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# Plant Resilience After Harvesting In The Hayward Brook Watershed 1997-1998

FUNDY MODEL FOREST

FINAL REPORT

MARCH 31, 1998

(For 1997-98 Project Year)

# Plant Resilience after Harvesting in the Hayward Brook Watershed

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## EXECUTIVE SUMMARY

This report presents results of the third and final year of a study of the resilience of herbaceous-layer species to forest harvesting in the Hayward Brook Watershed. The study was established in spring 1995. The pre-harvest distribution of species in relation to environmental factors within the study area was determined in the first year. Vegetation was resampled and disturbance conditions were described after harvesting in the second year (1996-97). Results from the first two years were presented in the 1995-96 and 1996-97 final reports. In this report, we summarize key findings relative to two deliverables addressed in previous final reports and address four new deliverables in detail, which focus on the recovery of vascular species in the herbaceous layer in the second growing season after harvesting in relation to harvesting treatments and biodiversity indicators for sustainable forest management.

Several lines of evidence suggest that forest harvesting may have long-term effects on herbaceous-layer species. First, direct comparisons of harvested and old-growth stands indicate that some species are lacking in the harvested stands even after 100+ years. Second, historical studies indicate that several forest types and many forest species have declined in abundance or have become extinct in North America as a result of the combined effects of European settlement. Finally, recent studies show that direct disturbance to the forest floor layer and changes in microclimate brought about by harvesting eliminates some species and greatly reduces the abundance of others in the first few years. Although many of these species may reinvade with time as the microclimate returns to pre-harvest levels, the limited dispersal and slow rate of expansion of many herbaceous species may prevent their recovery within the time period between successive harvest rotations. Thus, some species may gradually decline in abundance and eventually become extinct through the combined effects of successive harvests. Although we would expect to see similar changes in understory composition and abundance following natural disturbances such as fire or spruce budworm defoliation, intensive forest management practices (e.g., clearcutting with site preparation and planting, followed by herbicide application in years 3-5) involves more complete removal of canopy cover and woody biomass (including snags), and greater forest floor disturbance (depending on harvest system). Thus, we would expect to encounter more extreme conditions for herbaceous-layer plants in harvested stands than in naturally disturbed stands, and thus a greater potential loss of species and slower recovery rate in harvested stands.

Given the importance of the herbaceous layer in ecosystem function and biodiversity, as well as their economic importance, either directly in the form of specialty products or indirectly by providing competition or protective cover for seedlings of commercial tree species, it is critical to understand the response of this layer to forest harvesting. Indeed, because herbaceous-layer species constitute the majority of plant biodiversity in forests, are non-mobile, and are sensitive to changes in their environment, they are useful indicators of sustainable forest management (C&I criterion 1.2). The integrity of the herbaceous layer is a cornerstone of sustainable forest management. The global objective of this study is to assess the response of the herbaceous layer to specific forestry practices on a range of site conditions, identify species that may be at risk from harvesting (biodiversity indicators), and provide guidelines for harvesting which will minimize impacts on biodiversity.

**Deliverable 1: Document herbaceous-layer species (vascular plants, including trees and shrubs <1m tall), their abundance, and their habitat distribution before harvesting, relative to site characteristics. (C&I 2.2a, 1.1a/b, 1.2c)**

The study area occurs within the Continental Lowlands Ecoregion of New-Brunswick and the Anagance Ridge Ecodistrict 29 (NBDNRE 1996). Eight stand types identified in the FMF GIS database were characterized in terms of their overstory composition. Percent cover of all 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. 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.

**Deliverable 2: Assess specific disturbance conditions (e.g. degree of mineral soil exposure, slash loads) associated with specific forestry practices (clearcutting with natural regeneration, clearcutting followed by site preparation and planting). (C&I 2.1i, 3.1a)**

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), significantly more softwood slash and greater slash heights were created, less litter was disturbed, less mineral soil was exposed, and less area in machine tracks was created than in the other area that was clearcut, scarified (barrels and chains) and planted (CS).

**Deliverables 3 & 4: Determine survival of herbaceous-layer species and their microsite distribution immediately after the above harvesting regimes, relative to site characteristics and disturbance conditions; and document regeneration of herbaceous-layer species following harvest, relative to site and disturbance. (C&I 1.2b, 4.1c).**

The vegetation in the first two years after harvesting was affected by the intensity of the disturbance caused by the treatments, as indicated by cover of exposed mineral soil, undisturbed litter, coniferous and deciduous canopy, and slash. Post-harvest composition was also significantly related to the treatments and stand types which contained unique species. High canopy removal and forest floor disturbance are associated with more weedy invaders while high canopy cover and less forest floor disturbance are related to the survival of pre-harvest species. The CS treatment caused a greater shift in species composition away from unharvested conditions.

The similarity index is a sensitive indicator of sustainable forest management because it integrates changes in all species. Thus, when combined with changes in presence and abundance of individual species, the similarity index provides a complete picture of the effects of forestry practices and a measure of the degree of change relative to unharvested conditions.

**Deliverable 5: Provide lists of herbaceous-layer species that may be at risk under specific harvesting and site preparation treatments. (C&I 1.2b).**

All species that disappeared or greatly declined in abundance in the harvesting treatments were evaluated for suitability as indicator species. Species that may occur in open, disturbed areas and those that are known to readily reinvade within 1-2 decades after harvesting were removed from the list. The final list includes ten species that are indicators for both C and CS treatments: *Chimaphila umbellata, Clintonia borealis, Coptis trifolia, Linnaea borealis, Lycopodium dendroides, Mitchella repens, Mitella nuda, Orthilia secunda,* and *Oxalis montana.* Six species were indicators in the C treatment, including *Aster acuminatus, Cypripedium acaule, Gaultheria hispidula, Medeola virginiana, Thelypteris noveboracensis* and *Vaccinium vitis-idaea.*

There were 16 indicator species for the CS treatment, including *Aster lateriflorus, Aster umbellatus, Brachyelytrum erectum, Dennstaedtia punctilobula, Dryopteris sp., Goodyera tesselata, Gymnocarpium dryopteris, Lonicera canadensis, Luzula acuminata, Lycopodium clavatum, Moneses uniflora, Monotropa hypopithys, Pyrola americana, Ribes lacustre, Streptopus amplexifolius* and *Thelypteris phegopteris*. More species were affected by the CS treatment than the C treatment.

This final list of indicator species (32 total) represents the species that are negatively impacted by harvesting and that may have limited ability to reinvade cutovers. This list is our best estimate of indicators for sustainable forest management. These species should be the focus of monitoring efforts.

**Deliverable 6: Provide management guidelines for harvesting which will minimize impacts on biodiversity. (C&I 1.2b).**

1. To maintain populations of pre-harvest species, the advance regeneration, which provides the main shading after harvesting, should be preserved as much as possible during harvesting operations.
2. Forest floor disturbance, in terms of exposing mineral soil and disturbing the litter layer, should be minimized. Managing for natural regeneration where possible and using light forms of site preparation such as patch scarification are preferred.
3. Creating areas with excessive slash cover should be avoided. Light slash can provide shade for herbaceous vegetation, but excessive slash smothers herbaceous vegetation.
4. Wet areas and diversity hot spots (areas with high species diversity) should not be harvested. These areas may be unique communities which should be closely monitored.
5. Survey prospective harvest blocks and identify areas containing indicator species or diversity hot spots before harvesting is conducted.
6. Leave uncut patches or strips as appropriate to preserve representative populations of these indicator species and unique communities. These patches should b placed in such a manner that representative examples of all community types are maintained.
7. Evaluate riparian buffer strips with respect to their effectiveness in maintaining viable populations of species at risk.

## ACKNOWLEDGMENTS

The pre-harvest distribution of species in relation to environmental factors within the study area was determined by A. Hovey as part of her honors thesis in Biology. Analyses of post-harvest disturbance conditions and vegetation were carried out by L. Zhu as part of his M.Sc.F. program.

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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. Indeed, the Fundy Model Forest has explicitly identified species diversity as one of the main indicators of sustainable forest management (C&I 1.2).

Several lines of evidence suggest that forest harvesting may have long-term effects on herbaceous-layer species. First, direct comparisons of harvested and old-growth stands indicate that some species are lacking in the harvested stands even after 100+ years (Duffy and Meier 1992, Halpern and Spies 1995). Second, evidence from early botanical descriptions suggests that many forest species have declined in abundance or have become extinct in North America as a result of the combined effects of European settlement. For example, entire forest types (e.g., mature, tolerant hardwoods on calcareous soils) have been fragmented and dramatically reduced in abundance. Herbaceous species characteristic of these forests have also been dramatically reduced or lost. Finally, evidence from this study and others indicate that direct disturbance to the forest floor layer and changes in microclimate brought about by harvesting eliminates some species and greatly reduces the abundance of others. Although many of these species may reinvade with time as the microclimate returns to pre-harvest levels, the limited dispersal and slow rate of expansion of many herbaceous species may prevent their recovery within the time period between successive harvest rotations. Thus, some species may gradually decline in abundance and eventually become extinct through the combined effects of successive harvests.

To a certain extent, we would expect to see similar changes in understory composition and abundance following natural disturbances such as fire or spruce budworm defoliation. The fact remains, however, that intensive forest management practices (e.g., clearcutting with site preparation and planting, followed by herbicide application in years 3-5) differ in important ways from natural disturbances. These differences include more complete removal of the dominant canopy, removal of a greater proportion of woody biomass and snags, and greater forest floor disturbance (depending on harvest system) in harvested stands. Thus, we would expect to encounter more extreme conditions for herbaceous-layer plants in harvested stands than in naturally disturbed stands. The integrity of the herbaceous layer is a cornerstone of sustainable forest management.

Given the importance of the herbaceous layer in ecosystem function and biodiversity, as well as their economic importance, either directly in the form of specialty products or indirectly by providing competition or protective cover for seedlings of commercial tree species, it is critical to understand the response of this layer to forest harvesting. Indeed, because herbaceous-layer species constitute the majority of plant biodiversity in forests, are non-mobile, and are sensitive to changes in their environment, they are useful indicators of sustainable forest management (C&I criterion 1.2). The global objective of this study is to assess the response of the herbaceous layer to specific forestry practices on a range of site conditions, identify species that may be at risk from harvesting, and provide guidelines for harvesting which will minimize impacts on biodiversity.

In a previous study, we provided an analysis of patterns of change in stand structure, composition and diversity in plantations from age 5 to 17 years and compared the results to mature natural stands in Fundy National Park (Roberts and Methven 1996). The current study was initiated in 1995 to assess the initial effects of harvesting on plant composition and diversity. Thus, this study complements the earlier chronosequence study by describing patterns before year 5 and providing assessments of the effects of different harvesting treatments (clearcutting with site preparation and planting vs. clearcutting with natural regeneration) on early recovery of the herbaceous layer. The first year (1995-96) of the current 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. Results from the first two years were presented in the 1995-96 and 1996-97 final reports. In this report, we summarize key findings from the first two years (deliverables 1-2) and address four new deliverables in detail, which focus on the recovery of vascular species in the herbaceous layer in the second growing season after harvesting in relation to harvesting treatments and the disturbance conditions created by these treatments.

**Deliverables**

1. Document herbaceous-layer species (vascular plants, including trees and shrubs <1m tall), their abundance, and their habitat distribution before harvesting, relative to site characteristics.
2. Assess specific disturbance conditions (e.g. degree of mineral soil exposure, slash loads) associated with specific forestry practices (clearcutting with natural regeneration, clearcutting followed by site preparation and planting).
3. Determine survival of herbaceous-layer species and their microsite distribution immediately after the above harvesting regimes, relative to site characteristics and disturbance conditions. This provides information on availability of propagules and suitability of substrate and microclimate conditions.
4. Document regeneration of herbaceous-layer species following harvest, relative to site and disturbance.
5. Provide lists of herbaceous-layer species that may be at risk under specific harvesting and site-preparation treatments.
6. Provide management guidelines for harvesting which will minimize impacts on biodiversity.

## STUDY AREA AND METHODS

**Study Area**

This study was established in 1995, within the Hayward Brook Watershed, south of Petitcodiac, N.B. 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 is within the Continental Lowlands Ecoregion of New-Brunswick (NBDNRE 1996).

Before harvesting, the ridgetops contained stands of white birch (*Betula papyrifera* Marshall), red maple (*Acer rubrum* L.), trembling aspen (*Populus tremuloides* Michx.) and large-tooth aspen (*Populus grandidentata* Michx). Mixedwoods of 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) occupied mid-slopes. The bottom slopes were predominantely moist to wet areas with black spruce, red spruce, red maple and balsam fir. White pine (*Pinus strobus* L.) was 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.

N.B. site classification treatment units #6, 7, 9, 10 and 12 occur within the study area. These 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). Details of the study area are presented in Roberts (1997).

**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 in spring, 1995 (see Roberts 1997). 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.

The area was harvested by a feller-buncher, the trees were delimbed on site and carried out on a porter in August, 1995. Portions of the study area were scarified with barrels and chains in September, 1995. Plot centers were relocated and remarked in spring 1996. Disturbance and vegetation measurements were done in June-July, 1996, the first growing season after harvest. Vegetation measurements were taken again in June-July, 1997, the second growing season after harvest.

**Pre-Harvest Sampling - 1995**

A brief summary of sampling methods is presented below. Details can be found in Roberts (1997). For sampling the pre-harvest herbaceous layer, percent cover of all species of vascular plants was estimated in each 5 $m^2$ herb plot. 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.

The following environmental variables were measured in each plot:

(a) Litter composition - Percent composition of moss, needles, and leaves in the LFH layer of on a 3 point scale.

