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FUNDY MODEL FOREST

FINAL REPORT

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Effects of Forestry Practices on Species Composition, Diversity, Stand Structure and Succession

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ABSTRACT

This report presents results of Phase II (Harvesting Effects Study) of the project, which was established in the Hayward Brook Watershed in spring 1995. The pre-harvest distribution of species in relation to environmental factors within the study area was determined in the first year (1995-96). Vegetation was resampled and disturbance conditions were described after harvesting in the second year (1996-97).

The study area occurs within the Continental Lowlands Ecoregion of New-Brunswick and the Anagance Ridge Ecodistrict 29 (NBDNRE 1996). Eight stand types were characterized based on overstory composition.

Percent cover of all vascular and non-vascular plants $\leq$ 1 m tall was recorded by species in 169 circular 5 m^2 sample plots before harvesting in 1995. Non-vascular plants were recorded in three broad groups (*Sphagnum spp.*, other mosses and lichens). A total of 106 species and species groups were found. Diversity indices such as the Simpson Index, Shannon-Wiener Index, maximum H' and evenness showed slight differences between stand types before harvesting. Species evenness was relatively low, i.e. 80% of the species occurred in $\leq$ 20% of the plots. Species richness averaged 15 species/5 m^2 plot. Two stands contained the greatest richness with 70-72 species. These stands occurred in portions of the watershed that contained seepage springs.

Canonical correspondence analysis (CCA) showed that 24% of the species pattern was correlated with the environmental variables chosen in this study (canopy, topography and litter). Partial canonical correspondence analysis (PCCA) was employed to partition out the individual and combined effects of the environmental variables; litter nutrient content (particularly pH, Ca, and Mg) was most highly correlated with the species pattern. Changes in community composition after catastrophic disturbance were predicted using both equilibrium and non-equilibrium models.

Disturbance intensities differed in the two harvesting treatments in the first year after harvesting. In one area that was clearcut without site preparation and planting (C), more softwood slash was created, less litter was disturbed and less mineral soil was exposed than in the other area that was clearcut, scarified (barrels and chains) and planted (CS).

Harvesting treatments had different effects on species composition and species richness. In the CS treatment, 23 species were lost, 20 species invaded, and species richness decreased from 82 (pre-harvest) to 79 (the first year after harvesting). The Shannon-Wiener diversity index

decreased from 0.7842 to 0.7377. In the C treatment, 19 species were lost and 10 invaded; species richness changed from 60 (pre-harvest) to 51 (the first year after harvesting); and the Shannon-Weiner index increased from 0.5966 to 0.6578 after harvesting. The species that were lost or significantly reduced in abundance provide easily identifiable indicators of sustainable forest management which can be readily monitored. These species include *Actaea rubra, Aster ciliolatus, Aster macrophyllus, Brachyelytrum erectum, Cypripedium acaule*, *Dalibarda repens*, *Dennstaedtia punctilobula, Dryopteris sp., Gaultheria hispidula*, *Goodyera tellelata, Linnaea borealis, Luzula acuminata, Lycopodium annotinum, Lycopodium complanatum, Medeola virginiana, Mitella nuda*, *Moneses uniflora, Monotropa hypopithys, Orthilia secunda, Oryzopsis asperifolia, Osmumda spp., Oxalis montana*, *Prunella vulgaris, Ribes lacustre, Solidago flexicaulis, Sphagnum spp., Streptopus amplexifolius*, *Streptopus roseus*, *Thelypteris noveboracensis*, *Vaccinium vitis-idaea* and *Veronica officinalis*.

Areas within the watershed containing unique vegetation communities and high diversity were delineated. These areas should be monitored closely to determine effects of harvesting on species and communities. In addition, all community types should be monitored to insure that representative examples of each type are maintained.

ACKNOWLEDGMENTS

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INTRODUCTION

Environmentally sustainable forest resource use and development requires knowledge of how forestry practices impact the composition, diversity, structure and dynamics of the forest ecosystem. Measures of diversity along with assessments of species composition provide indices of the health of the ecosystem. Baseline data on species composition and diversity before and after harvesting have been provided by this study. Quantitative assessments of successional changes in composition and structure are essential for predicting and modeling long-term ecosystem dynamics.

The Chronosequence Study (Phase I of the overall study) provided an analysis of general patterns of change in stand structure, composition and diversity over relatively long time periods, starting at a minimum stand age of 5 years. Phase I was supported by Canada's Green Plan (Forestry Practices), Canada/New Brunswick Cooperation Agreement on Forest Development, and the Fundy Model Forest and was completed in 1995. Results were presented in a final report to the Canadian Forest Service (Roberts and Methven 1996). Phase II, the Harvesting Effects Study, complements the Chronosequence Study by providing information on the initial effects of harvesting disturbance on plant composition and diversity. This report presents results from the first two years (1995-97) of Phase II.

The first year (1995-96) of the Harvesting Effects Study focussed on the pre-harvest distribution of species in relation to site factors within the study area. The second year (1996-97) addressed disturbance conditions and vegetation response in the first growing season after harvest.

Objectives

1. Identify patterns of herbaceous layer composition and diversity in relation to soil and site conditions before harvest.
2. Assess response of herbaceous layer species to harvesting with and without site preparation.
3. Determine effects of different disturbance severities on herbaceous layer species composition and diversity.

STUDY AREA

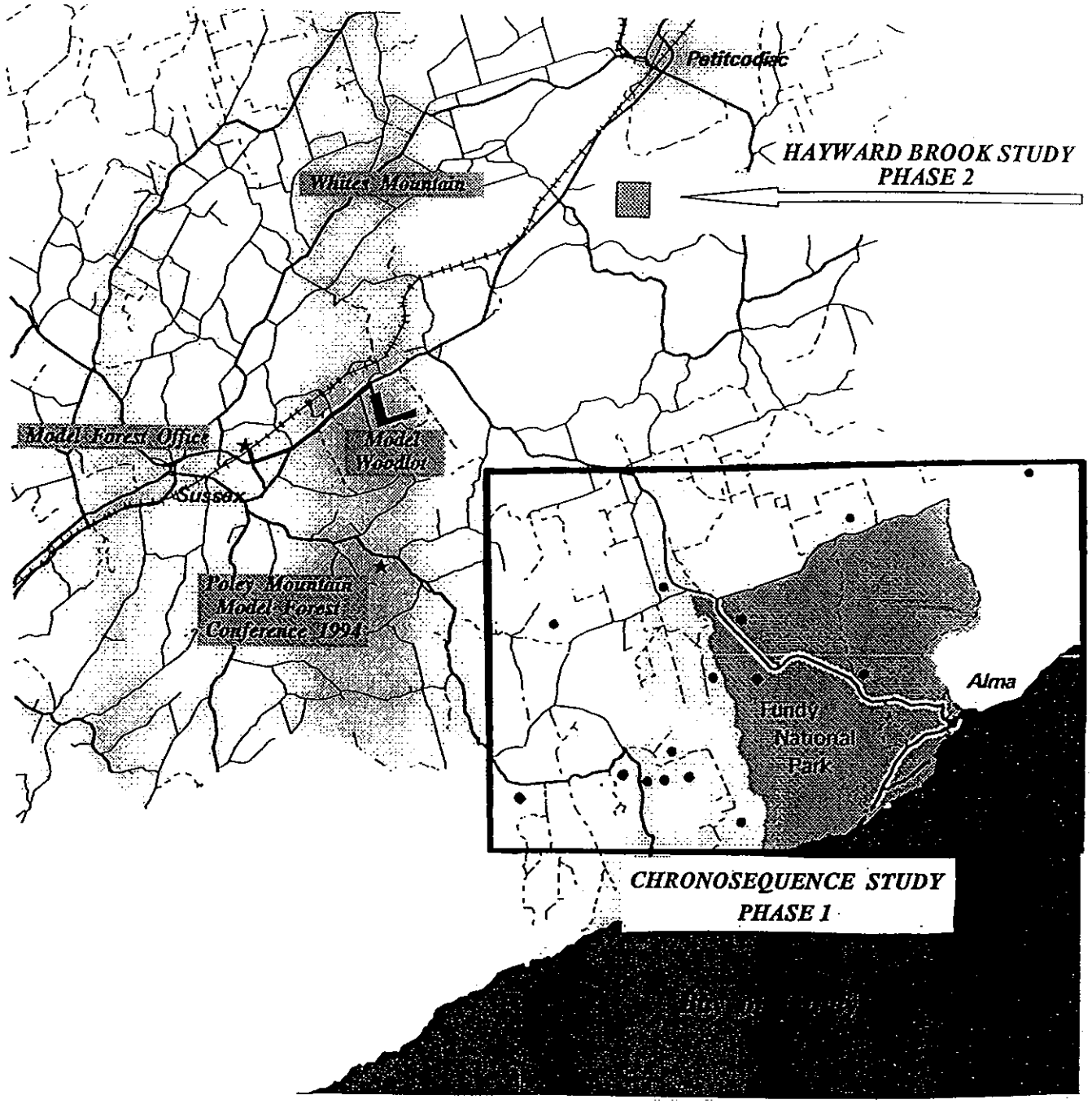
This study was established in 1995, within the Hayward Brook Watershed, south of Petitcodiac, N.B., in the Fundy Model Forest (latitude 45°53'N, longitude 65°11'W) (Figure 1). This study is integrated with bryophyte studies at UNBSJ (Department of Biology). The study area is a portion of the Hayward Brook Watershed which covers approximately 110 ha, and has predominantly NW aspect and SE aspects separated by a branch of Hayward Brook. The elevation above sea level ranges from 200 to 400 feet. The study area occurred within the Continental Lowlands Ecoregion of New-Brunswick (NBDNRE 1996). This area is part of the Acadian Forest Region (Ireland 1982).

The study area has hardwood ridge tops of white birch (*Betula papyrifera* Marshall), red maple (*Acer rubrum* L.), trembling aspen (*Populus tremuloides* Michx.) and large-tooth aspen (*Populus grandidentata* Michx). Within this stand type, the soil is well drained with a thin layer of organic matter. On mid-slopes, red spruce (*Picea rubens* Sarg.), white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Miller) BSP), red maple and balsam fir (*Abies balsamea* (L.) Miller) constitute the mixedwood stands. The bottom slopes are predominantely wet areas with black spruce, red spruce, red maple and balsam fir, and a thick layer of organic matter. White pine (*Pinus strobus* L.) is scattered throughout the entire area as well as a few red pine (*Pinus resinosa* Aiton) and jack pine (*Pinus banksiana* Lambert). Stand types are best described by NBDNRE's Anagance Ridge Ecodistrict 29.

Two bedrock types underlay this site. One is formed of grey-red sandstone, grey-green and red mudstone, with minor, grey and red, granule to cobble conglomerate and coal. The second bedrock, most likely infertile, is formed of greyish-green, plant bearing quartzose sandstone and quartz pebble conglomerate, with minor, red sandstone and grey mudstone, fossiliferous, bituminous limestone (McLeod *et al.* 1994).

The Sunbury and Parry soil series are found in this study area. Soil types included 2, 3, 5, and 6 which range from poorly to well drained soils. The vegetation types included 5, 7, 8, 9 and 11. These soil and vegetation types were associated with treatment units 6, 7, 9, 10 and 12 which represent dry-moderately poor mixedwood stands, moist-moderately poor mixedwood stands, moist-rich softwood stands, moist-rich mixedwood stands and dry-rich mixedwood stands (Zelazny *et al.* 1989).

Figure 1. Location of the study area.



METHODS

Study Design

A total of 169 permanent 5 m^2 circular plots were systematically located in two distinct blocks separated by a branch of the Hayward Brook (see Figure 3, p. 19). The plots were placed on transects which started in the riparian buffer strip and ran upslope. The spacing was 50 m between plots and approximately 50 m between the transects. All sample plots were established and sampled before harvest from May 16 to July 14, 1995. To facilitate relocating plots after harvest, the center of each plot was marked with a wooden stake flush with the ground. The three nearest trees >10 cm dbh were painted at the stump and their distances and bearings from the plot center were recorded.

The area was harvested by a Feller-buncher, the trees were delimbed on site and carried out on a Porter (6-wheel drive) from August 1 to 19, 1995. Portions of the study area were scarified by a Tree Farmer Skidder with barrels and heavy-chains, from September 19 to 22. Plot centers were relocated in spring 1996. Disturbance and vegetation measurements were done in summer 1996.

Pre-Harvest Sampling

Herbaceous layer variables

For sampling the pre-harvest herbaceous layer, each 5 m^2 herb plot was divided into four quadrats. Percent cover of all species of vascular plants was estimated by quadrat. Non-vascular plants were recorded in three broad groups: *Sphagnum spp.*, other mosses and lichens. The herbaceous layer was defined as extending from the forest floor to 1 m height, hence tree species $\leq$ 1 m tall were included. Table 1 lists all the species found in the sample plots before harvest.

Environmental variables

(a) Litter. A litter sample was taken from just outside each quadrat using a 10 cm diameter circular-cutter and the depth for each sample was determined. Percent composition of moss, needles, and leaves in the LFH layer of this sample was estimated using a 3 point

Table 1. Species list and abundances for Hayward Brook Watershed, NB., in order of frequency. Nomenclature follows Hinds (1986). Species codes are those used in plots of Correspondence and Canonical Correspondence Analyses.

