J-1.3 Estimation of changes in plant community patterns with a vegetation structure model using satellite data.

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Abstract To estimate changes in plant community patterns such as succession and distribution, we classified the vegetation around the Senjogahara moor in the Nikko National Park, Tochigi Prefecture, Japan, using Landsat TM data on 28 July 1986 and 19 July 1997. The area of wetlands was reduced from 1986 to 1997. On the other hand, the areas of grassland and *Sasa* community increased and the maximum dimension of multi-fractal spectrum of their spatial distributions also increased. To relate the multi-fractal spectrum of spatial distribution with interaction between populations, we developed a neighborhood-based lattice model as the Vegetation Structure Model, simulated with different levels of competition intensity and competitive asymmetry, and analyzed the multi-fractal spectrum of the spatial distribution of a steady state. The maximum dimension of multi-fractal spectrum of their spatial distributions increased with increasing levels of competition intensity and/or competitive asymmetry, suggesting that we can obtain model parameters of interaction between individuals for the neighborhood-based lattice model from the multi-fractal properties of vegetation distributions which were estimated using satellite data.

Key Words Landsat TM data, Multi-fractal spectrum, Vegetational change, Wetland

1. Introduction

To predict the changes in terrestrial ecosystems due to global warming, theoretical models which can connect to satellite data in necessary to analyze ecosystem changes on a broad scale. However, previous global models were too simple to deal with interspecific competition, succession, and distribution movements. Therefore, there were a few global models for analyzing vegetation movements and changes in species composition. On the other hand, there were many models to describe vegetational changes on a fine scale, but they cannot accept satellite data.

The objectives of this study are (1) to develop a spatial model, which was designed to accept satellite data and (2) to establish a methodology to analyze vegetational changes on a broad scale using the model. We call it the Vegetation Structure Model.

2. Methods

(1) Study area

We selected the Senjogahara moor in the Nikko National Park, Tochigi Prefecture, Japan, as a test area, because around this area there are a wide variety of land-cover types and a part of the moor has been invaded some tree species (Hukusima et al. 1986, Hukusima 1991, Hukusima & Mizogushi 1991, Hukusima & Yoshikawa 1997). The moor is 246 ha and 1400 m a.s.l. When air fronts or typhoons bring high precipitation to this area, the valley floods and alluvial materials overflows into Sakasagawa river, bringing about extreme run-offs into the moor and deposition of the alluvial materials at the edge of the moor, which allow some of the tree species to invade there.

(2) Land-cover classification of the Senjogahara moor in the Nikko National Park

The study area was dominated by high- and low-moor, grassland, *Sasa nipponica* var. *nana* community, *Spiraea salicifolia* community, *Malus sieboldii* community, broad-leaved forest including *Quercus mongolica* var. *grosseserrata* and *Ulmus japonica*, coniferous forest including *Larix kaempferi* and *Thujopsis dolabrata*, arable lands, and buildings including car parks and roads. Therefore, we classified the study area into nine types of vegetation, moor, grassland, *Sasa* community, *Spiraea* community, *Malus* community, broad-leaved forest, coniferous forest, arable lands, and buildings, using Landsat TM data on 28 may 1993. We used the maximum likelihood classifier and supervising areas for the classification were determined by field investigations and the vegetation map of the Senjogahara moor (Hukusima 1991).

(3) Analyses of year-to-year vegetational changes in the Senjogahara moor

We used two Landsat TM data on 28 July 1986 and 19 July 1997 to analyze the relationship between band reflectance and the identity of vegetation types. Prior to the analyses, we corrected the two imageries to coincide the mean values and the standard deviations of DN counts for each band of the two imageries. Moreover, we classified the vegetation around the Senjogahara moor into nine types of vegetation, moor, grassland, *Sasa* community, *Spiraea* community, *Malus* community, broad-leaved forest, coniferous forest, arable lands, and buildings, using the original Landsat TM data on 28 July 1986 and 19 July 1997 to analyze year-to-year vegetational changes in the Senjogahara moor. We also used the maximum likelihood classifier and supervising areas for the classification were the same areas between the two imageries of which vegetation was not changed from 1986 to 1997. In addition, multi-fractal analyses were performed against the distribution maps of the dominant species obtained by the classification.