(b) Litter chemistry - Litter pH, total nitrogen, exchangeable cations (K, Ca and Mg), available phosphorus, percent carbon and organic matter.

(b) Mineral soil - Samples were collected for 88 sample plots located on every second transect. Samples were measured for pH, total nitrogen, exchangeable cations (K, Ca and Mg), available phosphorus, percent carbon, organic matter and soil texture.

(c) Plant tissue chemistry - 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 for concentrations of phosphorus (P), nitrogen (N), potassium (K), calcium (Ca) and magnesium (Mg).

(d) Canopy - Total canopy closure was estimated in each plot with a densiometer using the average of four readings. Total canopy closure as well as proportion of deciduous and coniferous canopy were tallied.

(e) Macrotopography - 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).

(f) Aspect and slope - Estimated using a compass and a Suunto clinometer. Aspect was expressed as the sine and cosine of azimuth, indicating the degree of "northness" and "eastness" respectively. Slope position was also recorded as (1) ridge top, (2) upper slope, (3) mid slope, (4) lower slope and, (5) flat at bottom of slope.

Stand types were delineated within the study area from stand cover type maps provided by the FMF (see Figure 1). 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. The results are condensed in Table 1.

**Post-Harvest Sampling - 1996**

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. After relocating plot centers and replacing plot stakes destroyed by harvesting, disturbance conditions were measured from May 27 to June 14. To quantify disturbance, three groups of variables were measured, i.e., slash coverage, substrate and tracks. The following variables were measured:

**Table 1.** Overstory, understory and site characteristics 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.

STAND A - 26

| OVERSTOREY SPECIES | BA m2/ha | density #tree/ha | dbh-mean cm | UNDERSTOREY density #small trees/ha |
|---|---|---|---|---|
| BSP | 9.00 | 905.51 | 11.33 | 825.00 |
| RM | 8.00 | 419.62 | 15.92 | 0.00 |
| RSP | 6.00 | 232.34 | 9.28 | 100.00 |
| DEAD | 4.50 | 285.90 | 20.83 | 0.00 |
| TA | 3.00 | 40.84 | 22.75 | 0.00 |
| 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 |

| SITE CLASS VT | ST | TU |
|---|---|---|
| 7 | 3 | 10 |

STAND B - 40, 36

| OVERSTOREY SPECIES | BA m2/ha | density #tree/ha | dbh-mean cm | UNDERSTOREY density #small trees/ha |
|---|---|---|---|---|
| BSP | 23.00 | 1226.46 | 19.49 | 150.00 |
| WB | 10.00 | 924.59 | 14.56 | 0.00 |
| 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 |

| SITE CLASS VT | ST | TU |
|---|---|---|
| | | |

STAND C - 42

| OVERSTOREY SPECIES | BA m2/ha | density #tree/ha | dbh-mean cm | UNDERSTOREY density #small trees/ha |
|---|---|---|---|---|
| WB | 11.5 | 848.486907 | 10.75 | 0 |
| RM | 7.5 | 1497.25862 | 7.152381 | 50 |
| TA | 4.5 | 211.764897 | 14.75 | 0 |
| DEAD | 3.5 | 197.726238 | 30.5 | 175 |
| 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 |

| SITE CLASS VT | ST | TU |
|---|---|---|
| 8 | 6 | 12 |

STAND D - 20

| OVERSTOREY SPECIES | BA m2/ha | density #tree/ha | dbh-mean cm | UNDERSTOREY density #small trees/ha |
|---|---|---|---|---|
| RM | 8.00 | 317.67 | 20.07 | 0.00 |
| RSP | 8.00 | 265.06 | 22.60 | 266.67 |
| 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 |

| SITE CLASS VT | ST | TU |
|---|---|---|
| 7 | 5 | 12 |

Table 1 (cont'd)

STAND E - 34, 31

| 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 |
|---|---|---|
| 5 | 3 | 7 |

STAND F - 38

| 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 |
|---|---|---|
| 5 | 6 | 6 |

STAND G- 29

| 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 |
|---|---|---|
| 11 | 2 | 9 |

STAND H -30

| 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 |
|---|---|---|
| 9 | 5 | 12 |

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.

*Diversity Indices*

The differences among stands in diversity indices, including the Simpson Index (D), the Shannon-Wiener Index (H'), maximum H', evenness and average richness, were small. 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. The high diversity here is likely the result of the presence of seepages. These areas represent diversity hot spots which would be important to protect in harvesting operations.

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, 'Y' (clumped) or 'N' (not clumped).

2.2. *Living Slash.* Living but damaged plants > 1 m tall 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). *Disturbed Litter.* The percentage cover of disturbed litter.

4). *Exposed Mineral 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). *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.

After disturbance conditions were measured, the herbaceous vegetation on all the plots was measured using the same methods used to sample preharvest vegetation. The vegetation sampling was conducted in June-July, as done in the preharvest sampling.

**Post-Harvest Sampling - 1997**

Percent cover of each species was recorded in the plots following the same methods used in 1995-96. Sampling was done at the same time as the 1995 and 1996 samplings (June-July). Canopy cover readings using the spherical densiometer were also repeated.

**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). Canonical correspondence analysis (CCA) was used to examine 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. Partial Canonical Correspondence Analysis (PCCA) was used to determine effects of specific environmental variable categories (ie. litter, canopy, topography).

In the disturbance data, clumped slash was treated as a categorical variable with the value of "y" for all plots in which clumped slash was present and "n' for plots without clumped slash. Type of chips and type of tracks were excluded from data analysis since most plots had no or very little chips and tracks.

The effects of harvesting disturbance on the species composition and diversity of the herbaceous layer were analysed in three steps: (1) the disturbance conditions were characterized in terms of canopy, slash and forest floor in the three treatments; (2) the changes in herbaceous vegetation after each treatment were determined; and (3) the relationships between the disturbance conditions and the post-harvest vegetation and between the harvesting treatment and the changes in herbaceous vegetation were assessed.

To test for differences in the disturbance conditions among the three treatments, one-way ANOVA and multiple-range tests (Tukey test) were done on each of the disturbance variables (except for clumped slash), with the treatment as the main factor. The raw data for all percentage variables were ARCSIN transformed before being tested because most of the values were smaller than 30% ( Zar, 1984). Slash height and living slash height were not transformed because they were not recorded as percentages. All tests were done using the Statistical Analysis System ( SAS Institute, 1985). Because the three treatments had unequal sample numbers, the general linear models procedure (proc GLM) was used for the ANOVA tests (SAS Institute, 1985).

The changes in vegetation after harvesting were determined by treatment in terms of species composition, cover of each species, diversity indices and similarity indices. Species which occurred in any plot in a treatment in a year was considered as present in that treatment and year. The cover of a species in a treatment was calculated by dividing the sum of the cover of the species in the treatment by the number of the plots in the treatment. Three indices, i.e., species richness ( R ), Shannon-Wiener index ( H' ) and Simpson index ( D ), were used to quantify the diversity. Sørensen's similarity index (IS) was used to determine the similarity between pre-harvest and post-harvest herbaceous vegetation of a plot. The similarity index was calculated as follows:

$$IS = \frac{2w}{a+b} * 100$$

where: w is the smaller of the two cover values in the two years involved for a given species, summed across all species;
a is the sum of all cover values in one year;
b is the sum of all cover values in the other years.

The similarity index gives an overall measure of vegetation similarity between any two communities based on the species present in each community and their abundances. For example, two communities with the same species, each species with the same percent cover in both communities, would have complete similarity (IS = 1). Two communities with no species in common would have no similarity (IS = 0). In the current study, the index provides a useful measure of the degree of change in vegetation composition after harvesting.

The three diversity indices were calculated for each plot in each year and a paired-sample t-test was used to determine whether their changes after harvesting were significant or not. One-way ANOVA was done to determine whether these indices were significantly different among the three treatment areas before and after harvesting. Multiple-range tests (Tukey test) were done on all the indices which showed significant differences among treatments. The paired-sample t-test was also used to test whether the similarity index between pre-harvest vegetation and post-harvest vegetation were changing significantly over the first two years after harvesting. One-way ANOVA and multiple-range tests were done to determine whether the similarity index was significantly different among the treatments.

Canonical Correspondence Analysis (CCA) was used to determine which disturbance variables were important in affecting post-harvest herbaceous vegetation using the program CANOCO (ter Braak, 1988). The environmental dataset used in this analysis included the disturbances variables and the stand types.

## RESULTS AND DISCUSSION

Results are discussed below by deliverables as presented in the 1997-98 proposal. Deliverables 1-2 (pre-harvest vegetation patterns) are summarized; details on these deliverables can be found in the 1995 and 1996 final reports. The specific criteria and indicators addressed by each deliverable are listed with the deliverable.

**Deliverable 1: Document herbaceous-layer species, their abundance and their habitat distribution before harvesting relative to site characteristics. (C&I 2.2a, 1.1a/b, 1.2c)**

*Forest Types*

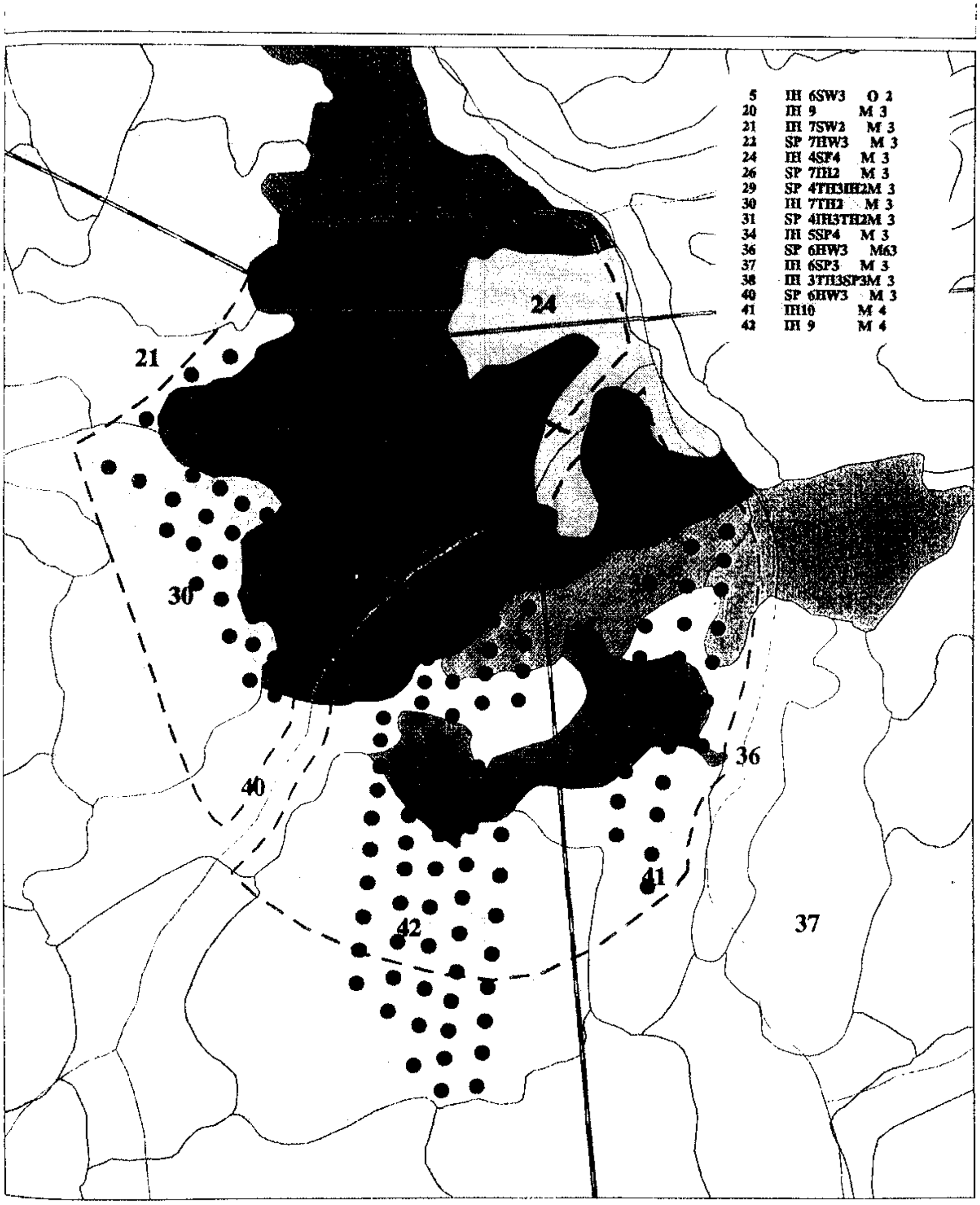
Hardwood stands, represented by stand C and stand H, are located on ridge tops (Figure 1). White birch, red maple, sugar maple, trembling aspen, beech and striped maple are found in these deciduous stands in which softwood represents less than 13 % of the stand. Stands A, B, D and E (Figure 1) are predominantly 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 1). 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.

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.

*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. On average, plots contained 15 species with 59% total herbaceous cover. Taxa which occurred in the greatest

**Figure 1.** 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.



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

The total cover of herbaceous species ranged from 0-175% within the plots, with a low mean evenness (80% of species occurred in ≤ 20% of plots). 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* (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.

*Vegetation Patterns and Relationships with Site Characteristics*

Correspondence analysis (CA) and canonical correspondence analysis (CCA) of pre-harvest vegetation revealed 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*) occurred as a group; these species are characteristically associated with moist to wet habitats, as distinct from *Lycopodium spp.*, *Cornus canadensis*, and *Vaccinium vitis-idaea*), which are generally associated with drier habitats. The stand types also demonstrated this moisture gradient, with both softwoods (e.g., stand type A), mixedwoods (G) and hardwoods (C and H) occupying different positions in the ordination diagrams. 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.

