Zeitschrift: Berichte des Geobotanischen Institutes der Eidg. Techn. Hochschule,

Stiftung Rübel

Herausgeber: Geobotanisches Institut der Eidg. Techn. Hochschule, Stiftung Rübel

Band: 36 (1964)

Artikel: Ordination ans classification of Swiss and Canadian coniferous forests

by various biometric and other methods

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Kapitel: 6: Results

DOI: https://doi.org/10.5169/seals-377646

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- (4) The permanent wilting point (P.W.P.) was determined with a pressure membrane apparatus on 4 samples of the A_2 horizon of each sample plot. The results are expressed on a per cent dry-weight basis.
- (5) The field capacity (F.C.) was determined as follows: Five small isolation plots were established at random within each sample plot (roots were cut, top of vegetation removed). Each isolation plot was drenched and covered with plastic sheeting to reduce evaporation. The soil was allowed to drain for 4 days, after which two samples were taken from the A₂ horizon of each isolation plot. The results are expressed on a per cent dry-weight basis.
- (6) "Available moisture" was determined by calculating the difference between P.W.P. and F.C.
- (7) The pH of the soil was determined in the field or in the field laboratory within a few hours after sampling, using a Beckman pH meter (Beckman Instruments, Inc., 2500 Harbor Blvd., Fullerton, California) with a combination glass electrode. The soil was prepared as a soil paste according to Doughty (1941). The "measured mean" and the range of pH on each sample plot were determined (VAN GROENEWOUD 1961).
- (8) Samples of foliage were taken in midwinter and always from the tops of the trees, to minimize the effects of seasonal fluctuation and of position on the tree. The tree tops were shot down with a .22 caliber rifle with telescopic sight. The foliage was kept at -18°C until it could be further processed. The spruce needles were dried at 60°C. After drying, scales and other contaminations were removed by hand. Dust adhering to the foliage was removed with an air-jet of 60 p.s.i. The samples were ground in a Wiley mill and stored at -18°C until the analysis could be performed. The nitrogen content was determined by the micro-Kjeldahl method. The results were corrected for moisture content of the samples at the time of analysis. Ten samples were analysed from each of the 43 plots. This number was considered necessary, because a preliminary study revealed considerable variation in foliage composition within each plot.

5.3 Interpretation

The habitat features were all tested for their relationship with the principal axes (covariance matrix), with the main axes of the constellation of points described by the D² matrix, and with the principal axes of the transformed D² matrices.

The levels of the habitat feature to be tested, were plotted against the corresponding projection of each plot on each axis. If a relationship was evident, a line or curve was fitted to the points. Where a straight line relationship was found, a correlation coefficient was calculated.

When groups of points could be recognized in the ordination, the differences among the mean levels of the habitat features in these groups were tested by a modified "t" test only for those features that had shown a relationship with the principal or main axes.

The differences among the mean levels of the habitat features in the groups of sample plots, as distinguished by the differential species-group method, were tested by "t" tests. To obtain a measure of the separation of the ranges occupied by these groups along the various gradients, the sum of the standard deviations were compared with the differences among the means.

6. Results

Only a relatively small number of the several hundreds of graphs prepared to test all possible relationships is presented. The number of figures has been limited by applying the following rules:

(a) only statistically significant relationships are shown;

(b) further, only those relationships are shown that convey information not already contained in other graphs, unless they are used to prove a certain point, such as showing the differences in the results of relationships among the various methods.

6.1 Sampling and small scale distribution

6.1.1 Comparison of vegetation sampling methods

Several factors have to be considered in judging the relative merits of different sampling methods.

The vegetation data collected by the line-interception method were practically identical to those taken by the point-quadrat-line method. The correlation coefficient was .9994. To facilitate the presentation, the results of both methods were regarded as being identical.

(1) The first factor to be considered is the accuracy of the estimation of the mean cover per plot for each species.

The variation is dependent on the dimensions of each sampling unit (length of line-intercept, area of sampling quadrat), the spatial distribution of the species, and the number of samples. The variance was calculated for different sizes of sampling unit and plotted for both line-intercepts and quadrats. Some of the results are shown in Fig.8 and 9.

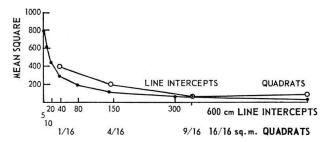


Fig. 8. Mean square/length of line-intercepts and mean square/quadrat size (Oxalis acetosella; plot 1, Ziegelwald, Roggwil).

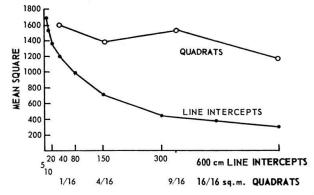


Fig. 9. Mean square/length of line-intercepts and mean square/quadratsize (Polytrichum formosum, Plot 4, Ziegelwald, Roggwil).

In general, the line-intercepts are more efficient in decreasing the variance with increasing size of sampling unit than the quadrats. This is probably due to the increased error in estimating the cover of the species with larger quadrats, opposed to the constant error by the line-interception method. For the same reason, the graphs of variance plotted against sample-unit size of the quadrat method also showed more irregularities than those of the line-interception method. The graphs of the line-intercept variance data were very regular.

These graphs also served to study the pattern of distribution of the species on the sample plots (see next paragraph)

(2) Another factor is the efficiency of the different sampling units in estimating the cover percentage of a high percentage of the total number of species present on the plot.

The results varied with the distribution of the species on the different plots. On some, the quadrat method was more effective; on others, the line-intercept (Figs. 10 and 11).

The overall assessment indicates that the line-interception method has the most advantages of the three methods.

The line-interception and the point-quadrat-line method have the added advantage that the vegetative cover can be rather easily related to habitat factors as measured along the lines.

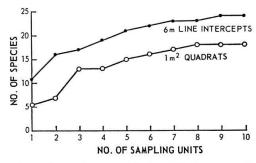


Fig. 10. Increase in number of species sampled, with increase in the number of sampling units (line-intercepts and quadrats, plot 4, Ziegelwald, Roggwil).