(4) Multi-fractal analyses using the Vegetation Structure Model

To relate the multi-fractal spectrum of spatial distribution with interaction between populations, we developed a neighborhood-based lattice model as the Vegetation Structure Model, simulated with different levels of competition intensity and competitive asymmetry, and analyzed the multi-fractal spectrum of the spatial distribution of a steady state.

3. Results and Discussion

(1) Vegetation maps of the Senjogahara moor

We classified the vegetation of Senjogahara moor using Landsat TM data on 28 may 1993, and obtained the vegetation map of the area (Fig. 1). In this map, legend was composed of wetlands which include high- and low-moor and grassland, arable land, deciduous forest, coniferous forest which includes *Malus* community, and others which include *Sasa* community, *Spiraea* community, and buildings. It seems that by the maximum likelihood classifier using Landsat TM data we can classify the *Malus* community and moors which were known to have been varied markedly in this areas (Hukusima et al. 1986, Hukusima 1991, Hukusima & Mizogushi 1991, Hukusima & Yoshikawa 1997).

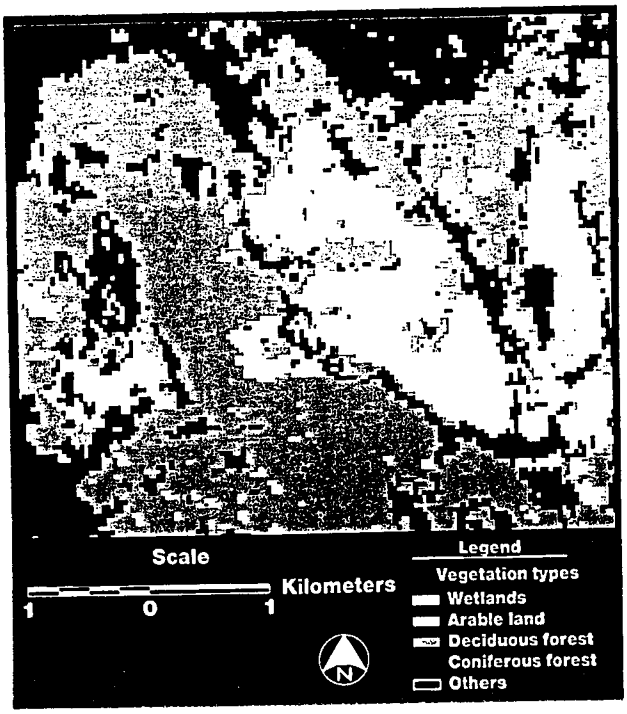

Fig.1 Vegetation map of the Senjogahara moor in the Nikko National Park.

(2) Year-to-year vegetational changes in the Senjogahara moor

Each classified vegetation type showed the specific seasonal change in the vegetation index (NDVI) and surface temperature calculated from TM data. Moreover, DN counts of TM band 4 (near-infrared) were high in forests and low in moors, but were reversed for those of TM band 6 (thermal), allowing us to identify the forests and moors by this relationships. Using this relationships, we were successful in identification of the areas in which moors in 1986 were changed into forests in 1997 using Landsat TM data on 28 July 1986 and 19 July 1997.

According the land-cover classification using the two imageries of Landsat, we estimated that the reduction of moor areas from 1986 to 1997 was 0.33 km^2 (Table 1). Instead, *Malus* community (0.27 km^2), grassland (0.50 km^2), and *Sasa* community (0.28 km^2) increased

(Table 1), supporting the previous studies (Hukusima et al. 1986, Hukusima & Mizogushi 1991, Hukusima & Yoshikawa 1997). This suggests that the Senjogahara moor has been degraded in the late decades. Moreover, broad-leaved forests decreased but coniferous forests increased in this area (Table 1).

Table 1 Vegetation changes around the Senjogahara moor in the Nikko National Park from July to July 1997

Vegetation types	Area in 1986 (km^2)	Area in 1997 (km^2)	Change (km^2)
Wetlands	1.95	1.62	-0.33
Grasslands	0.50	0.88	0.38
Sasa community	0.28	0.51	0.23
Spiraea community	1.19	0.90	-0.29
Malus community	1.36	1.62	0.27
Broad-leaved forests	7.05	6.32	-0.73
Coniferous forests	5.29	5.73	0.44
Arable lands	0.28	0.44	0.17
Road, and buildings	0.42	0.29	-0.14
Others	1.94	1.94	0.00
Total	20.25	20.25	

(3) Multi-fractal properties of the vegetation around the Senjogahara moor

The multi-fractal properties of the vegetation around the Senjogahara moor were also changed in response to the changes in the areas of vegetation. The maximum multi-fractal dimension of the moors, of which the area decreased, was reduced, but that of the grassland, the *Sasa* community, and the coniferous forests, of which the areas increased, increased (Fig. 2). However, this was not seen in the *Malus* community and the broad-leaved forests. These findings suggest that multi-fractal properties of vegetation distribution could be a useful tool to describe the vegetational changes, while its sensitivity was low for broad-leaved tree species.

