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山西霍山森林植被垂直带的定量划分

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摘　要　用计算边缘效应和聚合分析的方法,对山西霍山东西两坡每100 m的海拔取样区进行计测和聚合分析,确定其交错区。依据交错区及聚合分析结果,将霍山暖温带阔叶林植被定量划分为5个垂直带和3个亚带:农田灌丛带、低山针叶林带、典型阔叶林亚带、针阔叶混交林亚带、小叶林亚带、山地矮曲林带和亚高山草甸带。

关键词　定量划分　垂直带谱　交错区　边缘效应

QUANTITATIVE DIVISION OF ALTITUDE BELTS IN FOREST VEGETATION OF MT. HUOSHAN, SHANXI PROVINCE

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Abstract　Ecotone positions on the east and west slopes of Mt. Huoshan, Shanxi Province were identified by calculating edge effects of different sampling regions located at one hundred meters (altitude) intervals. A quantitative division of vegetation types was achieved using these identified ecotones and a cluster analysis of biotypes. The vegetation of the warm temperate broad-leaved forest in Mt. Huoshan in Shanxi Province was subsequently divided into five vegetation altitudinal belts and three subbelts.

Key words　Forest vegetation, Altitude belt, Edge effect

Continuity and disjunction exist in the vertical distribution of mountain vegetation. Disjunction should be emphasized in the division of vertical belts. There are many difficulties in the traditional qualitative analysis (Bi, 1998; 1991; 1992). Quantitative analysis is an effective way to reduce subjective factors in dealing with the relation between continuity and disjunction. In the paper, the forest vegetation of Mt. Huoshan in Shanxi is used as the study material and the quantitative division is completed according to the edge effect indices that reflect the boundary features of vegetation areas. We are aiming at exploring an effective method of the quantitative division of forest vegetation, showing the regularity of forest vegetation altitude belts, and providing ecological information for forest management and reconstruction in mountain vegetation.

1　The general situation natural environment

Mt. Huoshan is located in the south of Shanxi Province, in the intersection of 36°21′-36°45′ N and 111°40′-112°20′ E. It is a section of the middle chain in Mt. Taihang. The mountain goes in the northeast and southwest direction. The altitude ranges 900-2354 m above sea level. The soil consists mainly of drab soil. The climate is a warm temperate continental monsoon climate. The zonal vegetation is deciduous broad-leaved forest. It is the west edge of warm temperate deciduous broad-leaved forest region according to the division of China's vegetation (Wu, 1980). The original vegetation, because of human destruction, was replaced by the secondary vegetation at standing state. The dominant plants in this area are *Pinus tabulaeformis* and *Quercus liaotungensis*.

2　Material and method

2.1　Sampling

Sample sectors are obtained every hundred me-

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tres altitudinally on the east and the west slopes of Mt. Huoshan. Six quadrats, each of which covers 225 m^2, are set up in one sample sector. There are 174 quadrats in total, 90 of which are set up in 15 sectors of the west slope and the others in 14 sectors of the east slope.

2.2 Data analysis

Each sample sector is regarded as the boundary of a vegetation zone in certain altitude. Ecotones are selected by calculating the edge effect intensity of each zone. The dividing lines are drawn accordingly. The calculation formula (Wang & Peng, 1986) is as follows:

$$E = mD\sum_{i=1}^{m} d_i \qquad (1)$$

E: the edge effect intensity

M: the adjacent community number

D: the quantitative index of the community in calculated sector (See formula (2))

d_i: the quantitative index of the "i" adjacent community.

In this study, D and d_i are used in two ways for comparison. Firstly, the species diversity index (D) is calculated by Shannon-Weiner formula:

$$D = 3.3219(\lg N - 1/N\sum_{i=1}^{s} n_i \lg n_i) \qquad (2)$$

Secondly, the ecological dominance index (C) is calculated by Simpson formula:

$$C = \sum_{i=1}^{s} n_i(n_i - 1)/N(N-1) \qquad (3)$$

D: the index of biological diversity

C: the index of ecological dominance

s: the species number of sampling

N: the total individuals of individuals in sampling

n_i: the number of the "i" species

Finally, the index similarity (IS) between the ecotones and the adjacent communities was calculated by the Euclidian formula (4) and the cluster analysis was made using the group average method (Yang & Lu., 1981).

