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Spatial structure of habitat features in a maritime barren ecosystem

An analysis of quantitative data

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Introduction

Ecological variables tend to be spatially heterogeneous, or patchy, in structure. This patchiness apparently results from the heterogeneity of the environment and is a functional component of ecosystems (Legendre and Legendre 1998). Spatial autocorrelation is a property of ecological data at sites a given distance apart, to be more similar (or less similar) than expected for randomly associated pairs of observations (Legendre and Legendre 1998). Taken another way, closer locations are more similar to each other than those that are distant. There is growing evidence (Bell et al. 1993) that the natural world is organized as a gradient with variation in any environmental variable increasing indefinitely with increasing distance. Spatial autocorrelation indicates a lack of independence among observations. Many statistical analyses assume independence of the error component of data, so this violation is considered an annoyance and may complicate analyses of habitat selection (Horne and Schneider 1995). Information on spatial autocorrelation can however be very useful information (Bridges 2002). For example, it is of interest to know how animals respond to the gradient in variation of habitat related variables in the natural world. I intend to explore the response of caribou (*Rangifer tarandus*) to spatially continuous environmental variation.

As a pilot study, however, data were collected to investigate the spatial structure of caribou habitat related variables, such as percent cover of plant species. Data were recorded along a series of transects with a variable sampling step. It was expected that each of the recorded environmental variables would be spatially autocorrelated, but that the degree of autocorrelation might differ for each variable. I will explore the spatial structure of each variable and quantify the degree to which spatial distance (or lag) can account for the variation in each attribute. If spatial structure is indeed discovered, I will formulate hypotheses regarding the main determinants of structure at various spatial scales following Legendre et al. (1997).

Analyses of the relationship between habitat variables and spatial scale can be conducted in two domains. The first, the frequency domain, takes usually continuous data and groups it into various distance classes. Variance is then analyzed in relation to these distance classes. Another method is to explore variance in relation to lags. Working in the lagging domain involves sampling not continuously but at locations various distances from each other. In this paper, analyses will be conducted in both domains, but because the data was collected at lags, using it in the frequency domain is somewhat artificial, though still valid.

The purpose of this analysis is to explore potential patterns in the data using an iterative approach. No strict hypotheses will be tested and the batch of data will not be used to make inferences regarding the population. Thus exploratory, rather than confirmatory, data analysis will be employed to broadly infer from data and describe patterns.

Methods

I conducted field research just outside the southern border of Bay du Nord Wilderness Reserve, in south central Newfoundland, Canada in August to Septmeber, 2004. Six staked transects were established, each oriented to the north. The parallel transects were separated by east-west intervals of approximately 5 km. Their locations were systematically selected based upon major Universal Transverse Mercator Grid Coordinates and logistical access, and essentially represent random locations across the core winter range of the Middle Ridge herd of woodland caribou (*Rangifer tarandus caribou*). Transects were accessed by helicopter, all-terrain vehicle, and foot.

Along each transect sites were sampled with a varying step: at 0, 10, 30, 70, 200, 210, 230, 270, 400…870 meters north of the most southerly point, for a total of 20 sites on each transect. Along four of the transects, three additional sites were sampled at 5 meters east, south, and west of each of the 20 sites, to give 60 additional sites along each of these transects, and a total of 360 sites within the study area.

Each of these sites were characterized abiotically by taking measurements of soil depth slope of land. For each tree species, basal area, using a forester's prism, and number of stems within a radius of 5m, were recorded. Percent cover of trees and shrubs was characterized within 100 cm x 100 cm quadrats and within these, plants were characterized by species for herbs, genus for lichens, or as grasses or mosses within 50 cm x 50 cm quadrats. Percent cover was quantified within classes of <1, 1-5, 5-10, 10-25, 25-50, 50-100 %.

A variety of analyses were performed to explore this data set, including hierarchical analysis of variance (ANOVA) to explore the contribution of different scales to variance; variograms, to explore any spatial autocorrelation in the data; and principle components analysis (PCA) to simplify the multivariate data by reducing the number of variables to a few factors.

To measure the contribution of different scales to the population variance, a hierarchical (or nested) analysis of variance (ANOVA) design was employed. This model is a special case of the general linear model (GLM):

$$Y = \beta_o + \beta_{Transect} X_{Transect} + \beta_{Section \subset Transect} X_{Section \subset Transect} + \beta_{Site \subset Section \subset Transect} X_{Site \subset Section \subset Transect} X + \varepsilon$$

where Y is the ecological variable of interest in response to the spatial scale. The spatial scales, in this case, are *Transect* (5000 m), *Section* of a transect (200 m), *Site* within a section (50 m), and *Subsite* within a site (5 m) which is represented in the model as an error term. The ANOVA tables were analyzed for patterns, indicated by a screening criterion of less than 0.20.

The scale dependence of variance was then analyzed both for increasing or decreasing patterns with scale. The slope of the relationship between variance and scale was also explored. These measures give an indication of hue, which describes how variability changes with scale. The hue of each variable was then compared qualitatively in relation to the significance to caribou habitat.

Semi-variance $\gamma(h)$ gives another indication of the contribution of different scales to variance in the data. Rather than binning the data, as was done in hierarchical ANOVA, this measure of spatial autocorrelation instead uses lag distances. A semi-variogram (referred to simply as a variogram) was produced to graphically display semi-variance as a function of lag (ie: given distances on the ground), *h*. The equation

$$\gamma(h) = \frac{1}{2N(h)} \sum_{|s_i - s_j| = h} (y_i - y_j)^2$$

measures half the average squared difference between pairs of data values separated by lags, where y_i is the value of an ecological variable y at location s_i, y_j is the value of variable y at location s_j, and $N(h)$ is the number of pairs of observed data points separated by a lag of h.

Often environmental data consists of many variables, some of which are correlated. To reduce the number of dimensions in the data and identify a fewer number of meaningful underlying variables (or principle components), principle components analysis (PCA) is often employed (Grieg-Smith 1983). Principle components are those which account for the maximum variance. The number of principle components is somewhat subjectively determined, but should represent some defined fraction of variance accounted for that must be explained (Grieg-Smith 1983).

For the PCA, only variables with a minimum instance (non-zero values) of 25 were accepted into the analysis to avoid an emphasis on rare species. The correlation matrix (Figure ***) was used to extract the principle components, which standardizes by units of standard deviation. Correlated variables were grouped together. No rotation was used in the factor analysis. Factor score coefficients were estimated by regression.

Results

The spatial locations (as UTM coordinates) were mapped and displayed as Figure 1. The six transects are clearly visible with 5 sections (as circles) within each transect.

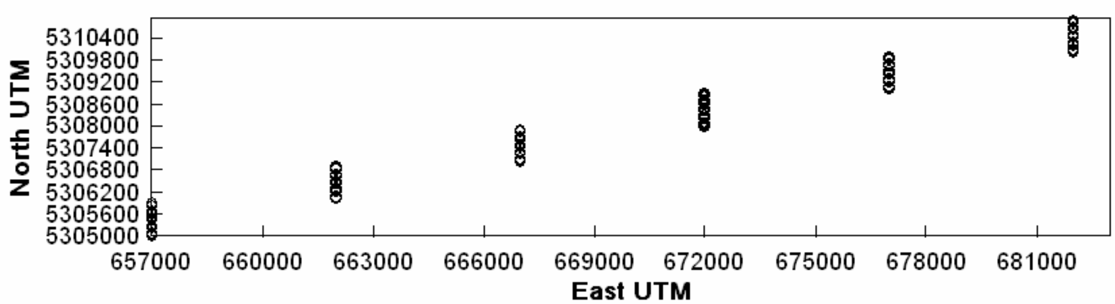


Figure 1: Map of data locations (circles) south of the Bay du Nord Wilderness Reserve, Newfoundland, arranged in six transects.

Descriptive statistics such as mean, standard deviation, variance, and range of habitat related variables are shown in Table 1.