(4) The Vegetation Structure Model

We developed a neighborhood-based lattice model of a single species as the Vegetation Structure Model, as follows:

$$\Delta S(i, j) = a S(i, j) \left[1 - b S(i, j) - \Sigma Cs(i, j) \cdot W(i, j) / N\right]$$

where S (i, j) is a individual size at a lattice (i, j), a and b are constants, Cs (i, j) and W (i, j) are competition intensity and the degree of competitive asymmetry at a lattice (i, j), respectively, and N is the number of neighboring individuals.

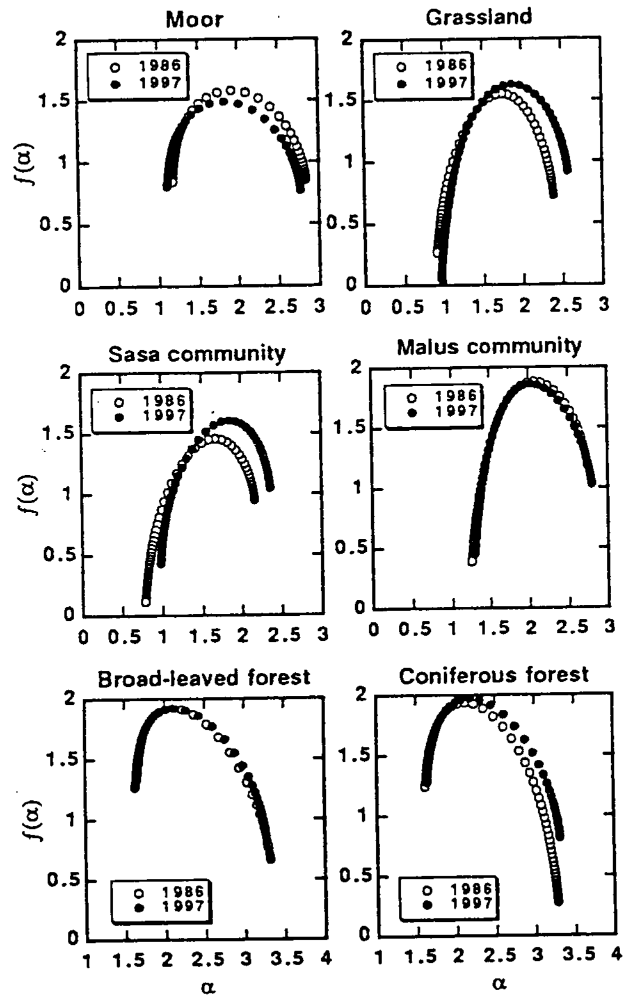

Fig. 2 Changes in the multi-fractal spectrum of moor, grassland, *Sasa* community, *Malus* community, broad-leaved forest, coniferous forest around the Senjogahara, Nikko National Park from July 1986 to July 1997. α: strength of singularity, $f(\alpha)$: multi-fractal dimension.

In this model, an individual at a lattice (i, j) grows and dies as a result of interaction with eight neighboring individuals. Moreover, recruitment and death due to disturbance are set up in the model. This model includes parameters of competition intensity and the degree of competitive asymmetry to deal with the dynamics of vegetation distribution caused by competition. Moreover, this is spatial model and be able to analyze the vegetation distribution by introducing a vegetation map derived from satellite data into the model as a initial distribution of vegetation.

(5) Multi-fractal properties simulated by the Vegetation Structure Model

To introduce multi-fractal properties into the Vegetation Structure Model, it is necessary to understand the relationship between multi-fractal properties and interaction between populations. Therefore, simulations by the Vegetation Structure Model were performed with different levels of competition intensity and competitive asymmetry, and then the multi-fractal spectrum of the spatial distribution of a steady state was analyzed. The maximum dimension of multi-fractal spectrum of their spatial distributions increased with increasing levels of competition intensity and/or competitive asymmetry (Fig. 3), suggesting that the multi-fractal properties of vegetation distribution may be attributable to the interaction mode between neighboring populations such as competition intensity and/or the degree of competitive asymmetry.