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.

Of the environmental variables, litter calcium, magnesium, and pH were most positively correlated with CCA axis one, whereas sine and cosine of the slope and litter potassium were negatively correlated with it. CCA axis two was positively correlated with percent deciduous canopy cover and litter depth, and negatively correlated with coniferous litter and canopy.

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 2). Litter, uniquely and in combination, contributed approximately 15% of the total, or >60% of the CCA total.

These results point to a separation of stands based on moisture and fertility on the one hand and a further separation based on topographic position on the other hand in the Hayward Brook study area. Stand type G represents a unique vegetation type with high moisture and fertility and a number of unique species. Softwood stands are characterized by low slope positions and thick litter. Hardwood stands occur at ridgetop positions. However, the pattern of herbaceous species was 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

**Table 2.** 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 |

**Deliverable 2: Assess specific disturbance conditions associated with specific forestry practices. (C&I 2.1i, 3.1a)**

*Canopy Closure*

Canopy closure was the only environmental variable which had been collected both before and after harvesting. Before harvesting, canopy cover was high (>90%) and similar in the three harvesting treatment areas, but in the CS area there was higher hardwood canopy cover than softwood while the opposite was true in the C area. The pre-harvest canopy closure data indicated that the C area had been softwood dominated and the CS area had been hardwood dominated before harvesting. The UC area was mixed-wood dominated, having approximately equal softwood and hardwood canopy cover. After harvesting, canopy cover was dramatically reduced in both the C and the CS area, but the C area had higher total canopy cover and higher softwood canopy cover than the CS area (Table 3). After harvesting, the canopy cover in the UC was reduced, from 96% to 73%. This change resulted from measurement error and year to year fluctuation in canopy cover. The readings were done by different crew members before and after harvesting, which could have resulted in observation error.

**Table 3**. Canopy closure (%) in the three treatments (UC = uncut, C = clearcut, CS = clearcut and scarified) before and after harvesting.

| Treatment | UC | C | CS |
|---|---|---|---|
| A. Pre-harvest (1995) | | | |
| Softwood | 49.41 | 69.06 | 35.75 |
| Hardwood | 45.13 | 21.50 | 57.93 |
| Total | 94.54 | 90.56 | 93.68 |
| | | | |
| B. Post-harvest (1996) | | | |
| Softwood | 32.13 | 14.38 | 4.30 |
| Hardwood | 40.91 | 5.35 | 4.56 |
| Total | 73.04 | 19.73 | 8.86 |

*Slash*

In general, the harvesting created slash, but the two harvesting methods were not significantly different. In the C and the CS area, slash covered 24.1% and 20.8% forest floor, respectively, both of which were significantly higher than that in the UC area (7%) (Table 4). The cover of small hardwood twigs (diameter <0.5 cm ) and attached foliage were low in all the three treatments while the two harvested areas had significantly higher cover of large twigs (diameter >0.5 cm) and small softwood twigs and attached foliage than the uncut area. The C area had higher cover of small softwood twigs and attached foliage than the CS area. This was a reflection of canopy composition before harvesting. Slash height was highest in the C area and lowest in CS area. Scarification made the slash more compact by crushing and compressing it.

*Living Slash*

Generally, the cover of living slash was low and softwood was the main part of the living slash. The cover of softwood living slash and total living slash as well as living slash height were significantly higher in the C area than in both the CS area and the UC area. This pattern was due to 1) living slash was mainly from advance regeneration, of which softwood was the main component; and 2) the C area had been softwood dominated, which had more advance regeneration than the CS area.

*Substrate*

Both the C treatment and the CS treatment disturbed the forest floor but the CS treatment disturbed the forest floor more severely in terms of the litter disturbed. The cover of disturbed litter in the CS area (60.9%) was significantly higher than that in the C area (36.3%). There was some disturbed litter in the UC area (5.5%) due to animal or human activities. Undisturbed litter had a reverse pattern, being highest in the UC area (88.8%) and lowest in the CS area (11.0%).

The scarification process had a greater effect on exposing mineral soil and rocks than the clearcutting process. The cover of exposed mineral soil in the CS area (10.8%) was significantly higher than that in both the C area (0.6%) and the UC area (0.04%). The cover of rocks was low in all the three treatments but significant higher in the CS area (0.6%) than in both the C (0.14%) area and the UC area (0.06%).

The harvesting created invisible substrate, but the two harvesting treatments were not significantly different. The cover of invisible substrate was significant higher in both the C (5.1%) and the CS (5.5%) area than in the UC area (0.02%). Invisible substrate, which was the forest floor covered by dense slash, was a portion of total slash cover.

Stumps and chips were created by cutting. They both had little cover even in the two harvested areas, although they were both significantly higher in the two harvested areas than in the uncut area. The two harvesting treatments were not significantly different. There were some stumps in the UC area due to previous cuttings and windthrow. The chips in the UC area were those blown in by wind from adjacent harvested areas.

All other substrate variables had low values in all the three treatments. Cones came from softwood, so it had highest value in the C area and lowest value in the CS area because the C area had highest softwood composition while the CS area had lowest softwood composition before harvesting. Cover of animal scat was significantly lower in the CS area than in the C area and the UC area because the scarified area apparently did not attract as many deer as the C area and the UC area. Bark cover was highest in the CS area because before harvesting the CS area had most white birch *(Betula papyrifera)*, from which most bark came. Rotten wood had similar cover in all the three treatments while the slash 2 -7 cm and slash > 7 cm, which were mainly created by harvesting, were significantly higher in the two harvested areas than in the UC area.

*Tracks*

Both the clearcutting process and scarification process created skidder tracks. The cover of skidder tracks was about 20% in the CS area, significantly higher than that in the C area (8%). There were no skidder tracks in the UC area. The track depth was about 2 cm in both the C area and the CS area.

**Table 4.** Means of disturbance variables in four categories (slash, living slash, substrate and tracks) by treatment (UC = uncut, C = clearcut, CS = clearcut and scarified) in the first year after harvesting. Values are percent cover except where indicated. Means with same letter within a row are not significantly different ($\alpha = 0.05$; see Appendix I)

| Treatment | UC | C | CS |
|---|---|---|---|
| A. Slash | | | |
| Slash < 0.5 cm | 1.15[a] | 1.69[a] | 2.36[a] |
| Slash < 0.5 cm Softwood | 0.81[a] | 7.22[b] | 3.86[c] |
| Slash > 0.5 cm | 4.81[a] | 15.15[b] | 14.58[b] |
| Total Slash | 6.77[a] | 24.06[b] | 20.80[b] |
| Slash Height (cm) | 19.19[a] | 33.61[b] | 23.77[a] |
| B. Living Slash | | | |
| Hardwood Living Slash | 0.06[a] | 0.26[a] | 0.25[a] |
| Softwood Living Slash | 1.20[a] | 3.87[b] | 0.65[a] |
| Total Living Slash | 1.26[a] | 4.13[b] | 0.90[a] |
| Living Slash Height (cm) | 2.01[a] | 23.81[b] | 7.93[a] |
| C. Substrate | | | |
| Invisible Substrate | 0.02[a] | 5.10[b] | 5.49[b] |
| Rocks | 0.06[a] | 0.14[a] | 0.64[b] |
| Stumps | 0.09[a] | 0.72[b] | 1.05[b] |
| Disturbed Litter | 5.51[a] | 36.28[b] | 60.92[c] |
| Exposed Mineral Soil | 0.04[a] | 0.64[a] | 10.79[b] |
| Slash 2-7 cm Substrate | 1.26[a] | 2.20[b] | 3.18[c] |
| Slash > 7 cm Substrate | 0.36[a] | 2.13[b] | 1.68[b] |
| Rotten Wood | 2.00[a] | 1.92[a] | 1.85[a] |
| Bark | 0.62[a] | 1.33[b] | 1.68[c] |
| Chips | 0.12[a] | 0.98[b] | 1.02[b] |
| Undisturbed Litter | 88.76[a] | 48.00[b] | 11.01[c] |
| Scat | 0.08[a] | 0.13[a] | 0.02[b] |
| Cones | 0.08[a] | 0.19[b] | 0.01[c] |
| Trunks | 0.89[a] | 0.11[b] | 0.24[b] |
| D. Track | | | |
| Cover | 0.00[a] | 8.01[b] | 19.56[c] |
| Depth (cm) | 0.00[a] | 1.55[b] | 2.08[b] |

**Deliverable 3: Determine survival of herbaceous-layer species and their microsite distribution after the above harvesting regimes, relative to site characteristics and disturbance conditions. (C&I 1.2b, 4.1c)**

**Deliverable 4: Document regeneration of herbaceous-layer species following harvest, relative to site and disturbance. (C&I 1.2b, 4.1c)**

These two deliverables are treated as a unit because they both deal with the response of the herbaceous-layer in relation to site and disturbance. Disturbance effects are addressed at two levels: 1) the treatment level, in which comparisons are made among treatments (e.g., UC, C, and CS), and 2) the plot level, in which comparisons are made among plots grouped by levels of disturbance regardless of treatment (e.g., plots with exposed mineral soil versus plots without exposed mineral soil).

*Patterns in the First Year after 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. Canonical correspondence analysis (CCA) showed that 1) the total inertia (variation) of the vegetation was 7.321; 2) the sum of all canonical eigenvalues was 2.408, indicating that the canonical axes captured 32.9% of the variation in the vegetation; and 3) no distinctly important axis was found in this analysis (Table 5) based on the criteria that the eigenvalues over 0.5 denote a good separation of the species along the axis (Jongman et al. 1987). Because there were no distinctly important axes and the eigenvalue of axis 3 was small compared to that of axis 1 and axis 2, only the first two ordination axes will be described because they are likely to contain all biologically relevant information.

The inter-set correlations of environmental variables with axes (Table 6) showed that axis one had the strongest relationship to stand type and it separated stand type G from other stand types (Figure 2). The plots within stand type G were pretty well separated from plots in other stand types (Figure 3). The plots within stand type G had unique species composition, including *Fragaria vesca, Trillium spp., Rubus pubescens, Aster macrophyllus, Circaea alpina, Galium triflorum, Fraxinus americana, Solidago rugosa, Sambucus canadensis, Equisetum sylvaticum, Gymnocarpium dryopteris* and *Oxalis montana* (Figure 4). All of these species need moist woods as habitats. At the other end of this axis, species which can grow in drier habitats, such as *Melampyrum lineare, Viburnum cassinoides, Kalmia angustifolia, Picea glauca* and *Vaccinium angustifolium* were present, indicating that axis one may partly represent a moisture gradient.

Axis two showed the strongest relationship to harvesting treatment and canopy cover. The CS treatment, exposed mineral soil, undisturbed litter and coniferous canopy had high correlations with this axis (Table 6). The plots which had CS treatment and high exposed mineral soil cover e.g., SI09 (64.75%), NK08 (66.5%), SJ09 (67.75%), SI10 (30.5%), NK09 (48.5%), NK07 (25%), NL06 (24.75%) and NJ09 (22%), were loosely grouped together in the upper part of Figure 3. In these plots, weedy species were abundant, including *Polygonum cilinode, Achillea millefolium, Pinus resinosa, Aster lateriflorus, Cardamine pensylvanica, Apocynum androsaemifolium, Betula papyrifera, Lycopodium tristachyum, Veronica officinalis, Prunus pensylvanica, Plantago major, Lycopodium dendroides* and *Rubus pensilvanicus* (Figure 4). The plots which had high coniferous canopy cover and high undisturbed litter cover, i.g., SH05 ( 37.96%, 67.5%), NF09 ( 79.04%, 97.75%), SJ05 (59.28%, 92.25%), SZ07 (63.44%, 91%), were shown on the bottom part of Figure 3, but were not well separated from other plots because the species composition in these plots was not unique. Because the covers of exposed mineral soil and undisturbed litter were strongly correlated with this axis, axis 2 represents disturbance intensity.

The three vectors representing the harvesting treatments were separated by approximately 120° in the ordination of environmental variables (Figure 2). The equal separation among the three treatments indicated that they differed in species composition. The CS area was abundant in weedy species as listed above; the C area was abundant in softwood regeneration and species which prefer dry habitats, such as *Antennaria spp., Abies balsamea, Vaccinium angustifolium, Picea rubens* and *Kalmia angustifolia*; and the UC area contained species which require wooded habitats, such as *Streptopus amplexifolius, Oxalis montana, Trillium spp.,* and *Thelypteris phegopteris*. Clearly, the vegetation in the first year after harvesting was a result of both harvesting treatments and stand types. However, in the CS area, the harvesting treatment had more impacts on the vegetation by exposing mineral soil and favouring weedy species while in the G stand type, the stand type had more impact on the vegetation by providing a unique wet habitat.