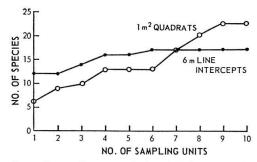


Fig. 11. Increase in number of species sampled, with increase in the number of sampling units (line-intercepts and quadrats, Plot 3, Ziegelwald, Roggwil).

In this study, only the line-intercept data was analysed using the methods mentioned before.

6.1.2 Small scale non-random pattern within sample plots

Seventy variance analysis graphs were prepared, one of which (*Polytrichum formosum*, plot 2, Roggwil) showed a peak at a length of 40 cm line-intercept. This pattern did not interfere with the planned analysis and was too unimportant to induce further investigation. All other graphs showed decreasing

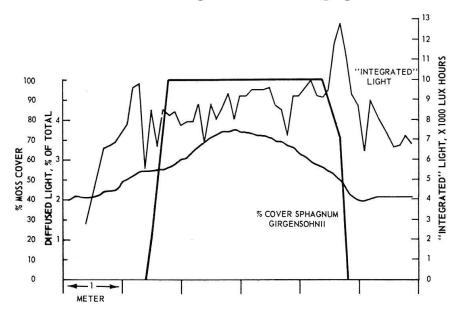


Fig. 12. Distribution of "integrated" and diffused light in relation to percentage cover of Sphagnum quinquefarium (not girgensohnii) along line-intercept (plot10, line3, Murgenthal).

variance with increasing lengths of line-intercepts, with an almost constant variance around a length of 600 cm (Figs. 8 and 9). Further increase of length of line intercepts would have been useless in this study. Based on this evidence, it must be assumed that, for the species investigated, small scale non-random patterns were not present within these sample plots.

6.1.3 Distribution of the vegetation along line-intercepts in relation to light.

The cover percentage of several species were plotted, together with light conditions along several line-intercepts of each plot. The data were collected in Swiss forests. The following results were noted:

- (1) Only in dense forest did the measurements of the light conditions along the lines coincide (Fig. 12);
- (2) In more open forest, the light as measured by the two methods shows an entirely different distribution pattern (Fig. 13);
 - (3) Only where the light, measured by the two methods, had the same

distribution, was this distribution related to the distribution of the vegetation, in particular with *Sphagnum quinguefarium* (Fig. 12);

(4) A total of 50 light and vegetation graphs were plotted but the patterns coincided only in the case of dense forest.

At this point, results of the Swiss data will be presented first, to be followed by the results of the Canadian data. Both were subjected to *identical* procedures.

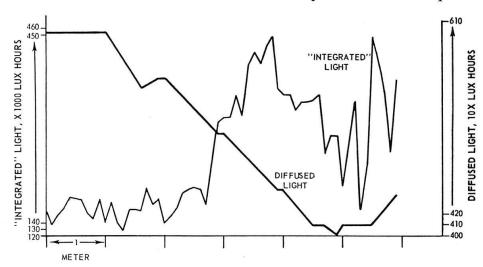


Fig. 13. Distribution of "integrated" and diffused light along line intercept (plot 12, line 5, Unterwald, Roggwil).

6.2 Swiss sample plots

6.2.1 Classification of sample plots (Zürich-Montpellier method)

Five groups of differential species were distinguished (Appendix I).

Group A comprises species which are present on all plots: Vaccinium myrtillus, the seedlings of Abies alba and Picea abies, Hylocomium splendens, Rhytidiadelphus triquetrus, Polytrichum formosum and Thuidium tamariscifolium.

Group B contains species which have fairly wide ecological amplitudes but which are particularly suited to delimit mull from mor soils (Ellenberg 1963, p.86). To this group belong the herbs; Anemone nemorosa, Fragaria vesca, Hedera helix, Lysimachia nemorum, Viola silvatica, Galium rotundifolium, and the mosses: Catharinea undulata, Mnium undulatum and Mnium affine. The species of this group are present on sample plots no.1, 2, 3, 6, and 12 (Vegetation unit I) and are absent (2 exceptions) in the other plots.

Group C comprises species which obviously have ecological requirements close to those of group B, but are differentiated by a somewhat wider amplitude. The species of group C are: Athyrium filix-femina, Dryopteris austriaca, Luzula pilosa, Maianthemum bifolium, Oxalis acetosella, Rubus spec., and Eurhynchium striatum.

Group D embraces species which flourish on moderately dry to moderately moist sols with a lower soil pH than foregoing groups. The species of this group have ecological amplitudes, which partly overlap those of the species of group C, but which almost completely differentiate this group from group B. The species of this group are: Pleurozium schreberi, Rhytidiadelphus loreus, Dicranum scoparium, Hypnum cupressiforme, and Plagiothecium undulatum.

Group E comprises species which have their optima on moderately moist to moist, and very acid soils. The species belonging to this group are: *Bazzania trilobata* and *Sphagnum quinquefarium*. These species occurred only in sample plots no. 4, 5, 8, 9, and 10 (Vegetation unit III).

Group C and D help differentiate a group of sample plots, containing no. 7, 11, 13, 14, and 15, (Vegetation unit II), which is intermediate between the plots differentiated, respectively, by the *Anemone nemorosa* and the *Bazzania trilobata* groups.

6.2.2 Habitat factors in relation to classification of sample plots

The groups of sample plots established in foregoing paragraph received the following average amounts of light with their respective standard deviations (all expressed in kilo-Lux-hours per day): 14.72 ± 7.35 , 19.22 ± 16.12 and 15.56 ± 6.72 . The differences among these average levels are not statistically significant.

The average soil pH of these groups of sample plots, with their standard deviations are $4.04 \pm .38$, $3.83 \pm .29$, and $3.61 \pm .22$, respectively. The differences among the means are all statistically significant. If, however, the ranges along the pH gradient occupied by these Vegetation units are considered, it is obvious that only the pH ranges of unit I and III are separated to some extent; the differences between the means is .43 and the sum of the standard deviations is .60.