Table 1: Descriptive statistics of habitat related variables near Bay du Nord Wilderness Reserve

Variable	N	Mean	StDev	Variance	Range
Soil depth (0 to 75)	266	35.31	18.15	329.36	72
Soil depth (>75 yes/no)	345	1.1246	0.3308	0.1094	1
Slope	298	1.812	2.925	8.557	12
Basal area	306	0.366	1.274	1.623	8
Number of stems (Larix laricina)	333	0.3814	1.3017	1.6945	9
Number of stems (Picea mariana)	333	0.1712	1.5281	2.3351	14
Alectoria spp. & Bryoria sp. (Black, brown hair lichens)	225	0.68	3.432	11.781	38
Alnus spp. (Alders)	345	0.1203	0.9114	0.8307	7.5
Andromeda glaucophylla (Bog rosemary)	344	2.427	5.323	28.333	37.5
Arctoparmelia sp. (Green crescent rock lichen)	225	0.247	2.754	7.585	37.5
Aster spp.	345	1.193	2.902	8.423	17.5
Betula spp. (Dwarf birches)	344	1.772	6.731	45.313	75
Cetraria spp. (Kelp/seaweed lichen)	225	0.0444	0.3475	0.1208	3
Chamaedaphne calyculata (Leatherleaf)	344	2.74	6.378	40.675	37.5
Cladina spp. (Caribou lichens)	344	24.03	30.26	915.74	75
Cladonia spp. (Caribou lichens)	225	1.304	4.642	21.546	37.5
Clintonia borealis (Yellow clintonia)	345	0.0304	0.4345	0.1888	7.5
Coptis groenlandica (Goldthread)	344	0.49	2.652	7.031	37.5
Cornus canadensis (Bunchberry)	344	3.94	8.934	79.822	37.5
Drosera rotundifolia (Round-leaved sundew)	344	1.096	4.993	24.928	75
Empetrum nigrum (Black crowberry)	344	6.032	17.054	290.834	75
Epilobium angustifolium (Fireweed)	344	0.01017	0.1639	0.02686	3
Eriocaulon septangulare (Common pipewort)	345	0.0217	0.4038	0.163	7.5
Fern (roundish leaves, margin entire)	345	0.0507	0.9422	0.8877	17.5
Fern (unknown - "Simpson's hands)	344	0.0494	0.4909	0.241	7.5
Fungii	344	0.00727	0.05993	0.00359	0.5
Gaultheria hispidula (Creeping snowberry)	344	0.0916	1.0496	1.1016	17.5

Grasses	344	17.98	27.22	740.87	75
Juniperus communis (Common juniper)	344	1.15	7.744	59.965	75
Ilex mucronata (Mountain holly)	344	0.2108	1.5376	2.3643	17.5
Kalmia spp. (Laurels)	344	8.391	16.433	270.037	75
Ledum groenlandicum (Labrador tea)	344	4.224	9.692	93.941	75
Larix laricina (Larch, Tamarack)	344	4.02	14.672	215.266	75
Lonicera villosa (Mountain fly honeysuckle)	345	0.0217	0.4038	0.163	7.5
Maianthemum canadense (Wild Lily-of-the-valley)	344	0.0567	0.3668	0.1345	3
Mitchella repens (Partridgeberry)	344	1.17	4.508	20.322	37.5
Mosses	344	20.2	29.36	861.92	75
Myrica gale (Bog myrtle or Sweet gale)	344	1.858	7.616	58.003	75
Ocholechia spp. (cloud lichens)	225	0.0978	0.5233	0.2739	3
Parmelia sp. (rock & arboreal lichens)	225	0.353	1.512	2.286	17.5
Peltigera sp. (Flakey black rock lichen)	225	0.00222	0.03333	0.00111	0.5
Photinia floribunda (Purple chokeberry)	344	0.275	2.237	5.004	37.5
Physcia spp. (rock lichens)	225	0.0156	0.2026	0.0411	3
Picea mariana (Black spruce)	344	1.446	9.375	87.899	75
Potentilla fruticosa (Shrubby cinquefoil)	345	0.1101	1.3396	1.7945	17.5
Potentilla tridentata (Three-toothed cinquefoil)	344	1.672	4.455	19.844	37.5
Pyrus melanocarpa (Black chokeberry)	344	0.475	2.047	4.188	17.5
Ranunculus acris (Common buttercup)	345	0.0217	0.4038	0.163	7.5
Rhododendron canadense (Rhodora)	344	1.749	7.33	53.722	75
Rosa nitida (Northeastern rose)	345	0.0449	0.5707	0.3257	7.5
Rubus chamaemorus (Bakeapple)	344	0.0392	0.4636	0.2149	7.5
Sanguisorba canadensis (Canadian burnet)	344	1	4.77	22.757	37.5
Sarracenia purpurea (Pitcher plant)	344	0.2282	0.8853	0.7838	7.5
Solidago purshii (Bog goldenrod)	344	0.2326	0.9451	0.8933	7.5
Spiraea alba (Broadleaf meadowsweet)	345	0.0087	0.16151	0.02609	3
Stereocaulon spp. (dry ice lichen)	225	0.1111	0.6672	0.4452	7.5
Thalictrum polygamum (Tall meadowrue)	344	0.1192	1.3505	1.8239	17.5

Thamnolia sp. (rubber grass lichen)	225	0.0156	0.2026	0.0411	3
Tridentalis borealis (Starflower)	344	0.1017	0.9977	0.9954	17.5
Utricularia cornuta (Horned blatterwort)	294	0.051	0.5033	0.2534	7.5
Vaccinium angustifolium (Blueberry)	344	7.994	13.507	182.452	75
Vaccinium oxycoccus, macrocarpon (Small and large cranberries)	344	1.786	5.338	28.497	37.5
Vaccinium vitis-idaea	345	0.0826	1.0363	1.0738	17.5
Viburnum cassinoides (Wild raisin)	344	0.305	2.648	7.013	37.5
Viola macloskeyi (Northern white violet)	345	0.0087	0.16151	0.02609	3
Unknown "spiral flower cluster"	345	0.00145	0.02692	0.000725	0.5
Unknown "tribush"	345	0.0507	0.9422	0.8877	17.5
Unknown "mint wood"	345	0.0217	0.4038	0.163	7.5
Xanthoria sp. (Orange rock lichen)	225	0.02	0.2077	0.0431	3
Cabin mold rock lichen	225	0.233	2.593	6.725	37.5
Grey Rock (mat) lichen (unkown)	225	0.184	2.507	6.286	37.5
Grey speckled lichen (unknown)	225	0.00222	0.03333	0.00111	0.5

For the hierarchical ANOVA example, the following typical residuals vs. fits plots show that the residuals are not homogeneous. They show clear patterns, although they do not seem to conform to typical bowls, arches, or cones. Typically, the plots are upward pointed cones, but some showed diamond shapes, such as in that of soil depth, or to a lesser extent, Cladina. For those with very few values (ie: 5 or less) the residuals vs fits plot could generally not be interpreted. Although assumptions of the GLM are not met, for the exploratory nature of the data, these assumptions can be relaxed. Furthermore, for most scales, the sample size is large (up to 345), so that recomputation of p-values via randomization would not produce substantially different results.

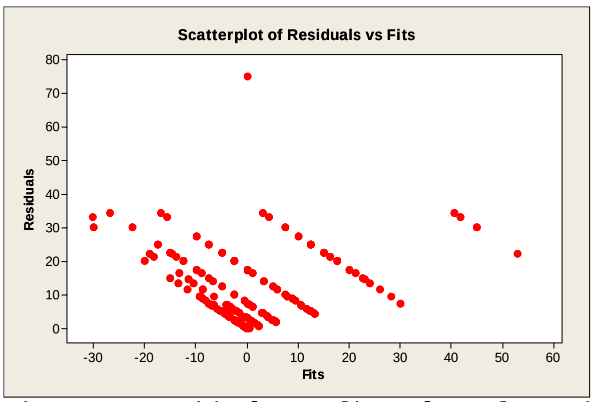


Figure 2: Residuals vs fits plot of Vaccinium angustifolia (Blueberry) in response to scale

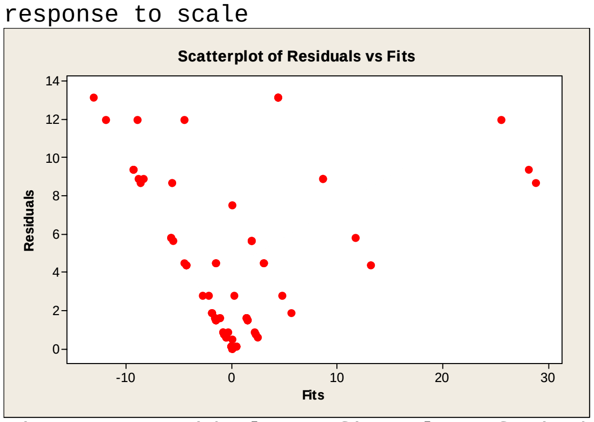


Figure 3: Residuals vs fits plot of Mitchella repens (Partridgeberry) in response to scale

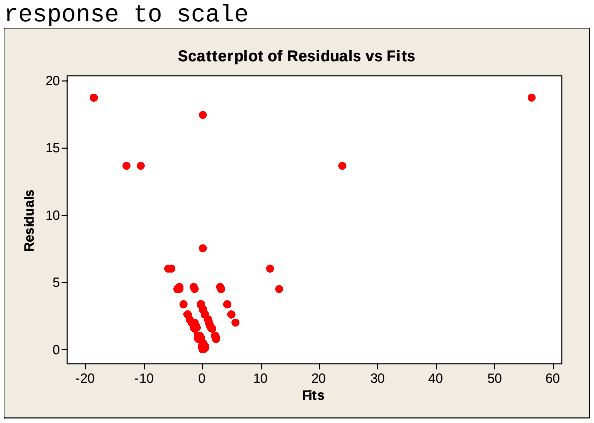


Figure 4: Residuals vs fits plot of Drosera rotundifolia (Round-leaved sundew) in response to scale