Species	Species code	Frequency (%) (n=169)	Mean % cover when present	mean % cover (all quad.)
Moss spp.	66	97.63	12.38	12.09
Maianthemum canadense Desf.	58	97.04	0.82	0.80
Abies balsamea (L.) Mill	1	82.25	15.22	12.52
Cornus canadensis L.	29	79.88	2.90	2.32
Gaultheria procumbens L.	43	54.44	0.98	0.53
Vaccinium angustifolium Ait.	101	52.66	1.36	0.72
Vaccinium myrtilloides Michx.	102	51.48	1.21	0.62
Pteridium aquilinum (L.) Kuhn	82	50.89	6.76	3.44
Acer rubrum L.	3	50.30	1.94	0.98
Trientalis borealis Raf.	98	47.34	0.72	0.34
Picea glauca (Moench) Voss	73	45.56	3.52	1.61
Amelanchier sp.	9	41.42	0.38	0.16
Acer pensylvanicum L.	2	39.64	2.40	0.95
Corylus cornuta Marsh.	30	37.28	5.47	2.04
Viola spp.	106	33.14	0.62	0.21
Aralia nudicaulis L.	12	30.77	0.86	0.26
Grass spp.	45	29.59	0.47	0.14
Chimaphila umbellata (L.) Spreng.	25	25.44	0.59	0.15
Viburnum cassinoides L.	105	24.26	0.23	0.06
Coptis trifolia (L.) Salisb.	28	21.89	1.92	0.42
Lycopodium clavatum L.	54	18.34	2.96	0.54
Picea rubens Sarg.	75	18.34	5.26	0.97
Picea mariana (Mill.) BSP.	74	17.16	7.79	1.34
Lycopodium dendroidium Michx.	56	15.38	2.30	0.35
Pinus strobus L.	76	14.79	0.92	0.14
Rubus pubescens Raf.	89	14.20	3.49	0.50
Streptopus roseus Michx.	95	13.61	0.40	0.05
Kalmia angustifolia L.	48	13.61	1.27	0.17
Populus tremuloides Michx.	78	13.02	0.35	0.05
Carex spp.	23	12.43	0.65	0.08

Table 1 (cont'd)

Mitchella repens L.	63	11.83	0.38	0.04
Trillium undulatum Willd.	99	11.83	0.26	0.03
Aster macrophyllus L.	16	11.24	0.27	0.03
Lichen spp.	49	11.24	2.07	0.23
Linnaea borealis L.	50	11.24	0.93	0.10
Hamamelis virginiana L.	47	11.24	0.89	0.10
Athyrium filix-femina (L.) Roth	18	10.65	3.67	0.39
Clintonia borealis (Ait.) Raf.	27	10.06	0.25	0.03
Prenanthes spp.	79	10.06	0.88	0.09
Oxalis acetosella L. (Syn. O. montana Raf.)	72	9.47	2.44	0.23
Pyrola elliptica Nutt.	85	8.88	0.44	0.04
Dryopteris spp.	35	7.10	1.88	0.13
Medeola virginiana L.	59	7.10	0.34	0.02
Brachyelytrum erectum (Schreb.) Beauv.	21	7.10	1.74	0.12
Aster acuminatus Michx.	13	6.51	0.34	0.02
Lonicera canadensis Bartr.	51	5.92	0.40	0.02
Mitella nuda L.	62	5.92	1.06	0.06
Solidago puberula Nutt.	92	5.92	0.20	0.01
Osmunda sp.	71	5.33	5.78	0.31
Fagus grandifolia Ehrh.	37	5.33	2.47	0.13
Pyrola chlorantha Sw.	84	4.73	0.28	0.01
Galium triflorum Michx.	41	4.73	0.55	0.03
Betula papyrifera Marsh.	19	4.14	0.79	0.03
Moneses uniflora (L.) Gray	64	4.14	0.18	0.01
Sphagnum spp.	93	3.55	5.02	0.18
Pyrola americana Sweet	83	3.55	0.33	0.01
Fraxinus americana L.	38	3.55	0.60	0.02
Gymnocarpium dryopteris (L.) Newm.	46	3.55	5.88	0.21
Lycopodium annotinum L.	53	3.55	7.46	0.26
Fragaria vesca L.	39	3.55	0.85	0.03
Actaea rubra (Ait.) Willd.	7	3.55	0.31	0.01
Acer spicatum Lam.	5	2.96	0.33	0.01
Aster lateriflorus (L.) Britt.	15	2.96	0.30	0.01
Circaea alpina L.	26	2.96	1.20	0.04
Gaultheria hispidula (L.) Muhl.	42	2.96	0.25	0.01

Table 1 (cont'd)

Lycopodium complanatum L.	55	2.96	0.95	0.03
Melampyrum lineare Desr.	60	2.96	0.18	0.01
Equisetum sylvaticum L.	36	2.37	1.50	0.04
Cypripedium acaule Ait.	31	2.37	0.16	0.00
Orthilia secunda (L.) House	67	2.37	0.50	0.01
Ribes lacustre (Pers.) Poir.	88	1.78	0.54	0.01
Achillea millefolium L.	6	1.78	0.17	0.00
Thelypteris phegopteris (L.) Slosson	97	1.78	2.67	0.05
Osmunda cinnamomea L.	69	1.18	10.63	0.13
Luzula acuminata Raf.	52	1.18	0.09	0.00
Apocynum androsaemifolium L.	11	1.18	0.50	0.01
Aster ciliolatus Lindl.	14	1.18	0.44	0.01
Goodyera tesselata Lodd.	44	1.18	0.13	0.00
Monotropa hypopithys L.	65	1.18	0.25	0.00
Streptopus amplexifolius (L.) DC.	94	1.18	0.25	0.00
Dennstaedtia punctilodula (Michx.) Moore	33	1.18	3.00	0.04
Dryopteris cristata (L.) Gray	34	1.18	0.63	0.01
Thelypteris noveboracensis (L.) Niewl.	96	0.59	15.75	0.09
Vaccinium vitis-idaea L.	103	0.59	0.38	0.00
Lycopodium lucidum Michx.	57	0.59	0.13	0.00
Veronica officinalis L.	104	0.59	0.25	0.00
Acer saccharum Marsh.	4	0.59	0.13	0.00
Antennaria sp.	10	0.59	0.25	0.00
Alnus incana (L.) Moench. (syn. A. rugosa (DuRoi) Preng.)	8	0.59	0.25	0.00
Unknown	100	0.59	0.13	0.00
Dalibarda repens L.	32	0.59	0.25	0.00
Prunus virginiana L.	80	0.59	0.25	0.00
Prunella vulgaris L.	81	0.59	0.13	0.00
Populus grandidentata Michx.	77	0.59	0.25	0.00
Oryzopsis asperifolia Michx.	68	0.59	0.25	0.00
Osmunda claytoniana L.	70	0.59	1.25	0.01
Galium circaezans Michx.	40	0.59	0.13	0.00
Carex umbellata Schkuhr	24	0.59	0.75	0.00
Aster umbellatus Mill.	17	0.59	0.13	0.00

Table 1 (cont'd)

Solidago flexicaulis L.	90	0.59	0.50	0.00
Solidago sp.	91	0.59	0.38	0.00
Ribes americanum P. Mill.	87	0.59	0.13	0.00
Carex arctata Boott	22	0.59	0.25	0.00
Botrychium matricariifolium A. Br.	20	0.59	1.13	0.01
Ranunculus acris L.	86	0.59	0.13	0.00
Grand mean $\pm$ s.e.		22.77$\pm$3.39	1.74$\pm$0.28	0.46$\pm$0.17

scale where 0 was *not present* and 3 was *100% composition*. For example, an LFH sample could score 2 for leaf and 1 for needle composition meaning the LFH was 30% leaf and 70% needles. The samples were dried at 55 ° Celsius for 48 hours and passed through a 2 cm wire mesh, removing leafs, branches and other forms of large debris. The pH was determined with a pH meter after adding deionized water to form a thin paste and allowing the mixture to equilibrate for one hour (McKeague 1978). Total nitrogen was determined for the sub-samples by the Kjeldahl method (Bremmer and Mulvaney 1982) using a Buchï autoanalyser distillation unit. Exchangeable cations (K, Ca and Mg) were determined by extraction of samples with 1 N NH_4OAc, pH7, and analysis of samples by atomic absorption spectrometry, using lanthanum chloride as the releasing agent for Ca and Mg (Baker and Shure 1982). Available phosphorus was obtained by extraction with dilute sulphuric acid and colorimetric analysis of the extract, using phospho-molybdo-blue method (Baker and Shure 1982). Percent carbon and organic matter were determined by dry combustion using a Leco Carbon Determinater and the formula O.M.= %C*1.72 (Anonymous 1977, Walkley 1946).

(b) Mineral soil. Mineral soil samples were taken from just outside each quadrat using a soil-corer. Samples were collected for 88 sample plots located on every second transect. Samples were dried at 55 ° C for 48 hours and passed through a 2 mm sieve, removing any prevalent root clumps. The pH, total nitrogen, exchangeable cations (K, Ca and Mg), available phosphorus, percent carbon and organic matter were measured following the same methodology as the forest floor analysis. In addition, soil texture was measured (proportion of silt, clay and sand) by the sedimentation method (Bouyoucos 1953).

(c) Plant tissue. Adjacent to each plot, 20 leaves of False lily-of-the-valley (*Maianthemum canadense* Desf.) were collected. The plant tissue of this ubiquitous species was analyzed in the laboratory for concentrations of phosphorus (P), nitrogen (N), potassium (K), calcium (Ca) and magnesium (Mg). Tissue nutrient concentrations provide an additional measure of nutrient availability.

The plant tissues samples were oven dried at 70 ° Celsius for 72 hours, ground in a Thomas-Wiley Mill / (Model ED-5) then reduced to ash in a furnace at 450 ° Celsius for three hours. The ash residue was moistened with distilled water and then 5 ml of 8NHCl was

added. The samples were then placed in a 95 ° Celsius water bath for 20 minutes to allow cooling. The ashes were then filtered through a Whatman #541 filter paper using a long stemmed funnel into a 50 ml volumetric flask. The ashes were diluted to 50 ml with deionized water. This final solution was mixed with HCl-vanadate-molybdate to induce color development. Percent transmittance of all the plant tissue samples were determined using the spectrophotometer, and converted into ppm of phosphorus.

A similar process was used to determined the amount of exchangeable cations (K, Ca, Mg) but the final solution was mixed with deionized water and lanthanum-chloride. The transmittance was recorded with the spectrophotometer and converted into ppm of K, Ca, Mg (Skoog 1969).

(d) Canopy. Canopy closure was estimated in each plot with a densiometer using the average of four readings. The observations were taken in the first and third quadrats above the herbaceous layer. Two readings were taken at the same point in each quadrat, by two people reading from different directions to account for observer effects (Vales and Brunnell 1988). Total canopy closure as well as proportion of deciduous and coniferous canopy were tallied. The general stand type was described, looking at the dominant tree species in the canopy around each sample plot.

(e) Macrotopography and aspect. Macrotopography was recorded as presence/absence of pits or mounds (visually +/- 50+cm deep) and coded as flat (0), to slightly mounded and >5 m apart (1), to moderately mounded and >1 m apart (2), to very mounded and <1 m apart (3). Aspect and slope were estimated using a compass and a Suunto clinometer respectively. Aspect, i.e. compass bearing of slope, was expressed as the sine and cosine of azimuth, indicating the degree of "northness" and "eastness" respectively. Slope position was also recorded and expressed as follow (1)ridge top, (2) upper slope, (3) mid slope, (4)lower slope and, (5) flat at bottom of slope.

Stand type characterization

Stand types were delineated within the study area from stand cover type maps provided by the New Brunswick Department of Natural Resources and Energy (NBDNRE) (see Figure 3, p. 19). To describe the stand types within the study area three overstorey and understorey sample plots were measured for each stand. Also one soil pit was described within each stand type using the Field Guide to Forest Site Classification in New Brunswick (Zelazny *et al.*, 1989) to identify soil types.

A prism count was done on trees $\geq$ 5 cm dbh (overstorey), and a fixed sample plot (5.64 m radius) was used for the stems $<$ 5 cm dbh (understorey). Number of trees and dbh were tallied for each tree species. The data from the three plots were averaged together by stand type for the overstorey and understorey samples separately. The vegetation type was also determined, using Field Guide to Forest Site Classification in New Brunswick, Harvey-Harcourt region (Zelazny *et al.*, 1989). The results are condensed in Table 2, showing the density, basal area, and the mean dbh by species for the overstorey. Density of the understorey tree species, vegetation types and soil types are also shown. Overstorey composition (% basal area) in each stand is presented in Figure 2.

Post-Harvest Sampling

The summer of 1996 was the first growing season after the harvesting disturbance. On the 169 plots established in 1995, disturbance data, herbaceous vegetation data and canopy closure data were collected. As done in the pre-harvest sampling, each plot was divided into 4 quadrats. The disturbance and herbaceous vegetation data were collected on each quadrat. Canopy closure was measured in quadrat one and quadrat three of each plot and then averaged to represent the canopy closure of the plot.

The schedule below was followed during the 1996 field season:

--May 16/ May 26 - relocate plots

--May 27/June 14 - measure disturbance

--June 24/June 26 - establish 36 permanent sample plots in buffer strips

--July 2/July 31 - measure vegetation and canopy cover

-- September 1/ Present - enter and analyze data

Table 2. Overstory, understory and site caharacteristics by stand type.

STAND A: 1356	OVERSTOREY			UNDERSTOREY	SITE CLASS			Plot used
	SPECIES	BA	density	dbh-mean	density			
		m2/ha	#tree/ha	cm	#small trees/ha	VT	ST	TU	PLOT
	BSP	9.00	905.51	11.33	825.00				
	RM	8.00	419.62	15.92	0.00	7	3	10	SJ01
	RSP	6.00	232.34	9.28	100.00				SHO1
	DEAD	4.50	285.90	20.83	0.00				SX01
	TA	3.00	40.84	22.75	0.00				SZ01
	WB	2.00	83.81	13.00	0.00				
	WSP	1.50	83.51	8.25	50.00				
	BF	0.50	44.21	3.00	5975.00				
	HE	0.00	0.00	0.00	25.00				
	WP	0.00	0.00	0.00	25.00				
	ALD	0.00	0.00	0.00	25.00				

STAND B: 466/1562	OVERSTOREY			UNDERSTOREY	SITE CLASS			PLOT
	SPECIES	BA	density	dbh-mean	density			
		m2/ha	#tree/ha	cm	#small trees/ha	VT	ST	TU	
	BSP	23.00	1226.46	19.49	150.00				SI03
	WB	10.00	924.59	14.56	0.00				SY05
	DEAD	6.00	401.35	25.25	100.00				
	RSP	3.00	164.46	8.33	600.00				
	BF	1.00	31.83	10.00	1050.00				
	WP	1.00	12.43	16.00	0.00				
	RM	1.00	64.96	7.00	0.00				

STAND C: 1365/869	OVERSTOREY			UNDERSTOREY	SITE CLASS			PLOT
	SPECIES	BA	density	dbh-mean	density			
		m2/ha	#tree/ha	cm	#small trees/ha	VT	ST	TU	
	WB	11.5	848.486907	10.75	0				SJ07
	RM	7.5	1497.25862	7.152381	50	8	6	12	SH11
	TA	4.5	211.764897	14.75	0				SF12
	DEAD	3.5	197.726238	30.5	175				SY10
	STM	1.5	253.529131	8	900				
	WSP	1	110.524251	8	475				
	BE	0.5	32.4806002	3.5	50				
	BF	0.5	44.2097058	3	800				
	WP				250				
	RSP				25				
	BSP				100				
	SM				75				

STAND D: 653	OVERSTOREY			UNDERSTOREY	SITE CLASS			PLOT
	SPECIES	BA	density	dbh-mean	density			
		m2/ha	#tree/ha	cm	#small trees/ha	VT	ST	TU	NF07
	RM	8.00	317.67	20.07	0.00				NF05
	RSP	8.00	265.06	22.60	266.67	7	5	12	NG03
	TA	5.33	83.21	30.00	0.00				
	WB	3.33	187.01	10.89	0.00				
	WSP	3.33	103.09	6.93	0.00				
	BF	2.67	147.46	10.67	3566.67				
	WP	1.33	18.17	10.33	66.67				
	STM				66.67				
	DEAD	7.33	485.99	32.89	8333.33				

Table 2 (cont'd)

STAND E: 1359

SPECIES	OVERSTOREY BA m2/ha	density #tree/ha	dbh-mean cm	UNDERSTOREY density #small trees/ha
BSP	6.5	736.348276	12.166667	1225
WB	5.5	346.984448	16.333333	0
RM	3.5	383.188525	10.625	0
RSP	2	63.3542066	5.25	1600
DEAD	1.5	63.1817847	14	0
TA	1.5	19.2493294	8	0
BF	0.5	44.2097058	3	6775
RP	0.5	1.89244876	14.5	0
WSP	0	0	0	200
WP	0	0	0	25