$$IS = \sqrt{\sum_{i=1}^{p}(X_{ij} - X_{ik})^2} \qquad (4)$$

X_{ij}: the importance value of the "i" species in the "j" belt

X_{ik}: the importance value of the "i" species in the "k" belt

3 Results and analysis

3.1 Demarcating the vegetation altitude belts

With the operating formula (1), (2), (3), the some results were shown in Table 1. The belts of the first greatest edge effects are selected from the east and west slopes as the ecotone of the vegetation alti-

Table 1 The edge effect index of different altitude belts in Mt. Huoshan in Shanxi

Altitude of west slope (m)	Index of species diversity (D)	Index of edge effect (E)	Ecological dominance (C)	Reciprocal of E	Ordinal	Altitude of east slope (m)	Index of species diversity (D)	Index of edge effect (E)	Ecological dominance (C)	Reciprocal of E	Ordinal
Below 950	1.798	0.628	1.404	0.642		Below 950	2.543	0.706	1.103	0.907	
950-1050	2.856	1.357	0.901	1.468	4	950-1000	3.601	1.268	1.213	0.842	
1050-1150	2.425	0.842	1.241	0.851		1000-1100	3.138	0.871	0.300	1.250	
1150-1250	2.898	0.991	1.221	0.772		1100-1150	3.606	1.107	0.790	1.406	4
1250-1350	3.422	0.989	0.631	1.236		1150-1200	3.379	0.912	1.012	0.988	
1350-1450	4.019	1.117	0.349	1.414	5	1200-1300	3.846	1.141	0.790	1.266	5
1450-1500	3.775	1.147	0.356	1.309		1300-1400	3.363	0.898	0.942	0.701	
1550-1650	2.566	0.635	0.583	0.548		1400-1500	3.646	1.251	0.529	1.891	3
1650-1750	4.309	1.630	0.283	2.110	2	1500-1600	2.643	0.710	2.344	0.427	
1750-1800	2.721	0.699	0.610	0.551		1600-1700	3.300	1.250	0.447	2.237	2
1800-1900	3.476	1.181	0.389	1.664	3	1700-1800	2.818	0.748	2.572	0.389	
1900-2000	3.164	0.982	0.685	0.930		1800-1900	4.240	1.698	0.298	3.367	1
2000-2100	2.971	1.057	0.886	0.780		1900-2000	2.176	0.633	1.658	0.603	
2100-2250	2.458	0.799	0.697	0.733		2000-2100	2.632	1.210	0.911	1.908	
2250-2354	3.179	1.293	0.136	5.128	1						

tude belts. The demarcation lines of the vegetation altitude belts which an ecotone is merged into either the upper or the lower belts were decided accordingly to its *IS* value. The cluster entity is the sample of sector in the east and the west slopes. The attribute is the accumulation of the importance value of species in different synusia of all sample sectors. The attribute selection needs to refer to the species groups, which are obviously different in ecological adaptation in the same synusia and are varied with the change of altitude gradient, for further the demarcation (Table 2). The cluster dendrogram was established using Group Average based on the formula(4) (Fig. 1). The important formation is selected with regards to the biggest distribution and the most typical formation of the belt (Table 3). To sum up, the forest vegetation in Mt. Huoshan is divided into five vegetation altitude belts.

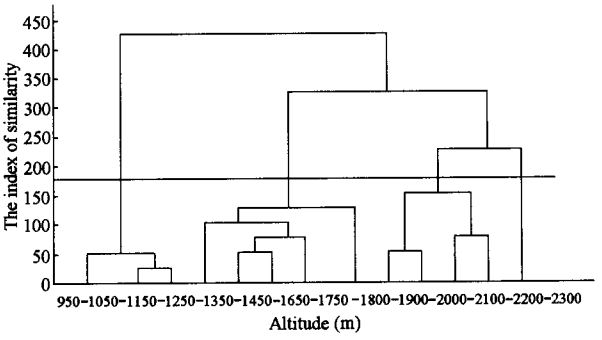

Fig. 1 The dendrogram of cluster demarcation on the west of Mt. Huoshan in Shanxi Province

Table 2 The attribute index (importance value I. V.) **of all entities in Mt. Huoshan in Shanxi**