6.2.3 Principal component analysis of the covariance matrix

The principal component analysis resulted in principal axes with the following eigenvalues:

trace of matrix = sum of all eigenvalues = 31875.0

Axes Eigenvalues

- I 12402.0 accounting for 38.91% (= $12402.0/31875.0 \times 100$) of the total variation.
- II 8016.5 accounting for 25.15% of the total variation.
- III 3833.3 accounting for 12.03% of the total variation.
- IV 2335.0 accounting for 7.33% of the total variation.
 - V 1798.2 accounting for 5.64% of the total variation.

The first two axes account for 64.06%, the first three axes for 76.09, and the first five axes for 89.06% of the total variation.

The 38 coefficients of the eigenvectors are listed in table 1. The coefficients which contribute most are in italics.

It is noteworthy that the variance of many species can only be satisfactorily described by more than one principal component, e.g. Oxalis acetosella by

Table 1. Eigenvalues and eigenvectors of the Swiss covariance matrix.

	I	II	III	IV	V
Eigenvalues	12402.	8016.5	3833.4 Eigenvecto	2335.0	1798.2
Species	2				
1. Oxalis acetosella	02317	17303	.43073	.44055	.20080
2. Carex brizoides	00782	00447	.01609	.02238	.02894
3. Rubus spec.	00543	00143	.02031	.03411	.02734
4. Polytrichum formosum	56862	74735	06078	15409	15084
5. Thuidium tamariscifolium	.02274	.03175	.05320	49471	.30432
6. Hylocomium splendens	02362	.10902	13904	13432	10456
7. Rhytidiadelphus triquetrus	.01274	.01593	04597	.07050	.03977
8. Abies alba (seedling)	04874	.02277	04145	.03446	.03192
9. Luzula luzuloides	00270	00275	.00078	.00139	.00041
10. Maianthemum bifolium	01351	.00184	00046	.00083	.01423
11. Vaccinium myrtillus	11249	.16698	27644	.26820	.04920
12. Hypnum cupressiforme	00965	.03602	04853	01272	.02898
13. Plagiochila asplenioides	02236	00742	.20060	.20261	.26078
14. Sphagnum quinquefarium	.12412	07078	33668	.07327	06556
15. Ptilidium ciliare	00718	01639	.00460	00086	00604
16. Picea abies (seedling)	08383	.06267	10661	.11761	.05315
17. Catharinea undulata	.00201	00089	.01515	.01717	.00664
18. Eurhynchium striatum	.03392	.23404	.33803	03699	58078
19. Mnium affine	.02879	.00318	.13410	.17271	.13835
20. Hedera helix	.00087	.00034	.00446	.00519	.00208
21. Viola silvatica	.00007	.00035	.00088	.00031	00253
22. Rhytidiadelphus loreus	03664	.01352	00817	00246	.01330
23. Lophocolea bidentata	.00170	00654	03063	00306	.00739
24. Dicranum scoparium	.00937	00273	05384	.01676	00941
25. Pleurozium schreberi	06675	.12852	19156	.20894	.01655
26. Bazzania trilobata	.23596	10909	56851	.15899	14877
27. Plagiothecium undulatum	.00052	00125	.00378	00267	.00194
28. Chiloscyphus polyanthemus	.00147	00083	00278	00370	.00105
29. Athyrium filix-femina	00874	00791	.00104	00265	.00178
30. Dicranella heteromalla	.00046	.00021	00122	00107	.00104
31. Agrostis tenuis	00186	.00018	.00243	.00557	.00658
32. Galium rotundifolium	.00128	00081	.00066	00426	.00296
33. Lophocolea heterophylla	.00215	.00001	00358	00179	06340
34. Mnium undulatum	00234	00266	.00031	00098	.00064
35. Abies alba	.58045	36666	02491	31329	.38070
36. Picea abies	48324	.34412	17508	27516	.42201
37. Fagus silvatica	0237	15145	.08981	.06435	01536
38. Quercus robur	.01288	.01035	.06829	.06512	02768

component 3 and 4, Polytrichum formosum by component 1 and 2, Eurhynchium striatum by component 3 and 5, Picea abies by component 1, 2, and 5. The variation of Bazzania trilobata and Sphagnum quinquefarium can be described almost completely by component 3.

If the ecological requirements of the species are known, this can be an aid in explaining the possible ecological meaning of the axes to which these species are important contributors.

The projections of the points representing sample plots, on the planes spanning the first and second, and the first and the third principal axes, are shown in Fig. 14.

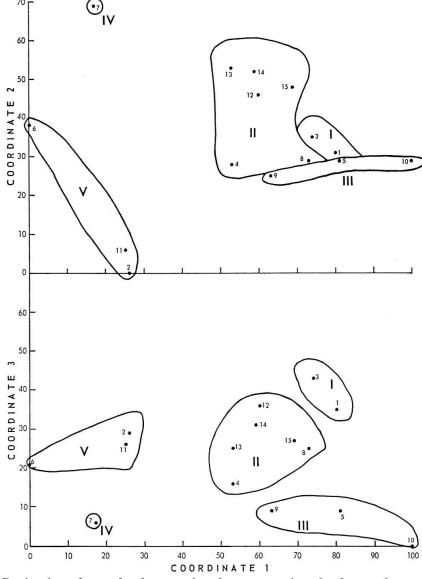


Fig. 14. Projection of sample plots on the planes spanning the first and second, and the first and third principal axes (covariance matrix, Swiss data) with clustering of plots indicated.

The relationships between the cover percentages of the more important species with the principal axes are shown in Fig. 15.

6.2.4 Habitat factors in relation to the principal axes

The habitat factors measured, light conditions and soil pH, were related to the principal axes. The "integrated light" levels and the soil pH on the sample

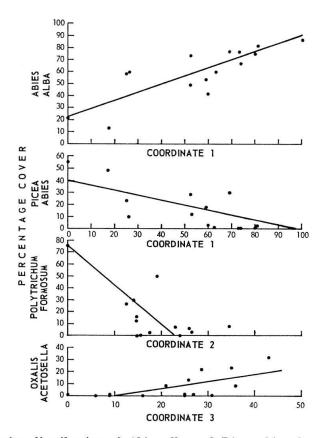


Fig. 15. Quantitative distribution of *Abies alba* and *Picea abies* along the first principal axis, *Polytrichum formosum* along the second principal axis and *Oxalis acetosella* along the third principal axis (cov. matrix, Swiss data).

