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CANONICAL CONTINGENCY TABLE ANALYSIS OF THE VEGETATION ALONG ELEVATION GRADIENTS OF THE GREATER XINGAN MOUNTAINS, CHINA

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Abstract. Canonical contingency table analysis is a method to measure structural sharpness and to detect compositional trends in structured phytosociological tables. The present paper analyzes species occupancy and life-form frequency records from the Greater Xingan Mountains of north-east China along elevation gradients. The analysis reveals a sharp group structure in the data by species and elevation class. It also reveals elevation related trends in species distributions of 4 basic types: skewed to low altitude, mode at mid altitude, skewed to high altitude, altitude indifferent. Typical species of the 4 types in the same order include: *Pinus sylvestris, Picea jezoensis, Pinus pumila,* and *Larix gmelini.*

Introduction

Canonical contingency table analysis (CCTA) has been designed to measure the success of phytosociological table rearrangements (Feoli and Orlóci 1979, Orlóci, 1991). When the data structure is sharp, it tends to be also sharply trended, and if the trend is monotonic, it will be detected by CCTA. If the trend is other, CCTA will still fit the monotonic model and collapse into the "untrended"or "random" component all variation that does not fit the trend. This is clearly shown by published results (Feoli and Orlóci 1979, 1985; Orlóci 1991) and also by the results presented in this paper.

Low sharpness of the data structure indicates lack of monotonic trends. CCTA thus helps to interpret the phytosociological table and validate the arrangement that was drawn up to bring forth specific properties suggestive of the existence of specific properties in the sampled vegetation. Structures that are not linked with monotonic trends will not be reliably detected. This means that in gradient studies, the gradient breadth should be not excessive.

The main point to be made in the present paper is that table structuring, a standard phytosociological method, can in fact identify the influential factors, as it can also detect species groups of significant indicator value for the states of the factors. In the present paper the species groups are the dominants of communities characteristic for specific elevation belt. The factor variables are implicitly climatic related to elevation.

Study site

The Greater Xingan Mountains extend approximately from 49° 20' N (near Yakeshi, Inner Mongolia) to 53°30' N (Me River, Heilongjiang Province) and 119° 41' E to 127° 22' E. The site covers the northern part of the Yilehuli Mountains with the Heilongjiang river marking the eastern, northeastern and northern boundaries, and the Ergun River the northwestern and western boundaries. The southeast boundary is at the Lesser Xingan Mountains. The average elevation is 700 to 1000 m. The highest elevation is approximately 1400 m and the lowest about 250 m. The mean annual temperature is -2 to -5°C and the mean annual precipitation 360 to 500 mm at low altitude station. The zonal vegetation is a cold temperate coniferous forest with some northern broad-leaved species (Yiliang Zhou 1992).

Sampling and data

It is not easy to draw a clear line between vegetation zones on the elevation gradient in a rolling mountainous region. The task can be made even more difficult by the secondary nature of the vegetation over large tracts of land. It is also problematic to determine which type of vegetation is typical at which elevation. To draw boundaries and to determine the typical vegetation, we performed surveys on elevation gradients. We sampled high mountains, including the White Caro Mountain (1410 m), Oclid Mountain (1530 m), Yinjli Mountain (1460 m), Youngth Hill (1350 m) and Little Nigulu Mountain (1446 m). Based on the landscape features and vegetation, we opted for a 10 x 20 m^2 quadrat size for sampling the elevation gradients. We located quadrats at 50 m elevation intervals (72 in total) and recorded species presence (absence).

We chose 5 groups of leading species with centers of distribution at different elevation levels. Presence scores are given for these species in Table 1. We note that the species groups overlap to some extent and that the overlapping species have different scores. The latter is the consequence of the descriptions of the groups being accomplished in separate surveys. Life-form spectra for a full complement of species (83) are given in Table 4. Both sets are analyzed.