Attribute / Entity altitude belt(m)	Warm temperate evergreen needle-leaved forest		Deciduous broad-leaved forest								Total %	Deciduous needle-leaved forest	
	Platycladus orientalis-Pinus bungeana		*Pinus tabulaeformis*		*Quercus liaotungensis*		*Carpinus turczaninowii*		*Populus-Betula*			I. V.	%
	I. V.	%	I. V.	%	I. V.	%	I. V.	%	I. V.	%			
On the west slope													
<950	0	0	0	0	0	0	0	0	0	0	0	0	0
950-1050	262.50	87.50	0	0	37.50	12.50	0	0	0	0	12.50	0	0
1050-1150	300.00	100.00	0	0	0	0	0	0	0	0	0	0	0
1150-1250	300.00	100.00	0	0	0	0	0	0	0	0	0	0	0
1250-1350	71.17	23.75	0	0	31.62	10.54	205.63	68.54	0	0	79.08	0	0
1350-1450	0	0	0	0	0	0	300.00	100.00	0	0	100.00	0	0
1450-1550	0	0	0	0	0	0	283.75	94.58	16.25	5.42	100.00	0	0
1550-1650	0	0	0	0	48.50	16.17	251.50	83.83	0	0	100.00	0	0
1650-1750	0	0	4.94	1.65	18.85	6.28	132.10	41.03	99.31	33.10	80.41	0	0
1750-1800	0	0	129.58	43.19	106.42	35.47	0	0	63.99	21.33	56.80	0	0
1800-1900	0	0	99.01	33.00	81.36	27.12	40.58	13.53	79.05	26.35	67.00	0	0
1900-2000	0	0	36.39	12.13	21.72	7.24	42.90	14.30	175.12	58.37	79.91	23.62	7.88
2000-2100	0	0	60.56	20.19	76.00	25.33	0	0	124.04	41.35	66.68	39.35	13.12
2100-2250	0	0	98.62	32.87	8.00	2.67	0	0	45.54	15.18	17.85	145.42	48.47
2250-2354	0	0	0	0	0	0	0	0	0	0	0	0	0
On the east slope													
<950	300.00	100.00	0	0	0	0	0	0	0	0	0	0	0
950-1000	26.18	8.73	80.08	26.69	130.26	43.42	63.48	21.16	0	0	64.58	0	0
1000-1100	0	0	75.96	25.23	144.15	48.05	80.16	26.72	0	0	74.77	0	0
1100-1150	0	0	0	0	83.77	27.92	216.23	72.08	0	0	100.00	0	0
1150-1200	0	0	0	0	92.93	30.98	207.06	69.02	0	0	100.00	0	0
1200-1300	0	0	83.34	27.78	14.56	4.85	145.56	48.52	56.54	18.85	72.22	0	0
1300-1400	0	0	196.81	56.60	59.85	19.95	51.37	17.26	16.54	5.51	42.72	0	0
1400-1500	0	0	135.12	45.04	11.31	3.77	74.67	24.89	79.29	26.43	55.09	0	0
1500-1600	0	0	140.38	46.94	46.73	15.58	22.56	7.52	79.87	26.62	49.72	0	0
1600-1700	0	0	54.89	18.30	53.08	17.69	41.23	13.74	100.56	33.52	64.95	0	0
1700-1800	65.13	21.71	57.06	19.02	7.57	2.52	41.33	13.77	195.40	65.13	81.42	0	0
1800-1900	0	0	150.00	50.00	32.26	10.75	90.99	30.32	21.70	8.30	48.37	0	0
1900-2000	0	0	174.70	58.23	0	0	33.26	11.08	66.52	22.17	33.25	23.08	7.69
2000-2100	0	0	138.05	46.02	0	0	18.08	6.03	139.32	46.44	52.47	10.29	3.43

Table 3 The vegetation altitude belts and characteristics of Mt. Huoshan in Shanxi