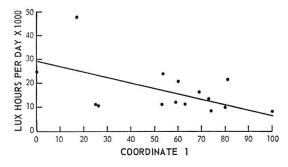


Fig. 16. Relationship between light conditions and the first principal axis (cov. matrix, Swiss data).

plots were plotted against the corresponding values (coordinates) of each plot, for each of the three principal axes. If any indication of a relationship existed, straight lines or regression curves were fitted.

Figs. 16 and 17 show the relationships of the first axis to light conditions and the third axis to soil pH. Both were statistically significant. No relationship was found with the second axis.

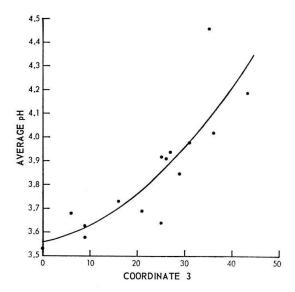


Fig. 17. Relationship between soil pH and the third principal axis (cov. matrix, Swiss data).

6.2.5 Analysis of the D² matrix

All D2's were statistically significant ($P \leq .05$).

The D² matrix was investigated according to the method developed by Torgerson. Three axes were constructed and the points representing sample plots were projected on the planes spanning these axes (Fig. 18).

The distances in two-dimensional space were compared with the D²'s, by calculating the correlation coefficient between these distances and the corresponding D²'s. The correlation coefficient is .939, which is significant at the .001 level. Thus 88.7% of the variation is accounted for by the two dimensional ordination.

6.2.6 Habitat factors in relation to the main axes (D² matrix)

The relationship between each axis and the forementioned habitat factors was tested. As under paragraph 6.2.4, the first axis was significantly related only to light conditions (method 1) and the third axis to soil pH. Although the relationships were largely identical to those mentioned under paragraph 6.2.4, they were statistically less significant (Figs. 19 and 20).

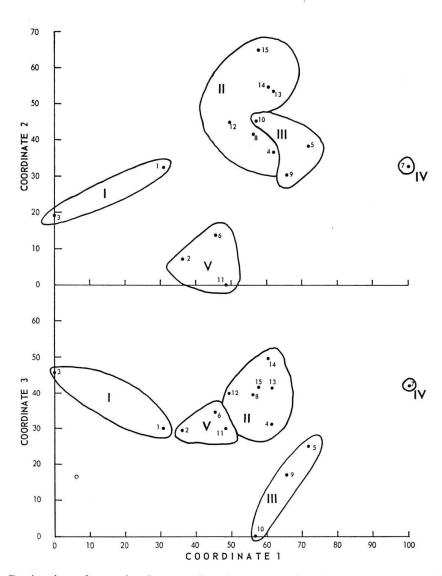


Fig. 18. Projection of sample plots on the planes spanning the first and second, and the first and third main axes (D² ordination, Swiss data) with clustering of plots indicated.

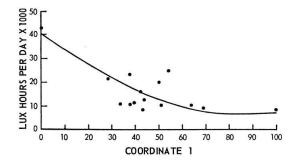


Fig. 19. Relationship between light conditions and the first main axis (D² ordination, Swiss data).

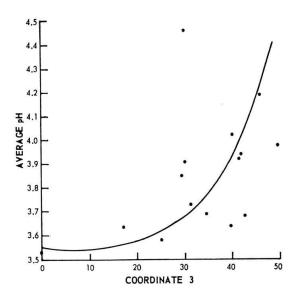


Fig. 20. Relationship between soil pH and the third main axis (D² ordination, Swiss data).

6.2.7 Principal component analysis (Q-method) of the transformed D² matrices.

Two transformations were used: $R = (1 + D^2)^{-1}$, and $R = e^{-D^2}$. The exponential subroutine used in Fortran on the G-20 computer, the $R = e^{-D^2}$ transformation works only with exponents between —63 and +63. Any exponent of which the absolute value was larger than 63 was automatically given the value 0. Since most of the off diagonal elements in the D^2 matrix were larger than 63 they were replaced by zeros in the transformed matrix. The resulting eigenvalues and eigenvectors were almost all zeros and ones. The results of this transformation were not analysed.

The results of the principal component analysis of the $R = (1 + D^2)^{-1}$ matrix are listed in table 2. Only the first three eigenvalues and the coefficients of their eigenvectors are listed.

The eigenvalues of the first three axes were as follows:

Trace of the matrix = sum of all eigenvalues = 15.0 Axes Eigenvalues

- I 1.1686522 accounting for 7.79% of the total variation.
- II 1.0373909 accounting for 6.92% of the total variation.
- III 1.0140313 accounting for 6.76% of the total variation.

The first two axes thus account for 14.71%, and the first three axes for 21.47% of the total variation.

Table 2. Eigenvalues and eigenvectors of the Swiss $(1 + D^2)^{-1}$ matrix.

Axes				Axes			
	I	II	III		\mathbf{I}	II	III
		Eigenvalues				Eigenvalues	k.
\mathbf{Plot}	1.1686522	1.0373909	1.0140313		1.1686522	1.0373909	1.0140313
numb	oer	Eigenvector	S	nun	nber	Eigenvector	S
1	.14222321	.17624994	.21756172	9	.25679214	.30200167	45595084
2	.12656551	.38099206	.35592580	10	.16825722	.21976787	42181803
3	.06633672	.15495798	.199353751	11	.13708974	.40578184	.31920601
4	.30028464	.19683786	27587316	12	.30902949	06469361	.12709984
5	.15062401	.19914597	.31330388	13	.45123823	28100184	.08031121
6	.14939449	.37723863	.28399513	14	.37905062	25283243	.07444108
7	.08432882	.12967207	08409874	15	.35159907	27186514	.09786224
8	.37135248	19260563	.03315040				

No projections of the plots on the planes spanning the first three axes are presented because they do not supply information not already contained in other figures and because these axes only account for a total of 21.47% of the total variation.