Table 1. Sample data stratified by species group and elevation intervals. Explanations are in the text. Legend: "-" species absent, "+" species present, a elevation 250 to 350 m, b 350 to 600 m, c 600 to 900 m, d 900 to 1250 m, e 1250 to 1450 m.

Group A	a	b	c	d	e
Larix gmelini	- + +	+ + + + -	+ + + + - +	- + + + - + -	+ + + + -
Pinus pumila	- - -	- - - - -	- - - - - -	- - - - + + +	- - + + +
Betula exilis	- - -	- - - - -	- - - - - -	- - - - - + +	- + + + +
B. middendorffii	- - -	- - - - -	- - - - - -	- - - - - + -	- + + + -
Juniperus davurica	- - -	- - - - -	- - - - - -	- - - - - - +	- - + + -
J. sibirica	- - -	- - - - -	- - - - - -	- - - - - + +	- - + + -
B					
Larix gmelini	- + +	- + + + -	- - + + + -	+ + + + + + +	+ + - - -
Betula ermanii	- - -	- - - - -	- - - - - -	- - - + + + +	- + + - -
Pinus pumila	- - -	- - - - -	- - - - - -	- - + + + + +	+ + - - -
Vaccinum uliginosum	- - -	- - - - -	- - - - - +	+ + + + + - -	+ - - - -
C					
Larix gmelini	+ + -	- + + + -	+ + + + + +	- + + - - + -	+ - - - -
Alnus mandshurica	- - -	- - - - +	+ + - - - -	- - - - - - -	- - - - -
Picea koraiensis	- - -	- - - - +	- + + + + -	+ - - - - - -	- - - - -
Abies nephrolepis	- - -	- - - - +	+ + + + - -	+ + - - - - -	- - - - -
Sorbus pohuashanensis	- - -	- - - - +	- + + + + -	- - - - - - -	- - - - -
Betula ermanii	- - -	- - - - -	- + + + + +	+ + + - - - -	- - - - -
Picea jezoensis	- - -	- - - - -	- - - + + +	+ + - - - - -	- - - - -
D					
Larix gmelini	- + +	+ + + + +	+ + + + + +	+ + + - + + +	- - - - -
Pinus sylvestris	- - +	- + + + -	- - - - - -	- - - - - - -	- - - - -
Rhododendron dauricum	- - -	- + + + +	+ + - - - -	- - - - - - -	- - - - -
Vaccinum vitis-idaea	- - -	- - + + +	+ + - - - -	- - - - - - -	- - - - -
Betula fruticosa	- - -	+ + + + +	+ + + - - -	- - - - - - -	- - - - -
E					
Larix gmelini	+ + +	+ + + + +	+ + + + + -	+ + + - - + +	+ + + - -
Quercus mongolica	+ + +	+ + - - -	- - - - - -	- - - - - - -	- - - - -
Betula davurica	+ + +	+ + - - -	- - - - - -	- - - - - - -	- - - - -
Populus davidiana	+ + -	+ + + - -	- - - - - -	- - - - - - -	- - - - -
Tilia amurensis	- + +	+ - - - -	- - - - - -	- - - - - - -	- - - - -
Fraxinus mandshurica	+ + -	- - - - -	- - - - - -	- - - - - - -	- - - - -
Corylus mandshurica	- + -	+ - - - -	- - - - - -	- - - - - - -	- - - - -
Lespedeza bicolor	- + +	+ - - - -	- - - - - -	- - - - - - -	- - - - -
Corylus heterophylla	- + +	- - - - -	- - - - - -	- - - - - - -	- - - - -
Populus suaveolens	+ - -	- - - - -	- - - - - -	- - - - - - -	- - - - -

Methods

The analysis has its basis in theory developed by Lancaster (1949) and Williams (1952). Typical applications in related context include Hill (1974) and Feoli and Orlóci (1979, 1985). Orlóci (1991) gives a review and algorithm.