Vegetation altitude belt		Distribution altitudes(m)		Species diversity index		Ecological dominance index		Main formation	Diagnostic species
		West slop	East slop	West slop	East slop	West slop	East slop		
Agranrian and shrub belt		Below 950	Below 950	1.798	2.543	0.904	0.727	Form. *Triticum aestivum* +*Zea mays* Form. *Vitex negundo* +*Ziziphus jujuba*	*Juglans regina* *Prinsepia uniflora*
Lower mountain needle-leaved forest belt		950-1250	950-1050	2.856	3.462	0.801	0.912	Form. *Platycladus orientalis* Form. *Pinus bungeana*	*Platycladus orientalis* *Elsholtzia stayn*
Deciduous broad-leaved forest belt	Typical deciduous broad-leaved forest subbelt	1250-1750	1050-1400	4.019	3.846	0.349	0.496	Form. *Quercus liaotungensis* Form. *Carpinus turczaninowl* Hance	*Quercus liaotungensis* *Philadelphus pekinensis*
	Mixed *Pinus* broad-leaved forest subbelt	1750-1900	1400-1900	3.476	3.463	0.489	0.387	Form. *Pinus tabulaef.* +*Quercus liaotungensis* Form. *Pinus tabulaef.* +*Acer hersii*+*Tilia* sp.	*Acer ginnala* *Cornus alba*
	Populus-Betula forest subbelt	1900-2100	1900-2100	2.971	2.176	0.786	0.819	Form. *Populus david.* +*Betula platyphylla*	*Pyrus xerophila* *Daphne giraldii*
Montane thicket elfin forest belt		2100-2200	2100-2200	2.458	2.632	0.697	0.746	Form. *Betula platyphylla* +*Betula albo-sinensis* Form. *Pinus tatulaef.*	*Betula chinensis*
Subalpine meadow belt		2200-2354	2200-2354	3.179		0.316		Form. *Serratula cupuliformis* +*Carex atrata*	*Ajuga lupulina* *Serratula cupuliformis*

3.2 Establishing the spectrum of the altitude belts

Basing on the demarcative results and refering to the change regularity of the vertical gradient of environment factors, such as soil, water and temperature, the vegetation in Mt. Huoshan is divided into seven vegtation altitude belts (the boundary lines of the agrarain belt below 950 m and the montane thicket and subalpine meadow belt can be seen clearly). The deciduous broad-leaved forest is dominant in all the three continual belts from 1250-1750 m, 1750-1900 m and 1900-2100 m. Accordingly, three belts were defined for the deciduous broad-leaved forest belts and the original three belts regarded as subbelts. As a result, the vegetation in this area is divided into five belts and three subbelts that make up the vertical belt spectrum of Mt. Huoshan vegetation (Fig. 2). The names of dominant vegetation type as well as the names of geomorphology of certain height and range of certain vegetational area are used to name every vegetational altitude belt.

3.3 The vegetational features of Mt. Huoshan in Shanxi

3.3.1 Changed greatly in the vegetation of the basic zone

The Mt. Huoshan lies in the warm temperate summer green forest region. But its basic zone is not covered with the decidous broad-leaved forest as it otherwise should be. The dwarf and remote needle-leaved forest below 1250 m of the basic zone consists of *Platycladus orientalis* and *Pinus bungeana* of 4-8 m height with 50%-60% coverage. The shrubs are thorny *Sophora viciifolia*, *Gleditsia heterophylla*, *Rosa xanthina*, *Sageretia paucicostata* and so on. This is the secondary forest after the destruction of deciduous broad-leaved forest. The heliophiles that are calciphilous, dry-resistant and anti-inverse are adaptable to the harsh habitat because the basic zone is limestone outcrop, little fertility and drought. In

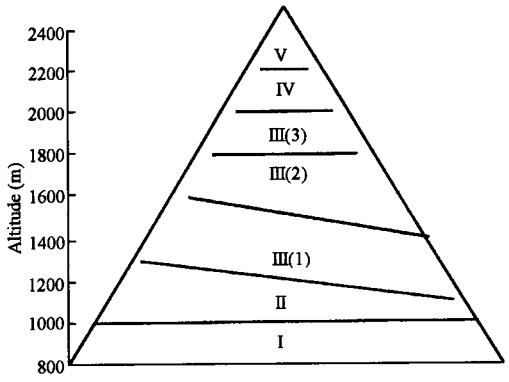

Fig. 2 The vegetation altitude belt chart in Mt. Huoshan in Shanxi Province

I. Agrarain and shrub belt II. Lower mountain needle-leaved forest belt II (1). Typical deciduous broad-leaved forest subbelt II (2). Mixed *Pinus* broad-leaved forest subbelt II (3). *Populus betula* forest subbelt IV. Montane thicket elfin forest V. Subalpine meadow belt

addition, it is not far from human habitations and receives frequent interference from human beings. While the pedogenesis is rather slow than the soil loss and water is serious.