**Table 5** Summary of the first four axes of CCA in the first year after harvesting (all plots included).

| Axis | Eigenvalues | % variance of species data | % variance of species-environment relation |
|---|---|---|---|
| 1 | 0.391 | 5.3 | 16.2 |
| 2 | 0.338 | 4.7 | 15.1 |
| 3 | 0.308 | 4.2 | 12.8 |
| 4 | 0.211 | 2.8 | 8.7 |
| Total | 1.248 | 17 | 51.8 |

**Table 6.** Inter set correlations of environmental variables with axes in the first year after harvesting. For variable codes, see Figure 2.

| N | Variable | Axis1 | Axis2 | Axis3 | Axis4 |
|---|---|---|---|---|---|
| 1 | SLLHHW | -.0443 | .2467 | .0301 | -.0686 |
| 2 | SLLHSW | .0243 | .0736 | -.1977 | .1171 |
| 3 | SLGHCM | .1254 | .1321 | -.4265 | -.0416 |
| 4 | SLAHT | .1356 | .0393 | -.1370 | .0594 |
| 5 | LIVHD | -.0142 | .0503 | .0235 | .0226 |
| 6 | LIVSD | -.0828 | -.1774 | -.0684 | .0005 |
| 7 | LIVHT | -.1697 | -.1039 | -.1939 | -.0331 |
| 8 | INVSUB | .0556 | .0621 | -.1704 | .0381 |
| 9 | ROCKS | -.0762 | .2100 | -.0372 | .0597 |
| 10 | STUMPS | .2187 | .1038 | -.1626 | .0439 |
| 11 | DISLITT | .0403 | .3423 | -.1682 | .1951 |
| 12 | EXPSOL | -.0259 | .5162 | -.0608 | .2477 |
| 13 | SBSLA27 | .1675 | .3428 | -.0238 | .0441 |
| 14 | SBSLAG7 | -.0503 | .0540 | -.2216 | -.0164 |
| 15 | ROTWOOD | -.1229 | .0358 | -.0277 | -.1114 |
| 16 | BARK | .2454 | .0529 | -.3084 | -.0460 |
| 17 | CHPCOV | -.1379 | -.1173 | -.0663 | .3993 |
| 18 | UNDISLT | -.0421 | -.4559 | .2341 | -.2470 |
| 19 | SCATS | -.1327 | -.1326 | -.1461 | -.0438 |
| 20 | CONES | -.1414 | -.2635 | .0010 | .2942 |
| 21 | TRUNKS | .0250 | .0039 | .0865 | .0568 |
| 22 | TRKCOV | .0394 | .2649 | -.0931 | .0873 |
| 23 | TRKDEP | -.0347 | -.0021 | .0630 | .5879 |
| 24 | A | -.0721 | -.1250 | -.2021 | -.1042 |
| 25 | B | -.1309 | -.2294 | .0721 | .3317 |
| 26 | C | -.0440 | .2751 | .5355 | -.2064 |
| 27 | D | -.2669 | -.1691 | -.3403 | -.1288 |
| 28 | E | -.1055 | .0554 | -.1536 | -.0053 |
| 29 | F | -.0899 | -.0561 | .0932 | .0921 |
| 30 | G | .7380 | -.1064 | -.0959 | .0725 |
| 31 | H | -.0309 | .3056 | -.1777 | .0042 |
| 32 | TC | -.3608 | -.2126 | -.3102 | .1517 |
| 33 | TCS | .1766 | .6447 | -.1870 | .1701 |
| 34 | TUC | .2148 | -.3036 | .4543 | -.2846 |
| 35 | N | -.0470 | -.0792 | .4521 | .0725 |
| 36 | Y | .0470 | .0792 | -.4521 | -.0725 |
| 37 | CCO | .0741 | -.5265 | -.0885 | -.0669 |
| 38 | CDE | .0060 | .0498 | .5639 | -.4154 |
| 39 | TCC | .0600 | -.3544 | .3727 | -.3732 |
| 40 | TSLASH | .0988 | .1599 | -.3973 | .0070 |
| 41 | TLSLSH | -.0838 | -.1716 | -.0657 | .0027 |

**Figure 2.** CCA ordination diagram showing the relationships between the environmental variables and the first two axes in the first year after harvesting. TCS = clearcutting and scarification harvesting treatment, TC = clearcutting harvesting treatment, TUC = uncut, A - H = stand types, CCO = coniferous canopy cover, CDE = deciduous canopy cover, TCC = total canopy cover, TSLASH = total slash, SLLHHW = hardwood slash < 0.5 cm, SLLHSW = softwood slash < 0.5 cm, SLGHCM = slash > 0.5 cm, SLAHT = the height of slash, LIVHD = hardwood living slash, LIVSD = softwood living slash, LIVHT = the height of living slash, INVSUB = invisible substrate, DISLITT = disturbed litter, EXPSOL = exposed mineral soil, SBSLA27 = substrate slash between 2 - 7 cm, SBSLAG7 = substrate slash > 7 cm, ROTWOOD = rottenwood, CHPCOV = chips, UNDISLT = undisturbed litter, TRKCOV = the cover of tracks, TRKDEP = the depth of track, N = no clumped slash and Y = with clumped slash.

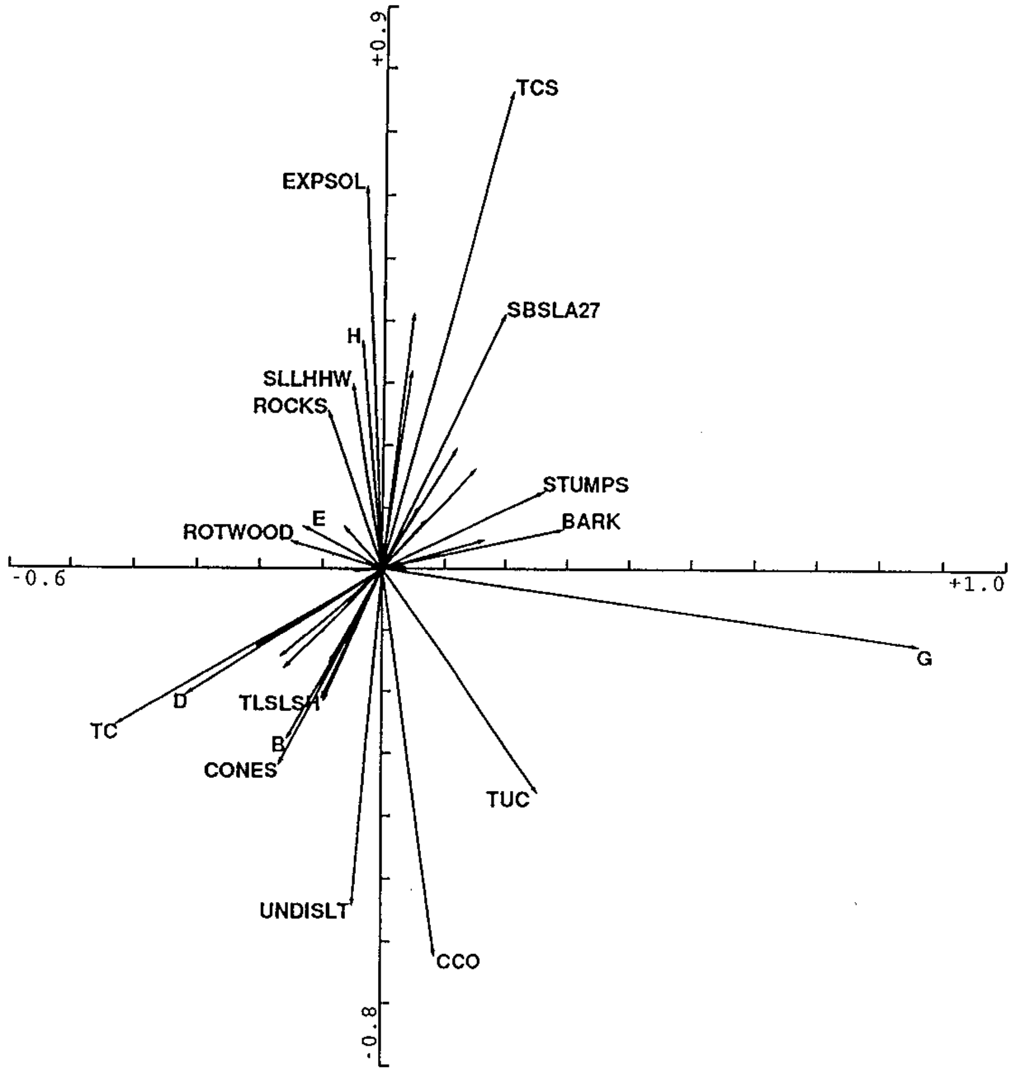


**Figure 3.** Distribution of the 169 plots on the first two axes of CCA in the first year after harvesting.

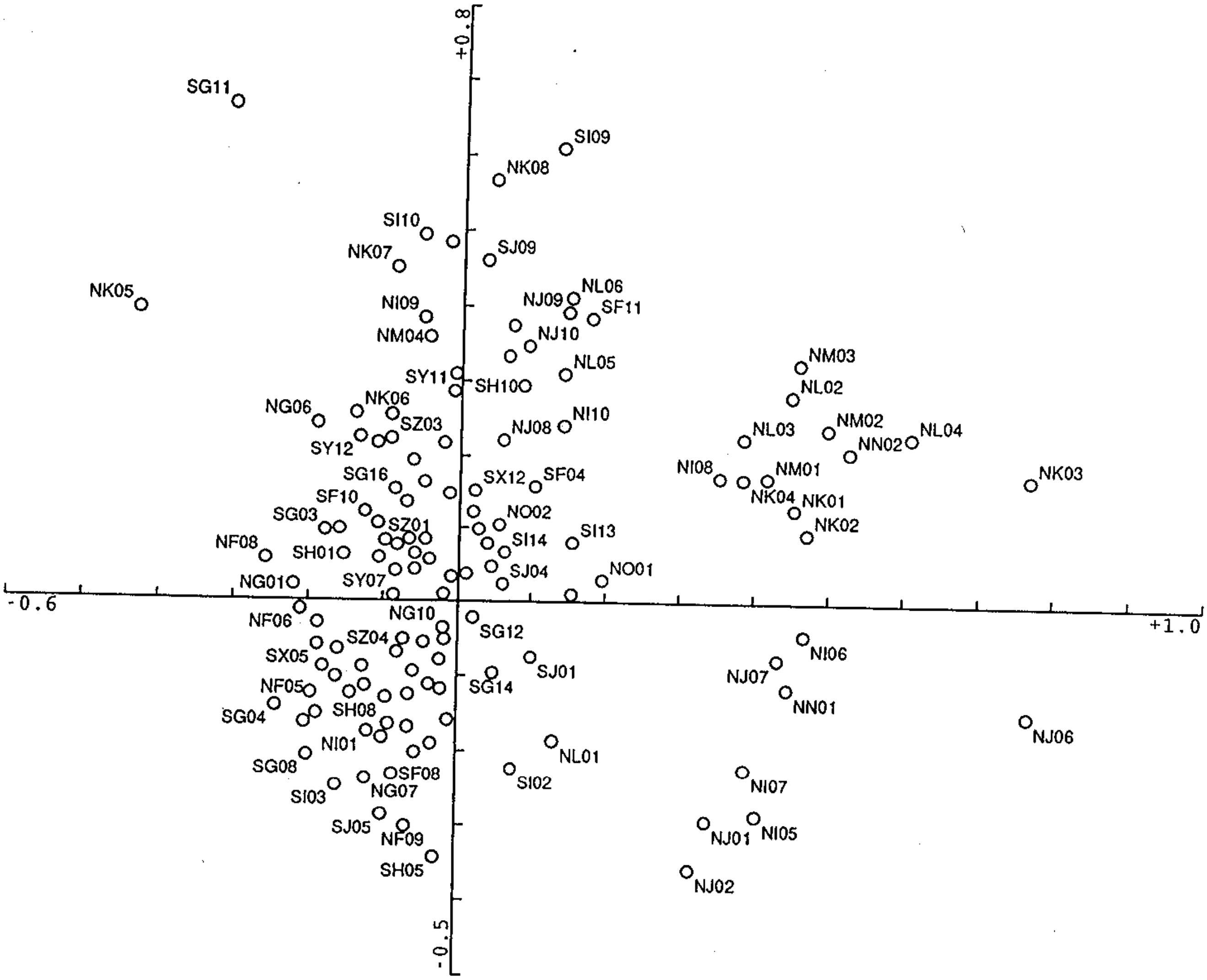
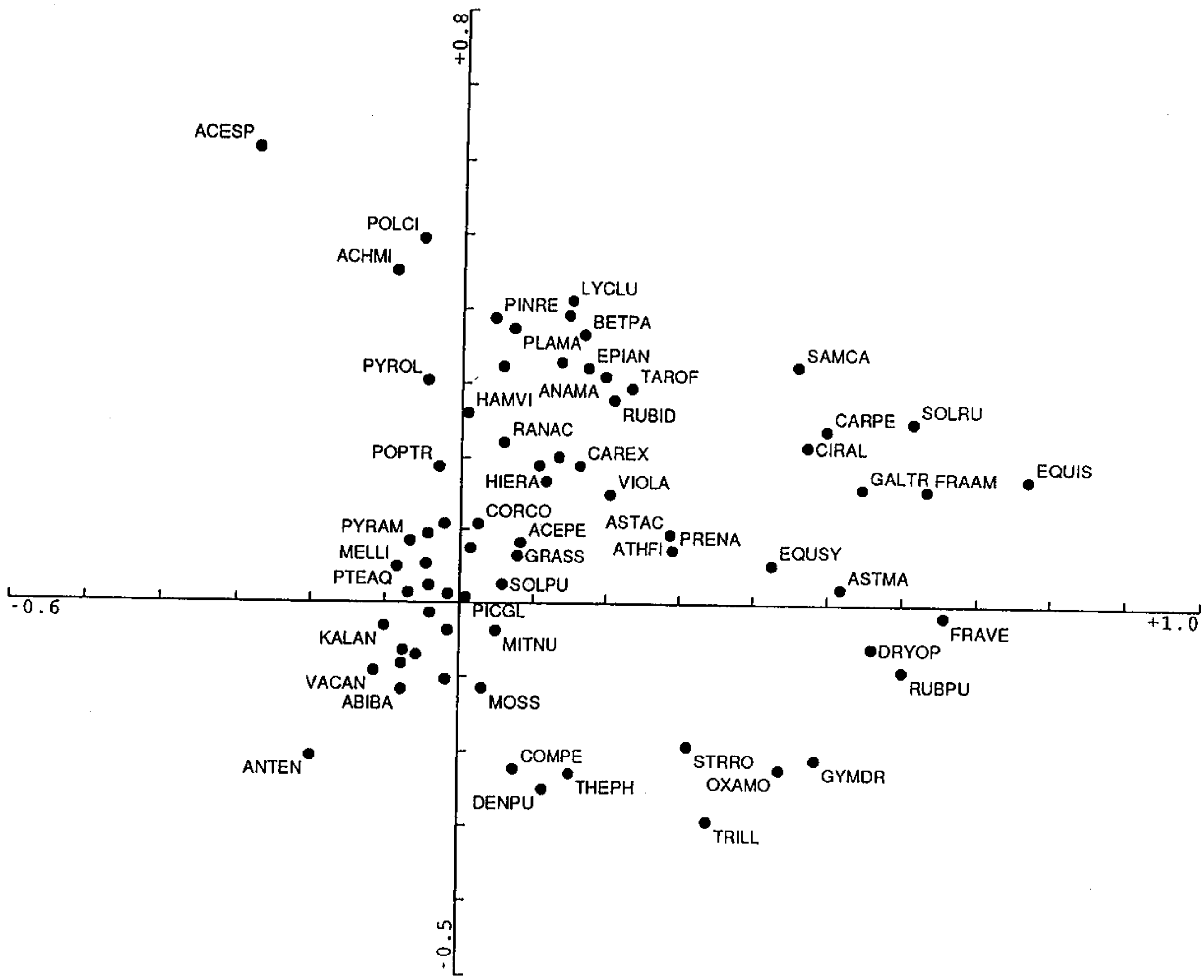


**Figure 4.** Species scores on the first two axes of CCA in the first year after harvesting. For species codes, see Appendix I.