The elements (U_{rs}, $r = 1, ..., p$, $s = 1, ..., n$) in the original p x n table (here p = 32, n = 26) are occupancy (0, 1) records. Matrix **U** is condensed into a table of q (=5 species groups) x t (=5 elevation classes) block totals (occupancy counts **F** matrix). These are given for Table 1:

$$\begin{bmatrix} 2 & 4 & 5 & 13 & 18 \\ 2 & 3 & 4 & 21 & 8 \\ 2 & 7 & 28 & 11 & 1 \\ 3 & 20 & 13 & 6 & 2 \\ 21 & 15 & 5 & 6 & 3 \end{bmatrix}$$

The block sizes (**n** matrix) are:

$$\begin{bmatrix} 18 & 30 & 36 & 42 & 30 \\ 12 & 20 & 24 & 28 & 20 \\ 21 & 35 & 42 & 49 & 35 \\ 15 & 25 & 30 & 35 & 25 \\ 30 & 50 & 60 & 70 & 50 \end{bmatrix}$$

Based on symbolic data, the following definitions are relevant:

f_{ij} - sum of all U_{rs} values in the ijth block of **U**

$f_{i.}$ - sum of all U_{rs} values in the ith row group

$f_{.j}$ - sum of all U_{rs} values in the jth column group

$f_{..}$ - grand sum for the table

n_{ij} - block size in the ij block

It is clear that the sums are affected by block size, therefore adjustment according to

$$f_{ij} := \frac{\frac{f_{ij}}{n_{ij}} f_{..}}{\sum_{k=1}^{q} \sum_{m=1}^{t} \frac{f_{km}}{n_{km}}}$$

is essential. In this formula, "f_{ij}:=" reads "the occupancy count in block ij becomes". The adjustment does not change the grand total. The adjusted matrix is:

$$\begin{bmatrix} 3.51 & 4.21 & 4.39 & 9{,}78 & 18.96 \\ 5.27 & 4.74 & 5.26 & 3.71 & 12.64 \\ 3.01 & 6.32 & 1.07 & 7.09 & 0.90 \\ 6.32 & 25.28 & 13.69 & 5.42 & 2.53 \\ 22.13 & 9.48 & 2.63 & 2.71 & 1.89 \end{bmatrix}$$

Testing structure sharpness and the dimensionality of the compositional trend are of interest and can be accomplished by running the application CONAPACK (Orlóci 1991). For sharpness, the null hypothesis is stated as $E(f) = f^o$, i.e. the observed concentrations within the q x t table blocks of **U** do not deviate significantly from the elements in a null table f^o, which in the present case are proportional to the table's marginal totals. CONAPACK computes the associated total chi-squared value and it partitions the total according to the m dimensional compositional trend into m= INF (q-1, t-1) components, in a simple additive way,

$$\chi^2 = \chi_1^2 + ... + \chi_m^2 = f_{..}R_1^2 + ... + f_{..}R_m^2$$

The value m depends on the complexity of the structure. The coefficients $R_1^2, ..., R_m^2$ are squared correlations of canonical variables. Each chi-squared component associates with a pair of canonical variables. One member of the ith pair $X_i = [X_{1i} X_{2i} ... X_{qi}]$ is specific to the q row groups, and the other member $Y_i = [Y_{i1} Y_{i2} ... Y_{it}]$ is specific to the t column groups.

Each set of deviations from expectation defines a profile over the ordering variable [$\Delta_{hj} = f_{hj} - f^o_{hj}$, j = 1...t or h = 1...q]. As chi-squared is partitioned, the profile is also partitioned into m independent profiles. The ith independent profile is constructed from deviations [Δ_{ihj}, j = 1...t, h = 1...q]. For any hj cell in **F** there are m deviation partitions $\Delta_{hj} = \Delta_{1hj} + \Delta_{2hj} + ... + \Delta_{mhj}$ of which the ith is defined according to

$$\Delta_{ihj} = \frac{X_{hi} Y_{ij} R_i f_{h.} f_{.j}}{f_{..}}$$

There are m sets of q x t Δ_{ihj} values: $\Delta_1, \Delta_2, ..., \Delta_m$. The chi-squared term associated with Δ_i is $\chi_i^2 = f_{..} R_i^2$. The terms are arranged so that $f_{..}R_1^2 > f_{..}R_2^2 > ... > f_{..}R_m^2$. A positive Δ_{ihj} indicates an f_{hj} value higher than expected and a negative Δ_{ihj} indicates an f_{hj} lower than expected. The expectation under H_o is the zero line in the graph. CONAPACK makes screen drawings of the graphs and stores them in picture files.