3. 3. 2 High relatively the low limit of the zonal vegetation

The typical deciduous broad-leaved forest lies above the lower mountain needle-leaved forest. In the sun slope, the dominant species are *Quercus liaotungensis* and *Quercus aliena*; in the shade slope, there is a mixture of *Carpinus cordata*, *Acer davidii*, *A. truncatum*, *Tilia* spp. and so on ; in the ravince bottom area, there are *Juglans mandshurica*, *Populus* spp. , *Salix* spp. The community is 8-14 m high with 80% coverage degree. The plant species is the most abundant in this deciduous broad-leaved forest belt. The reason for this kind of vegetation distribution is that the humidity, which is a restrictive factor in the lower mountain needle-leaved forest belt, becomes more and more favorable for the development of deciduous broad-leaved forest in the upper mountain. The fact is that the bottom line of the broad-leaved forest at 1050 m in the east slope, because of greater humidity and exposure to south-east season wind rise at 1250 m in the west slope. This shows that water is apparently a restrictive factor.

3. 3. 3 Wide distribution and significant function of *Pinus tabulaeformis*

As a warm temperate evergreen needle-leaved species, *Pinus tabulaeformis* distributed through out the area from 1100 m to 2200 m, growing well with the exception of the shrub forest at 2200 m. It may form pure forests or mixed forests with broad-leaved species. As a eurytopic plant, *P. tabulaeformis* cannot be used as the differential or the diagnostic species for the purpose of dividing vertical belts. But it is obviously the dominant vegetation type in the area from 1400 m to 1900 m, forming the oak-pine mixed forest with *Quercus liaotungensis* and *Q. aliena*. For this reason, the belt (1400-1900 m) is defined as a subbelt of mixed *Pinus* and broad-leaved forest in the deciduous broad-leaved forest belt to show its independence and a stage of deciduous broad-leaved forest succession.

3. 3. 4 The montane thicket elfin forest belt

In the montane thicket elfin forest belt (2100-2200 m), the arborous trees are *Betula platyphylla*, *B. albo-sinensis*, *B. chinensis*, *P. tabulaeformis*, *Picea wilsonii* and so on. All trees are lower than 3 m, the shrub includes *Potentilla glabra*, *Pertya sinensis*, *Cotoneaste*, *Spiraea*, *Salix*, *Artemisia* and so on. In comparison with similar belts in other mountains, this belt is altitudinally lower and different in the species composition and in the community structure. In the case, that is attributed to the hill-top effect because the altitude of Mt. Huoshan is relatively low.

4 Discussion

In the division of vertical belts, the vegetation of a certain altitudinal region is divided into the types of belts according to the altitudinal and regional features of the vegetation types, which showing the functional results of all the environmental factors in the region. The main basis for the division is the features of vegetation coenology in a certain altitudinal region and the ecological factors that play a leading role in the vegetation development. The vertical belts have spatial continuity, completeness and unduplication.

The edge effect index is used in the quantitative division of vertical belts because it is taken into con-

sideration that each natural vegetation zone has a boundary and an ecotone exists between two adjacent vegetation belts. The ecotones that are inter-percolated, inter-affected and inter-propagated by adjacent vegetation belts are different from the adjacent belts in species composition, construction and function, holding complexity communities of various species as a result of the edge effect. The complexity is expressed as the edge effect index value E, by which the ecotones are determined and the vegetation altitude belts are divided. The method turns out to be effective in the vegetation division of Mt. Huoshan.

The method of clustering analysis is employed on the ground that the composition of the biotype in a certain altitudinal zone is a sayndrome of the integrative environmental factors in the zone. The vertical belts are divided by attributions of the quantified physiognomic features of the communities in a certain altitudinal region and by clustering the entities in the vertical belts. This method is simple and convenient. The result obtained through cluster analysis is rather graphics.

To management and reconstruction of the vegetation on Mt. Huoshan, we proposed that: 1) to reduce the interference and disruption of man is necessary at the agrarian and shrub belt (I) and lower mountain needle-leaved forest belt (Ⅱ), it is proposed to plant photophilous, sun-form trees which are drought hardy at these belts; 2) at the deciduous broad-leaved forest belt (Ⅲ) where there are abundant plant species, rich resources, a high capability forest self-recovery, and greater potential to use forest resources, it is proposed to develop rapid growth forests and reconstruct the *Quercus liaotungensis* forest; 3)the economic profit of the vegetation is poor at the montane thicket elfin forest belt (Ⅳ) and subalpine meadow belt (Ⅴ). Therefore, it is proposed to plant deciduous needle-leaved forests and cold-resistant needle-leaved forests.

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