Because stand type G was an overwhelming factor on axis 1, all the other plots were grouped on the left side of the ordination diagram (Figure 3). To examine any possible patterns among these plots, another CCA was done in which the plots in the group on the right side of Figure 3 were deleted (NM03, NL02, NL03, NM02, NN02, NL04, NI08, NM01, NK04, NK01, NK02, NK03, NI06, NJ07, NN01, NJ06, NI07, NI05, NJ01 and NJ02).

In the CCA ordination of the reduced dataset (above plots deleted), the total inertia was 6.467 and the sum of all canonical eigenvalues was 2.144, which captured 33.2% of the total variation in vegetation. No distinctive axis was found (Table 7).

The CS treatment, exposed mineral soil, undisturbed litter, and coniferous canopy had relatively high correlations with axis one (Table 8). This axis separated the plots which had CS treatment and high exposed mineral soil cover from those which had high cover of undisturbed litter and high coniferous canopy cover (Figure 5). The plots with high cover of exposed mineral soil and CS treatment contained weedy species, e.g., *Achillea millefolium, Apocynum androsaemifolium, Veronica officinalis* and *Plantago major*, and vegetative sprouts of *Acer spicatum, Betula papyrifera* and *Populus grandidentata* (Figure 7). Two species common in wet habitats, i.e., *Equisetum sylvaticum* and *Gymnocarpium dryopteris,* occurred in these plots. These two species were abundant in a small portion of the CS area on the North side of the watershed. The plots with high cover of undisturbed litter and high coniferous cover were not very well separated from other plots and they generally had forest regeneration *(Abies balsamea*) and pre-harvest species. Axis 1 represents a disturbance intensity axis which separates the CS treatment from the C and UC treatments. Thus, the removal of plots in stand type G resulted in a more clear separation of the remaining plots along the gradient from CS treatment and exposed mineral soil to undisturbed litter and high coniferous canopy cover. This same gradient was observed on axis 2 in the previous ordination.

Axis 2 represents a combination of stand type and harvesting treatment. Slash > 0.5 cm, total slash, clumped slash, treatment C and stand type D were negatively correlated with this axis while stand type C, treatment UC, no clumped slash and deciduous canopy cover were positively correlated with this axis. This pattern occurred because: 1) stand type C was located on the upper slope of the South side (see Figure 1) where there was high deciduous canopy cover and the area was not cut, and 2) stand type D was located on the middle slope of the North side (see Figure 1) which was cut. Most (28/40) of the plots in the stand type C were in the UC treatment

**Table 7.** Summary of the first four axes of CCA in the first year after harvesting when most plots in stand type G were removed.

| Axis | Eigenvalues | % variance of species data | % variance of species-environment relation |
|---|---|---|---|
| 1 | 0.359 | 5.6 | 16.8 |
| 2 | 0.343 | 5.3 | 16 |
| 3 | 0.231 | 3.5 | 12.7 |
| 4 | 0.193 | 3 | 9.1 |
| Total | 1.126 | 17.4 | 52.6 |

**Table 8.** Inter set correlations of environmental variables with axes in the first year after harvesting when most plots in stand type G were removed. For variable codes, see Figure 2.

| N | Variable | Axis1 | Axis2 | Axis3 | Axis4 |
|---|---|---|---|---|---|
| Fraction Extracted: | | .0622 | .0653 | .0314 | .0272 |
| 1 | SLLHHW | .2058 | .0368 | -.0716 | -.0522 |
| 2 | SLLHSW | .1149 | -.2037 | .0523 | -.2074 |
| 3 | SLGHCM | .1805 | -.4266 | -.0654 | -.1159 |
| 4 | SLAHT | .0403 | -.1223 | .0721 | -.0769 |
| 5 | LIVHD | .0488 | .0278 | .0159 | .0403 |
| 6 | LIVSD | -.1861 | -.0932 | .0239 | .0643 |
| 7 | LIVHT | -.1126 | -.2257 | -.0232 | .0603 |
| 8 | INVSUB | .0986 | -.1687 | -.0257 | -.1826 |
| 9 | ROCKS | .2102 | -.0281 | .0549 | -.0548 |
| 10 | STUMPS | .1103 | -.1094 | .0027 | .0537 |
| 11 | DISLITT | .3349 | -.1401 | .1308 | -.0679 |
| 12 | EXPSOL | .5193 | -.0340 | .3006 | .3214 |
| 13 | SBSLA27 | .3761 | .0045 | -.0027 | -.0970 |
| 14 | SBSLAG7 | .0620 | -.2350 | -.0037 | .0734 |
| 15 | ROTWOOD | -.0206 | -.0355 | -.1052 | -.0720 |
| 16 | BARK | .1195 | -.2897 | -.0475 | .0012 |
| 17 | CHPCOV | -.1445 | -.1181 | .3689 | -.2779 |
| 18 | UNDISLT | -.4670 | .2026 | -.1989 | .0134 |
| 19 | SCATS | -.1056 | -.1971 | -.0644 | -.0651 |
| 20 | CONES | -.2695 | -.0513 | .2983 | -.1695 |
| 21 | TRUNKS | .0090 | .0677 | .1982 | .4112 |
| 22 | TRKCOV | .2683 | -.1135 | .0529 | -.1325 |
| 23 | TRKDEP | -.0258 | .0294 | .5371 | -.3421 |
| 24 | A | -.1116 | -.2238 | -.0971 | .0479 |
| 25 | B | -.2555 | .0245 | .3429 | -.0949 |
| 26 | C | .1933 | .5607 | -.1270 | .1720 |
| 27 | D | -.1741 | -.3899 | -.1287 | -.0976 |
| 28 | E | .0625 | -.1628 | -.0108 | -.0130 |
| 29 | F | -.0844 | .0759 | .1245 | .0758 |
| 30 | G | -.0267 | .0146 | -.1189 | .0335 |
| 31 | H | .3724 | -.1546 | -.0466 | -.1623 |
| 32 | TC | -.2320 | -.3929 | .1655 | -.1988 |
| 33 | TCS | .6962 | -.1108 | .1037 | -.0197 |
| 34 | TUC | -.3062 | .4839 | -.2482 | .2166 |
| 35 | N | -.1195 | .4580 | .1366 | .1927 |
| 36 | Y | .1195 | -.4580 | -.1366 | -.1927 |
| 37 | CCO | -.4858 | -.1817 | -.0515 | .3310 |
| 38 | CDE | -.0413 | .5899 | -.3407 | .0355 |
| 39 | TCC | -.3719 | .3464 | -.3092 | .2594 |
| 40 | TSLASH | .2087 | -.3974 | -.0379 | -.1766 |
| 41 | TLSLSH | -.1804 | -.0900 | .0254 | .0680 |

**Figure 5.** CCA ordination diagram showing the relationships between the environmental variables and the first two axes in the first year after harvesting after most of the plots in stand type G were removed. For the variable codes, see Figure 2.

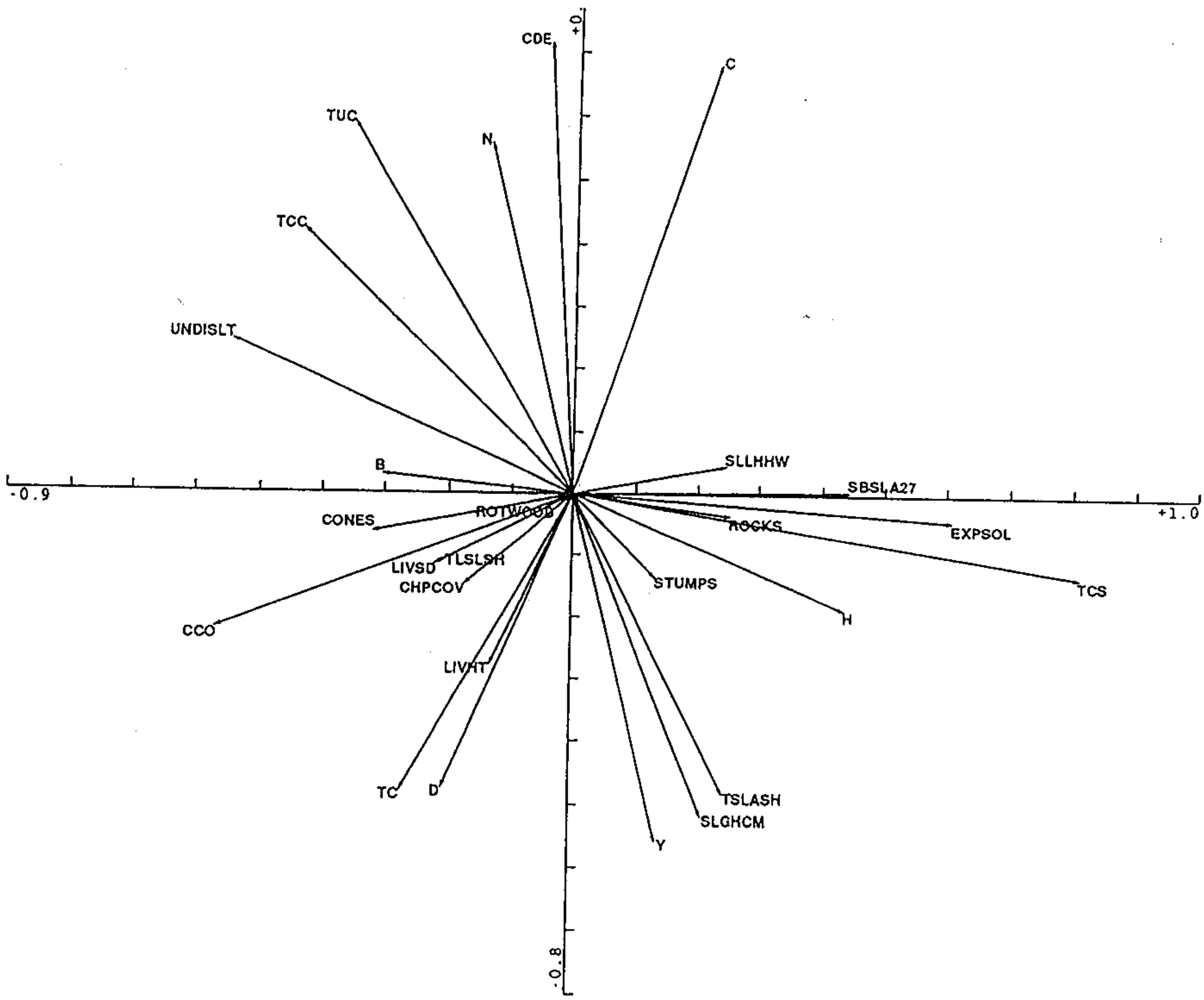


**Figure 6.** CCA ordination diagram showing distribution of the plots on the first two axes in the first year after harvesting after most of the plots in stand type G were removed.