SITE CLASS VT	ST	TU	PLOT
			SG03
5	3	7	SG04
			SX04
			SZ03

STAND F: 1262

SPECIES	OVERSTOREY BA m2/ha	density #tree/ha	dbh-mean cm	UNDERSTOREY density #small trees/ha
TA	10.00	198.36	26.53	0.00
WB	8.67	626.56	15.67	0.00
RM	4.00	537.28	10.67	33.33
BSP	3.33	537.00	14.44	1866.67
BF	2.67	312.68	10.89	3100.00
DEAD	2.00	102.66	11.00	0.00
LTA	0.67	5.88	12.67	0.00
WP	0.67	58.95	4.00	133.33
RSP	0.67	43.31	4.67	1233.33
WSP	0.00	0.00	0.00	600.00

SITE CLASS VT	ST	TU	PLOT
			SI05
5	6	6	SH07
			SX08

STAND G: 659

SPECIES	OVERSTOREY BA m2/ha	density #tree/ha	dbh-mean cm	UNDERSTOREY density #small trees/ha
WSP	13.33	320.49	26.90	133.33
RM	10.00	496.17	20.81	0.00
BF	5.33	458.55	17.33	2300.00
WB	4.67	92.19	30.50	100.00
WAS	3.33	295.03	10.17	33.33
DEAD	2.00	32.81	28.00	0.00
YB	1.33	32.27	7.67	0.00
TA	1.33	238.92	19.33	0.00
I	0.67	132.63	2.67	33.33

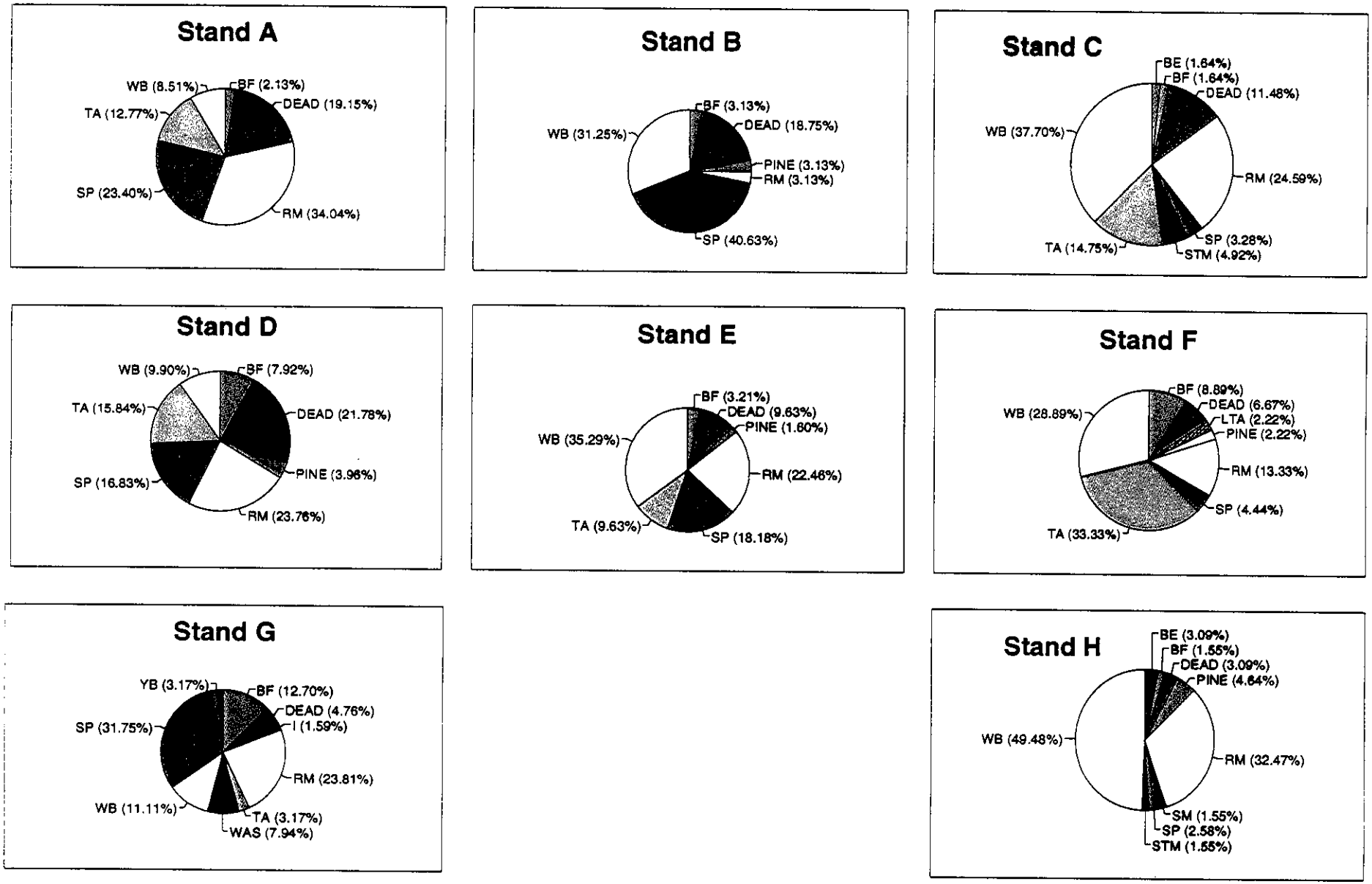
SITE CLASS VT	ST	TU	PLOT
			NM01
			NL02
11	2	9	NK03

STAND H: 357

SPECIES	OVERSTOREY BA m2/ha	density #tree/ha	dbh-mean cm	UNDERSTOREY density #small trees/ha
WB	21.33	1157.90	17.20	0.00
RM	14.00	2237.25	10.67	33.33
WP	2.00	14.39	32.33	33.33
WSP	2.00	64.96	6.67	166.67
DEAD	1.33	19.12	20.00	0.00
BE	1.33	268.94	7.33	33.33
BF	0.67	132.63	2.67	4033.33
BSP	0.67	21.22	6.67	33.33
STM	0.67	235.79	2.00	300.00
SM	0.67	235.79	2.00	33.33
RSP	0.67	17.54	7.33	100.00

SITE CLASS VT	ST	TU	PLOT
			NM05
			NL07
9	5	12	NK06

Figure 2. Basal area of overstory tree species by stand type. BE=beech, BF=balsam fir, DEAD=dead standing trees, I=ironwood, LTA=large-tooth aspen, PINE=pine species, RM=red maple, SP=spruce, SM=sugar maple, STM=striped maple, TA=trembling aspen, WAS=white ash, WB=white birch, YB=yellow birch.



The harvesting, especially scarification, destroyed some plot stakes and stumps of reference trees. From May 16 - May 26, all of the plots were relocated using available stakes or reference trees and marked with new plot stakes. In the cases where plot stakes were missing, the plot was relocated from the bearings to the reference trees which had been marked with red paint at their stumps last year before harvesting. Three reference trees were marked near each plot before harvest and at least one was found on each plot after harvest in 1996.

From May 27 to June 14, disturbance conditions were measured. To quantify disturbance, three groups of variables were measured, i.e., slash coverage, substrate and tracks. The following variables were measured:

1. *Treatment.* There were three kinds of treatments, including two harvesting methods and one uncut control in the study area, i.e., UC (uncut), CS (cut and scarified) and C (cut). In total, 65 plots were in the C treatment, 49 plots in the CS treatment and 96 plots in the UC treatment.

2. *Total Slash.* Any fresh (not rotten) wood or foliage material alive or dead. If touching the ground, they were also considered as substrate. Total slash included slash and living slash.

2.1. *Slash*: Dead twigs, branches, logs and foliage attached onto them. Four variables defined the Slash:

1). *< 0.5 cm HW.* The percentage cover of the dead hard wood twigs of diameter less than 0.5 cm and the foliage attaching to them.

2). *< 0.5 cm SW.* The percentage cover of the dead soft wood twigs of diameter less than 0.5 cm and the foliage attaching to them.

3). *Height.* The height under which 90% of the slash cover occurs.

4). *Clumped.* Whether the slash is clumped or not. The answer can only be' Y' (clumped) or 'N' (not clumped).

2.2. *Living Slash.* Living plants with stems higer than 1 m and with the angle from the stem to horizonal < 45°. Three variables were used to define living slash:

1). *HW.* The percentage cover of living hard wood.

2). *SW.* The percentage cover of living soft wood.

3). *Height.* The height under which 90% of the living slash occurs.

3. *Substrate*. The ground surface of the quadrat, divided into invisible substrate and visible substrate.

3.1 *Invisible Substrate*. The substrate that is under slash and can not be seen.

3.2 *Invisible Substrate*. The substrate that is not covered by slash. It is composed of the following items:

1). *Rocks*. The percentage cover of rocks with diameter > 7.5 cm.

2). *Stumps*. The percentage cover of fresh stumps.

3). *D. Litter*. The percentage cover of disturbed litter.

4). *Exp. Min. Soil*. The percentage cover of exposed mineral soil.

5). *Slash (2-7cm)*. The percentage cover of slash with diameter between 2 - 7 cm.

6). *Slash (7cm)*. The percentage cover of slash with diameter > 7 cm.

7). *Rotten Wood*. The percentage cover of rotten wood.

8). *Bark*. The percentage cover of bark.

9). *Chips*. Fragmented wood. Two variables were used to define chips:

a. *Cover*. Percentage cover of chips.

b. *Type*. The pattern of the distribution of chips. 'Y' = clumped; 'N' = not clumped.

10). *Undist. Litter*. Undisturbed Litter. The percentage cover of undisturbed litter.

11). *Scat*. Percentage cover of animal scat.

12). *Cones*. Percentage cover of cones.

13). *Trunks*. Percentage cover of trunks (stems of living trees).

4. *Tracks*. The tracks made by skidders. Three variables were used to define tracks:

1). *Cover*. Percentage cover of tracks.

2). *Type*. The type of track: L (litter), M (mixed litter and soil), S (soil), W (crushed wood), LW (litter and crushed wood) and WS (soil and crushed wood).

3). *Depth*. The depth of the track.

All of the above variables were measured visually except for the depth of track which was measured with a ruler. Percent canopy cover was measured with a densiometer at the ground surface in quadrats 1 and 3. The cover of bracken fern (*Pteridium aquilinum*) was ignored or avoided.

Thirty-six new plots were established in the buffer strips bordering the brook in 1996 to supplement the plots established in this area before harvesting. Along with the plots in the uncut area, they will be used as controls in data analysis. After disturbance conditions were measured and the plots in the buffer strips were established, the herbaceous vegetation on all the plots including the ones in the buffer strips was measured using the same methods used to sample preharvest vegetation.

Data Analysis

Correspondence analysis (CA) was performed on the pre-harvest vegetation x plot matrix to detect relationships in the species and samples using CANOCO (ter Braak 1988). No transformation, weighting, or detrending were used.

Canonical correspondence analysis (CCA) was used to simultaneously ordinate the pre-harvest vegetation x plot matrix and the environment x plot matrix. This constrained CA detects linear correlations between the patterns of the vegetation x plot matrix and the individual environmental variables. In CCA, environmental variables related to forest floor, forest canopy and macrotopography were used as canonical variables to determine the total species pattern (expressed as a sum of canonical eigenvectors) that can be directly related to the environmental data. The final groups of environmental variables that provided the best prediction of species composition were identified.

In Partial Canonical Correspondence Analysis (PCCA), effects of specific environmental variable categories (ie. litter, canopy, topography) were successively partitioned out as covariables, and CCA was run on the residual variation (Appendix I). The resulting sum of eigenvalues for each run represents the proportion of the total pattern captured in the residual CCA uniquely attributable to a particular environmental variable category. For example, to determine the unique contribution of topography, the litter and canopy variables were designated as covariables. Shared contributions were determined by subtraction of unique runs from combined runs.

Correspondence analysis (CA) was also performed on the post-harvest vegetation data. Plot locations in the ordination diagram were plotted by treatment to examine the relationships between harvest treatments and vegetation composition in the first year after harvesting.

Disturbance data were collected by quadrat and averaged by plot. Plot-level data were used to derive treatment means, which were compared graphically.

RESULTS

Pre-Harvest Patterns

Forest Types

The tree species in the Hayward Brook study area are predominantely white, red and black spruce, balsam fir, white birch, red maple and trembling aspen. Large red and white pines are scattered through the entire area. Hardwood stands represented by stand C and stand H, are located on ridge tops (Figure 3). White birch, red maple, sugar maple, trembling aspen, beech and striped maple are found in these deciduous stands in which softwood represents less than 13 % of the stand.

Stands A, B, D and E (Figure 3) are predominantly softwood forests of black, red and white spruce which also contain intolerant hardwood species such as red maple, white birch and trembling aspen. Hardwoods represent 20 to 45 % of these stands. Stands A, B, D and E are located near the streams. The two stands that make a transition between softwood and hardwood forest types are stand F and G which are mixedwood stands (Figure 3). Stand G is unique because it is on a wet site and contains yellow birch, white ash and ironwood which are not present elsewhere. Stand G is mainly a mixedwood stand of white spruce, red maple and balsam fir. The overstorey of stand F is mainly trembling aspen, white birch, red maple, black spruce and balsam fir.

Balsam fir was abundant in the understorey in all stand types (Table 2). Spruces were also abundant in the understorey of softwood and mixedwood stands. Striped maple was a dominant species in harwood stand understories along with balsam fir (Table 2).

Community Composition

Before harvest in 1995, the 169 plots contained 106 taxa including 15 tree species and 17 species of ferns and fern allies, and three groups of non-vascular plants (Table 1). On average, plots contained 15 species (Figure 4) with 59% total herbaceous cover (Figure 5). Taxa which occurred in the greatest number of plots were moss spp., *Maianthemum*

Figure 3. Map of stand types and sample transects in the Hayward Brook Watershed. Stand types: A (#26), B (#40), C (#41&42), D (#22), E (#34), F (#38), G (#29) and H (#30). Dots show quadrat locations. Dashed lines delimit north and south blocks (true north at top of page). Scale 1:30,000.