6.2.8 Habitat features in relation to the principal axes (Q-method)

The relationship between each axis and the habitat factors was tested. As before, the first axis was only significantly related to light conditions (method 1) and the third axis to soil pH. The relationships are expressed in Figs. 21 and 22.

6.2.9 Clustering of sample plots

The projection of the points, representing sampling plots, on the planes spanning the principal axes is shown in Fig. 14. There is a tendency to cluster, which coincides with that shown by the projection of the plots on the planes spanning the main axes of the hyper-space described by the D² matrix (Fig. 18). The clusters contain the following plots: Cluster I, plot 1 and 3; Cluster II, plot 4, 8, 12, 13, 14, and 15; cluster III, plot 5, 9, and 10; cluster IV, plot 7, and cluster V, plot 2, 6, and 11.

The D² matrix was analysed by the method developed by Tocher (Appendix III). This analysis showed the existence of five groups which were identical to the clusters mentioned before.

6.2.10 Habitat factors in relation to clustering of sample plots

The mean values of the habitat factors for each cluster were compared by "t" test, following an approximate method due to Cochran and Cox (Greig-

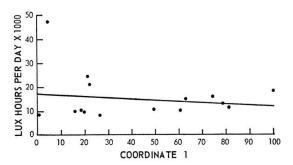


Fig. 21. Relationship between light conditions and the first principal axis $((1 + D^2)^{-1}$ matrix, Swiss data).

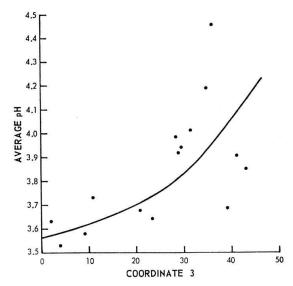


Fig. 22. Relationship between soil pH and the third principal axis $((1 + D^2)^{-1})$ matrix Swiss data).

SMITH 1964). The frequency distributions are close to normal, and no transformation was deemed necessary.

Most of the clusters have significantly different average light conditions. Not significant are the differences between the means of the levels of light received, of cluster I and III and of II and V. The average levels of light received by these sites with their standard deviations are 9.00 ± 1.56 ; 15.20 ± 12.43 ; 13.92 ± 10.45 ; 47.89 ± 24.51 ; and 16.92 ± 12.97 kilo-Lux hours per day respectively, at the time these measurements were made. The clusters are, with the exception of two, significantly different forsoil pH's. The mean pH's with their standard deviations are $4.31 \pm .26$; $3.89 \pm .28$; $3.58 \pm .20$; 3.68 ± 1.17 ; and $3.81 \pm .31$ respectively. Clusters II and V with pH 3.89 and pH 3.81 respectively, which are not significantly different, occupy completely overlapping ranges along the third principal axis (covari-

ance matrix). Also cluster IV is not significantly different from clusters II, III, and V.

If the differences among the means are considered in relation to the sum of the standard deviations, only the differences among cluster I, II, and III and between cluster I and V carry weight.

6.3 Canadian sample plots

6.3.1 Classification of sample plots (Zürich-Montpellier method)

As is obvious from the plant tables (Appendix II), the vegetation of the white spruce forests in Saskatchewan is very homogeneous, with many species occurring in most of the plots. Nevertheless, it was possible to recognize, according to the differential species-group method, two groups of species which are predominantly present in a limited group of plots. These groups of species were used to group the plots into three units.

The first group (A) of species comprises: Lonicera involucrata, Lonicera dioica, Ribes hirtellum, Ribes triste, Shepherdia canadensis, Amelanchier alnifolia, Lathyrus ochroleucus, Habenaria obtusata, Geocaulon lividum, Actaea rubra, Galium boreale and the moss Eurhynchium pulchellum. These species were, with few exceptions, not present in the following plots: 1, 3, 5, 6, 7, 8, 13, 16, 19, and 38 (Vegetation unit III).

The second group (B) of species contains Galium triflorum, Elymus innovatus, Equisetum scirpoides, Equisetum pratense, Hieracium canadense, Carex capillaris and the lichen Peltigera spec. These species occurred predominantly in the following sample plots 9, 10, 11, 14, 22, 23, 27, 29, 31, 32, 35, 36, 37, and 43 (Vegetation unit I).

The species of group A did, and those of group B did not occur, in the following sample plots: 2, 4, 12, 15, 17, 18, 20, 21, 24, 25, 26, 28, 30, 33, 34, 39, 40, 41, and 42 (Vegetation unit II).

6.3.2 Habitat features in relation to classification of sample plots

The average level of each habitat feature for each vegetation unit, established in the foregoing paragraph, was compared statistically with those of the other two units with the following results. No significant differences were found among the average values of permanent wilting point (mean value with standard deviations in vegetation unit I, II, and III, respectively, 3.80 ± 1.96 , 3.09 ± 1.16 and $2.86 \pm .99$), nitrogen content of the white spruce foliage (1.26 \pm .04, 1.25 \pm .06, 1.24 \pm .09), basal area of white spruce (139.9 \pm 40.9, 137.9 \pm 50.3, 139.3 \pm 33.9), "measured mean" pH of the mineral soil (4.95 \pm 1.15, 4.94 \pm 1.14, 4.71 \pm 1.26), "measured mean" pH of

humus layer (5.63 \pm .53, 5.45 \pm .53, 5.09 \pm .7), "measured mean" pH of the fermentation layer (5.92 \pm .48, 5.99 \pm .28, 5.56 \pm .47).

Significant differences (at P=.05) were found among the average levels of the field capacity (unit II and III), "available moisture" (unit I and III) and height growth (I.H.G.I.) (unit I and III). The average levels for the three units are as follows: field capacity: 15.20 ± 2.05 , 15.36 ± 1.30 , and 16.85 ± 2.16 ; "available moisture": 11.52 ± 2.04 , $12.06 \pm .95$ and 13.93 ± 2.03 ; I.H.G.I.: $1.075 \pm .19$, $1.10 \pm .15$ and $1.18 \pm .24$.