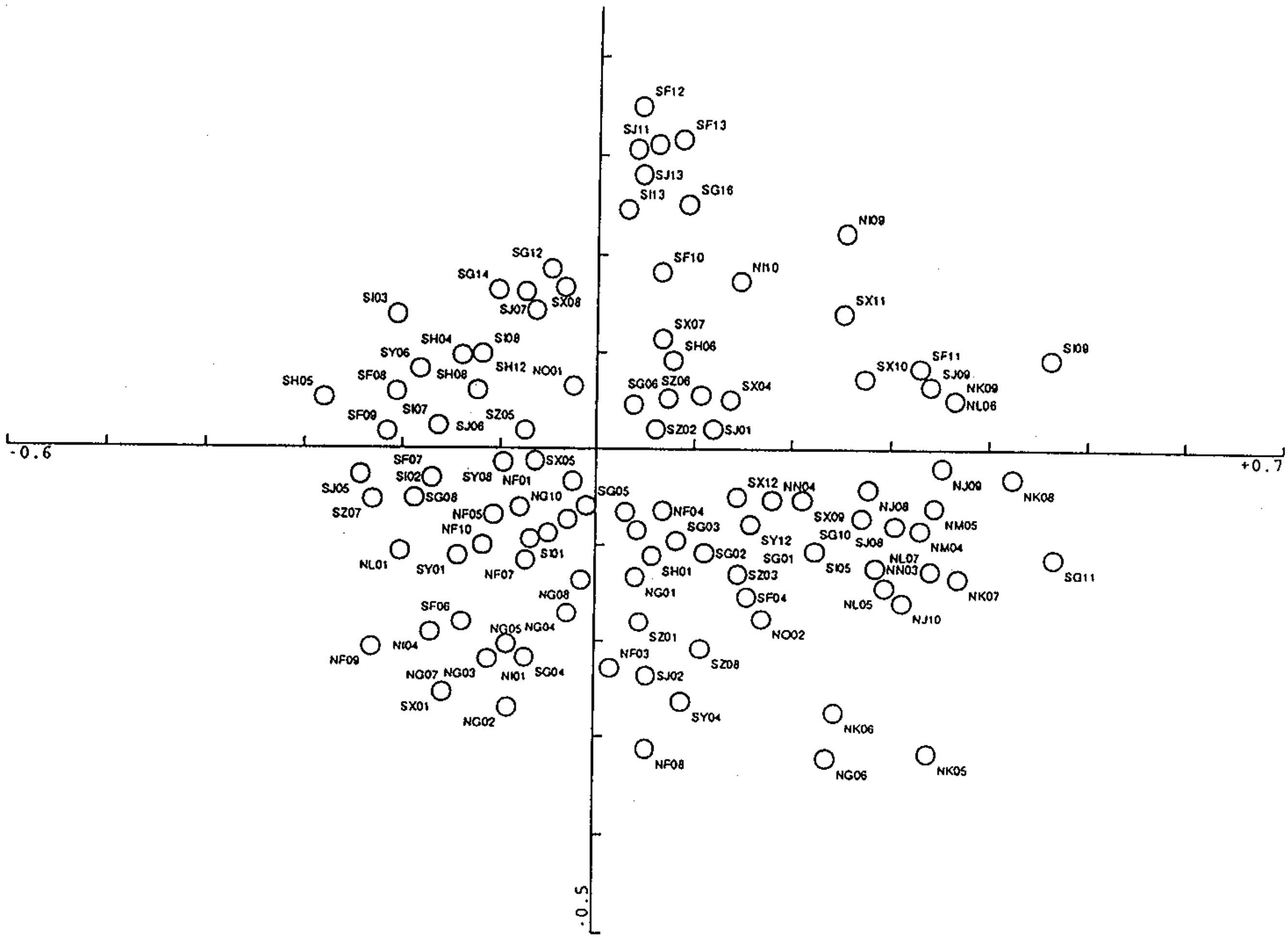
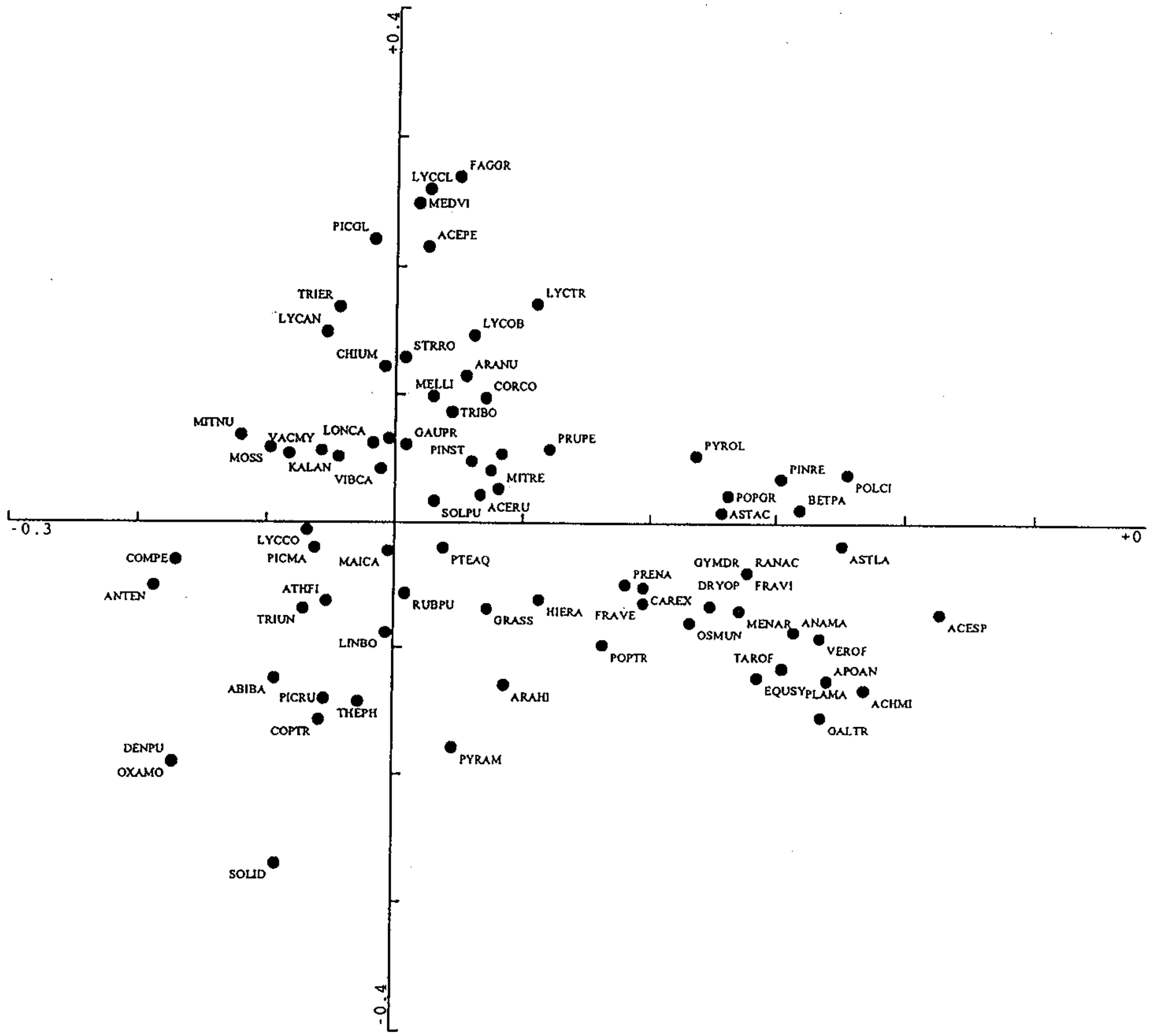


**Figure 7.** Species scores on the first two axes of CCA in the first year after harvesting after most of the plots in stand type G were removed. For species codes, see Appendix I.



and were associated with high deciduous canopy cover and no clumped slash. These plots, e.g., SF12, SI14, SF13, SG16, SI13, SG13 and SG16, had similar species composition and were loosely grouped in the upper part of Figure 6. Tolerant hardwoods (e.g., *Fagus grandifolia, Acer pensylvanicum, Picea glauca*), and forest herbaceous species (e.g., *Medeola virginiana, Lycopodium clavatum*) occurred in these plots. Most (10/13) of the plots in stand type D received the C treatment and were associated with clumped slash and high total slash cover. Thus, axis 2 separated the UC and C treatments.

In summary, the three treatments, stand types G, C and D, exposed mineral soil, undisturbed litter, coniferous canopy cover, deciduous canopy cover, the cover of slash >0.5 cm, total slash cover and clumped slash were the important variables in affecting post-harvest vegetation in the first growing season. Among them, exposed mineral soil, undisturbed litter, coniferous canopy, deciduous canopy, the cover of slash >0.5 cm and the cover of total slash indicated the intensity of the harvesting disturbance.

*Patterns in the Second Year after Harvesting*

The CCA ordination of vegetation in the second year showed that 1) the total inertia (variation) of the vegetation was 6.516; 2) the sum of all canonical eigenvalues was 2.322, which represented a capture of 35.6% of the variation in the vegetation by the canonical axes; and 3) one distinctly important axis was found (Table 9).

The inter-set correlations of environmental variables with axes showed that disturbed litter, undisturbed litter, stand type G, the CS harvesting treatment, coniferous canopy cover and total canopy cover had high correlations with axis 1 (Table 10). Along this axis, two groups of species can been seen (Figure 8). The group shown on the right include species typical of open sites which invaded the CS area after harvesting, i.e., *Rubus idaeus, Epilobium angustifolium* and *Plantago major*. Both the species which occur on wet sites, e.g., *Typha spp., Salix spp.* and *Circaea alpina* (these species were found in stand type G), and the species which can grow in dry sites, e.g., *Plantago major* and *Epilobium angustifolium*, were present in this group. The group on the left hand site of Figure 8 included species which occurred in the plots with high cover of undisturbed litter and high cover of total canopy and coniferous canopy. Most of these species were pre-harvest species, such as *Abies balsamea* and mosses.

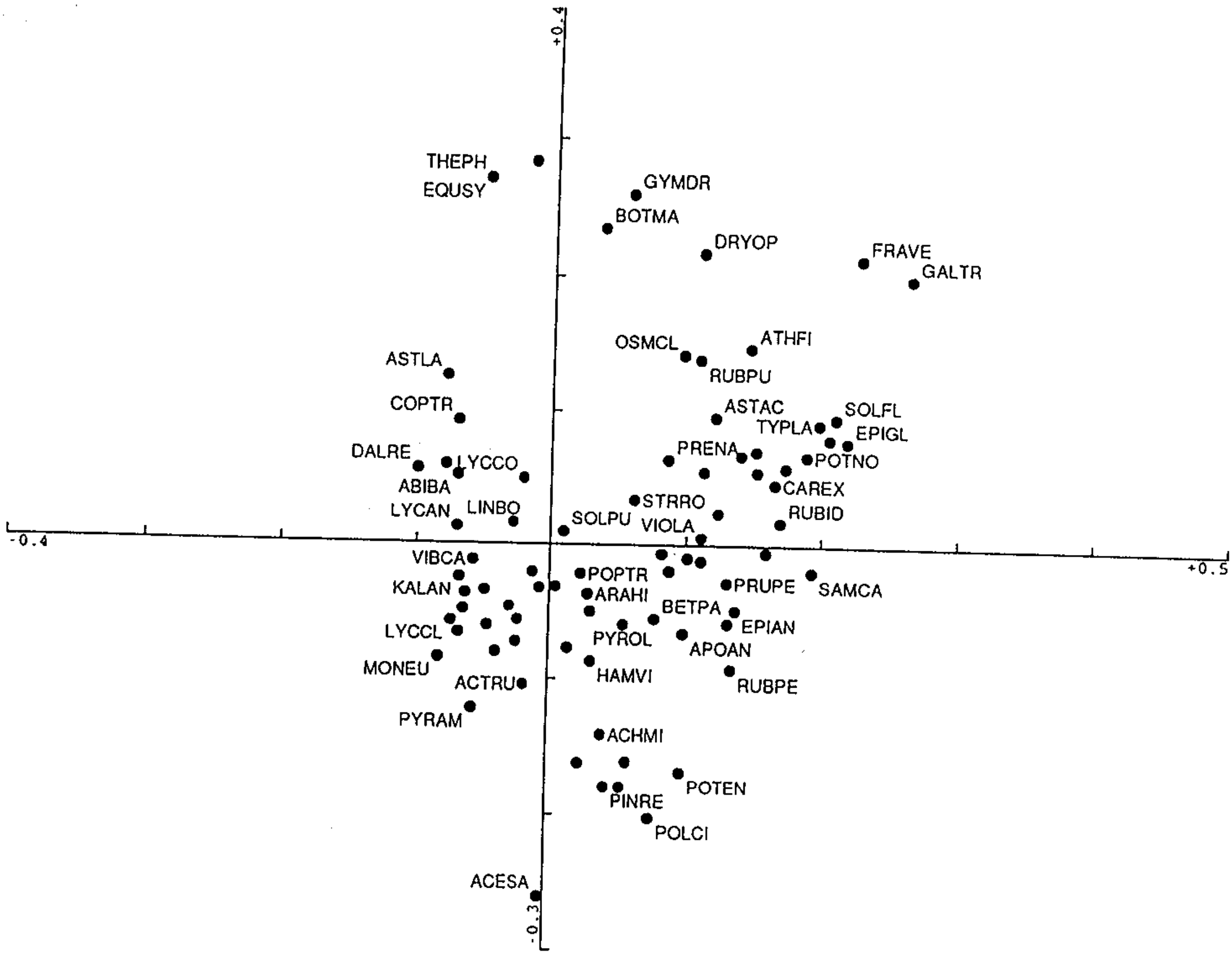
**Table 9.** Summary of the first four axes of CCA in the second year after harvesting.

| Axis | Eigenvalues | % variance of species data | % variance of species-environment relation |
|---|---|---|---|
| 1 | 0.506 | 7.8 | 21.8 |
| 2 | 0.275 | 4.2 | 11.8 |
| 3 | 0.224 | 3.4 | 9.7 |
| 4 | 0.176 | 2.7 | 7.6 |
| Total | 1.18 | 18.1 | 50.9 |

**Table 10.** Inter set correlations of environmental variables with axes in the second year after harvesting. For vriable codes, see Figure 2.

