean distance (centroid polygon perimeter/polygon number), the score is 2. If smaller, the score

is 1.
Qualitative: Various edge combinations can be assigned relative weight factors ranging from 0 to 1. Edge weight factors used in the calculation of juxtaposition in this study were assigned using the criteria shown in Table-2 below

Table 2. Edge weight factors for calculation of juxtaposition

		Evaluation level of center cell or polygon			
		I	II	III	IV
Evaluation level of adjacent cells or polygons	I	0.8	0.6	0.4	0.2
	II	0.6	0.6	0.4	0.2
	III	0.4	0.4	0.4	0.2
	IV	0.2	0.2	0.2	0.2

4. RESULTS

4-1 Ecosystem Analysis
  The results of the four indices used for evaluation of natural symbiosis are shown in Figure 1 through Figure 4; and the overall results in Figure 5. These results show that small watershed units with high degree of natural symbiosis are concentrated along the western mountain ridges. In addition, units with fairly high degree of natural symbiosis are also found along the mountain slopes and in the hilly areas along the northeastern coast. Lowlands, on the other hand, show a much lower degree of natural symbiosis.

4-2 Spatial Diversity
  Analysis of spatial diversity, as seen in Figure 6 and 7, shows that even among the western mountains, where many high suitability watershed units are concentrated, there are still some units with high interspersion scores, indicating that they are isolated. On the other hand, the juxtaposition results indicate that many of the highly suitable watershed units have good connectivity.
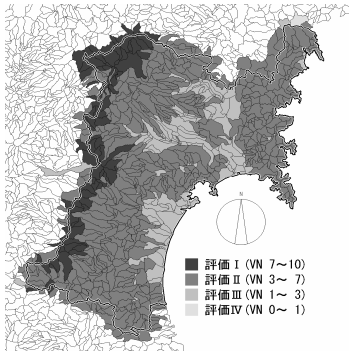

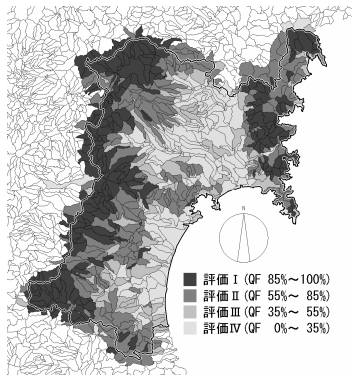Figure 1.   Vegetation Naturalness Index (VN)

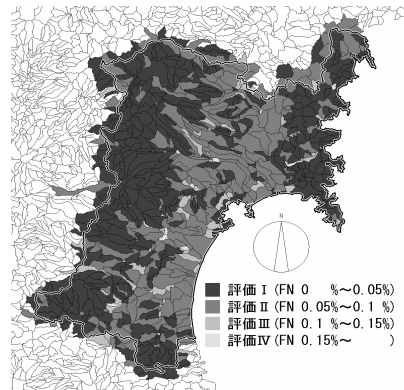Figure 2. Quantitative Index of Forest (QF)

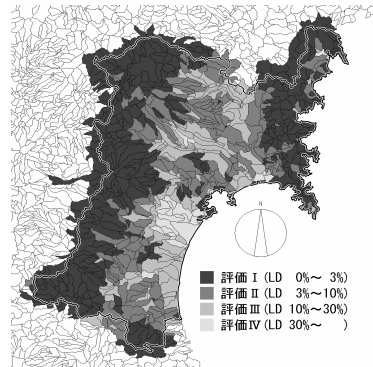Figure 3.   Index of Fragmentation of Natural Environment (FN)

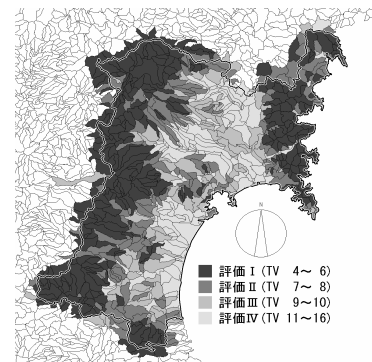Figure 4.   Index of Land Modification Level (LD)
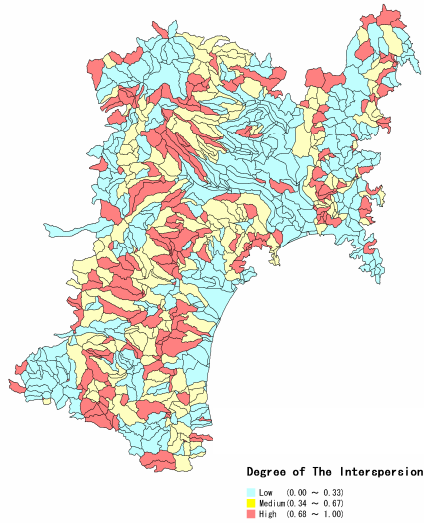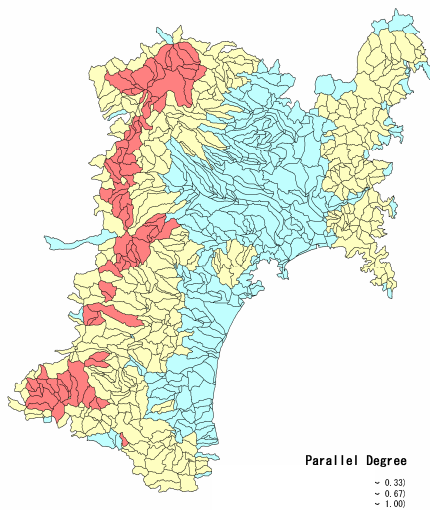

Figure 5.   Total Evaluation Level (TV)

Figure 6. Interspersion Map

Figure 7. Juxtaposition Map

5. CONCLUSIONS

The ecosystem evaluation using small watershed units was judged to be effective when compared with data on environmental and biological diversity. Employing the exiting data for comparison, it was clear that the number of species and plant communities were higher in the units that have higher scores in the evaluation system. This indicates that the system adopted in this study provides a simple, easily applied but reliable tool for spatial environmental evaluation.

This research demonstrates that GIS analysis is a convenient tool for evaluation of habitat suitability over a broad area, and that the results can be quickly incorporated into regional plans for environmental and species management.

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