Assuming that the block structure is significant and sharp, a search can begin for the influential factors which underlie compositional variation among the blocks. It is convenient to use the canonical variates whose correlation with the factor variables reveal the intensity of the environmental influence. Monotonic relationships are assumed to justify the mathematics.

Results

Species pattern

The criterion interaction chi-squared is 149.587 with 16 degrees of freedom, which far exceeds the .001 probability point of the chi-squared distribution (39.257). This indicates rejection of the H_o and the structure is deemed significantly sharp. The Cramer coefficient $C = \chi^2/f_{..}(INF(t-1,q-1)) = 149.5870/223x4 = 0.1676$ or 16.76% is considered reasonably high for the type of data used. The deviations and their canonical partitions are given in Table 2.

Note that $\Delta = \Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$ and that each vector in each of $\Delta_1, \Delta_2, \Delta_3, \Delta_4$ defines a profile drawn for the species groups over different elevation gradients in Fig.1.

Regarding Fig 1, the Δ_1 graphs (X_1, Y_1 canonical plane) are the most significant, on average, in chi-squared terms, since they account collectively for 48% of the interaction chi-squared vis-a-vis the Δ_2, Δ_3, Δ_4 graphs which account in that order for 34%, 11% and 7%. The interpretation of the profiles is based on height and shape. Height indicates the magnitude and sense of deviation from the hypothetical state of total indifference of populations to elevation. Small deviations are probably the consequences of weak random and other nonlinear effects. It is seen that groups A and B have similar monothonic ascending profiles in Δ_1. This indicates that the pooled species sets in the groups perform better than expected as the elevation increases. Group C retains strong unimodality in Δ_2, while D retains a weak one in D_3. Both C and D have descending monotonic components, strong for D and weaker for C. E has a descending profile, that is, the species in the group decline on average more than expected as elevation increases. Group A and B are strongly convergent in Δ_1, but somewhat divergent in Δ_3. Unpartitioned profiles are shown for individual species in Fig. 2. *Larix gmelini* stands out as the only species population largely indifferent to elevation in occupancy terms.

Table 2. Deviations and deviation partitions as explained in the text. The rows represent the species groups and the columns the elevation classes in Table 1.

	Δ_1	-3.560	-4.986	-3.714	0.825	11.436
	Δ_2	-4.360	-7.972	-5.772	13.331	4.773
Δ =	Δ_3 =	-4.213	-2.946	14.021	-1.335	-5.526
	Δ_4	-3.977	15.589	1.228	-6.699	-6.141
	Δ_5	16.110	0.316	-5.763	-6.122	-4.541
	Δ_{11}	-4.569	-6.142	-2.579	6.201	7.089
	Δ_{12}	-5.605	-7.536	-3.164	7.608	8.697
Δ_1=	Δ_{13} =	1.583	2.128	0.894	-2.149	-2.457
	Δ_{14}	4.482	6.025	2.530	-6.083	-6.954
	Δ_{15}	4.109	5.524	2.319	-5.577	-6.376
	Δ_{21}	1.734	-0.334	-1.668	-0.136	0.404
	Δ_{22}	1.094	-0.211	-1.053	-0.086	0.255
Δ_2=	Δ_{23}	-8.907	1.718	8.569	0.697	-2.078
	Δ_{24}	-4.467	0.862	4.297	0.350	-1.042
	Δ_{25}	10.545	-2.034	-10.145	-0.826	2.460
	Δ_{31}	-1.167	2.537	-1.528	-0.637	0.795
	Δ_{32}	0.673	-1.464	0.881	0.368	-0.459
Δ_3=	Δ_{33}=	2.966	-6.450	3.884	1.621	-2.021
	Δ_{34}	-3.881	8.439	-5.082	-2.121	2.644
	Δ_{35}	1.408	-3.062	1.844	0.770	-0.960
	Δ_{41}	0.442	-1.047	2.060	-4.602	3.147
	Δ_{42}	-0.522	1.238	-2.436	5.441	-3.721
Δ_4=	Δ_{43}=	0.144	-0.342	0.674	-1.505	1.029
	Δ_{44}	-0.111	0.263	-0.517	1.155	-0.790
	Δ_{45}	0.047	-0.111	0.219	-0.489	0.334