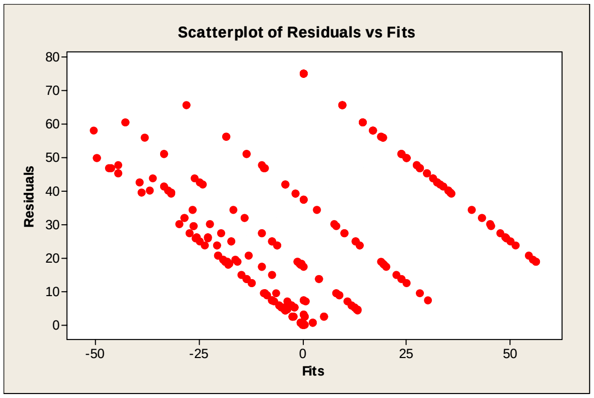


Figure 5: Residuals vs fits plot of Cladina spp. (Caribou lichens) in response to scale

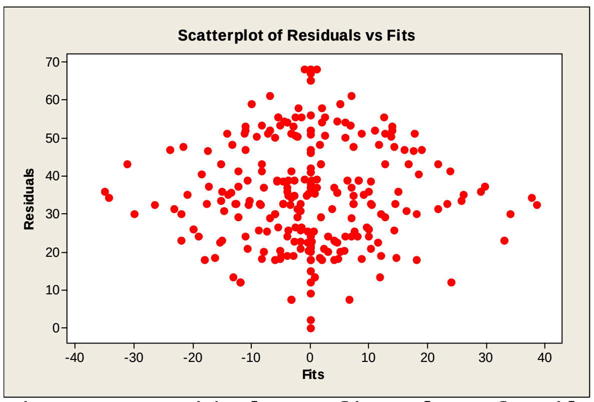


Figure 6: Residuals vs fits plot of Soil depth (0 to 75cm) in response to scale

Set of Tables 1 shows the ANOVA tables for each variable, the results of which are summarized in Table 3.

<u>Set of Tables 1: Hierarchical analysis of variance tables for habitat related variables. Note that variables marked with an "x" an exact F-test was not performed.</u>

Analysis of Variance for Continuous soil depth, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	5531.3	6142.3	1228.5	1.67	0.179	x
Section(Transect)	22	19388.9	18410.6	836.8	2.39	0.003	x
Site(Transect Section)	73	26227.2	26227.2	359.3	1.64	0.005	
Error	165	36131.8	36131.8	219.0			
Total	265	87279.1					

Analysis of Variance for Binary soil depth, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	1.21654	1.17623	0.23525	1.11	0.378	x
Section(Transect)	24	5.20559	5.20610	0.21692	1.77	0.029	x
Site(Transect Section)	90	11.05179	11.05179	0.12280	1.37	0.033	
Error	225	20.16667	20.16667	0.08963			

Total	344	37.64058

Analysis of Variance for Slope, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	278.920	415.711	83.142	1.69	0.179	x
Section(Transect)	22	1158.007	1148.165	52.189	3.63	0.000	x
Site(Transect Section)	78	1101.350	1101.350	14.120	847.19	0.000	
Error	192	3.200	3.200	0.017			
Total	297	2541.477					

Analysis of Variance for Basal area, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	29.4697	35.9963	7.1993	0.85	0.532	x
Section(Transect)	22	196.8702	196.4573	8.9299	2.64	0.001	x
Site(Transect Section)	80	268.6667	268.6667	3.3583	**		
Error	198	0.0000	0.0000	0.0000			
Total	305	495.0065					

Analysis of Variance for Number of stems (Larix laricina, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	48.7929	46.5462	9.3092	1.12	0.375	x
Section(Transect)	24	209.7300	209.1132	8.7131	2.47	0.001	x
Site(Transect Section)	87	303.2917	303.2917	3.4861	1004.00	0.000	
Error	216	0.7500	0.7500	0.0035			
Total	332	562.5646					

Analysis of Variance for Number of stems (Picea mariana), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	31.5564	27.9495	5.5899	0.90	0.494	x
Section(Transect)	24	154.9368	154.6547	6.4439	0.94	0.547	x
Site(Transect Section)	87	588.7500	588.7500	6.7672	**		
Error	216	0.0000	0.0000	0.0000			
Total	332	775.2432					

Analysis of Variance for Alectoria spp. & Bryoria sp., using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	28.78	28.58	14.29	0.59	0.568	x
Section(Transect)	12	292.05	290.36	24.20	2.80	0.006	x
Site(Transect Section)	45	388.71	388.71	8.64	0.74	0.882	
Error	165	1929.42	1929.42	11.69			
Total	224	2638.96					

Analysis of Variance for Alnus spp. (Alders), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	16.0330	15.7738	3.1548	0.97	0.454	x
Section(Transect)	24	84.1000	81.1201	3.3800	2.90	0.000	x
Site(Transect Section)	90	105.3250	105.3250	1.1703	3.28	0.000	
Error	225	80.3000	80.3000	0.3569			
Total	344	285.7580					

Analysis of Variance for Andromeda glaucophylla, using Adjusted SS for

Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	362.42	341.25	68.25	1.28	0.305	x
Section(Transect)	24	1284.58	1325.32	55.22	1.00	0.480	x
Site(Transect Section)	90	5007.35	5007.35	55.64	4.07	0.000	
Error	224	3063.83	3063.83	13.68			
Total	343	9718.18					

Analysis of Variance for Arctoparmelia sp., using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	7.720	7.643	3.821	0.54	0.599	x
Section(Transect)	12	85.642	85.617	7.135	1.00	0.465	x
Site(Transect Section)	45	321.156	321.156	7.137	0.92	0.624	
Error	165	1284.542	1284.542	7.785			
Total	224	1699.060					

Analysis of Variance for Aster spp., using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	374.412	372.591	74.518	6.03	0.001	x
Section(Transect)	24	303.793	305.338	12.722	1.02	0.455	x
Site(Transect Section)	90	1128.831	1128.831	12.543	2.59	0.000	
Error	225	1090.396	1090.396	4.846			
Total	344	2897.432					

Analysis of Variance for Betula spp. (Dwarf birches), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	392.85	394.17	78.83	1.42	0.252	x
Section(Transect)	24	1344.36	1347.36	56.14	1.43	0.117	x
Site(Transect Section)	90	3540.19	3540.19	39.34	0.86	0.796	
Error	224	10264.94	10264.94	45.83			
Total	343	15542.34					

Analysis of Variance for Cetraria spp. (Kelp/seaweed lic, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.2344	0.2031	0.1015	0.97	0.405	x
Section(Transect)	12	1.1578	1.2493	0.1041	0.81	0.639	x
Site(Transect Section)	45	5.7884	5.7884	0.1286	1.07	0.374	
Error	165	19.8750	19.8750	0.1205			
Total	224	27.0556					

Analysis of Variance for Chamaedaphne calyculata (Leathe, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	342.37	327.53	65.51	0.85	0.527	x
Section(Transect)	24	1819.96	1897.84	79.08	1.62	0.053	x
Site(Transect Section)	90	4386.62	4386.62	48.74	1.47	0.011	
Error	224	7402.51	7402.51	33.05			
Total	343	13951.46					

Analysis of Variance for Cladina spp. (Caribou lichens), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	15735.0	14517.2	2903.4	1.51	0.224	x
Section(Transect)	24	49635.6	47693.1	1987.2	1.76	0.030	x
Site(Transect Section)	90	102044.8	102044.8	1133.8	1.73	0.001	
Error	224	146684.6	146684.6	654.8			
Total	343	314099.9					

Analysis of Variance for Cladonia spp. (Caribou lichens), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	101.77	101.32	50.66	2.20	0.153	x
Section(Transect)	12	276.80	276.58	23.05	0.79	0.659	x
Site(Transect Section)	45	1316.49	1316.49	29.26	1.54	0.027	
Error	165	3131.33	3131.33	18.98			
Total	224	4826.40					

Analysis of Variance for Clintonia borealis, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	1.0586	1.0566	0.2113	1.80	0.144	x
Section(Transect)	24	2.7000	2.7000	0.1125	0.83	0.696	x
Site(Transect Section)	90	12.2344	12.2344	0.1359	0.63	0.994	
Error	225	48.9375	48.9375	0.2175			
Total	344	64.9304					

Analysis of Variance for Coptis groenlandica (Goldthread, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	52.413	52.503	10.501	0.92	0.486	x
Section(Transect)	24	280.302	280.626	11.693	1.71	0.037	x
Site(Transect Section)	90	614.916	614.916	6.832	1.05	0.391	
Error	224	1464.083	1464.083	6.536			
Total	343	2411.714					