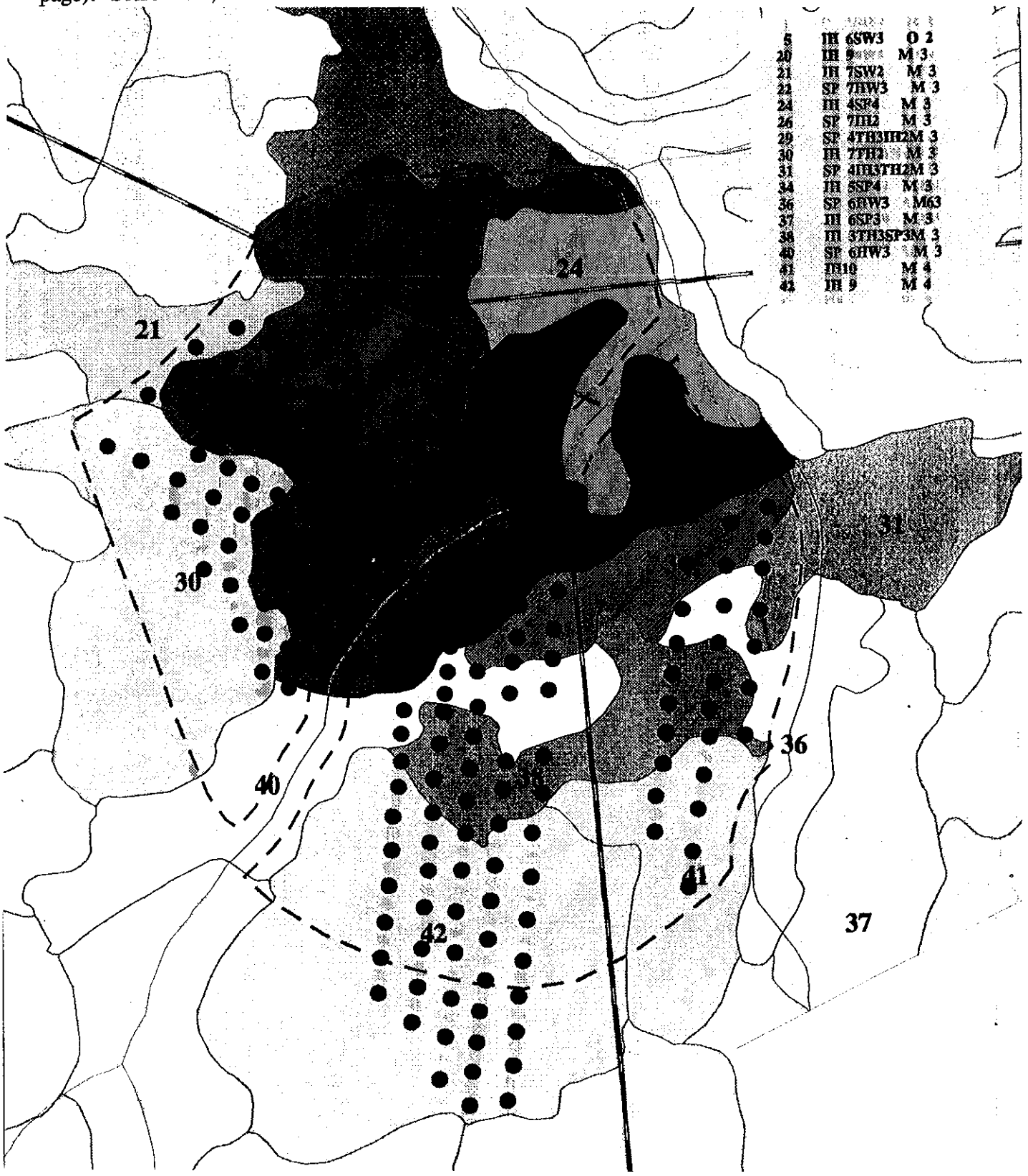


Figure 4. Frequency distribution of herbaceous species richness in $5m^2$ quadrats (n=169 quadrats, 106 species).

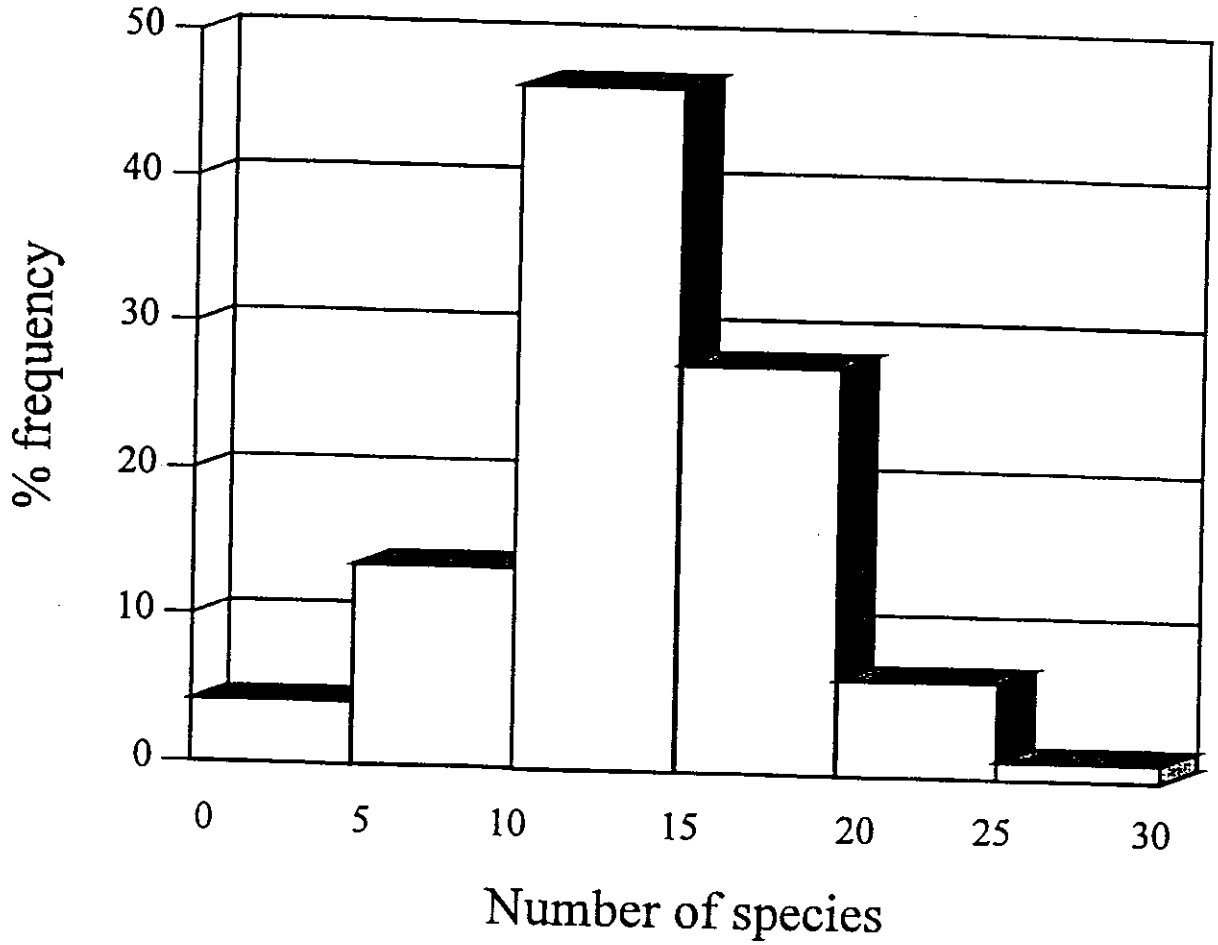
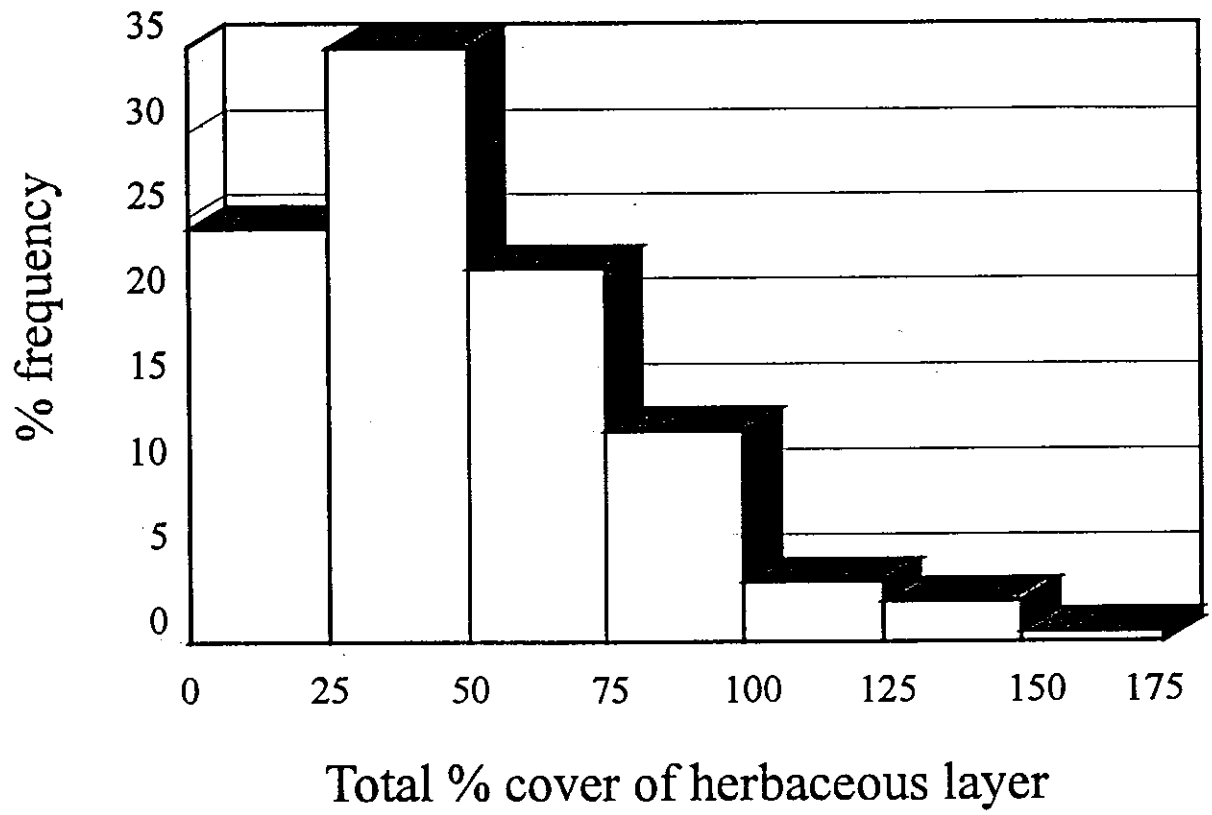


Figure 5. Frequency distribution of total percent cover of the herbaceous species in $5m^2$ quadrats (n=169 quadrats).



canadensis and *Abies balsamea*. Of the 106 species, 80 occurred in $\leq 20\%$ of the plots (Figure 6). *Abies balsamea*, *Pteridium aquilinum* and moss spp. had the highest total cover in the study area; however, 98 species had cover values of $\leq 1\%$ (Figure 7). At the local scale, i.e. cover when present in a plot, 69 species covered $\leq 1\%$, however three species regularly covered 13-18% (*Abies balsamea*, *Picea mariana* and *Lycopodium annotinum*) (Figure 8).

Correspondence Analysis (CA) and Canonical Correspondence Analysis (CCA)

Correspondence analysis (CA) showed that total variability (total inertia) in the species data was 6.581 before harvest (Table 3). The first CA axis captured 8.4% of this variability, while the second captured 6.7%. Species scoring high on CA axis one included *Thelypteris noveboracensis* (#96), *Sphagnum spp.* (#93), *Aster umbellatus* (#17), and *Prunella vulgaris* (#81) (Figure 9). At the low end of axis one was *Lycopodium annotinum* (#53), *Lycopodium dendroides* (#56), and *Alnus rugosa* (#8). The samples formed two groups along axis one: a string at the high end and a larger, denser cluster at the low end which separated somewhat on axis two. The softwood stands (A,B,D,E) formed two dense clusters at both ends of axis one (Figure 10). The hardwood stands C and H formed a string that ran parallel to CA axis two. The mixed stands (F,G) formed two clusters: G along the first axis, and F along the second.

The sum of all canonical eigenvalues was 1.582, or 24% of the total inertia (Table 3b). The remainder (76%) represents the loss of capture of the vegetation variability due to the compromise between species and environmental variable axes, to make them maximally parallel to one another. CCA axes one and two each captured slightly less of the species data variability than the CA axes (Table 3a&b). The species-environment axes were highly correlated: $r^2 = 0.893$ and 0.791 for axes one and two respectively (Table 3b).

Aster umbellata (#17), *Prunella vulgaris* (#81), *Solidago flexicaulis* (#90) scored high on CCA axis one (Figure 11). At the low end of axis one were *Populus grandidentata* (#77), *Fagus grandifolia* (#37), and *Vaccinium vitis-idaea* (#103). CCA was similar to CA in two ways: (1) plots separated along the first two CCA axes (Figure 12), with similar spread, and (2) plot 6NJ06 (#138) scored high on axis one, joined by 6NM02 (#160), and 6NK01 (#143). Unlike CA, plots at the low end of CCA axis one included 6SH11 (#74), 6SI14 (#92) and 6SX17 (#47).

Figure 6. Frequency distribution of frequency of species occurrence in $5m^2$ quadrats (n=169 quadrats).

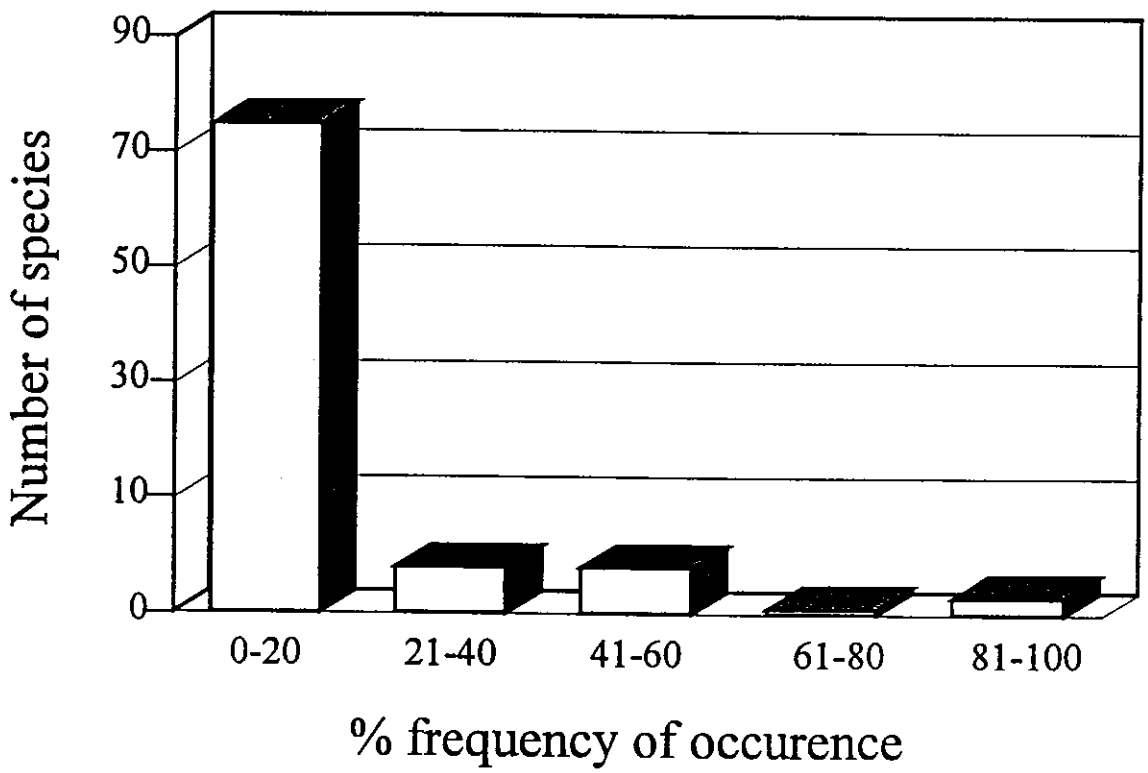


Figure 7. Frequency distribution of mean percent cover in $5m^2$ quadrats (n=169 quadrats, 106 species).