Table 3 describes conditions on the elevation gradient. A clearly defined relationship can be seen between the vegetation type and the first canonical variate. The second canonical variate suggests a weaker influence by precipitation that peaks in interval c. The third canonical variate probably represents random effects. We note that the canonical scores in Table 3 are adjusted to have their sum of squares equal to the relevant squared canonical correlation. This adjustment standardizes the scores and enhances comparability.

Based on the canonical scores, we construct the row and column group scatter diagrams in 2 and 3 dimensions (Figs. 3, 4). These have similar utility as the scatter diagrams in ordinations. In these we superimpose the species group symbols (A,B,C,D,E) on the elevation groups configuration (a,b,c,d,e).

Life-form pattern

To analyze species life-form pattern in relation to changing elevation, we set up the contingency table as shown in

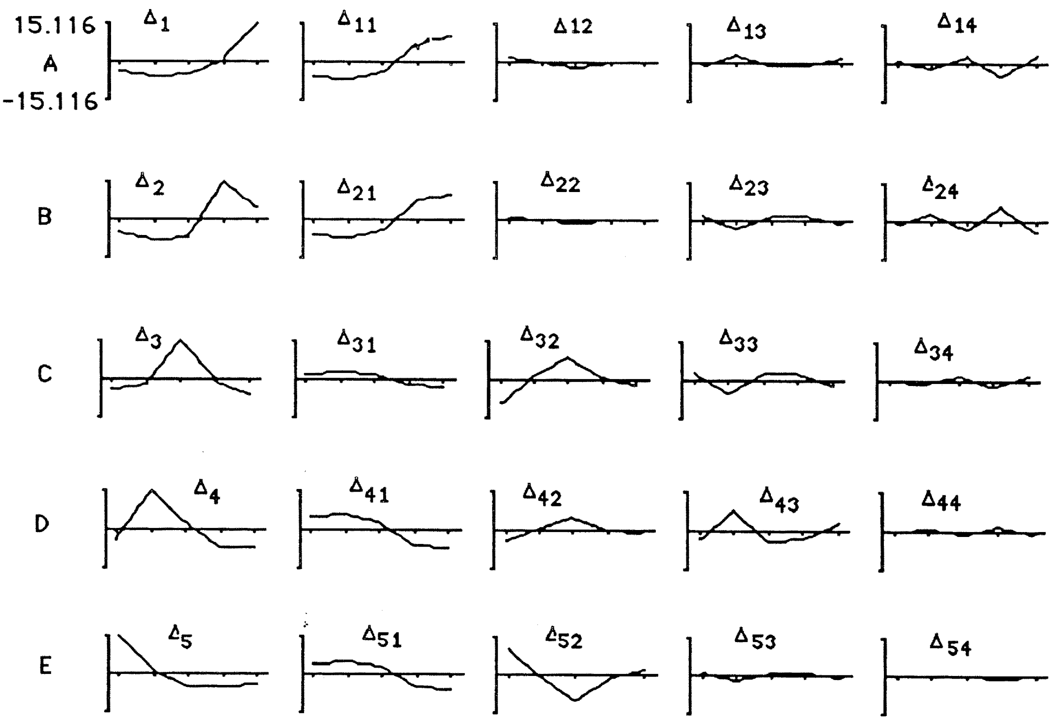

Figure 1.Deviation profiles for species groups A, B, C, D and E over the elevation gradient groups a, b, c, d (tick marks on horizontal axis) of Table 1. Elevation axis indicates deviations from random expectation. All graphs are drawn to same scale.