| N | Variable | Axis1 | Axis2 | Axis3 | Axis4 |
|---|---|---|---|---|---|
| 1 | SLLHHW | .1011 | -.1761 | .0469 | .2885 |
| 2 | SLLHSW | .1926 | .1069 | .2646 | -.0254 |
| 3 | SLGHCM | .2594 | .0319 | .2992 | .2194 |
| 4 | SLAHT | .0097 | .0694 | .1841 | .1593 |
| 5 | LIVHD | .0571 | -.0942 | .0348 | .0144 |
| 6 | LIVSD | -.2159 | .1646 | .0216 | -.0820 |
| 7 | LIVHT | -.2214 | .0646 | .2248 | .0567 |
| 8 | INVSUB | .2441 | .1436 | .1559 | .0945 |
| 9 | ROCKS | -.0041 | -.2810 | .0252 | -.0632 |
| 10 | STUMPS | .3082 | .1485 | .0924 | .0792 |
| 11 | DISLITT | .4895 | -.1315 | .1729 | -.1475 |
| 12 | EXPSOL | .2799 | -.3704 | .0216 | -.0728 |
| 13 | SBSLA27 | .3715 | -.1410 | .0187 | .0405 |
| 14 | SBSLAG7 | .0973 | -.0303 | .1430 | .0173 |
| 15 | ROTWOOD | .1111 | -.0063 | .0446 | .0562 |
| 16 | BARK | .2317 | -.0325 | .0857 | .0714 |
| 17 | CHPCOV | .0818 | .0157 | .1106 | -.2645 |
| 18 | UNDISLT | -.5954 | .1907 | -.2180 | .1240 |
| 19 | SCATS | -.1363 | .0640 | .1971 | .0607 |
| 20 | CONES | -.2342 | .1049 | .1681 | -.1891 |
| 21 | TRUNKS | -.1748 | .0534 | -.1476 | -.0680 |
| 22 | TRKCOV | .3541 | -.0818 | .0189 | .0319 |
| 23 | TRKDEP | .2140 | -.0298 | .0537 | -.3356 |
| 24 | A | -.0794 | .1739 | .1060 | .0305 |
| 25 | B | -.3082 | .0803 | .1198 | -.2944 |
| 26 | C | -.1323 | -.4450 | -.4699 | .0936 |
| 27 | D | -.1711 | .0522 | .3787 | .2033 |
| 28 | E | -.0447 | -.0643 | .2138 | .0479 |
| 29 | F | -.1932 | -.0774 | -.0040 | -.1766 |
| 30 | G | .5820 | .4531 | -.1898 | -.0425 |
| 31 | H | .2702 | -.1372 | .1187 | .1951 |
| 32 | TC | -.3784 | .0618 | .5128 | -.0597 |
| 33 | TCS | .7434 | -.2456 | -.0074 | -.0106 |
| 34 | TUC | -.3947 | .2002 | -.5581 | .0775 |
| 35 | N | -.1833 | -.0664 | -.2679 | -.1974 |
| 36 | Y | .1833 | .0664 | .2679 | .1974 |
| 37 | CCO | -.5034 | .3780 | -.1155 | -.0426 |
| 38 | CDE | -.2323 | -.0860 | -.5259 | .3457 |
| 39 | TCC | -.5145 | .2013 | -.4538 | .2160 |
| 40 | TSLASH | .2782 | .0471 | .3312 | .1752 |
| 41 | TLSLSH | -.2070 | .1515 | .0258 | -.0795 |

**Figure 8.** Species scores on the first two axes of CCA in the second year after harvesting. For species codes, see Appendix I.



Four variables, i.e., coniferous canopy cover, stand type C, stand type G and total canopy cover showed relatively high correlation with axis 2. This axis separated two distinct groups of species (Figure 8). The group on the upper end of axis 2 included *Oxalis montana* and *Mitella nuda*. These species were present in the plots with high coniferous canopy cover within stand type G and are typical forest species which are found in moist, wooded habitats. The group at the lower end of axis 2 (*Polygonum cilinode, Potentilla spp., Diervilla lonicera, Pinus resinosa, Achillea millefolium* and *Populus grandidentata*) were abundant in the plots with high cover of exposed mineral soil in stand type C. Except for *Pinus resinosa*, which was planted in the CS area, all the species are typical pioneer species.

In summary, in the second year after harvesting, the species composition in the CS area were different from that in the C area and the UC area. Many weedy species invaded the CS area. The vegetation in the C area and the UC area was composed of mainly pre-harvest species. Site moisture was still a important factor affecting species composition.

To summarize the patterns in the first two years after harvesting, the following variables were the most important in affecting the post-harvest vegetation: the treatments; stand types G, C and D; exposed mineral soil; undisturbed litter; coniferous canopy cover; deciduous canopy cover; the cover of slash >0.5 cm; total slash cover; and clumped slash. All of these variables except stand type reflected the intensity of the disturbance caused by the treatments. The CCA's for the first two years showed similar patterns; that is, high canopy removal and forest floor disturbance are associated with more weedy invaders while high canopy and less forest floor disturbance are related to the survival of pre-harvest species. The main differences between the two years were that more weedy invaders were present in the second year and the species composition in the CS treatment became more dissimilar from the UC and C treatments in the second year. These results supported our hypothesis that disturbance intensity, which is in turn related to harvesting treatment, is an important factor controlling the survival and regeneration of herbaceous-layer species.

*Similarity Between Pre-harvest and Post-harvest Vegetation*

In the two harvested areas, the similarity index between the second year after harvesting (1997) and pre-harvest was significantly higher than that between the first year after harvesting

(1996) and pre-harvest (Table 11). Thus, the vegetation after harvesting became slightly more similar to the pre-harvest vegetation with time.

The wide ranges between the maximum and minimum values and high standard deviations of the similarity index in any treatment-year combination indicates that different plots responded to the treatment differently in terms of species and cover. After harvesting, in some plots, the vegetation was more similar to pre-harvesting vegetation than in other plots.

In the two harvested areas, the similarity index between the first year after harvesting and pre-harvest and the similarity index between the second year after harvesting and pre-harvest were both significantly lower than that in the UC area (Table 11). Clearly, the post-harvest vegetation was less similar to pre-harvest vegetation in the harvested areas than in the UC area. The fact that the index was higher in the C area than in the CS area indicated that the CS treatment changed the pre-harvest vegetation more dramatically.

In the UC area, the similarity index between pre-harvest vegetation and the first year after harvesting was significantly higher than that between pre-harvest vegetation and the second year after harvesting (Table 11). This indicated that the vegetation after harvesting become slightly less similar to pre-harvest vegetation from year one to year two. The similarity indices indicated that the post-harvest vegetation was 57-63% similar to the pre-harvest vegetation in the UC treatment. Factors that contributed to the change in vegetation composition in the UC treatment include invasion of weedy species in plots adjacent to the harvested areas due to inrceases in light and influx of seeds from the harvested areas, changes in timing of phenology of species among years, and slight differences in cover estimates among observers from one year to the next.

Results of the similarity index analyses confirmed the CCA patterns: higher disturbance intensity, represented by the CS treatment, caused a greater shift in species composition away from unharvested conditions. The similarity index is a sensitive indicator of sustainable forest management because it integrates changes in all species. Thus, when combined with changes in presence and abundance of individual species, the similarity index provides a complete picture of the effects of forestry practices and a measure of the degree of change relative to unharvested conditions.

**Table 11.** Similarity index between pre-harvest vegetation and each of the two years after harvesting (1996 = first year; 1997 = second year) for the three treatments. Means with different superscript letters within a column are significantly different ($\alpha = 0.05$; paired sample t test) and means with different subscript letters in a row are significantly different ($\alpha = 0.05$, ANOVA)

| Treatment | UC | C | CS |
|---|---|---|---|
| Pre-harvest versus 1996 | $63.16^{a}_{a}$ | $30.25^{a}_{b}$ | $23.87^{a}_{b}$ |
| Pre-harvest versus 1997 | $56.73^{b}_{a}$ | $35.85^{b}_{b}$ | $28.91^{b}_{b}$ |

**Deliverable 5: Provide lists of herbaceous-layer species that may be at risk under specific harvesting and site-preparation treatments. (C&I 1.2b)**

The species which were lost after or decreased in cover or frequency in the two years after harvesting are shown in Table 12. Most of these species are found in woods or wet habitats. The harvesting affected these species by removing canopy and creating warmer and drier conditions on the forest floor. A few species, i.e., *Antennaria sp., Kalmia angustifolia, Pinus strobus, Prunus virginiana* and *Pteridium aquilinum,* which can grow in open areas, were also affected. *Antennaria sp.* and *Prunus virginiana* were two uncommon species which occurred in only one plot before harvesting. *Kalmia angustifolia, Pinus strobus* and *Pteridium aquilinum* were not eliminated by the harvesting, but decreased in cover or frequency. These decreases could have been resulted from physical damage which occurred by chance in the few plots where these species occurred. These uncommon species would be particularly susceptible to being eliminated by chance due to physical damage. The probability of elimination would be greater in the CS treatment which disturbs a greater proportion of the forest floor area.

A final list of potential indicator species was created after taking into account the habitats and the post-harvest frequency and cover of these species. Only species that are typically found in wooded habitats and wet sites were included. In addition, species that are known to reinvade cutovers readily, such as *Cornus canadensis* and *Acer spicatum*, were excluded. There were ten species that are indicators for both C and CS treatments. These include *Chimaphila umbellata, Clintonia borealis, Coptis trifolia, Linnaea borealis, Lycopodium dendroides, Mitchella repens, Mitella nuda, Orthilia secunda,* and *Oxalis montana*. All these species were not affected in the UC area.

Six species were indicators in the C treatment, including *Aster acuminatus, Cypripedium acaule, Gaultheria hispidula, Medeola virginiana, Thelypteris noveboracensis* and *Vaccinium vitis-idaea*. Among them, *Aster acuminatus* and *Medeola virginiana* persisted in the CS treatment. *Aster acuminatus* and *Medeola virginiana* had much lower cover and frequency in the C area than in the CS area before harvesting. *Aster acuminatus* occurred in only one plot before harvesting in the C area. Rare species are more severely affected by logging than abundant species (Meier et al 1995). The remaining four species did not occur in the CS area before harvesting.

**Table 12.** Species negatively affected by the harvesting (- = not present before harvesting, L = lost, DC = continually decreasing in cover, DF = continually decreasing in frequency) in each treatment and their habitats.

| Species | UC | C | CS | Habitats |
|---|---|---|---|---|
| Abies balsamea | DC, DF | | | moist woods & swamps |
| Acer spicatum | L | - | L | rocky woods & bottomlands |
| Alnus rugosa | - | L | - | streambanks and old fields |
| Amelanchier spp. | DF | | | |
| Antennaria sp. | L | - | - | dry open Laces |
| Aster lateriflorurs | - | - | L | dry, open woods or thickets |
| Aster umbellatus | - | - | L | open woods, meadows, thickets |
| Aster macrophyllus | L | | | dry to moist open woods, thickets |
| Aster acuminatus | | L | | moist woods, clearings |
| Brachyelytrum eretum | L | - | L | mixed woods & hardwoods |
| Chimaphila umbellata | | DF, DC | DF, DC | dry woods |
| Clintonia borealis | | L | DF | coniferious, mixed wood & alpine meadows |
| Coptis trifolia | | DC | DF | moist woods |
| Cornus canadensis | | | DF | heaths, bog edges, mixed woods, damp openings |
| Cypripedium acaule | L | L | - | boggy heathland, coniferous/mixed woods |
| Dennstaedtia punctilobula | | - | L | rocky open wood, slope meadows & pastures |
| Dryopteris sp. | | | DF | moist woods |

| | | | | |
|---|---|---|---|---|
| Equisetum sylvaticum | DC | - | | woodlands, thickets, openings, streambanks |
| Galium triflorum | DC | - | | cool woods |
| Galium circaezans | L | – | – | swamps, damp Laces, bottomlnad |
| Gaultheria procumbens | DF, DC | DF | | sandy swamps, low woods, hummocks |
| Gaultheria hispidula | – | L | – | mossy woods & & bogs |
| Goodyera tesselata | – | – | L | dry to moist woodland, arborvitae bogs |
| Gymnocarpium dryopteris | DC | - | DC | moist woodlands, talus slopes |
| Kalmia angustifolia | | DF | | |
| Linnaea borealis | | DF | L | |
| Lonicera canadensis | | | DC | |
| Luzula acuminata | – | – | L | |
| Lycopodium annotinum | DC | - | | |
| Lycopodium clavatum | DC | | L | |
| Lycopodium dendroides | | DC | DF | |
| Lycopodium lucidulum | L | – | – | |
| Maianthemum canadense | | | DF | |
| Medeola virginiana | DF | L | | |
| Metchella repens | | L | DF | |
| Mitella nuda | | L | DC | |
| Moneses uniflora | | – | L | |
| Monotropa hypopithys | L | – | L | |
| Orthilia secunda | | L | L | |
| Osmunda cinnamomea | L | | – | |
| Oxalis montana | DC | L | DC, DF | |

| | | | | |
|---|---|---|---|---|
| Picea spp. | DC, DF | DC | | |
| Pinus strobus | DF, DC | | DF | |
| Poaceae | DC | | | |
| Prunus virginiana | L | – | – | |
| Pteridium aquilinum | DC | | | |
| Pyrola americana | | - | L | |
| Ribes lacustre | L | – | L | |
| Ribes americanum | L | – | – | |
| Rubus pubescens | DF, DC | | | |
| Sphagnum spp. | – | L | L | |
| Streptopus amLexifolius | – | – | L | |
| Thelypteris phegopteris | - | - | L | |
| Thelypteris noveboracensis | – | L | – | |
| Trientalis borealis | | | DF | |
| Trillium undulatum | | L | L | |
| unknown#1 | L | – | – | |
| Vaccinium vitis-idaea | – | L | – | |
| Vaccinium myrtilloides | | | DF | |
| Viburnum cassinoides | | | DF | |
| Viola spp. | DC | | | |

There were 16 indicator species for the CS treatment. These were *Aster lateriflorus, Aster umbellatus, Brachyelytrum erectum, Dennstaedtia punctilobula, Dryopteris sp., Goodyera tesselata, Gymnocarpium dryopteris, Lonicera canadensis, Luzula acuminata, Lycopodium clavatum, Moneses uniflora, Monotropa hypopithys, Pyrola americana, Ribes lacustre, Streptopus amplexifolius* and *Thelypteris phegopteris.* Among them, *Dryopteris sp., Lycopodium clavatum* and *Trientalis borealis* persisted in the C area. The remaining species did not occur in the C area before harvesting. Obviously, more species were affected by the CS treatment than the C treatment.