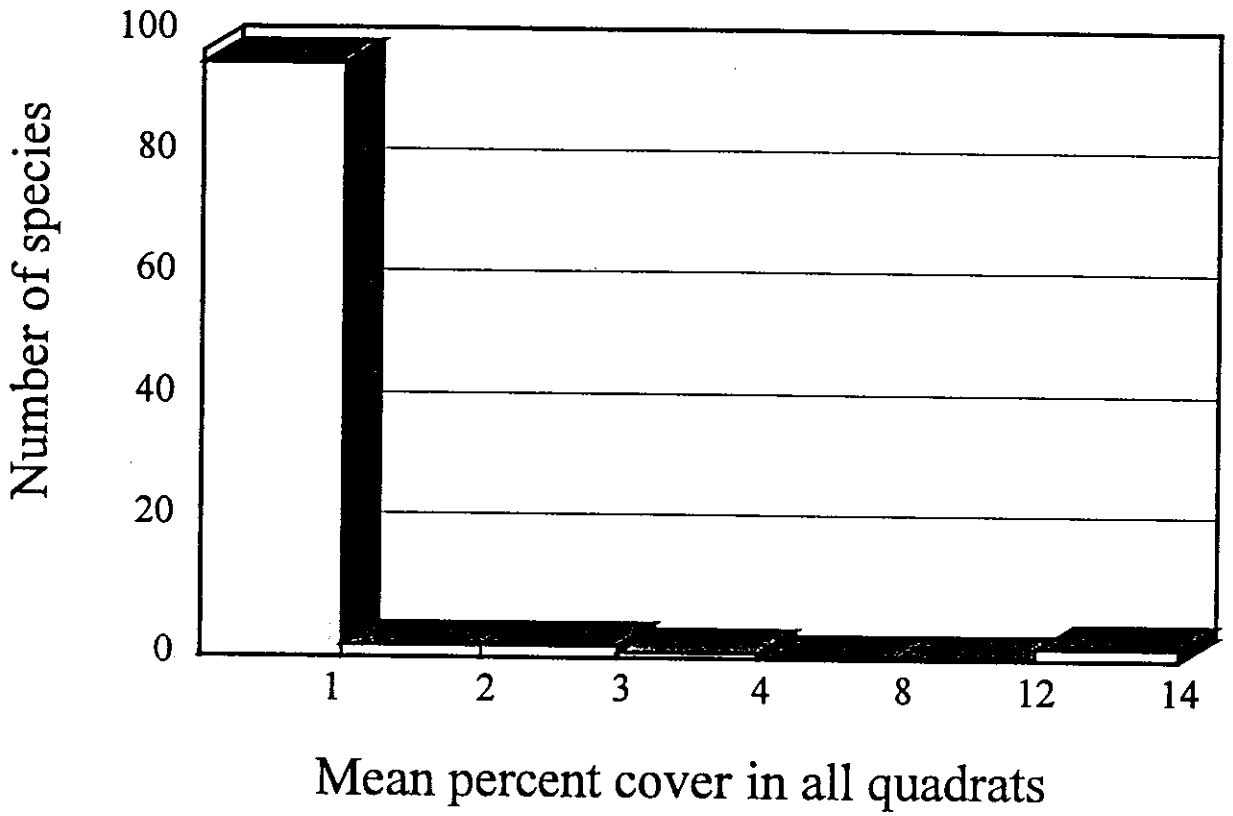


Figure 8. Frequency distribution of local mean percent cover, i.e. cover when present, of 106 species in $5m^2$ quadrats.

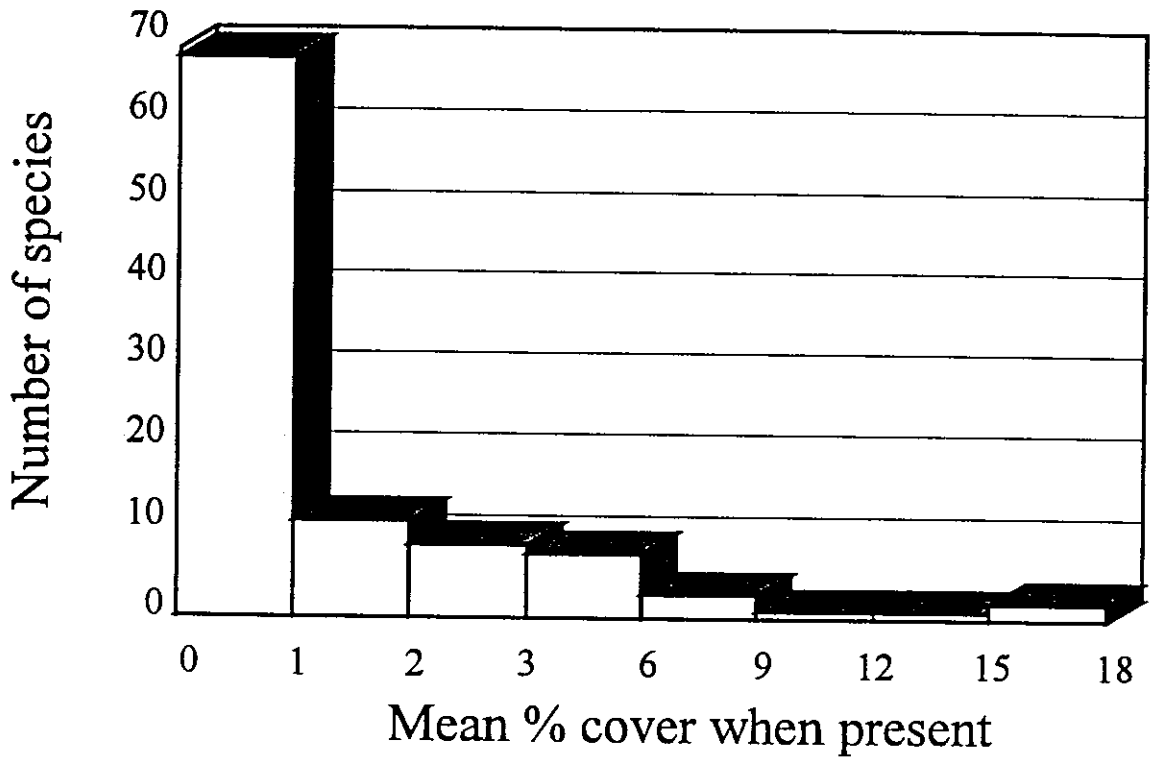


Table 3. **Summary of the first axes of (a) CA and (b) CCA on herbaceous vegetation and environmental data before harvesting from Hayward Brook.**

	(a) CA		(b) CCA		
	EV	%	EV	%	Sp/env r^2
1ST AXIS	0.551	8.4	0.408	6.2	0.893
2ND AXIS	0.442	6.7	0.257	3.9	0.791
INERTIA	6.581 (total)	100	1.582 (canonical)	24 of total	

Figure 9. Species scores on the first two axes of Correspondence Analysis (CA) on 106 species in 169 5m^2 quadrats. Numbers represent species codes (see Table 1).

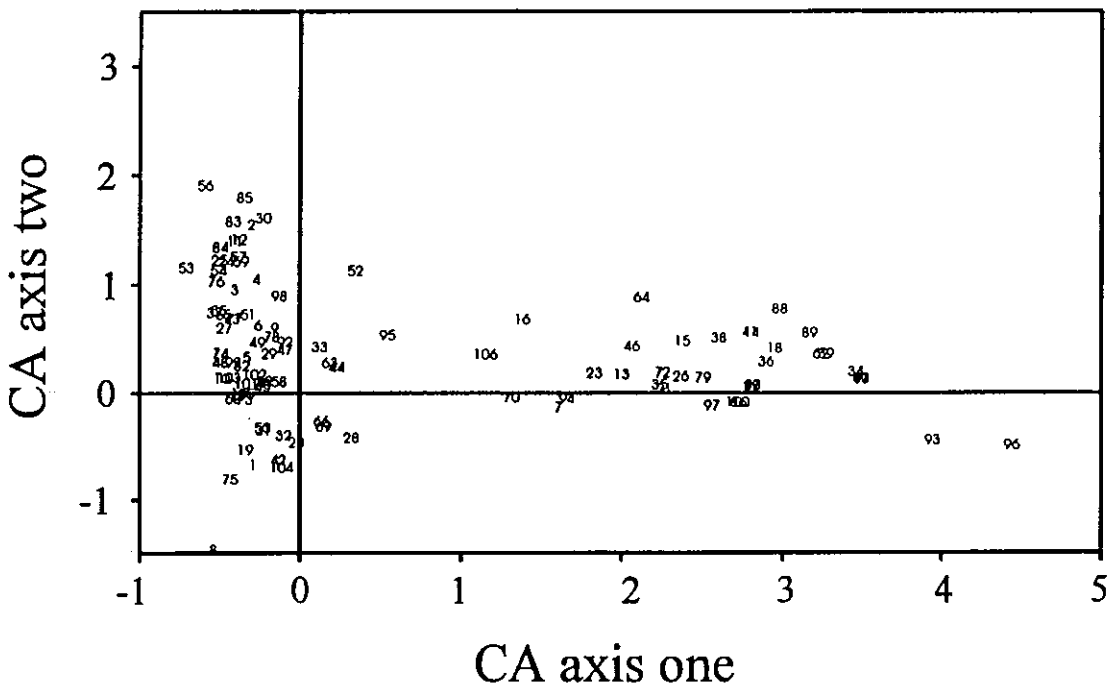


Figure 10. Distribution of 169 5m^2 quadrats (grouped by stand type) on the first two axes of Correspondence Analysis (CA). Softwood stand types A, B, D, E; mixed stand types F, G; hardwood stand types C, H.

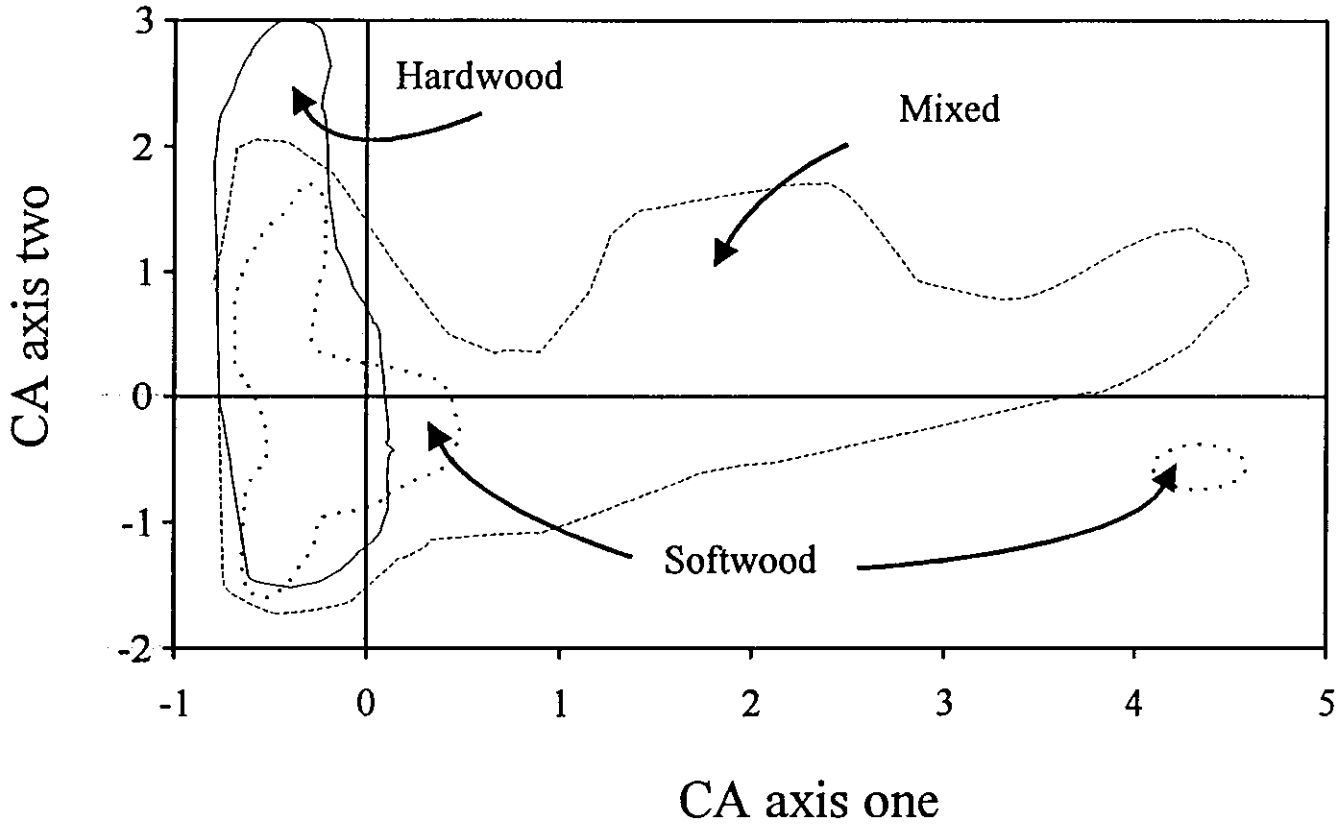


Figure 11. Species scores on the first two axes of Canonical Correspondence Analysis (CCA) with environmental biplots. Numbers represent species codes (see Table 1). TC=total canopy cover, DC=deciduous canopy, CC=coniferous canopy, DL=litter depth, LM=litter moss component, LD=litter deciduous component, LC=litter coniferous component, S1=slope of the microtopography, SLO=slope of the plot, PIT=pitted, MOU=mounded, FLA=flat, MAC= macrotopography, S2=slope of the area, POS=slope position, COS=cosine of azimuth, SIN=sine of azimuth, pH=litter pH, K=litter potassium, Ca=litter calcium, Mg=litter magnesium, P= available phosphorus (litter), C=percent carbon (litter), N=total nitrogen (litter), C/N=carbon to nitrogen ratio (litter), OM=percent organic matter (litter).