Table 3. The characteristics of different elevation intervals in the Greater Xingan Mountains. Y_1, Y_2 ,Y_3 are canonical variates for which the proportion of total chi-squared (149.587) accounted for as a percentage and adjusted scores are given.

Level	Altitude	Vegetation	Precipitation	Temperature	Disturbance	Y_1 48%	Y_2 34%	Y_3 12%
a	250-350	Oak-Larch	410.00	highest	heavy logging	-0.23	0.35	0.11
b	350-600	Pine-Larch	460.00		logging	-0.21	-0.04	-0.19
c	600-900	Spruce-Larch	650.00		selective logging	-0.13	-0.30	0.10
d	900-1250	Birch-Larch	440.00		light logging	0.24	-0.03	0.09
e	1250-1450	Alpine	390.00	lowest	no logging	0.39	0.09	-0.10

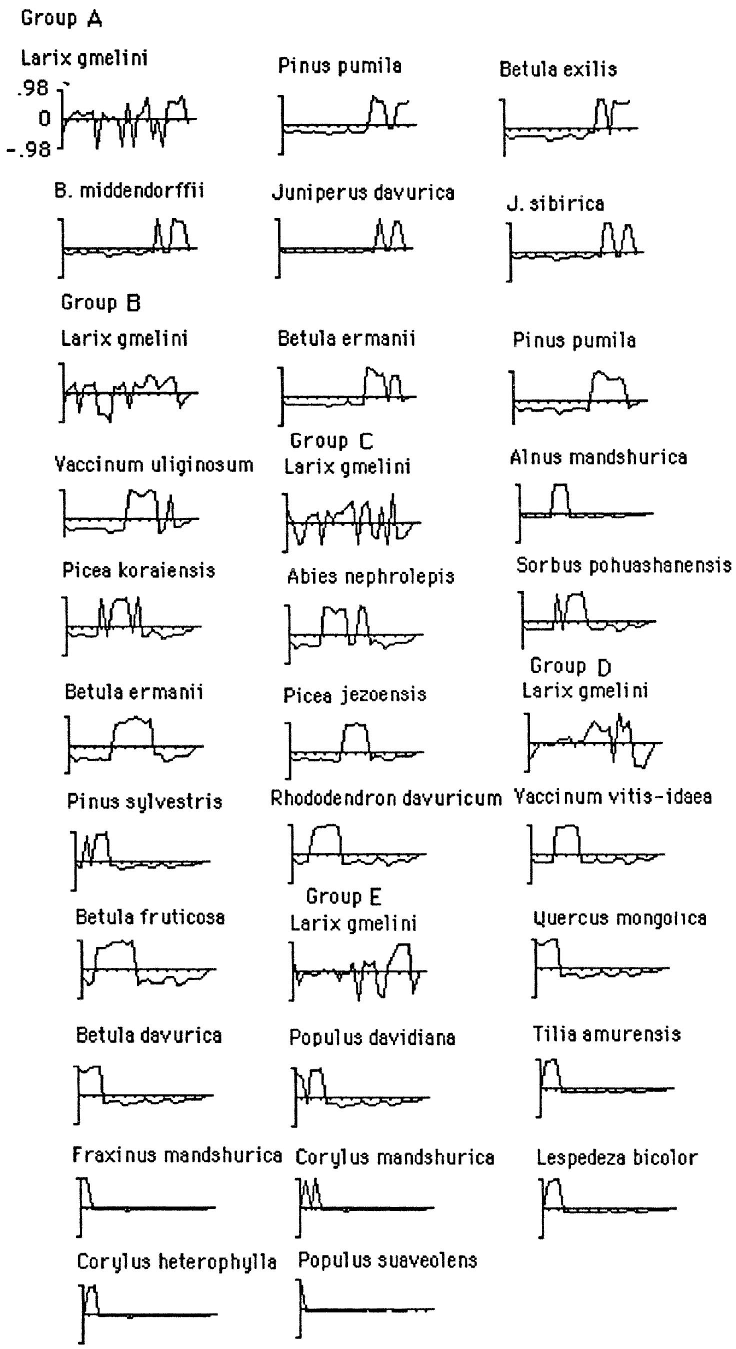

Figure 2. Unpartitioned deviation profiles of species over the elevation gradient. Deviations are measured on the vertical axis. Tick marks on the horizontal axis indicate elevation intervals (a,b,c,d,e) as defined in the caption of Table 1.

Table 4. The detailed results are taken from a run of the CONAPACK application. These include the criterion interaction chi-squared, 57.89 with 12 degree of freedom, which exceeds the .05 probability point of the chi-squared distribution (21.02). This justifies the rejection of the H_o and the conclusion that the structure in the life-form table is significantly sharp. The Cramer coefficient $C = \chi^2/f..(INF(t-1,q-1)) = 57.8873/480x3 = 0.041$ or 4.1% is relative high for life-form spectra. The deviation profiles for species life-form spectra over different elevation gradients are shown in Fig. 5.