Besides the species listed above, there were many species, e.g., *Abies balsamea*, moss and *Picea spp.*, which substantially decreased in cover and frequency after harvesting. These species were not listed as indicator species because they had started recovering or they still had substantial cover in the second year. However, their decrease in cover and frequency may be of concern to forest managers.

**Deliverable 6: Provide management guidelines for harvesting which will minimize impacts on biodiversity. (C&I 1.2b)**

1. To maintain populations of pre-harvest species, the advance regeneration, which provides the main shading after harvesting, should be preserved as much as possible during harvesting operations.
2. Forest floor disturbance, in terms of exposing mineral soil and disturbing the litter layer, should be minimized. Managing for natural regeneration where possible and using light forms of site preparation such as patch scarification are preferred.
3. Creating areas with excessive slash cover should be avoided. Light slash can provide shade for herbaceous vegetation, but excessive slash smothers herbaceous vegetation.
4. Wet areas and diversity hot spots (areas with high species diversity) should not be harvested.
5. Survey prospective harvest blocks and identify areas containing indicator species or diversity hot spots before harvesting is conducted.
6. Leave uncut patches or strips as appropriate to preserve representative populations of these indicator species and unique communities.
7. Evaluate riparian buffer strips with respect to their effectiveness in maintaining viable populations of species at risk.

**RESPONSE TO COMMENTS FROM FMF 97/98 RESEARCH PROJECT REVIEW**

In this section, we address the comments and suggestions by Dr. L. LaPierre concerning the 1997-98 Plant Resilience Project proposal.

*Comment 1.1: How will tree and shrub layer data bases be presented - GIS compatible?*

Yes, the tree overstory database and the herbaceous layer database (including the shrub layer) are GIS compatible. All the vegetation data are summarized by the stand types identified in the FMF GIS database. The stand type map for the Hayward Brook study area was provided by Walter Emrich. These databases will be provided in digital format to the FMF database manager.

*Comment 1.2: Time frames not well identified for representation of herbaceous layer.*

This comment probably relates to the recovery rates of the herbaceous vegetation after harvesting. There is little agreement in the literature concerning the long-term effects of harvesting on herbaceous-layer composition and diversity. Given the slow rates of reproduction and vegetative spread of most mesic forest understory herbs, it is unlikely that all species will recover to pre-harvest levels within the time period of a harvest rotation. One objective of this study is to identify the species that are negatively impacted by harvesting and their initial response in the first two years after harvesting. These species can be used as indicators of sustainable forest management and should be the focus of monitoring efforts. The current study provides a network of permanent plots and baseline information which can be used to assess long-term changes in the herbaceous layer. These plots should be remeasured periodically to determine the long-term response (see Recommendations for Further Studies).

*Suggestion 1.a: Need to identify specific indicators in the deliverables.*

Done. Specific indicators (C&I's) are listed with each deliverable.

*Suggestion 1.b: Need to identify existing databases.*

Done. See Comment 1.1. Databases include tree layer (basal area, density and average dbh by stand type); pre-harvest herbaceous layer (% cover by species in $5m^2$ plots by stand type); and post-harvest herbaceous layer in year 1 and year 2 (% cover by species in $5m^2$ plots by stand type and harvesting treatment).

*Suggestion 1.c: Need link to the soil and water studies done at Hayward Brook.*

Direct links with the soil and water studies are provided by our measurements of the degree of soil disturbance (% exposed mineral soil, % cover of tracks, % disturbed litter) and canopy cover. Soil disturbance provides a measure of erosion and stream siltation potential, whereas canopy cover indicates evapotranspiration potential of the vegetation. We are hopeful that a workshop will be organized on the Hayward Brook Watershed Project in which all researchers can present their integrated results (see Recommendations for Further Studies).

*Suggestion 1.d: Need indicators to assess potential impacts on biodiversity.*

Done. The objective of this study is to identify indicators of harvesting impacts on biodiversity. Two types of indicators are provided: 1) lists of indicator species that reflect the impacts of harvesting treatments, and 2) similarity indices which indicate the overall vegetative similarity between managed stands and the unmanaged condition with respect to biodiversity levels. These indicators are required to determine the degree to which forest management scenarios are sustainable.

## CONCLUSIONS

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.

It was found that more forest species were lost and more weedy species invaded in the CS area than in the C area because of 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. Some uncommon species were probably eliminated by chance due to physical damage from harvesting. There is concern that many of the uncommon species (low frequency or cover values), in particular, will be at risk following forest harvest.

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. Two stand types that were diversity "hot spots" were identified in this study. 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 forest management. Those species that were lost or significantly reduced by harvesting provide a focus for monitoring and assessment. The similarity index (a measure of overall vegetation similarity based on presence and abundance of all species) was found to be a good indicator of vegetation response to harvesting treatments.

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 for the first two years after harvest against which changes can be detected. Long-term changes in species composition, including the loss of additional species and the reinvasion of some pre-harvest species, will undoubtedly occur with time. It is unlikely, however, that species composition will return to pre-harvest conditions within the time frame of a 40-60 year harvest rotation. Sustainable forest management will require additional measures to protect the herbaceous layer.

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.

# RECOMMENDATIONS FOR FURTHER STUDIES

1. Organize a conference to integrate and synthesize the studies in the Hayward Brook Watershed Project. Other studies on wildlife and water resources have been conducted as part of the overall project. A workshop for all the studies in the area will provide an opportunity to comprehensively assess the effects of harvesting on vegetation, water and soil resources, and wildlife.

2. Continue sampling the herbaceous vegetation in the permanent plots within the study area. The herbaceous vegetation in the permanent plots has been sampled before harvesting and in the first two years after harvesting. Datasets containing detailed information on herbaceous-layer composition are rare and valuable. To monitor the long term effects of the harvesting on herbaceous vegetation, the areas should be sampled at 3 -5 year intervals. The next sampling should be conducted before the end of the second Model Forest agreement.

3. Assess the effectiveness of riparian buffer strips in maintaining viable populations of the indicator species within harvest blocks in the Hayward Brook Watershed. The occurrences and abundances of the indicator species should be thoroughly surveyed in all buffer strips in the watershed.

4. Assess the effects of herbicide application, as planned in the Hayward Brook Watershed, on herbaceous vegetation. The effects of herbicide application on the herbaceous layer should be assessed by sampling and comparing the vegetation before and after herbiciding. This will enable us to separate the effects of herbicides from the effects of harvesting treatments.

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**Appendix I. List of species encountered in the Hayward Brook Watershed before and after harvesting with species codes.**

| Code | Latin Name |
|---|---|
| ABIBA | *Abies balsamea* |
| ACEPE | *Acer pensylvanicum* |
| ACERU | *Acer rubrum* |
| ACESA | *Acer saccharum* |
| ACESP | *Acer spicatum* |
| ACHMI | *Achillea millefolium* |
| ACTRU | *Actaea rubra* |
| ALNRU | *Alnus rugosa* |
| AMELA | *Amelanchier spp.* |
| ANAMA | *Anaphalis margaritacea* |
| ANTEN | *Antennaria spp.* |
| APOAN | *Apocynum androsaemifolium* |
| ARAHI | *Aralia hispida* |
| ARANU | *Aralia nudicaulis* |
| ASTAC | *Aster acuminatus* |
| ASTCI | *Aster ciliolatus* |
| ASTER | *Aster spp.* |
| ASTLA | *Aster lateriflorus* |
| ASTMA | *Aster macrophyllus* |
| ASTUM | *Aster umbellatus* |
| ATHFI | *Athyrium filix-femina* |
| BETPA | *Betula papyrifera* |
| BOTMA | *Botrychium matricariaefolium* |
| BRAER | *Brachyelytrum erectum* |
| CARAR | *Carex Arctata* |
| CAREX | *Carex spp.* |
| CARPE | *Cardamine pensylvanica* |
| CARUM | *Carex umbellata* |
| CHIUM | *Chimaphila umbellata* |
| CIRAL | *Circaea alpina* |
| CLIBO | *Clintonia borealis* |
| COMPE | *Comptonia peregrina* |
| COPTR | *Coptis trifolia* |
| CORCA | *Cornus canadensis* |
| CORCO | *Corylus cornuta* |

| | |
|---|---|
| CYPAC | *Cypripedium acaule* |
| DALRE | *Dalibarda repens* |
| DENPU | *Dennstaedtia punctilobula* |
| DIELO | *Diervilla lonicera* |
| DRYOP | *Dryopteris spp.* |
| EPIAN | *Epilobium angustifolium* |
| EPIGL | *Epilobium glandulosum* |
| EPILE | *Epilobium leptophyllum* |
| EQUIS | *Equisetum sp.* |
| EQUSY | *Equisetum sylvaticum* |
| FAGGR | *Fagus grandifolia* |
| FRAAM | *Fraxinus americana* |
| FRAVE | *Fragaria vesca* |
| FRAVI | *Fragaria virginiana* |
| GALCI | *Galium circaezans* |
| GALTR | *Galium triflorum* |
| GAUHI | *Gaultheria hispidula* |
| GAUPR | *Gaultheria procumbens* |
| GOOTE | *Goodyera tesselata* |
| GYMDR | *Gymnocarpium dryopteris* |
| HAMVI | *Hamamelis virginiana* |
| HIERA | *Hieracium sp.* |
| KALAN | *Kalmia angustifolia* |
| LINBO | *Linnaea borealis* |
| LONCA | *Lonicera canadensis* |
| LUZAC | *Luzula acuminata* |
| LYCAN | *Lycopodium annotinum* |
| LYCCL | *Lycopodium clavatum* |
| LYCCO | *Lycopodium complanatum* |
| LYCDE | *Lycopodium dendroides* |
| LYCLU | *Lycopodium lucidulum* |
| LYCTR | *Lycopodium tristachyum* |
| MAICA | *Maianthemum canadense* |
| MEDVI | *Medeola virginiana* |
| MELLI | *Melampyrum lineare* |
| MENAR | *Mentha arvensis* |
| MITNU | *Mitella nuda* |
| MITRE | *Mitchella repens* |
| MONHY | *Monotropa hypopithys* |
| MONUN | *Moneses uniflora* |

| | |
|---|---|
| MOSS | *Bryophytes* |
| ORTSE | *Orthilia secunda* |
| ORYAS | *Oryzopsis asperifolia* |
| OSMCI | *Osmunda cinnamomea* |
| OSMCL | *Osmunda claytoniana* |
| OXAMO | *Oxalis montana* |
| PICGL | *Picea glauca* |
| PICMA | *Picea mariana* |
| PICRU | *Picea rubens* |
| PINRE | *Pinus resinosa* |
| PINST | *Pinus strobus* |
| PLAMA | *Plantago major* |
| POACE | *Poaceae* |
| POLCI | *Polygnum cilinode* |
| POPGR | *Populus grandidentata* |
| POPTR | *Populus tremuloides* |
| POTEN | *Potentilla sp.* |
| POTNO | *Potentilla norvegica* |
| PRENA | *Prenanthes spp.* |
| PRUPE | *Prunus pensylvanica* |
| PRUVI | *Prunus virginiana* |
| PRUVU | *Prunella vulgaris* |
| PTEAQ | *Pteridium aquilinum* |
| PYRAM | *Pyrola americana* |
| PYROL | *Pyrola spp.* |
| RANAC | *Ranunculus acris* |
| RIBAM | *Ribes americanum* |
| RIBLA | *Ribes lacustre* |
| RUBID | *Rubus idaeus* |
| RUBPE | *Rubus pensilvanicus* |
| RUBPU | *Rubus pubescens* |
| SALIX | *Salix spp.* |
| SAMCA | *Sambucus canadensis* |
| SOLFL | *Solidago flexicaulis* |
| SOLPU | *Solidago puberula* |
| SOLRU | *Solidago rugosa* |
| SORAM | *Sorbus americana* |
| STRAM | *Streptopus amplexifolius* |
| STRRO | *Streptopus roseus* |
| TAROF | *Taraxacum officinale* |

| | |
|---|---|
| THENO | *Thelypteris noveboracensis* |
| THEPH | *Thelypteris phegopteris* |
| TRIBO | *Trientalis borealis* |
| TRILL | *Trillium spp.* |
| TRIUN | *Trillium undulatum* |
| TYPLA | *Typha latifolia* |
| VACAN | *Vaccinium angustifolium* |
| VACMY | *Vaccinium myrtilloides* |
| VACVI | *Vaccinium vitis-idaea* |
| VEROF | *Veronica officinalis* |
| VIBCA | *Viburnum cassinoides* |
| VIOLA | *Viola spp.* |