Analysis of Variance for Cornus canadensis (Bunchberry), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	1004.26	1027.88	205.58	1.96	0.119	x
Section(Transect)	24	2700.61	2561.44	106.73	1.08	0.376	x
Site(Transect Section)	90	8864.62	8864.62	98.50	1.49	0.010	
Error	224	14809.53	14809.53	66.11			
Total	343	27379.03					

Analysis of Variance for Drosera rotundifolia (Round-lea, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	56.54	59.05	11.81	0.51	0.768	x
Section(Transect)	24	556.61	555.30	23.14	1.03	0.439	x
Site(Transect Section)	90	2020.97	2020.97	22.46	0.85	0.811	
Error	224	5916.21	5916.21	26.41			
Total	343	8550.33					

Analysis of Variance for Empetrum nigrum (Black crowberr, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	8115.0	8183.5	1636.7	1.38	0.268	x

Section(Transect)	24	29795.1	29693.5	1237.2	5.71	0.000	x
Site(Transect Section)	90	19519.0	19519.0	216.9	1.15	0.208	
Error	224	42327.0	42327.0	189.0			
Total	343	99756.1					

Analysis of Variance for Epilobium angustifolium (Firewe, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.08216	0.07995	0.01599	0.81	0.549	x
Section(Transect)	24	0.46259	0.45803	0.01908	0.99	0.488	x
Site(Transect Section)	90	1.73214	1.73214	0.01925	0.62	0.995	
Error	224	6.93750	6.93750	0.03097			
Total	343	9.21439					

Analysis of Variance for Eriocaulon septangulare (Common, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.5401	0.5366	0.1073	0.89	0.499	x
Section(Transect)	24	2.8125	2.8079	0.1170	1.00	0.479	x
Site(Transect Section)	90	10.5469	10.5469	0.1172	0.63	0.994	
Error	225	42.1875	42.1875	0.1875			
Total	344	56.0870					

Analysis of Variance for Fern (roundish leaves, margin e, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	2.940	2.922	0.584	0.91	0.486	x
Section(Transect)	24	15.313	14.915	0.621	0.97	0.509	x
Site(Transect Section)	90	57.422	57.422	0.638	0.63	0.994	
Error	225	229.687	229.687	1.021			
Total	344	305.362					

Analysis of Variance for Fern (simpsons hands), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	1.2262	1.2663	0.2533	1.65	0.180	x
Section(Transect)	24	3.3774	3.5598	0.1483	0.79	0.743	x
Site(Transect Section)	90	16.9313	16.9313	0.1881	0.69	0.978	
Error	224	61.1250	61.1250	0.2729			
Total	343	82.6599					

Analysis of Variance for Fungii, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.016967	0.016967	0.003393	1.02	0.425	x
Section(Transect)	24	0.079448	0.078903	0.003288	1.35	0.157	x
Site(Transect Section)	90	0.218750	0.218750	0.002431	0.59	0.997	
Error	224	0.916667	0.916667	0.004092			
Total	343	1.231831					

Analysis of Variance for Gaultheria hispidula (Creeping, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	3.387	3.346	0.669	0.67	0.650	x
Section(Transect)	24	24.590	23.813	0.992	0.99	0.493	x
Site(Transect Section)	90	90.563	90.563	1.006	0.87	0.776	
Error	224	259.325	259.325	1.158			
Total	343	377.866					

Analysis of Variance for Grasses, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	26200.1	26055.0	5211.0	3.44	0.017	x
Section(Transect)	24	36192.4	37539.5	1564.1	1.48	0.094	x
Site(Transect Section)	90	95124.6	95124.6	1056.9	2.45	0.000	
Error	224	96601.6	96601.6	431.3			
Total	343	254118.8					

Analysis of Variance for Juniperus communis (Common juni, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	555.89	528.23	105.65	1.69	0.172	x
Section(Transect)	24	1577.10	1510.52	62.94	0.78	0.747	x
Site(Transect Section)	90	7240.67	7240.67	80.45	1.61	0.003	
Error	224	11194.39	11194.39	49.97			
Total	343	20568.04					

Analysis of Variance for Ilex mucronata (Mountain holly), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	15.399	15.298	3.060	0.73	0.608	x
Section(Transect)	24	102.792	102.898	4.287	1.98	0.011	x
Site(Transect Section)	90	195.267	195.267	2.170	0.98	0.543	
Error	224	497.513	497.513	2.221			
Total	343	810.970					

Analysis of Variance for Kalmia spp. (Laurels), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	1227.1	1256.7	251.3	0.51	0.765	x
Section(Transect)	24	12279.7	12103.8	504.3	1.66	0.047	x
Site(Transect Section)	90	27449.3	27449.3	305.0	1.32	0.051	
Error	224	51666.5	51666.5	230.7			
Total	343	92622.7					

Analysis of Variance for Ledum groenlandicum (Labrador t, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	1061.80	1039.84	207.97	1.58	0.201	x
Section(Transect)	24	3267.27	3218.03	134.08	1.07	0.397	x
Site(Transect Section)	90	11332.17	11332.17	125.91	1.70	0.001	
Error	224	16560.52	16560.52	73.93			
Total	343	32221.76					

Analysis of Variance for Larix laricina (Larch, Tamarack, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	3530.1	3481.5	696.3	1.66	0.182	x
Section(Transect)	24	10609.6	10353.1	431.4	1.94	0.014	x
Site(Transect Section)	90	20073.8	20073.8	223.0	1.26	0.087	
Error	224	39622.8	39622.8	176.9			
Total	343	73836.4					

Analysis of Variance for Lonicera villosa (Mountain fly, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.5401	0.3434	0.0687	0.87	0.511	x
Section(Transect)	24	2.8125	1.7532	0.0731	0.85	0.670	x
Site(Transect Section)	90	7.7344	7.7344	0.0859	0.43	1.000	
Error	225	45.0000	45.0000	0.2000			
Total	344	56.0870					

Analysis of Variance for Maianthemum canadense (Wild Lil, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.6217	0.6052	0.1210	0.97	0.456	x
Section(Transect)	24	3.0073	2.9976	0.1249	0.91	0.586	x
Site(Transect Section)	90	12.3281	12.3281	0.1370	1.02	0.453	
Error	224	30.1875	30.1875	0.1348			
Total	343	46.1446					

Analysis of Variance for Mitchella repens (Partridgeberr, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	546.82	506.36	101.27	3.03	0.028	x
Section(Transect)	24	857.28	816.33	34.01	2.71	0.000	x
Site(Transect Section)	90	1126.28	1126.28	12.51	0.63	0.994	
Error	224	4439.92	4439.92	19.82			
Total	343	6970.30					

Analysis of Variance for Mosses, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	17739.9	17824.1	3564.8	2.27	0.078	x
Section(Transect)	24	38915.2	38786.6	1616.1	1.30	0.188	x
Site(Transect Section)	90	112187.2	112187.2	1246.5	2.20	0.000	
Error	224	126795.7	126795.7	566.1			
Total	343	295638.1					

Analysis of Variance for Myrica gale (Bog myrtle or Swee, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	397.25	392.85	78.57	2.05	0.103	x
Section(Transect)	24	891.37	892.66	37.19	0.80	0.729	x
Site(Transect Section)	90	4181.42	4181.42	46.46	0.72	0.962	
Error	224	14424.97	14424.97	64.40			
Total	343	19895.02					

Analysis of Variance for Ocholechia spp. (cloud lichens), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.4405	0.4124	0.2062	0.56	0.586	x
Section(Transect)	12	4.4449	4.4307	0.3692	1.73	0.092	x
Site(Transect Section)	45	9.6094	9.6094	0.2135	0.75	0.868	
Error	165	46.8542	46.8542	0.2840			
Total	224	61.3489					

Analysis of Variance for Parmelia sp. (rock & arboreal l, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Transect	2	8.873	8.811	4.406	1.02	0.389	x
Section(Transect)	12	51.981	51.873	4.323	0.95	0.505	x
Site(Transect Section)	45	204.431	204.431	4.543	3.04	0.000	
Error	165	246.875	246.875	1.496			
Total	224	512.160					

Analysis of Variance for Peltigera sp. (Flakey black roc, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.002014	0.002000	0.001000	0.96	0.410	x
Section(Transect)	12	0.012500	0.012480	0.001040	1.00	0.466	x
Site(Transect Section)	45	0.046875	0.046875	0.001042	0.92	0.624	
Error	165	0.187500	0.187500	0.001136			
Total	224	0.248889					

Analysis of Variance for Photinia floribunda (Purple cho, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	15.672	15.426	3.085	0.78	0.571	x
Section(Transect)	24	92.956	92.519	3.855	1.10	0.363	x
Site(Transect Section)	90	315.287	315.287	3.503	0.61	0.996	
Error	224	1292.375	1292.375	5.770			
Total	343	1716.290					

Analysis of Variance for Physcia spp. (rock lichens), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.06118	0.06284	0.03142	0.82	0.462	x
Section(Transect)	12	0.46250	0.45779	0.03815	1.00	0.467	x
Site(Transect Section)	45	1.72188	1.72188	0.03826	0.91	0.638	
Error	165	6.95000	6.95000	0.04212			
Total	224	9.19556					