In Fig. 5, the Δ_1 graphs (X_1,Y_1 canonical plane) account collectively for 78 % of the interaction chi-squared vis-a-vis the Δ_2 (21%) and Δ_3 (1%). Regarding the distribution pat-

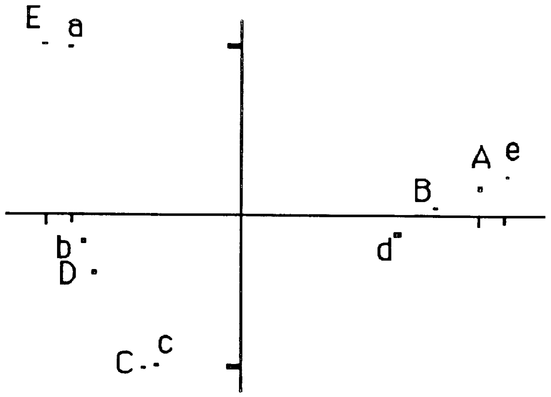

Figure 3. Two dimensional scatter diagram of the joint distribution of canonical variates for species groups (A,B,C,D,E) and elevation interval groups (a,b,c,d,e) described in Table 1.

Table 4. Life-form distribution patterns over the elevation groups a, b, c, d, e. Symbols are defined in the caption of Table 1. Legend: Ph -- phanerophyte, Ch -- chamaephyte, H -- hemicryptophyte, G -- geocryptophyte (Yiliang Zhou 1992).

	a	b	c	d	e
Ph	61	43	51	57	34
Ch	9	14	22	18	21
H	24	26	2	15	39
G	6	7	15	10	6

terns in the deviation profiles, there are sharp trends of the species life-forms along the elevation gradient. It is seen that the phanerophytes and chamaephytes have similar unimodlity in Δ_1 and strong opposing trends in the Δ_2. The latter indicate that phanerophytes have a strong component of decline with increasing elevation, but the chamaephytes have a component of increase. Hemicryptophytes retain strong unimodality in Δ_1, however, they do not show any trend in Δ_2. In other words, hemicryptophytes in Δ_2 show a distribution according to random expectation. Geocryptophytes show strong trend in Δ_1, practically mirroring the hemicryptophyte profile. A weaker ascending trend occurs of this life-form in Δ_2.