The significant differences between the average levels of "available moisture" and height growth in units I and III suggest that height growth is correlated with the available moisture. To test this relationship further, all levels of available moisture were plotted against the corresponding levels of height-growth and a correlation coefficient was calculated. No statistically significant relationship was found to exist (r = .20, P > .10). A relationship did exist, if only the sample plots contained in unit I and III were used (r = .40, P = .05).

Table 3. Eigenvalues and eigenvectors of the Canadian covariance matrix.

	Axes						
	I	П	III	IV	V		
Eigenvalues	34419	7106.4	3483.3	2945.5	1405.6		
Species	Eigenvectors						
1. Rosa acicularis	.02997	00142	04535	02109	04783		
2. Linnaea bor. var. amer.	.08841	.09679	57951	23789	42702		
3. Petasites palmatus	.05866	01554	32896	.03517	.22979		
4. Cornus canadensis	.18676	07685	53373	.14256	.31060		
5. Fragaria vesca	.00366	.00123	00638	01131	.01474		
6. Fragaria virginiana	.06284	00548	10823	.03739	.12304		
7. Mitella nuda	.01005	.01577	10223	02328	.13508		
8. Mertensia paniculata	.10699	04036	22644	.02635	.37971		
9. Maianthemum canadense	.02280	00705	11046	01176	.01194		
10. Pyrola secunda	.00624	00321	00928	00692	00755		
11. Aralia nudicaulis	.03371	01406	07949	.04377	02303		
12. Vaccinium v.id.v.m.	.00004	.00017	00065	.00014	.00059		
13. Pyrola virens	00300	00301	01792	00354	.00075		
14. Trientalis borealis	.00634	00097	04825	.00843	02151		
15. Rubus pubescens	.05164	02624	18379	.03222	.16242		
16. Hylocomium splendens	78547	39106	21676	.40044	10261		
17. Pleurozium schreberi	28288	.87947	07136	.32474	.15732		
18. Cornus stolonifera	.00677	.00454	.00277	00122	.02461		
19. Symphoricarpus alba	.00277	.00404	.00297	01089	.01708		
20. Picea glauca	33991	06533	.13128	.54098	.60846		
21. Populus tremuloides	.34709	22530	.21387	.59620	.23259		
22. Populus balsamifera	.00076	01140	.06081	03706	0159		

6.3.3 Principal component analysis of the covariance matrix

The principal component analysis resulted in principal axes with the following eigenvalues.

Trace of the matrix = sum of all eigenvalues = 51859.0

Axes Eigenvalues

- I 34419.0 accounting for 66.3% of the total variation.
- II 7106.4 accounting for 13.7% of the total variation.
- III 3483.3 accounting for 6.7% of the total variation.
- IV 2945.5 accounting for 2.7% of the total variation.

The first two axes account for 80.0%, the first three axes for 86.7%, the first five axes for 95,1% on the total variation.

The eigenvalues and coefficients of the eigenvectors are listed in table 3. The coefficients which contribute the most are in italics.

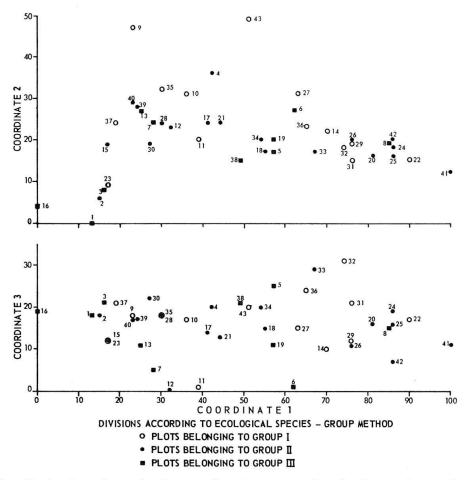


Fig. 23. Projection of sample plots on the planes spanning the first and second, and the first and third principal axes (cov. matrix, Canadian data) with classification of sample plots according to the differential species-group method, indicated.

As in table 1, it is noticeable that the variance of several species can only be explained by more than one component. The fourth and fifth components, however, have such low eigenvalues that for all practical purposes they can be omitted. On this basis the variance of Linnaea borealis var. americana, Petasites palmatus, Cornus canadensis, Mertensia paniculata and perhaps Rubus pubescens can be explained by component 3 and Picea glauca by component 1.

The variance of *Hylocomium splendens* and *Pleurozium schreberi* can only be explained by components 1 and 2. To explain the variance of *Populus tremuloides* all of the first three components are needed.

The projections of the points representing sample plots, on the planes spanning the first and second, and the first and third principal axes are shown in Fig. 23.

The relationships between the cover percentages for the more important species and the principal axes are shown in Figs. 24 to 27 inclusive.

6.3.4 Habitat features in relation to the principal axes

The habitat features measured, mentioned under Methods, were related to the principal axes. When the graphs indicated a possible significant relationship either a straight line or a curve was fitted to the data.

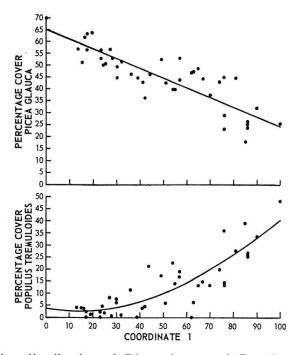


Fig. 24. Quantitative distribution of *Picea glauca* and *Populus tremuloides* along the first principal axis (cov. matrix, Canadian data).

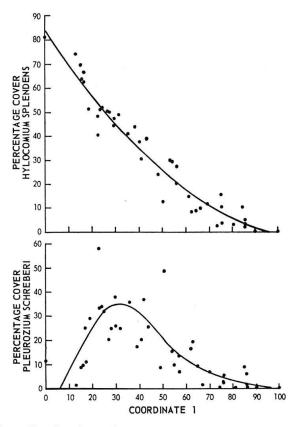


Fig. 25. Quantitative distribution of *Hylocomium splendens* and *Pleurozium schreberi* along the first principal axis (cov. matrix, Canadian data).