Analysis of Variance for Picea mariana (Black spruce), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	872.87	868.80	173.76	1.62	0.191	x
Section(Transect)	24	2629.76	2621.71	109.24	0.88	0.628	x
Site(Transect Section)	90	11198.72	11198.72	124.43	1.80	0.000	
Error	224	15447.92	15447.92	68.96			
Total	343	30149.26					

Analysis of Variance for Potentilla fruticosa (Shrubby c, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	68.0145	67.9894	13.5979	3.12	0.026	x
Section(Transect)	24	109.4250	109.4250	4.5594	0.94	0.555	x
Site(Transect Section)	90	439.8750	439.8750	4.8875	**		
Error	225	0.0000	0.0000	0.0000			
Total	344	617.3145					

Analysis of Variance for Potentilla fruticosa (Shrubby c, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	68.0145	67.9894	13.5979	3.12	0.026	x

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Section(Transect)	24	109.4250	109.4250	4.5594	0.94	0.555	x
Site(Transect Section)	90	439.8750	439.8750	4.8875	**		
Error	225	0.0000	0.0000	0.0000			
Total	344	617.3145					

Analysis of Variance for Potentilla tridentata (Three-to, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	623.78	631.42	126.28	3.40	0.018	x
Section(Transect)	24	946.26	915.11	38.13	2.27	0.003	x
Site(Transect Section)	90	1510.70	1510.70	16.79	1.01	0.469	
Error	224	3725.65	3725.65	16.63			
Total	343	6806.38					

Analysis of Variance for Pyrus melanocarpa (Black chokeb, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	79.836	80.854	16.171	2.49	0.058	x
Section(Transect)	24	159.634	158.598	6.608	2.52	0.001	x
Site(Transect Section)	90	235.653	235.653	2.618	0.61	0.996	
Error	224	961.417	961.417	4.292			
Total	343	1436.540					

Analysis of Variance for Pyrus melanocarpa (Black chokeb, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	79.836	80.854	16.171	2.49	0.058	x
Section(Transect)	24	159.634	158.598	6.608	2.52	0.001	x
Site(Transect Section)	90	235.653	235.653	2.618	0.61	0.996	
Error	224	961.417	961.417	4.292			
Total	343	1436.540					

Analysis of Variance for Ranunculus acris (Common butter, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.5401	0.3434	0.0687	0.87	0.511	x
Section(Transect)	24	2.8125	1.7532	0.0731	0.85	0.670	x
Site(Transect Section)	90	7.7344	7.7344	0.0859	0.43	1.000	
Error	225	45.0000	45.0000	0.2000			
Total	344	56.0870					

Analysis of Variance for Rhododendron canadense (Rhodora, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	658.01	593.24	118.65	1.17	0.351	x
Section(Transect)	24	2563.62	2496.70	104.03	1.66	0.046	x
Site(Transect Section)	90	5659.20	5659.20	62.88	1.48	0.011	
Error	224	9545.67	9545.67	42.61			
Total	343	18426.50					

Analysis of Variance for Rosa nitida (Northeastern rose), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	10.5567	10.5607	2.1121	3.14	0.025	x
Section(Transect)	24	16.8875	16.8828	0.7034	0.75	0.783	x

Site(Transect Section)	90	84.4094	84.4094	0.9379	1055.12	0.000	
Error	225	0.2000	0.2000	0.0009			
Total	344	112.0536					

Analysis of Variance for Rubus chamaemorus (Bakeapple), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.9868	0.9772	0.1954	0.80	0.557	x
Section(Transect)	24	6.0169	5.8832	0.2451	0.99	0.486	x
Site(Transect Section)	90	22.2790	22.2790	0.2475	1.25	0.097	
Error	224	44.4375	44.4375	0.1984			
Total	343	73.7202					

Analysis of Variance for Sanguisorba canadensis (Canadia, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	176.80	156.69	31.34	0.60	0.700	x
Section(Transect)	24	1400.47	1288.42	53.68	2.61	0.001	x
Site(Transect Section)	90	1849.63	1849.63	20.55	1.05	0.378	
Error	224	4378.60	4378.60	19.55			
Total	343	7805.50					

Analysis of Variance for Sarracenia purpurea (Pitcher pl, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	4.3455	4.4452	0.8890	0.70	0.630	x
Section(Transect)	24	31.4307	31.1853	1.2994	1.68	0.041	x
Site(Transect Section)	90	69.5061	69.5061	0.7723	1.06	0.366	
Error	224	163.5542	163.5542	0.7302			
Total	343	268.8365					

Analysis of Variance for Solidago purshii (Bog goldenrod, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	23.9919	24.0446	4.8089	4.00	0.008	x
Section(Transect)	24	30.3451	29.5394	1.2308	0.96	0.519	x
Site(Transect Section)	90	115.0667	115.0667	1.2785	2.09	0.000	
Error	224	136.9917	136.9917	0.6116			
Total	343	306.3953					

Analysis of Variance for Spiraea alba (Broadleaf meadows, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.08641	0.05495	0.01099	0.87	0.511	x
Section(Transect)	24	0.45000	0.28052	0.01169	0.85	0.670	x
Site(Transect Section)	90	1.23750	1.23750	0.01375	0.43	1.000	
Error	225	7.20000	7.20000	0.03200			
Total	344	8.97391					

Analysis of Variance for Stereocaulon spp. (dry ice lich, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	1.8042	1.7781	0.8891	1.02	0.389	x
Section(Transect)	12	10.4857	10.4594	0.8716	2.36	0.018	x
Site(Transect Section)	45	16.5781	16.5781	0.3684	0.86	0.722	
Error	165	70.8542	70.8542	0.4294			

Total	224	99.7222					

Analysis of Variance for Thalictrum polygamum (Tall mead, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	20.092	19.467	3.893	1.41	0.254	x
Section(Transect)	24	73.617	68.020	2.834	0.91	0.588	x
Site(Transect Section)	90	280.904	280.904	3.121	2.79	0.000	
Error	224	251.000	251.000	1.121			
Total	343	625.613					

Analysis of Variance for Thamnolia sp. (rubber grass lic, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.09868	0.09802	0.04901	0.96	0.409	x
Section(Transect)	12	0.61250	0.61151	0.05096	1.48	0.167	x
Site(Transect Section)	45	1.54688	1.54688	0.03438	0.82	0.783	
Error	165	6.93750	6.93750	0.04205			
Total	224	9.19556					

Analysis of Variance for Tridentalis borealis (Starflowe, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	3.980	2.748	0.550	0.82	0.548	x
Section(Transect)	24	17.578	15.629	0.651	0.93	0.564	x
Site(Transect Section)	90	62.923	62.923	0.699	0.61	0.996	
Error	224	256.958	256.958	1.147			
Total	343	341.439					

Analysis of Variance for Utricularia cornuta (Horned bla, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.9684	0.5443	0.1089	0.58	0.716	x
Section(Transect)	21	3.8652	3.8641	0.1840	1.03	0.440	x
Site(Transect Section)	78	13.9219	13.9219	0.1785	0.61	0.994	
Error	189	55.4792	55.4792	0.2935			
Total	293	74.2347					

Analysis of Variance for Vaccinium angustifolium (Bluebe, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	5203.9	5175.7	1035.1	2.43	0.064	x
Section(Transect)	24	10823.1	10553.3	439.7	2.57	0.001	x
Site(Transect Section)	90	15396.0	15396.0	171.1	1.23	0.113	
Error	224	31158.0	31158.0	139.1			
Total	343	62581.0					

Analysis of Variance for Vaccinium oxycoccus, macrocarpo, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	347.87	345.79	69.16	2.69	0.043	x
Section(Transect)	24	606.12	615.08	25.63	0.84	0.676	x
Site(Transect Section)	90	2741.60	2741.60	30.46	1.12	0.247	
Error	224	6078.96	6078.96	27.14			
Total	343	9774.55					

Analysis of Variance for Vaccinium vitis-idaea, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	7.524	7.510	1.502	1.37	0.267	x
Section(Transect)	24	26.387	26.388	1.099	0.94	0.555	x
Site(Transect Section)	90	105.797	105.797	1.176	1.15	0.203	
Error	225	229.688	229.688	1.021			
Total	344	369.396					

Analysis of Variance for Viburnum cassinoides (Wild rais, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	20.553	19.299	3.860	0.63	0.680	x
Section(Transect)	24	154.038	146.389	6.100	0.92	0.570	x
Site(Transect Section)	90	593.672	593.672	6.596	0.90	0.709	
Error	224	1637.187	1637.187	7.309			
Total	343	2405.451					

Analysis of Variance for Viola macloskeyi (Northern whit, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.08641	0.05495	0.01099	0.87	0.511	x
Section(Transect)	24	0.45000	0.28052	0.01169	0.85	0.670	x
Site(Transect Section)	90	1.23750	1.23750	0.01375	0.43	1.000	
Error	225	7.20000	7.20000	0.03200			
Total	344	8.97391					