Conclusions

The quantification of vegetation pattern in north-eastern China is in the analytical phase aimed to support amelioration and ecosystem reconstruction projects. In these, the reinstatement of an economically viable and ecologically desirable community composition and structure is a primary objective. The present study contributes information on the natural vertical distribution of native species under natural conditions. The result suggests some general tendencies:

1. *Larix* shows little regular response in occupancy terms to elevation changes within the local amplitude, and through this to temperature and precipitation variation as related to elevation.

2. Species populations are categorizable as distinct groups. There are definite ascenders, descenders and unimodally distributed populations.

3. The tendency is high sensitivity of the mode to elevation associated with orographic precipitation and temperature effects.

4. Most dominant species have high plasticity in relation to low temperature and low moisture, particularly at the high elevations.

5. Species richness decreases with elevation.

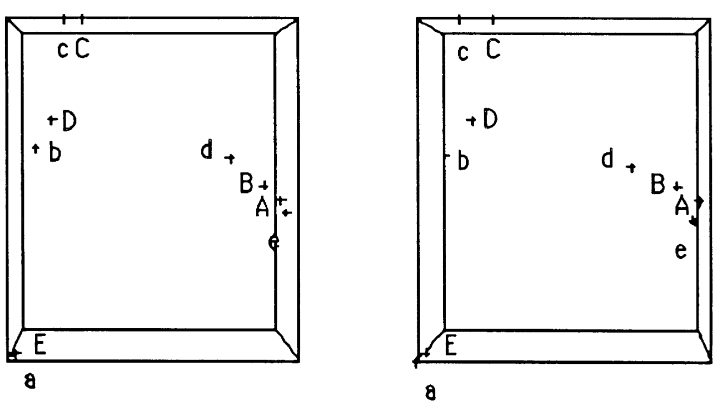

Figure 4. Three dimensional scatter diagram of the joint distribution of canonical variates for species groups (A,B,C,D,E) and elevation interval groups (a,b,c,d,e).

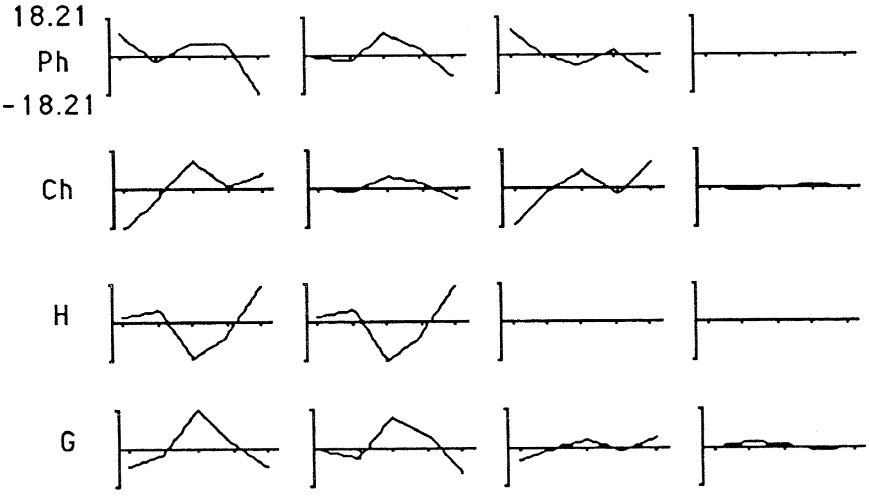

Figure 5. Deviation profiles for life-form spectra over the elevation gradient a, b, c, d, e (tick marks on horizontal axis) of Table 1. Vertical axis indicates deviations from random expectation. Legend to life-forms is given in Table 4.

6. Different life-forms have specific distribution patterns. Phanerophyte is the main life-form at all elevations. Geocryptophytes and chamaephytes prefer the higher elevations.

Based on these tendencies, we may conclude that the vegetation does in fact show a distribution pattern related to elevation. In other words, the vegetation pattern has significant elevation-related regularity. However, this is not readily apparent on visual inspection of the communities at the lower elevations. In analytical terms the different elevations do depict different communities and life-forms.

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