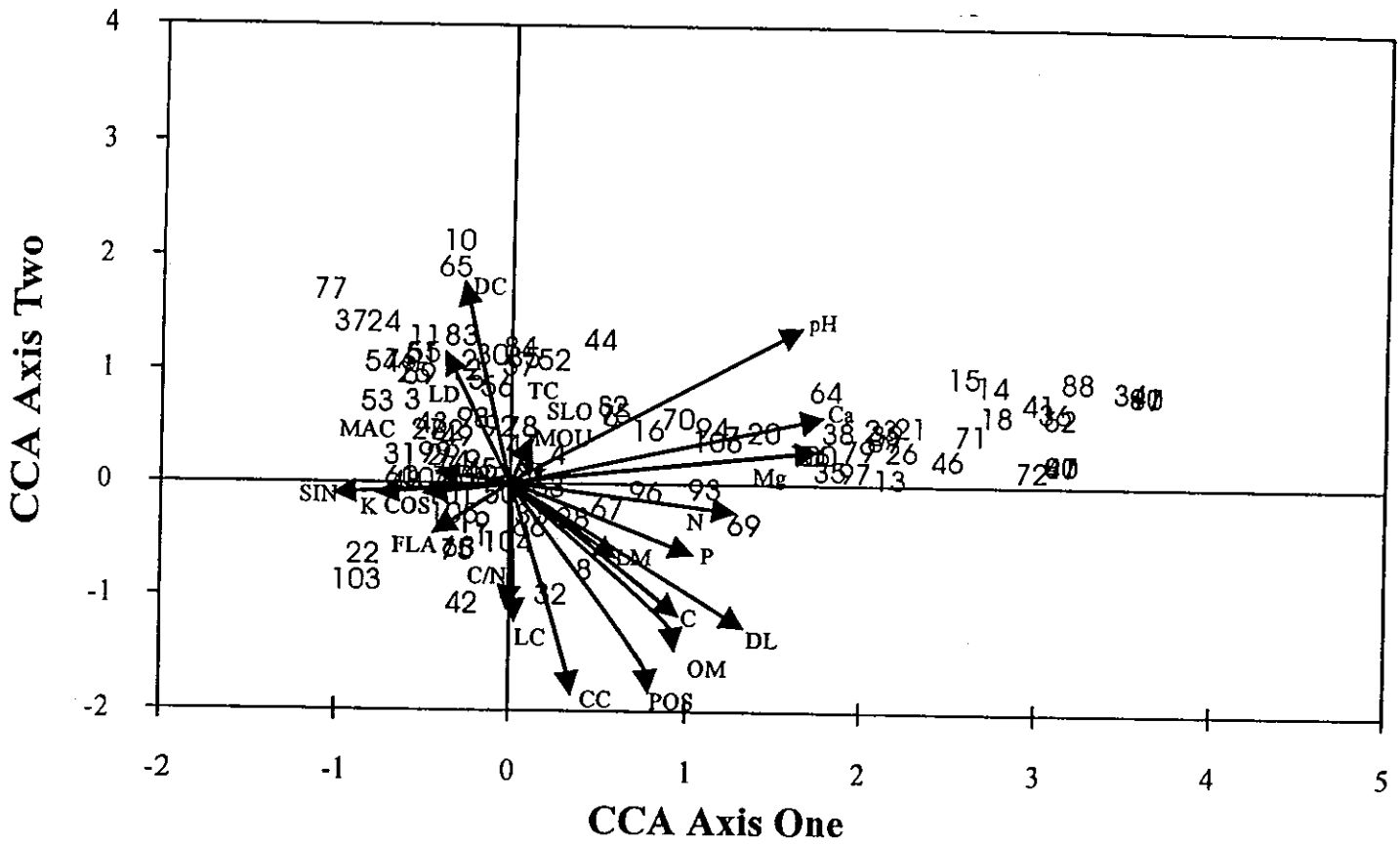
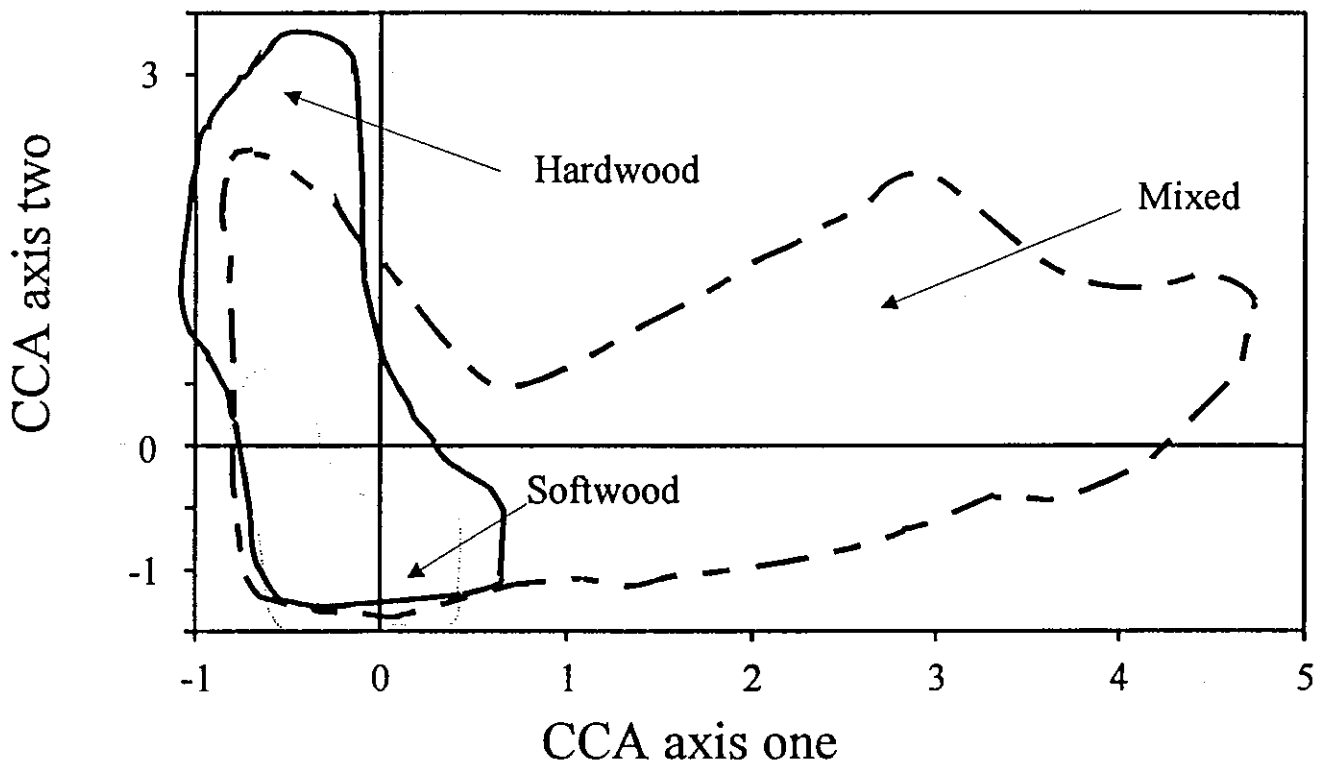


Figure 12. Distribution of 169 5m^2 quadrats (grouped by stand type) on the first two axes of Canonical Correspondence Analysis (CCA).



The distribution of the softwood mixed and hardwood stand types (Figure 12) were similar to the CA ordination (Figure 11), except the softwood stands occurred in a tighter cluster at the low end of both axes.

Biplot scores of the environmental variables (Figure 11) indicate that litter calcium (#20), magnesium (#15), and pH (#11) were most positively correlated with CCA axis one, whereas sine and cosine of the slope (#17, #16) and litter potassium (#19) were negatively correlated with it. CCA axis two was positively correlated with percent deciduous canopy cover (#2) and litter depth (#4), and negatively correlated with coniferous litter (#7) and canopy(#3). Interset correlations are shown in Appendix II.

PCCA showed that canopy and topography accounted for $<10\%$ of the total inertia, or $<30\%$ of the variability in the species that was related to environmental factors (Table 4). Litter, uniquely and in combination, contributed approximately 15% of the total, or $>60\%$ of the CCA total.

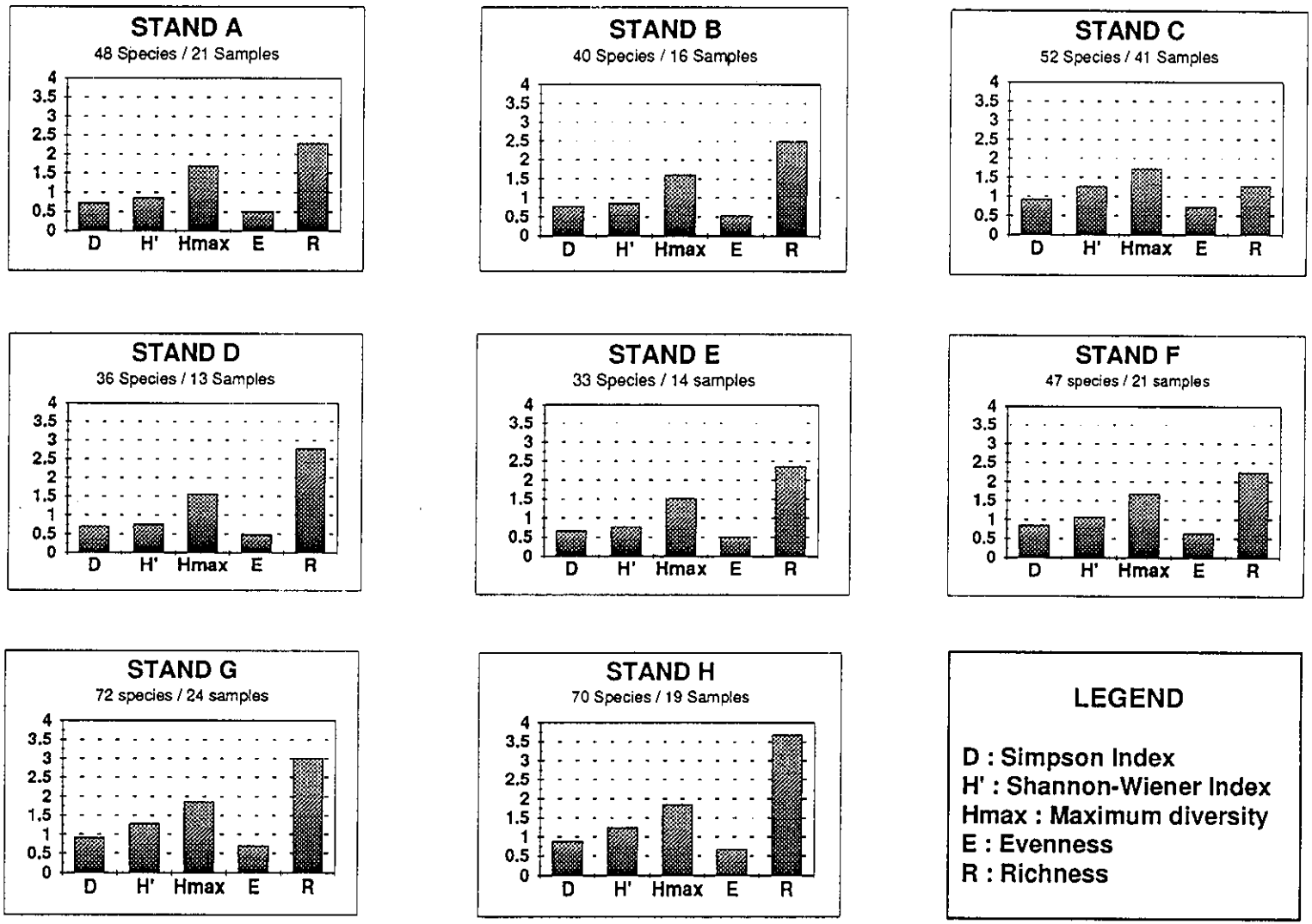
Table 4. **PCCA of the vegetation pattern in Hayward Brook, showing unique and shared contributions of environmental variables as a % of sum of canonical eigenvalues (= 1.582) and as % of the total inertia (= 6.582).**

	Environmental Variable Categories	Sum of eigenvalues	Percent of sum of canonical eigenvalues	Percent of total inertia (= 6.582)
Unique Effects	Litter	0.815	51.52	12.39
	Topography	0.347	21.93	5.27
	Canopy	0.108	6.83	1.64
Shared Contributions	Topography+ Litter	0.172	10.87	2.61
	Canopy+Litter	0.020	1.26	0.30
	Canopy+Topography	0.023	1.45	0.35
	Canopy+Litter+ Topography	0.097	6.13	1.47
	TOTAL	1.582	99.99	24.04

Diversity Indices

Diversity indices including the Simpson Index (D), the Shannon-Wiener Index (H'), maximum H', evenness and average richness were calculated for each stand type (Figure 13). Average richness was calculated as the total number of species in the stand divided by the number of samples (plots) in the stand. The differences between stands were small, except for average richness which may change from one stand to another because of the number of sample plots taken. Overall, stands A, B, D and E could be grouped together because of low Shannon-Wiener Index value ($H' < 1.0$), a low Simpson Index value ($D < 0.75$) and low evenness (approximately 0.5). Stands C, F, G and H had higher values than the above stands, with Shannon-Wiener Index values between 1.0 and 1.5, Simpson Index values from 0.75 to 1.0 and evenness above 0.5. Stands G and H had the greatest richness by far with 70-72 species (3.0-3.7 average richness). These results indicate that stands G and H contained the highest diversity of vascular plants before harvesting.

Figure 13. Diversity indices by stand type.



Post-Harvest Patterns

Disturbance Variables

The harvesting (both C and CS treatments) resulted in more softwood slash <0.5 cm than hardwood slash <0.5 cm. The C treatment caused more softwood slash <0.5 cm than the CS treatment, whereas the CS treatment caused more hardwood slash <0.5 cm than the C treatment (Figure 14 A-B). The cover of slash >0.5 cm had very little difference in the C and CS treatments (Figure 14 C).

Both the C and CS treatments created dense clumps of slash and areas with invisible substrate (Figure 14 D-E).

The CS treatment disturbed the forest floor more severely than the C treatment. The cover of disturbed litter, rock and exposed mineral soil was greater in the CS area than the C area (Figure 14 F-H). In addition, the cover of machine tracks was 20% in the CS area as compared to 8% in the C treatment. Conversely, cover of undisturbed litter was lowest in the CS treatment (10%) and highest in the UC treatment (90%).

Response of Herbaceous Layer Species to Harvesting

The initial effects of harvesting and site preparation were determined during the summer of 1996; these results represent vegetation response (survival and some initial germination) in the first growing season after harvesting. We will continue to monitor the plots in future years with a focus on the relationships between post-harvest species composition and disturbance factors (residual canopy cover, forest floor disturbance and slash levels).

Correspondence Analysis (CA) was applied to the herbaceous vegetation data collected in 1996. The plots were classified by treatment, i.e, clearcutting (C), clearcutting and scarification (CS) and uncut (UC). The results of CA showed that the total variation (inertia) of the herbaceous vegetation was 7.321 and the first four axes captured 26.1% of the variation.