Analysis of Variance for Unknown "spiral flower cluster", using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.0024004	0.0015264	0.0003053	0.87	0.511	x
Section(Transect)	24	0.0125000	0.0077922	0.0003247	0.85	0.670	x
Site(Transect Section)	90	0.0343750	0.0343750	0.0003819	0.43	1.000	
Error	225	0.2000000	0.2000000	0.0008889			
Total	344	0.2492754					

Analysis of Variance for Unknown "tribush", using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	2.940	1.870	0.374	0.87	0.511	x
Section(Transect)	24	15.313	9.545	0.398	0.85	0.670	x
Site(Transect Section)	90	42.109	42.109	0.468	0.43	1.000	
Error	225	245.000	245.000	1.089			
Total	344	305.362					

Analysis of Variance for Unknown "mint wood", using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	5	0.5401	0.5366	0.1073	0.91	0.486	x
Section(Transect)	24	2.8125	2.7394	0.1141	0.97	0.509	x
Site(Transect Section)	90	10.5469	10.5469	0.1172	0.62	0.994	
Error	225	42.1875	42.1875	0.1875			
Total	344	56.0870					

Analysis of Variance for Xanthoria sp. (Orange rock lich, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.16312	0.15491	0.07745	2.40	0.132	x
Section(Transect)	12	0.38750	0.38675	0.03223	0.81	0.636	x
Site(Transect Section)	45	1.78437	1.78437	0.03965	0.89	0.664	
Error	165	7.32500	7.32500	0.04439			
Total	224	9.66000					

Analysis of Variance for Cabin mold rock lichen, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	6.897	6.730	3.365	0.52	0.605	x
Section(Transect)	12	76.947	76.936	6.411	1.00	0.464	x
Site(Transect Section)	45	288.281	288.281	6.406	0.93	0.598	
Error	165	1134.375	1134.375	6.875			
Total	224	1506.500					

Analysis of Variance for Grey Rock (mat) lichen (unkown), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	13.361	13.270	6.635	0.98	0.404	x
Section(Transect)	12	81.531	81.411	6.784	1.21	0.303	x
Site(Transect Section)	45	251.391	251.391	5.586	0.87	0.705	
Error	165	1061.812	1061.812	6.435			
Total	224	1408.096					

Analysis of Variance for Grey speckled lichen (unknown), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	0.002014	0.002000	0.001000	0.96	0.410	x
Section(Transect)	12	0.012500	0.012480	0.001040	1.00	0.466	x
Site(Transect Section)	45	0.046875	0.046875	0.001042	0.92	0.624	
Error	165	0.187500	0.187500	0.001136			
Total	224	0.248889					

Analysis of Variance for number of lichen genera, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
Transect	2	83.734	84.883	42.442	32.61	0.000	x
Section(Transect)	12	13.141	12.357	1.030	0.34	0.978	x
Site(Transect Section)	45	138.308	138.308	3.074	1.43	0.098	
Error	59	126.800	126.800	2.149			
Total	118	361.983					

Table 2 shows that among scales, the greatest number of patterns were found at the section (within transect) scale, with the fewest patterns found at the transect scale. There were only 6 variables which exhibited patterns at all scales examined but 27 variables with no pattern at any scale. Generally, those variables not exhibiting any pattern were infrequently occurring species. The p-value decreased with scale for 8 of the 74 variables examined, and increased for 17 variables. There is therefore no general pattern of increasing or decreasing level of patterning with scale. The lowest p-value was discovered at the section scale for 43% of the variables examined.

Table 2: Summary of hierarchical analyses of variance of variables in relation to scale

Variable	Number of variable with patterns ($p < 0.2$)			Patterns at all scales examined	No patterns at any scale examined	With decreasing scale, p-value of variable		Number of variables with lowest p-value		
	Transect scale	Section scale	Site scale			Decreases	Increases	Transect scale	Section scale	Site scale
Percent cover	2	4	3	2	1	3	1	1	3	3
Other variables	17	25	21	4	26	5	16	16	29	17
Total	19	29	24	6	27	8	17	17	32	20

Although the p-value (Table 2) gives an interesting comparison of the scale dependence of patterns, an analysis of the variance (or mean squared, MS) permits a more rigorous and powerful approach. By assigning scales of analysis typical numerical values and comparing MS at these scales, the direction of pattern can be determined (Set of Tables 2). This gives an indication of the hue of the variable. Hue is an expression of the scale dependence of variability of the data (Schneider 1994). For example, a red variable has low variability at small scale and this variability increases as scale increases. A white hue indicates consistent variability at all scales, whereas blue indicates decreasing variability with increasing scale. Green variance shows low variability at large and small scales but high variability at moderate scales.

In addition to the scale dependence of variability and the direction in which it changes, it was possible to investigate the relationship of variance to bin size quantitatively using the following formula:

$$MS / f = f^{Slope}$$

Where f is the inverse of bin size and the slope is the relationship between the log of variance over f and the log of f. The slope is a representation of the hue of the data, where –2 indicates red, 0 indicates white, -1 indicates variability between red and white, called pink, and 2 indicates blue. The slope of green variability is expected to look like white variability, but the relationship isn't linear, so an analysis of the variance (MS) values is more telling.

There were 27 variables which showed decreasing trends of variance with decreasing scale (Set of Tables 2). About the same number (28) showed no consistent trend, and 18 showed consistently increasing trends with decreasing scale.

Interestingly, the hue suggested by the pattern of variance between scales is not always analogous to that suggested by the slope (Set of Tables 2). For red and pink variables, decreasing slopes are evident. However, for apparently blue variables, negative slopes are still evident. One explanation for this is that most of the blue variables seem to have variance of relatively low magnitude, and only four scales were examined. Considering the low frequency of blue variables in nature, those that appear blue from the MS values may actually be pink. Notably, blue variables were less negative than most pink hued variables. Green variables also seem to be unusually common, but their slopes indicate that they are also more likely to be pink. It is obviously very error prone to assume a non-linear relationship from only four points.

Accepting these likely errors, a gross comparison of variables can still be made using hue. Table 4 compares those variables classed as red, pink, green, and blue. No variables were found to be white. Qualitatively, it seems clear from Table 4 that those species listed as red, with increasing variability with scale, are those variables for which data was more abundant (e.g. non-zero values were recorded for plant species). They seem to be those species which are significant indicators of caribou habitat quality, such as their major food sources, slope of land, and indicators of biotic and abiotic conditions like grasses and mosses. Those variables that were classed as blue (but which actually show pinkish, more consistent variability) were generally rarer species.

Next variograms were created for each variable to avoid the binning spatial scales and instead using a lagging approach. These are shown as Figure Set 1, below, with $\gamma|h|$ representing the semi-variance and $|h|$ representing the lag distance.

At a lag of zero, the semi-variance is expected to also be zero, indicating that if a single location is sampled several times, generally the same data values should be discovered. Those variograms not approaching the origin are said to exhibit a “nugget” effect. This could be caused by non-spatial or random variability, variability at a smaller scale than that which was measured, or measurement error (Legendre and Legendre 1998).

Of the 65 variograms of percent cover of taxa, 35 were negative. This unexpected result requires explanation. I explored whether the predominance of negative sloped variograms was due to the observation that many of the response variables in question (ie: percent cover of plant species) had very few observed values, and thus may have been caused by small sample size. When only variograms with greater than ten non-zero values were accepted, 20 of 34 (58.8%) of variograms showed negative trends.

One major source of these unexpected variograms could be that the data is simply too noisy, that is, that they are showing random variation. For example, the quadrats for most variables were only 50 cm by 50 cm, and rather than take the mean of all subsites within a site, each subsite was used as the unit of analysis. This prediction was be tested by randomizing the spatial locations of percent cover measurements to investigate random variograms and compare their shapes to those already created. This test was performed (due to the volume of computations) for only two variables.

Figure Set 2 shows that when the spatial locations of *Cladina* spp. were randomized 30 times, a nugget of about semi-variance = 900 was observed and values ranged from 650 to 1150, with generally little change in variance with scale relative to the experimental variogram of this genus. *Cladina* spp. experimentally showed (Figure 7) a deviation from this trend, with a nugget of about 540, a maximum semi-variance of about 600, and a decreasing trend to as low as 180.

Likewise, Figure Set 3 shows that when the spatial locations of *Kalmia* sp. were randomized 30 times, a nugget of 270 was observed and values of semi-variance ranged from 120 to 650. By contrast, the experimental variogram of this genus (Figure 8) displayed a nugget of around 160, with a maximum value of about 180 and a decreasing trend towards a minimum semi-variance of about 70.