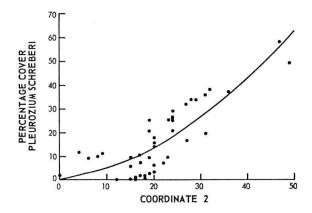


Fig. 26. Quantitative distribution of *Pleurozium schreberi* along the second principa axis (cov. matrix, Canadian data).

Basal area of white spruce, maximum pH of the humus layer, maximum pH of the top mineral soil, and the "measured mean" pH of the fermentation layer were all significantly linearly related to the first principal axis, with correlation coefficients, $r_{BA} = -.745$, P = .001; $r_{PH,H} = -.56$, P = .001;

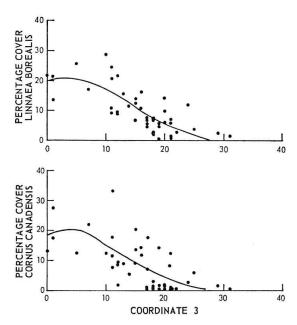


Fig. 27. Quantitative distribution of *Linnaea borealis* and *Cornus canadensis* along the third principal axis (cov. matrix, Canadian data).

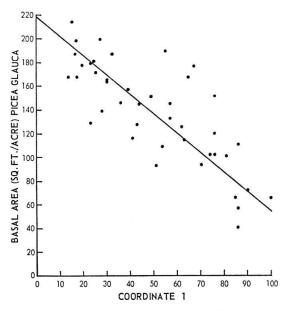


Fig. 28. Relationship between the basal area (sq. ft./acre) of *Picea glauca* and the first principal axis (cov. matrix, Canadian data).

 $r_{pH,S.} = -.30$, P = .05; and $r_{pH,F.} = .62$, P = .001 (Figs. 28, 29, 30, and 31). No other features showed a significant relationship with the first axis.

Only "available moisture" (% dry weight) was linearly related to the second principal axis, r = -.50, P = .001 (Fig. 32). No other features showed a significant relationship to the second axis.

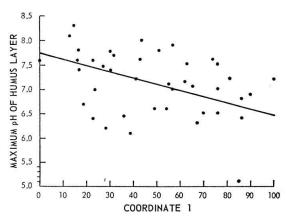


Fig. 29. Relationship between the maximum pH of the humus layer and the first principal axis (cov. matrix, Canadian data).

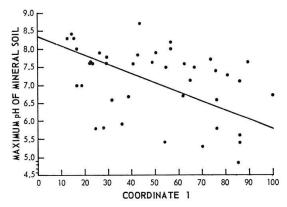


Fig. 30. Relationship between the maximum pH of the top of the mineral soil and the first principal axis (cov. matrix, Canadian data).

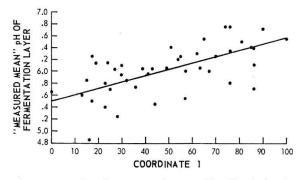


Fig. 31. Relationship between the "measured mean" pH of the fermentation layer and the first principal axis (cov. matrix, Canadian data).

The "measured mean" pH of the humus layer was significantly related to the third principal axis, $r_{pH,H} = .32$, P = .05 (Fig. 33).

Contrary to expectations, no relationships were found with either the height-growth of white spruce, the nitrogen content of the white spruce foliage, field capacity, or permanent wilting point.

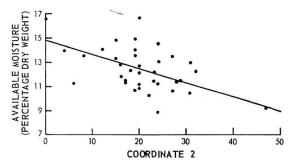


Fig. 32. Relationship between the "available moisture" and the second principal axis (cov. matrix, Canadian data).

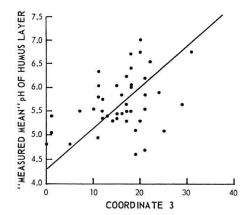


Fig. 33. Relationship between the "measured mean" pH of the humus layer and the third principal axis (cov. matrix, Canadian data).

6.3.5 Analysis of the D² matrix

The D² matrix was investigated according to a method developed by Torgerson.

The first two axes were constructed and the points representing sample plots were projected on the plane spanning these axes (Fig. 34).

The distances between the points in the one and two dimensional projections, respectively, were correlated with the corresponding D²'s. The correlation coefficients were .777 and .854 respectively. Both correlation coefficients were significant of the 0.1% level. This means that the first axis accounts for 60.37% of the variation present in the D² matrix. The two axes account for 72.93% of the variation.

6.3.6 Habitat features in relation to the main axes

The relationships between the above mentioned axes and habitat features were investigated. The graphs closely resembled those found with the principal axes (R method) but the relationships were slightly less significant, e.g. the correlation coefficient expressing the relationship between the first main

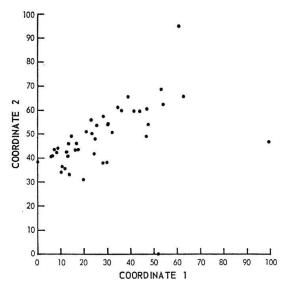


Fig. 34. Projection of the sample plots on the plane spanning the first and second main axes (D² ordination, Canadian data).

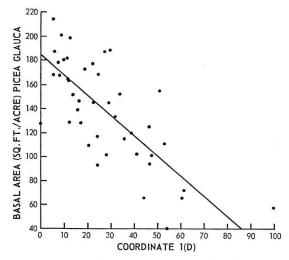


Fig. 35. Relationship between the basal area (sq. ft./acre) of *Picea glauca* and the first main axis (D² ordination, Canadian data).

axis and the basal area of the white spruce was -.725 (Fig. 35). No figures (except Fig. 35) are shown here because the graphs do not convey any information not already contained in Figs. 24 to 27 inclusive.

6.3.7 Principal component analysis (Q-method) of transformed D^2 matrices The transformation, $R = e^{-D^2}$, was not successful for the reasons mentioned before (paragraph 6.2.7).

The first three eigenvalues and the coefficients of their eigenvectors resulting from the principal component analysis of the $(1 + D^2)^{-1}$ matrix are listed in Table 4.

Table 4. Eigenvalues and eigenvectors of the Canadian $(1 + D^2)^{-1}$ matrix.