The plots in the CS area tended to gather in the upper left quarter of the CA ordination of plots (Figure 15). The species diagram showed that many weedy species, hardwood seedlings and hardwood stump sprouts, such as *Acer spicatum, Prunus pensylvanica, Achillea millefolium, Aster lateriflorus* and *Epilobium angustifolium* occurred in these plots (Figure 16).

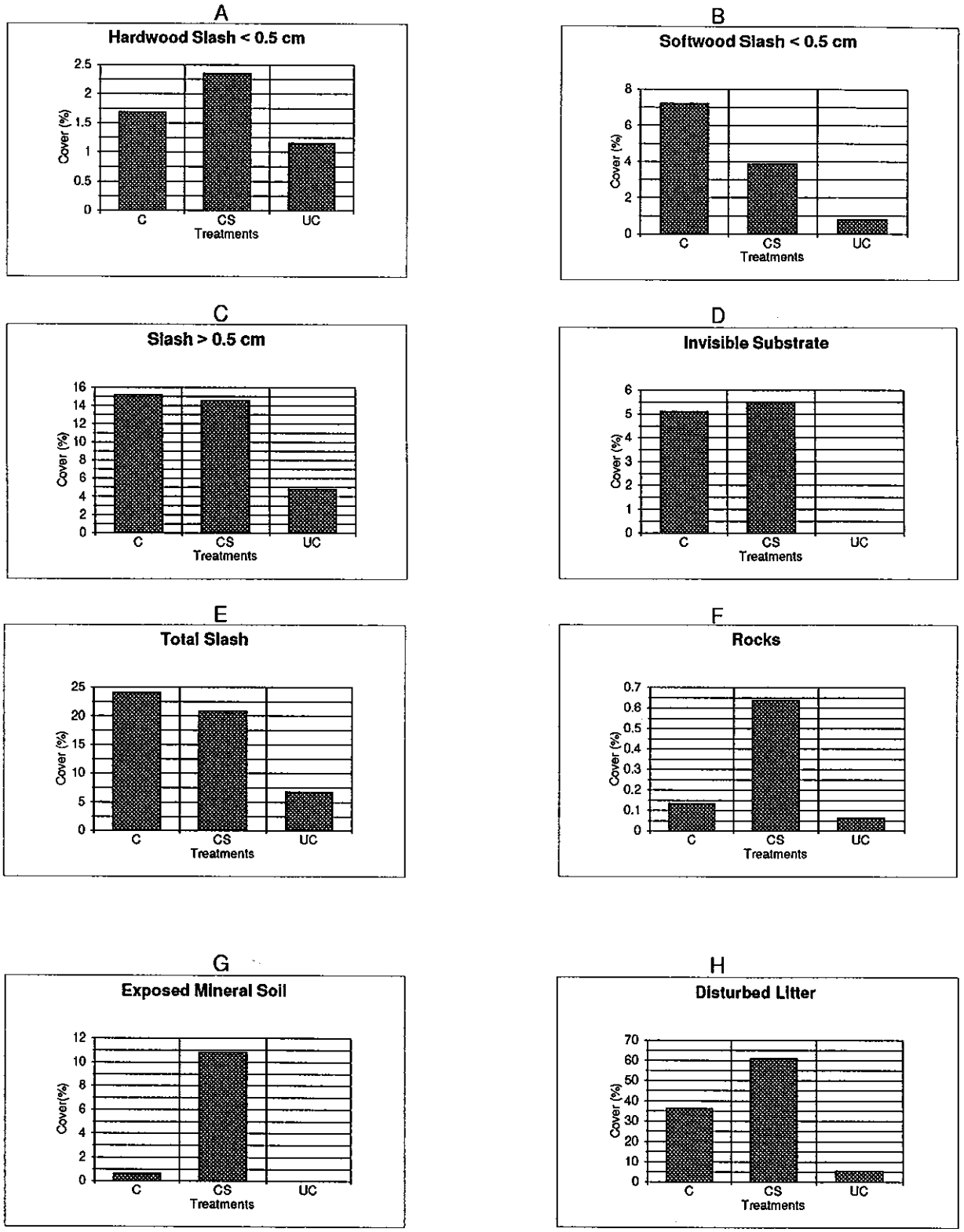


Figure 14 Disturbance conditions in the C, CS and UC areas

Figure 15. Plot scores on the first two axes of Correspondence Analysis (CA) on 169 - 5m^2 plots (grouped by treatment type) in the first year after harvest (1996). Codes indicate plot numbers.

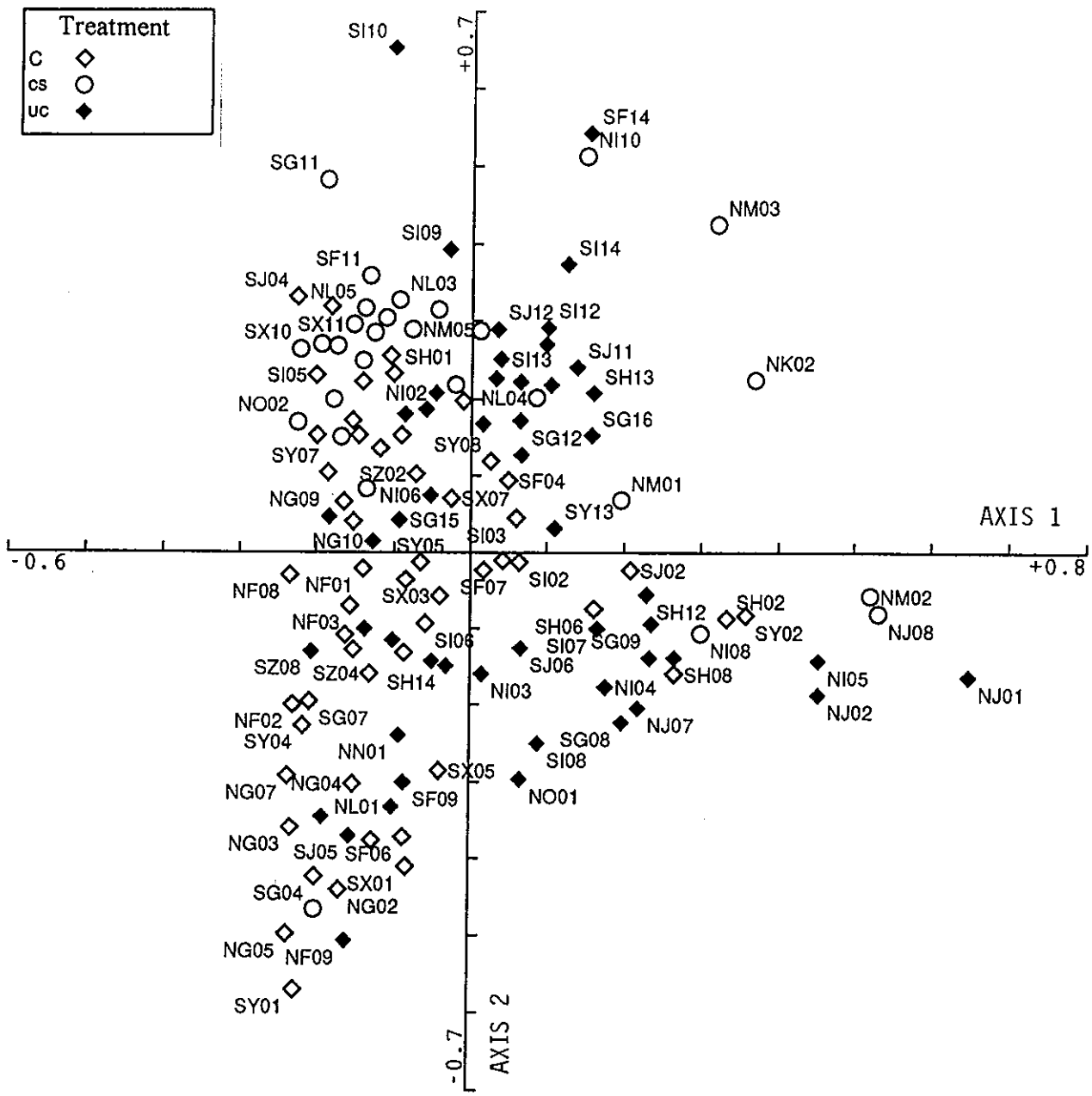
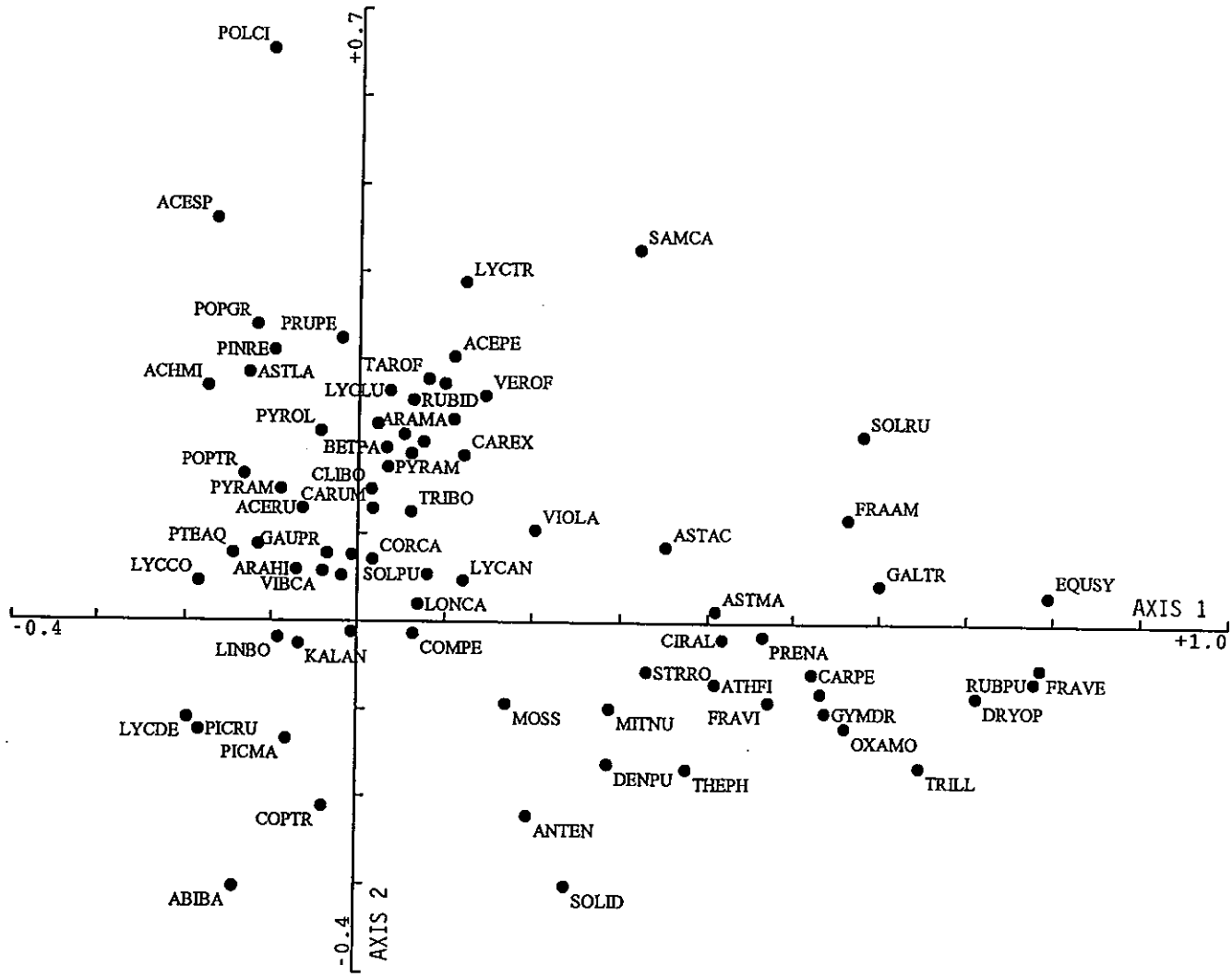


Figure 16. Species scores on the first two axes of Correspondence Analysis (CA) on 169 - 5m^2 plots (grouped by treatment type) in the first year after harvest (1996).



Most of the plots in the C treatment were grouped in the left half of the plot diagram (Figure 15). In addition to the species listed above, many other species which are found in open and dry conditions occurred in these plots, such as *Populus tremuloides, Acer rubrum, Pinus strobus, Viburnum cassinoides, Aralia hispida, Pteridium aquilinum, Pinus resinosa, Lycopodium obscurum, Lycopodium dendroides, Vaccinium myrtilloides, Picea rubens* and *Maianthemum canadense* (Figure 16).

In the right-most portion of the plot diagram (Figure 15), most of the plots were those located in the bottom of the watershed, where conditions were relatively wet and rich. The species occurring in these plots were *Equisetum sylvaticum, Rubus pubesens, Fragaria vesca, Dryopteris sp., Trillium sp., Oxalis montana, Galium triflorum* and *Fraxinus americana* (Figure 16).

The species number in the whole study area decreased from 106 to 91 after harvesting. In the CS area, 23 species were lost and 20 species invaded after harvesting; species richness changed from 82 to 79. The species lost were *Acer saccharum, Actaea rubra, Aster ciliolatus, Brachyelytrum erectum, Dennstaedtia punctilobula, Goodyera tellelata, Linnaea borealis, Luzula acuminata, Lycopodium annotinum, Lycopodium complanatum, Medeola virginiana, Moneses uniflora, Monotropa hypopithys, Orthilia secunda, Osmumda spp., Prunella vulgaris, Ribes lacustre, Solidago flexicaulis, Sphagnum spp., Streptopus amplexifolius* and one unknown species. The species which invaded were *Anaphalis margaritacea, Aralia hispida, Betula papyrifera, Epilobium angustifolium, Fragaria virginiana, Hieracium sp., Lycopodium lucidulum, Lycopodium tristachyum, Mentha arvensis, Osmunda cinnamomea, Pinus resinosa, Plantago major, Polygnum cilinode, Prunus pensylvanica, Rubus idaeus, Sambucus canadensis, Solidago rugosa, Taraxacum officinale* and *Veronica officinalis*.

In the C area, 19 species were lost and 10 species invaded after harvesting, with a decrease in species richness from 60 to 51. The species lost were *Achillea millefolium, Alnus rugosa, Aster macrophyllus, Cypripedium acaule, Dalibarda repens, Dryopteris sp., Gaultheria hispidula, Medeola virginiana, Mitella nuda, Orthilia secunda, Oryzopsis asperifolia, Osmunda spp., Oxalis montana, Sphagnum sp., Streptopus roseus, Thelypteris noveboracensis, Vaccinium vitis-idaea* and *Veronica officinalis*. The species which invaded were *Aralia hispida, Comptonia peregrina, Epilobium angustifolium, Hieracium sp.,*

Lycopodium annotinum, Populus grandidentata, Prunus pensylvanica, Osmunda claytoniana, Rubus idaeus and *Solidago sp.*.