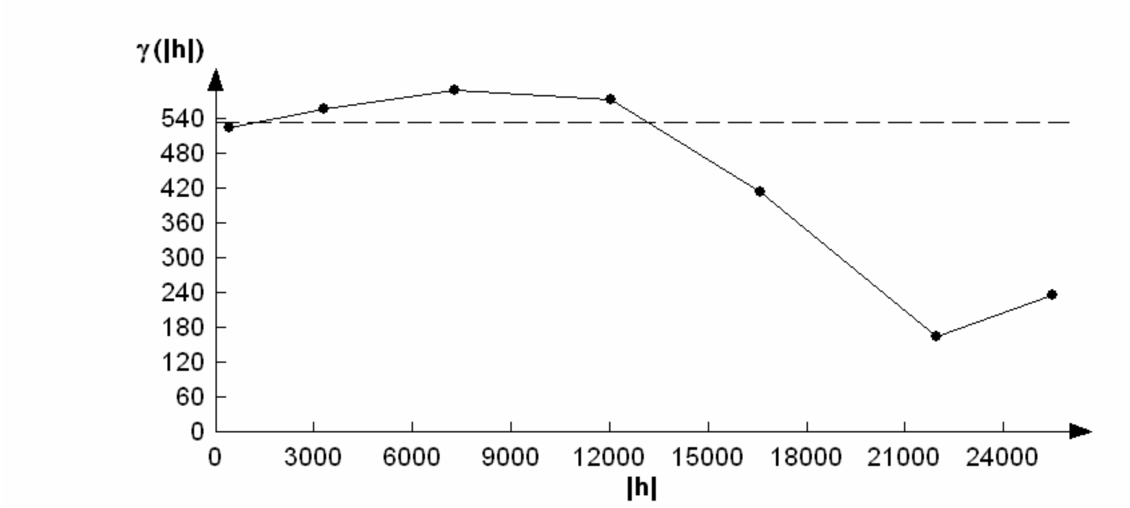


Figure 7: Experimental variogram of *Cladina* spp. (from Figure Set 1)

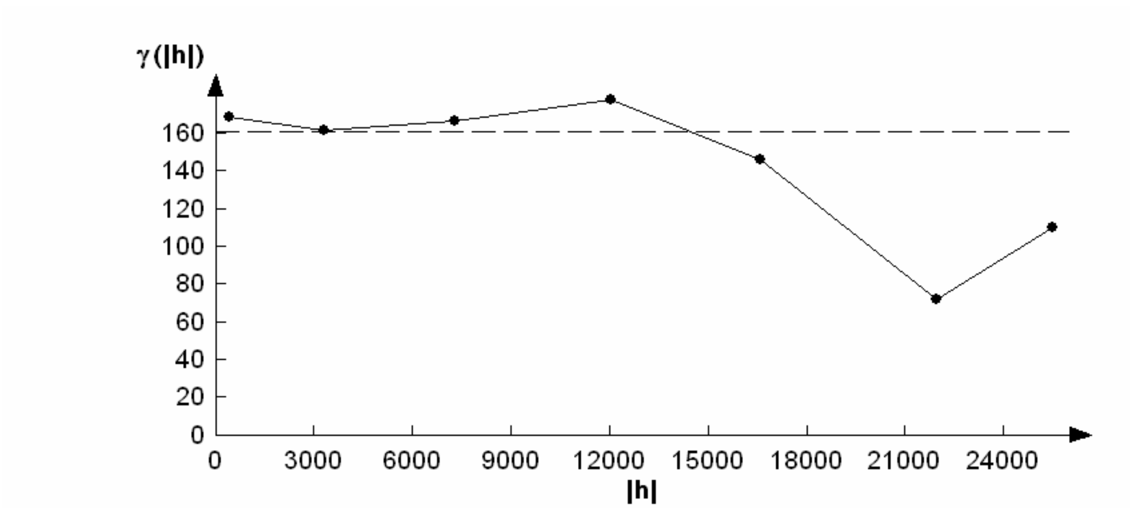
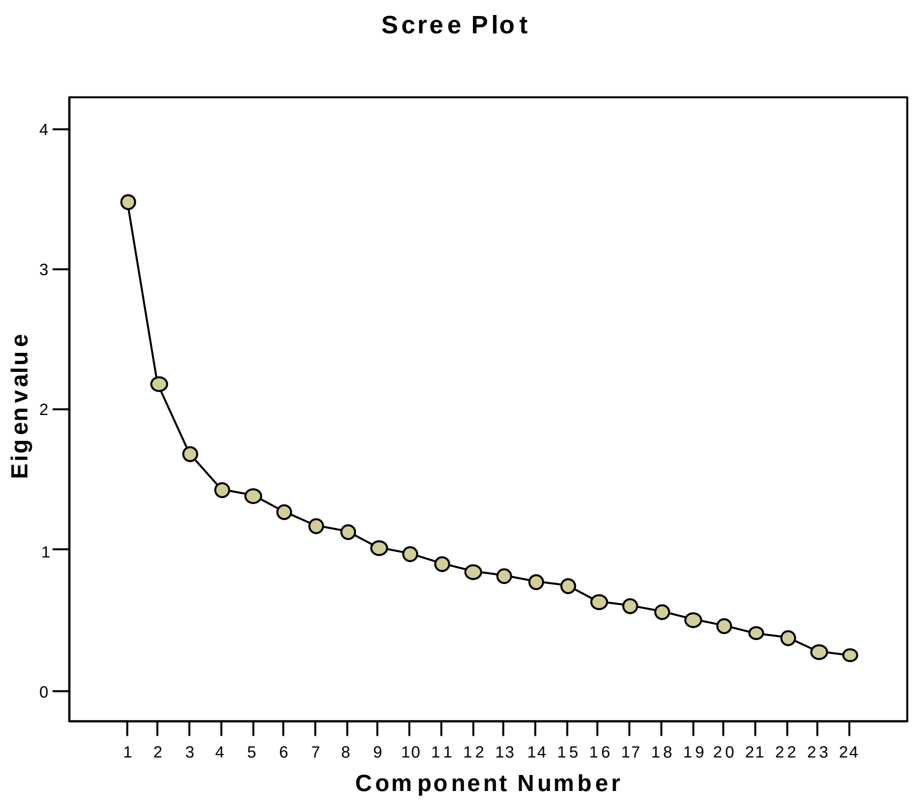


Figure 8: Experimental variogram of *Kalmia* spp. (from Figure Set 1)

The variograms of these two commonly present species deviate from what would be expected if the spatial locations were random. Therefore the trends are not due to simple noise. Another possible explanation for the strangely shaped variograms is that they result from non-contiguous samples. The non-adjacent transects and sites may have caused this pattern in variograms which may be more suited to application to contiguous data sets, such as continuous transects.

Principle components analysis was then performed to reduce the 76 variables to a small number of factors that can explain a significant proportion of the variance in the data. The variables were grouped using a correlation matrix (Figure 9)

Figure 10 shows a scree plot that indicates that the first three factors extracted provide the greatest relative contribution to the explanation of variance in the data, explaining greater than 6% each, and any potential additional components add relatively little to this explanatory power.



<u>Figure 10: Scree plot produced by Principle Components Analysis.</u>

Figure 11 shows the component scores by variable that provide an indication of the degree to which new variables show gradients. For example, a Component 1 shows relative large negative versus positive loading and thus describes a larger gradient than Component 3. Overall, however, the gradients for all the new components are fairly weak.

Component Score Coefficient Matrix

	Component		
	1	2	3
Continuous soil depth	.128	.150	.006
Andromeda glaucophylla (Bog rosemary)	.126	.028	.182
Aster spp.	.121	-.095	.087
Betula spp. (Dwarf birches)	.006	.090	.137
Cladina spp. (Caribou lichens)	-.158	.066	.217
Cladonia spp. (Caribou lichens)	-.036	-.005	.022
Coptis groenlandica (Goldthread)	.093	.247	.106
Cornus canadensis (Bunchberry)	-.067	.285	.084
Drosera rotundifolia (Round-leaved sundew)	.077	.005	.000
Grasses	.212	-.074	.073
Juniperus communis (Common juniper)	.019	-.019	-.011
Ilex mucronata (Mountain holly)	.042	.221	-.362
Kalmia spp. (Laurels)	-.140	.105	.128
Ledum groenlandicum (Labrador tea)	-.014	.179	.087
Larix laricina (Larch, Tamarack)	-.078	-.015	.033
Mosses	.210	.095	-.047
Myrica gale (Bog myrtle or Sweet gale)	.087	.195	.150
Picea mariana (Black spruce)	.011	.121	-.474
Sanguisorba canadensis (Canadian burnet)	.089	-.105	.005
Sarracenia purpurea (Pitcher plant)	.129	.109	.052
Solidago purshii (Bog goldenrod)	.108	-.076	.030
Vaccinium angustifolium (Blueberry)	-.116	.207	.121
Vaccinium oxycoccus, macrocarpon (Small and large cranberries)	.140	.084	.135
Viburnum cassinoides (Wild raisin)	-.029	.177	-.138

Extraction Method: Principal Component Analysis.
Component Scores.