	Axes				Axes			
	I	II	III		I	II	III	
	Eigen					Eigenvalues		
Plot	4.0806686	1.8414362	1.6545757	Plot	4.0806686	1.8414362	1.6545757	
number		Eigenvectors		num]	ber	Eigenvectors		
1	.20518162	.32619265	32774792	23	.15197713	.02036635	06348675	
2	.24044327	.32953310	23929013	24	.04943476	124469254	±12125866	
3	.25562373	.34163588	22040681	25	.05120825	13622218	12974217	
4	.16712484	12401396	.14859947	26	.06658242	16450270	14332642	
5	.13033962	19461947	18080734	27	.06418442	11944390	07672237	
6	.03592506	06887253	05870816	28	.28425387	.02207873	.21035904	
7	.11047054	09594629	03622257	29	.06327470	14348925	12240309	
8	.05520553	13105740	12363875	30	.29817677	1.17514492	.07243274	
9	.14213920	07366455	.19829468	31	.08458285	17758661	16518164	
10	.22174998	09770317	.20514791	32	.08849949	18908332	17954269	
11	.02789219	04236062	03669437	33	.05794918	09023190	10923668	
12	.05505172	07654838	04998491	34	.15478582	18599630	10503147	
13	.14705452	06792552	.03131438	35	.25702541	06008116	.33602007	
14	.05373110	11997895	10965319	36	.11933932	23806116	19634325	
15	.19527573	.04616300	.03421793	37	.27149510	.12739532	.17038237	
16	.18256004	.28617043	23673914	38	.13846497	13885203	13263136	
17	.16980892	13020093	.00813848	39	.19590994	02729770	.16600462	
18	.07005728	11537413	10632461	40	.25495578	02206047	.28823524	
19	.05662565	18391777	11756376	41	.02713084	06485623	06370964	
20	.04151320	09466050	08648553	42	.02023899	04192575	03992062	
21	.11655024	13487681	05092089	43	.10970964	13128951	.07590625	
22	.03776468	09555740	09051711					

Trace of the matrix = sum of all eigenvalues = 43. Eigenvalue I is 4.0806686 and thus accounts for 9.49% of the total variation,

Eigenvalue II is 1.8414362 and accounts for $4.28\,\%$ of the total variation, Eigenvalue III is 1.6545757 and accounts for $3.85\,\%$ of the total variation.

The first two axes thus account for 13.77%, and the first three axes for 17.62% of the total variation.

For comparison only, the relationships of *Picea glauca* and *Hylocomium* splendens with the first principal axis are shown (Figs. 36 and 37).

Projections of the plots on the planes spanning the principal axes are not shown for the same reasons mentioned under paragraph 6.2.7.

6.3.8 Habitat features in relation to principal axes (Q-method)

The habitat features were related to the principal axes mentioned above. They were found to be similar to the relationships described before. For comparison, the relationships of the basal area of *Picea glauca* with the first axis is shown in Fig. 38. The correlation coefficient was calculated to be .592 which is significant at the 0.1% level.

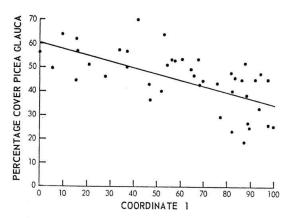


Fig. 36. Quantitative distribution of *Picea glauca* along the first principal axis $((1 + D^2)^{-1}$ matrix, Canadian data).

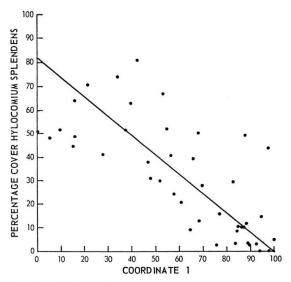


Fig. 37. Quantitative distribution of *Hylocomium splendens* along the first principal axis $((1 + D^2)^{-1}$ matrix, Canadian data).

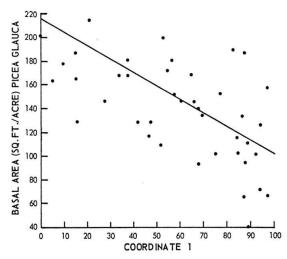


Fig. 38. Relationship between the basal area (sq. ft./acre) of *Picea glauca* and the first principal axis $((1 + D^2)^{-1}$ matrix, Canadian data).

6.3.9 Clustering of sample plots

Neither the projection of the points representing plots on the planes spanning the principal axes, nor the projection on the planes spanning the main axes of the constellation described by the D² matrix, showed any tendency of clustering.

Practically all D2's were significant (P \leq .05). A group of thirteen sample plots, all with a high cover percentage for *Picea glauca* and *Hylocomium splendens*, had very few significant D2's among them. Because the significance of the D2's, however, is greatly dependent on the number and size of the samples, it is not a satisfactory criterion for grouping sample plots.

The D² matrix was also analysed by the method developed by Tocher. This analysis showed that no clustering of the points occurred.

7. Discussion

A comparison of the data obtained by three different methods of sampling indicates that there is no single procedure which is superior in all respects. An intensive investigation of this problem should involve a time-study and include different types of vegetation. This was outside the scope and interest of this study.

Of the three methods tested, the quadrat method was the quickest, but it was not generally superior either in the relative number of species sampled or in minimizing the variance. In fact, increasing the size of the sampling quadrat did not markedly decrease the variance. This is probably due to an increased error in the estimates of the cover percentages with increased size of sampling unit.

The point-quadrat-line method as used by Kershaw, was quite as efficient in the relative number of species sampled and it was much more efficient in minimizing the variance than the quadrat method. This method was, however, more time consuming than the line-interception method, due to the particular type of distribution of the species (mostly mosses).

The line-interception method was equally as efficient in the relative number of species sampled and in minimizing the variance as the point-quadrat-line method. The agreement between the data by the last two methods was very close (r = .9994, P = .001).

Summarizing, it can be stated that, in the particular vegetation types investigated, considering the accuracy of the estimates required for this study, the line-interception method proved to be the most efficient way of sampling.