Diversity indices were also changed by the harvesting. In the CS area, both average species richness per plot and the average Shannon-Wiener index per plot decreased after the harvesting. The average species richness per plot was 16.2 before harvesting and 15.5 after harvesting. The Shannon-Wiener index was 0.791 before harvesting and 0.759 after harvesting. In the C area, species richness per plot decreased but the Shannon-Wiener index increased. Species richness per plot was 11.83 before harvesting and 11.14 after harvesting. The Shannon-Wiener index was 0.5966 before harvesting and 0.6578 after harvesting.

DISCUSSION

Pre-Harvest Patterns

The Hayward Brook stand types are found in the Anagance Ridge Ecodistrict which contains coniferous vegetation of spruce and fir mixed with intolerant hardwoods and scattered pines. Higher hills with more fertile soils in this Ecodistrict contain tolerant harwood species such as beech, sugar maple, and yellow birch, with a minor component of white ash and ironwood according to NBDNRE (1996), although our stand type inventory showed a dominant forest canopy of intolerant hardwood such has white birch and red maple. Ironwood and white ash were present as minor species in one midslope stand (stand G). A long history of fire and forest cutting has favored the maintenance of trembling aspen and largetooth aspen which are found on this site (Rowe 1977). The large red and white pines and the jack pines might also have been favored by the past fires.

Measures of species richness determined that on average there were 15 species/5 m^2 within the study area. Comparisons with the literature are difficult due to the differences in scales; this study used 5 m^2 plots , whereas others generally use 1 m^2 plots for herbaceous vegetation (Smith 1980). Richness is expected to increase with plot size (Ashby 1971).

The total cover of herbaceous species ranged from 0-175 % within the plots, with a low mean evenness (80 % of species occurred in $\leq$ 20 % of plots) (Fig. 5). This component of diversity showed that there were many infrequently represented species. Some were particularly uncommon both in the study site and in this geographical area, e.g., the orchids *Cypripedium acaule* and *Goodyera tesselata* and some of the Pyrolaceae, including *Chimaphila umbellata* and *Pyrola americana* (Table 1) (Hinds 1986).

Species evenness was determined to be relatively low primarily because there were many species that occurred infrequently or with low cover within the plots, whereas a few other species had consistently high frequency and cover, e.g. moss spp., *Maianthemun canadensis*, *Pteridium aquilinum*, and *Abies balsamea*.. The richness of the area was high, however, with a relatively large number of species present within the study area.

The first CA axis appears to represent a broad scale moisture gradient. *Sphagnum spp.*, *Moneses uniflora*, and many fern species (*Thelypteris noveboracensis*, *Thelypteris phegopteris*, *Osmunda spp.*, *Athyrium filix-femina*, and *Gymnocarpium dryopteris*) at the high end of CA axis one are characteristically associated with moist to wet habitats, whereas those

at the other end (*Lycopodium spp.*, *Cornus canadensis*, and *Vaccinium vitis-idaea*) are generally associated with drier habitats. The stand types also demonstrated this moisture gradient, with both softwood (A) and mixed (G) stands at the high end of axis one. This study did not measure moisture directly, but moisture can be deduced from stand types as well as factors influencing drainage. For example, steepness of slope and position on the slope (e.g.. top vs. bottom) influence moisture retention and drainage directly.

Furthermore, steepness and aspect of the slope, along with canopy height, will determine the path and duration of insolation and will affect moisture availability (Collins *et al.* 1985). However, the PCCA indicated topography (including macro slope position, slope of the plot, and moundedness/pittedness of the area etc.) accounted for approximately 6% of the total inertia. The common influence of canopy and topography, which includes precipitation interception by the canopy, accounted for only 10% of the total inertia.

The second CA axis was related to canopy oriented factors. At the low end were predominately coniferous stands (A,B,D,E) and species which are common under a coniferous canopy, e.g.. *Gaultheria hispidula*, *Coptis trifolia*, and seedlings of *Abies* and *Picea* species. At the high end were typically deciduous stands (C, H) and species common under deciduous canopies: *Pyrola spp.*, *Aralia nudicaulis* , *Medeola virginiana*, and *Chimaphila umbellata.* Canopy type influences both the light available to the understorey, and rainfall interception (Anderson *et al.* 1969). However, canopy cover and its composition accounted for only 4% of the total inertia that could be captured by the environmental variables measured.

The pattern of herbaceous species is therefore only weakly correlated with the canopy and topography variables measured in this study. Species presence / absence at the plot scale is therefore not primarily related to the amount or composition of canopy cover, implied moisture levels, or even the drainage pattern of the area.

Other features related to canopy, such as the litter fall and decomposition, may have more intimate effects on the herbaceous understorey vegetation. The grouping of herbaceous species according to canopy may result from the type and amount of litter such canopy produces, as shown in the PCCA. Further, the litter variables most closely related to vegetation in this study were primarily litter chemistry: litter pH, and calcium and magnesium contents, which are influenced by the historical accumulation of past canopies.

Litter pH had the strongest correlation with vegetation composition. Its importance may be due to its influence on chemical availability of the nutrients from the decomposing litter in soil solution. The chemical forms, and thus solubility, of certain elements, change with pH (Mauseth 1995). Nutrients in the litter layer may also be in unavailable inorganic forms until after some microbial decomposition has occurred. The rate of the nutrient cycling varies with both the nature of the litter and the environmental conditions (Brady 1974). For example, coniferous litter with its high concentration of lignin is both mechanically difficult to break down and sufficiently acidic to inhibit many microbial decomposers. In contrast, litter from angiosperms and deciduous trees have a higher surface area to volume ratio, making it easier to mechanically break down and have a lower concentration of tannins, making it less acidic to the microbial decomposers. Similarly, the two types of litter decomposition are inhibited by waterlogged conditions.

There are several ways to account for the remainder (76.96%) of community structure that was not related to environmental variables used in this study.

1) Equilibrium models would predict that the herbaceous community is structured by some critical environmental variables that were not measured in this study, such as soil chemistry or moisture. The species present would be there because they have out-competed all competitors to utilize the resources available within the environment. Based on these models, the resulting post-disturbance community will return to pre-disturbance structure given enough time for the best competitors to re-establish themselves.

2) Non-equilibrium models would predict that the herbaceous community is structured by stochastic processes. For example, localized disturbances may displace superior competitors, allowing weaker competitors to persist in the community; this is the premise of gap dynamics models. Disturbances increase the heterogeneity of the landscape, and break up monospecific patches by allowing different species to become established (Thompson 1980). Other stochastic processes contribute to unique history of the stand (Smith and Cottam 1967). The past fire regime in the area may affect the herbaceous community, but this would more than likely be at the stand scale. The occurrence of isolated lightening strikes, however, may affect the herbaceous community at a localized scale. Based on these models, the post-disturbance community is unpredictable and may not resemble the pre-disturbance community.

3) The underlying pattern by which the vegetation was originally structured may have become blurred over time, and the resulting correlations with the habitat characteristics may no longer be detectable. For example rhizomatous species become established according to habitat preference, but clonal spread would increase their range by allowing surplus resources to be channeled into ramets in less suitable environments.

4) Sampling and analytical procedures affect the ability to detect patterns. Correspondence analysis detects only linear relationships within and between data (ter Braak 1988). It is possible that the relationship between species and environmental variables is non-linear, much like a bimodal or bell-shaped range of tolerance for a species. However, this technique is considered to be sufficiently robust to deal with some curvature, and a trial analysis using detrending (means of removing curvature) did not significantly increase information capture.

Similarly, pattern detection is influenced by the scale of sampling. The spatial scale of 5 m^2 used to sample vegetation and environmental features in this study may be unsuitable in that, factors affecting a small localized area may not be the same factors that affect populations at a larger scale. However, personal observation suggests that the scale was appropriate because: (a) the quadrat size was sufficient to capture most species in the area and (b) the environmental variables measured in this study appear to vary at the plot.

Post-Harvest Patterns

Harvesting treatments, both C and CS, removed the canopy and exposed the forest floor to sunlight and desiccating winds. The environmental conditions in the herbaceous layer were changed from favouring forest species, which need shade and moisture, to favouring weedy species, which need more sunlight. Though many forest species survived through the changes, some of them were lost while some weedy species invaded. In the CS area, the forest species that were lost included: *Actaea rubra, Brachyelytrum erectum, Goodyera tesselata, Linnaea borealis, Luzula acuminata, Medeola virginiana, Moneses uniflora, Monotropa hypopithys, Orthilia secunda, Solidago flexicaulis* and *Streptopus amplexifolius.* The weedy species which invaded were *Anaphalis margaritacea, Aralia hispida, Betula papyrifera, Epilobium angustifolium, Fragaria virginiana, Mentha arvensis, Plantago major, Polygnum cilinode, Rubus idaeus, Sambucus canadensis, Taraxacum officinale* and *Veronica officinalis.* In the C area, the lost forest species were *Cypripedium acaule, Dalibarda repens, Gaultheria hispidula, Medeola*

virginiana, Mitella nuda, Orthilia secunda, Oryzopsis asperifolia, Oxalis montana, Sphagnum spp., Streptopus roseus, Thelypteris noveboracensis and *Trillium undulatum*. The weedy species which invaded were *Aralia hispida, Comptonia peregrina, Epilobium angustifolium, Populus grandidentata* and *Rubus idaeus*.

The physical damage that resulted from harvesting also might have caused the loss of some species, especially the rare ones, which occurred in very few plots before harvesting. In the CS area, *Acer saccharum, Dennstaedtia punctilobula, Lycopodium annotinum, Prunella vulgaris* and *Ribes lacustre* were such rare species. In the C area, *Achillea millefolium, Alnus rugosa, Aster macrophyllus, Dryopteris sp., Vaccinium vitis-idaea* and *Veronica officinalis* were such rare species.

Some rare forest species, such as *Goodyera tesselata* in CS area, were susceptible to both changes in environmental conditions and physical damage caused by harvesting.

It was found that more forest species were lost and more weedy species invaded in the CS area than in the C area. This is due to the difference in the disturbance intensities caused by the two harvesting treatments. In the CS area, the canopy was removed and the advance regeneration was mostly destroyed in the harvesting, while in the C area, much of the advance regeneration was retained and provided some shade to the forest floor after harvesting. In addition, the CS treatment caused more physical damage to the herbaceous layer than the C treatment.

After the C and CS treatments, many forest species were lost but not as many weedy species invaded to take their place in the first year just after the harvesting, resulting in an overall decline in species richness. The Shannon-Wiener index increased in the C treatment and decreased in the CS treatment. The Shannon-Wiener index is made up of two components: species richness and evenness. The C treatment increased diversity by reducing the dominance of a few species and increasing evenness since the species richness after harvesting in C area was lower than before harvesting. How the Shannon-Wiener index was reduced in the CS treatment is not clear; species richness declined but evenness may or may not have decreased.

This study has identified a number of species that are eliminated or significantly reduced in abundance by harvesting. These species could be used as criteria and indicators of sustainable forest management and should be the focus of monitoring efforts. Additional species may be lost and some of the species that were initially lost may reinvade with time. Additional monitoring will be required before a complete list of indicator species can be finalized.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Correspondence analysis of the pre-harvest herbaceous community in the Hayward Brook Watershed, southeastern New Brunswick, indicated that the community composition was most highly correlated with litter variables (> 60%) and less so with those of canopy, topography and aspect. Composition was strongly related to litter chemistry, specifically pH, and calcium and magnesium components. The herbaceous community had low species evenness. However, the community was rich with species that are particularly uncommon for the area; this increased the relative diversity of the area.

There is concern that many of the rare species, i.e. those that were infrequent or had low cover values, will be at risk following forest harvest. Catastrophic disturbance such as clearcutting would be expected to have profound effects on herbaceous community diversity: it may eliminate these species locally, it may increase the chance of new species colonizing the area, it may change the relative abundances of the species that were present in the pre-disturbance community, or a combination of these may result. It is essential to track the post-disturbance response of species in relation to stand development stages and site quality to determine the effects of forest management practices and the effect of clearcutting on the biodiversity of the herbaceous vegetation in a mixed forest setting. This study provides baseline data against which changes can be detected.

It is also important to determine where unique herbaceous communities and uncommon species occur within the study area to propose strategies for protecting or managing these areas. This study has delineated the stand types and herbaceous communities associated with those stand types within the study area. In addition, the relationships between these communities and environmental factors have been identified. With this information, predictions of the location of certain communities can be made based on simple environmental factors, including topography and canopy composition. This will simplify the sampling of herbaceous communities and will facilitate management planning.

This study has also provided critical information for identifying indicator species of sustainable forst management. Those species that were lost or significantly reduced by harvesting provide a focus for monitoring and assessment.

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Appendix I. Summary of PCCA procedure. In each analysis (numbered), the environmental data set was successively partitioned to isolate individual environmental variable groups by assigning the remainder as covariates. The sum of eigenvectors (CEV) represents the unique contribution of the canonical variables.

	Canonical	Covariate	CEV
1.	All	None	1.582
	Topography+Litter	Canopy	1.334
	Topography	Canopy+Litter	0.347
2.	Topography+Canopy	Litter	0.478
	Canopy	Topography+Litter	0.108
3.	Litter+Canopy	Topography	0.943
	Litter	Topography+Canopy	0.815

Appendix II. Weighted correlation matrix for the first two species and environmental Canonical Correspondence Analysis (CCA) axes vs environmental variables.

Environmental Variable	Species CCA Axis 1	Species CCA Axis 2	Env. CCA Axis 1	Env. CCA Axis 2
Total canopy	0.0612	0.1721	0.0693	0.2132
Deciduous canopy	-0.0944	0.6299	-0.1070	0.7803
Coniferous canopy	0.1068	-0.5861	0.1210	-0.7261
Litter depth	0.4841	-0.4545	0.5486	-0.5630
Moss litter	0.2363	-0.2492	0.2678	-0.3087
Deciduous litter	-0.1119	0.4281	-0.1268	0.5303
Coniferous litter	0.0213	-0.4307	0.0241	-0.5335
Slope 1	0.0527	0.0367	0.0597	0.0454
Slope	0.0757	0.0774	0.0858	0.0959
Pit	-0.0211	0.0228	-0.0240	0.0283
Mound	0.0675	0.0896	0.0765	0.1110
Flat	-0.1389	-0.1782	-0.1574	-0.2207
Macrotopography	-0.1620	0.0392	-0.1836	0.0486
Slope2	0.1435	0.2249	0.1626	0.2786
Slope position	0.2862	-0.5780	0.3243	-0.7160
Cosine of slope	-0.2142	-0.0262	-0.2427	-0.0325
Sine of slope	-0.3593	-0.0237	-0.4072	-0.0294
Litter pH	0.5918	0.5014	0.6707	0.6211
Litter K	-0.2560	-0.0219	-0.2901	-0.0272
Litter Ca	0.6316	0.2304	0.7158	0.2853
Litter Mg	0.6251	0.1091	0.7084	0.1351
Litter P	0.3663	-0.2141	0.4151	-0.2652
Litter C	0.3273	-0.4200	0.3709	-0.5203
Litter N	0.4472	-0.0888	0.5068	-0.1100
C/N ratio	0.0019	-0.3383	0.0021	-0.4191
Organic matter	0.3292	-0.4184	0.3731	-0.5183