Figure 11: Component Score Matrix by PCA (prev. page)

Figure 12 shows the percent of variance explained by each factor and the cumulative percent of 30.670% of the variance explained by the three extracted components combined.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.270	14.865	14.865	3.270	14.865	14.865
2	1.944	8.835	23.700	1.944	8.835	23.700
3	1.533	6.968	30.668	1.533	6.968	30.668
4	1.287	5.852	36.520			
5	1.261	5.734	42.254			
6	1.203	5.469	47.723			
7	1.136	5.164	52.887			
8	1.047	4.757	57.645			
9	1.004	4.565	62.210			
10	.940	4.274	66.484			
11	.922	4.191	70.675			
12	.858	3.898	74.573			
13	.801	3.640	78.214			
14	.732	3.328	81.542			
15	.693	3.150	84.692			
16	.678	3.081	87.773			
17	.623	2.831	90.604			
18	.537	2.439	93.043			
19	.474	2.157	95.200			
20	.446	2.025	97.225			
21	.355	1.615	98.840			
22	.255	1.160	100.000			

Extraction Method: Principal Component Analysis.

Figure 12: Variance explained by extracted components

Figure 13 shows a component plot of the first 2 components (for ease of interpretation in 2 dimensions). Those variables along the Component 1 (X) axis seem to be more common speices, such as blueberry (VA), Laurels (Kal), mosses, and grasses.

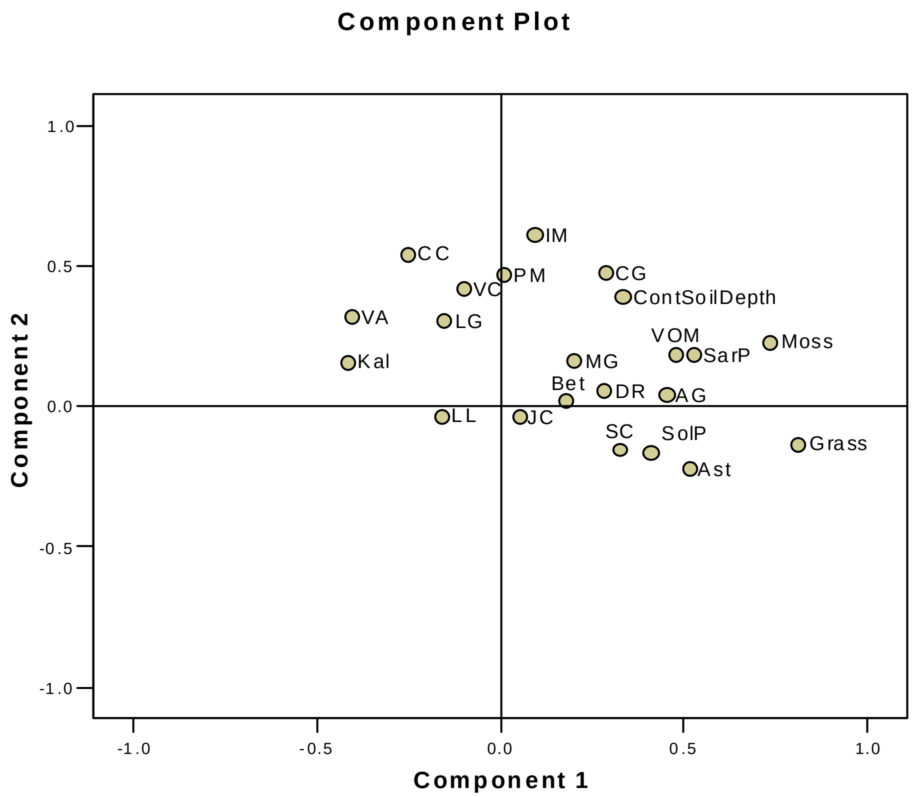


Figure 13: Component plot of first 2 components

Figure 14 shows the component plot of all three components in three dimensions. The component plots, rather than having variables distributed cleanly along axes, look more like a cloud of mush – indicating minimal correlation between variables and little variance explained by the extracted components.

Component Plot

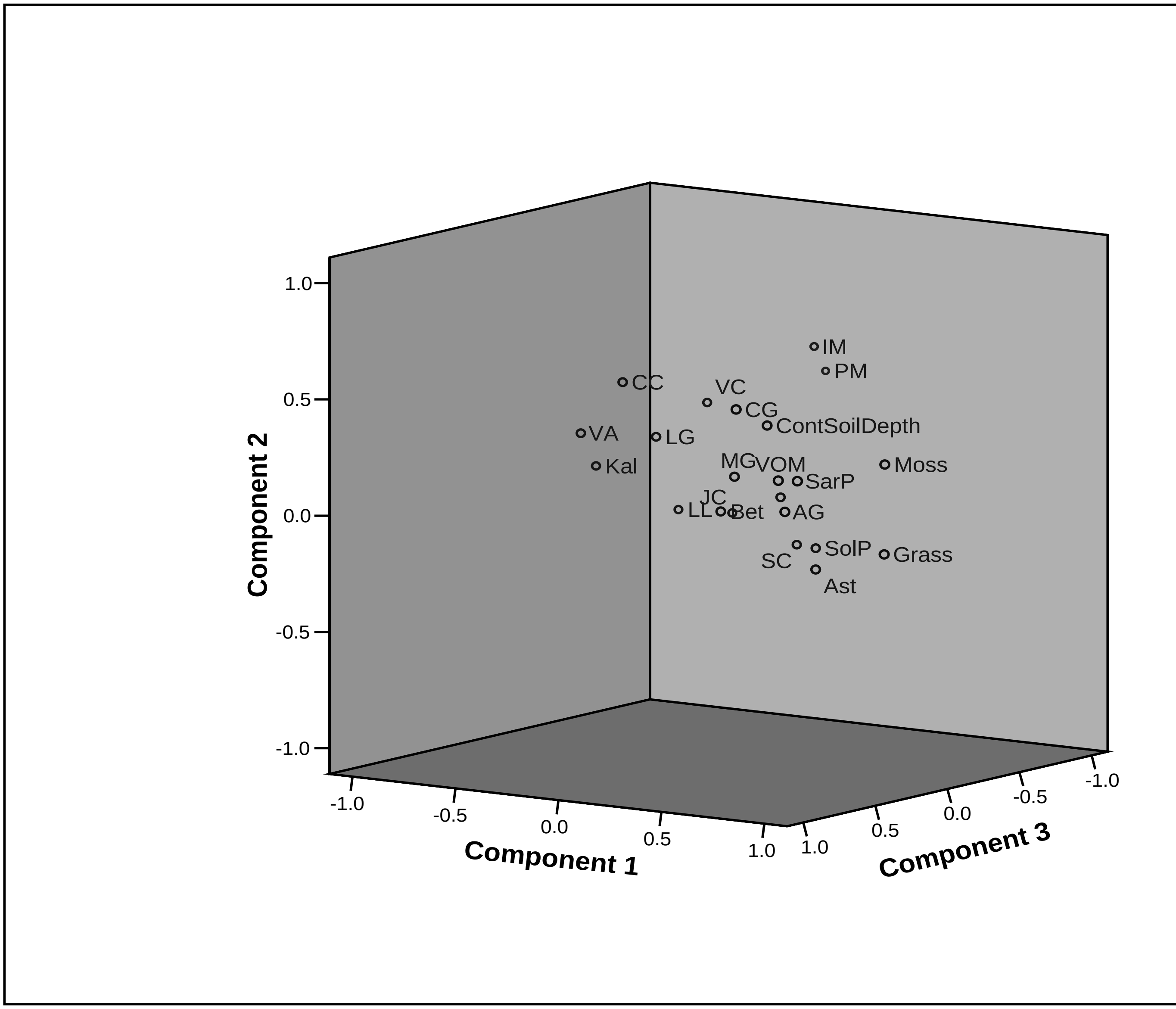


Figure 14: Three dimensional component plot of habitat variables

Further analyses which in retrospect might be highly applicable to this dataset could include Principle Components Neighbour Matrices (PCNM). This method partitions variance among scales and is useful for investigations of spatial structure of ecological data at multiple scales (Bocard et al. 2004). PCNM creates a set of explanatory variables (like in PCA) that have structure at all scales encompassed by the data and determines to which of these components the data are statistically responding. Thus it models spatial structure at all scales perceived by the data set – in this case, between 5 and 30 000 metres.

Conclusions

Spatial patterns were generally found at only some, if any, of the scales of analysis when examining the p-values in the frequency domain. However, many common species and those variables expected to be important factors in caribou habitat selection showed clear scale dependence of variance, as expected. In the lagging domain, variograms unexpectedly sometimes showed decreasing variance with increasing lag. Three principle components explained only 30 % of the variation in the data, half of which was explained by the first component. This data set is quite noisy, but this exploratory analysis revealed that some variables (ie: *Cladina* spp., grasses) are better indicators of spatial structure than less frequently measurable variables.

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