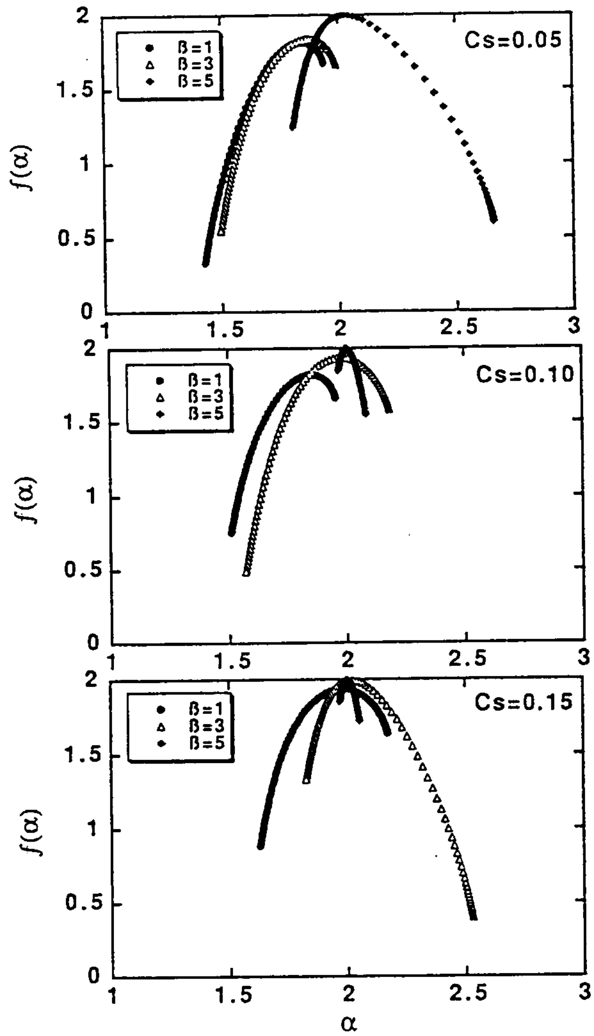

Fig. 3 Multi-fractal spectrum of vegetation distributions of a steady state simulated by the vegetation structure model with different levels of competition intensity (Cs) and competitive asymmetry (β). α: strength of singularity, $f(\alpha)$: multi-fractal dimension. Mortality of all individuals was assumed to be 0.001.

We also found that the multi-fractal properties could reflect the year-to-year changes in vegetation distribution which were estimated by land-cover classification using Landsat data (Fig. 2). Therefore, these findings suggest that we can obtain model parameters of interaction between individuals for the neighborhood-based lattice model from the multi-fractal properties of vegetation distributions which is estimated using satellite data.

Herewith, we propose the methodology to analyze vegetational changes on a broad scale using the Vegetation Structure Model: (1) land-cover classifications using multi-temporal satellite data, (2) analyses of multi-fractal properties of each vegetation distribution, (3) estimation of parameters, competition intensity and the degree of competitive asymmetry, for the Vegetation Structure Model from the multi-fractal properties, and (4) predictions of vegetation dynamics under a given environmental condition using the Vegetation Structure Model.

4. Conclusions

(1) We classified vegetation around the Senjogahara moor in the Nikko National Park, Tochigi Prefecture, Japan, using Landsat TM data.

(2) The area of wetlands was reduced from 1986 to 1997, but the areas of grassland and *Sasa* community increased.

(3) The maximum dimension of multi-fractal spectrum also increased in the vegetation of which the area increased.

(4) We developed a neighborhood-based lattice model as the Vegetation Structure Model which was designed to accept satellite data and could deal with competition between neighboring populations.

(5) By simulations with the Vegetation Structure Model, we found that the maximum dimension of multi-fractal spectrum of their spatial distributions increased with increasing levels of competition intensity and/or competitive asymmetry, suggesting that we can obtain model parameters of interaction between individuals for the neighborhood-based lattice model from the multi-fractal properties of vegetation distributions which are estimated using satellite data.

(6) We proposed the methodology to analyze vegetational changes on a broad scale using the Vegetation Structure Model.

5. References

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