NATURAL RECOVERY OF LOGGED

AND BURNED PLANT COMMUNITIES

IN THE LAKE WINNIPEG EAST

FOREST SECTION, MANITOBA.

by

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Acknowledgments

Table of Contents

1.   Introduction.

Cutting rights over a substantial portion of the Canadian boreal forest are licensed to a number of pulp and paper companies. Along with its fiber use, the same forest supports many other uses, performs essential ecological functions and has intrinsic value. If we want the forest to continue to fulfill these roles for future generations then it is essential that we ensure that logged areas regenerate back to a healthy forest. Unfortunately, we have limited information on post-logging vegetation recovery in the boreal forest. Even post-fire recovery is only partially understood (Bonan and Shugart 1989; Payette 1992; Thompson and Welsh 1993; Zoladeski and Maycock 1990). The overall objective of this project was to determine how well the vegetation of a portion of the central Canadian boreal forest was recovering from the effects of logging using post-fire forest vegetation to describe what is typical for the area.

People are dependent in many ways on the boreal forest's continuing ability to provide goods and services. The most visible dependency is that of the economies of numerous small communities which derive a large proportion of their income and employment from forest products. Even in areas where communities are not dependent on commercial forestry activities, many local people obtain essential supplementary income, food and fuelwood from the forest. Aboriginal communities deserve special mention because, in addition to their use of the forest in these ways, they have an intimate cultural connection with forests that predates European settlement by several millennia. A testament to that close connection is the manner in which aboriginal spirituality is tightly interwoven with the forest. Aboriginal spirituality recognizes that everything in the forest is connected with everything else in some way. It teaches respect for all living and inanimate things within it[1].

Spiritual and aesthetic values extend beyond aboriginals to others who live within and beyond the forest. Many individuals spend time in the forest to renew their sense of place. This often occurs in conjunction with recreational activities such as canoeing, boating, hunting, hiking and snowmobiling. Portions of the boreal forest contain cottage subdivisions which are an important part of Canadian summer culture. For others, physical presence in the forest is not a prerequisite to deriving value from it. Many people who are too infirm, too busy, or too remote to enjoy the spiritual, aesthetic and recreational opportunities of the boreal forest are satisfied just to know that it is there, that it exists.

Even people who never visit the forest or value its existence derive benefits from it. The forest performs essential ecological functions such as the storage and provision of clean water, replenishment of oxygen for us to breathe, carbon fixation, removal of pollutants and dust from the air and soil formation. Such functions produce benefits which extend far beyond the forest's boundaries.

Emphasis is often placed solely on the benefits people derive from the forest. Many would argue that to focus exclusively on human benefits is fundamentally wrong (Devall and Sessions 1985). In recognition of other values, they point out that we need to acknowledge that the forest, and all the organisms in it, have an inherent right to exist on an equal footing with humans. Therefore, we have an ethical responsibility towards the forest and our actions should be guided accordingly.

These cursory observations are simply intended to highlight the broad range of benefits and values related to the forest without implying a greater or lesser importance to any one of them. Given the forest's importance to individuals and society at large, steps must be taken to ensure that our use of it does not diminish or destroy its ability to continue to provide economic and social benefits into the future.

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1   The intention is not to condense aboriginal spirituality into one simple statement but to highlight one of its teachings that is relevant to this introduction.

When assessing the impacts of human activities on the forest, drastic impacts on ecological functions are often not readily observable. Consequently, it is tempting to think that ecosystems are highly resilient and capable of recuperating from such activities. Allen and Hoekstra (1994) argue that small shortfalls from what is sustainable may not result in the immediate loss of the productive ability of the forest but these deficits will accumulate over time and eventually reveal themselves. They give several examples going back through history where this has occurred- some which resulted in the collapse of civilizations. Perhaps the Atlantic cod fishery is an example close to home where the cumulative effects of unsustainable activities revealed themselves in a sudden, catastrophic manner. Rowe (1992) makes a similar point in another way. He likens ecosystems to "capital" and their flow of goods and services as "interest". The implication is that if we behave like an investor who not only spends all the interest on his capital each year but also a portion of the capital then the size of the interest payment will go down each year until it eventually disappears. If the rate of interest can be increased (by increasing productivity) then the decline in the size of the interest payment can be delayed. Of course this occurs at a cost (silvicultural treatment) which may even be greater than the decline in interest it is designed to offset and simply delays the inevitable. A salient difference between interest on capital and human impacts on ecosystem function is that there is a direct, visible relationship between interest and capital whereas small changes in ecological functions may go unnoticed or be attributed to random fluctuations.

Many have argued that the health of the forest must become the foremost goal of forest managers if continued economic and social benefits are to be derived from it (Allen and Hoekstra 1994; Booth et al. 1993; Grumbine 1994; OFPP 1993; Maser 1994; Salwasser and Pfister 1994). That there is cause for concern given the high risks to society seems to be gaining general acceptance. Along with this concern comes a recognition that the paradigm used in forest management must change to an ecosystem centered one. The philosophy behind this ecosystem centered paradigm is not novel (viz. Leopold 1966; Muir cited in Worster 1977). However, its current incarnation is still undergoing convergent evolution under the guise of several names. In this report, the term ecosystem based management[2] is used. As might be expected from an evolving paradigm, ecosystem based management (EBM) lacks a generally accepted definition and set of principles (Grumbine 1994). Herein, it is taken to refer to an approach to forest management which, at least in ideals,[3]:

1. Takes forest ecosystem health (i.e. ecological integrity[4]) as its first and overriding objective. All other objectives are pursued subject to this one since it is the naturally imposed constraint on human activities;

2. Recognizes that people are part of the forest and that existing economic and social patterns have developed over a long period of time. Management objectives must include the continued viability of existing forestry operations and forest uses. Where existing conditions conflict with the overriding objective of forest ecosystem health, change should be implemented in a manner that minimizes disruption to economic and social patterns;

3. Takes into account the values of all people who derive value, in whatever form, from the forest. This is an informal definition of a stakeholder;

4. Incorporates a process whereby stakeholder values influence management goals. This process, and the establishment of forest ecosystem health as the overriding objective of

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[2] Other terms in use which are taken to be sufficiently similar in intent to be synonymous with ecosystem based management are ecosystem management (Grumbine 1994), natural forest landscape management (Booth et al. 1993), sustainable forestry (CCFM 1992) and new forestry (Hunter 1990, 1992). Not all of these approaches state that ecological integrity has overriding emphasis .

[3] By no means do the points which follow summarize a consensus. However, they do incorporate the essentials of the dialogue.

[4] Ecological integrity is used here as a catch-all phrase which is interchangeable with health. It incorporates all those aspects of pattern and process essential to maintaining the structure and function of the forest over time. Examples include evolutionary processes, management boundaries reflecting ecological rather than institutional realities, biodiversity conservation, integration of different analytical, temporal and spatial scales, nutrient cycling, etc.. Some authors argue that the health analogy is a poor one (Wicklum and Davies 1995).

management, are the most substantive differences between ecosystem based management and integrated resource management (IRM). The main impetus behind the move towards ecosystem based management is a conflict between the benefits stakeholders wish to derive from the forest and the capacity of the forest to satisfy those desires over the long term. Before an operational ecosystem based management plan can be implemented, it must set specific goals and targets. This is why an ecosystem based management plan requires a process whereby stakeholder concerns are expressed, discussed and reconciled.

5. Is adaptive.

Clearly, each of these points has numerous facets related to the social, economic and political aspects of implementation. Such details are not relevant to this report. An overview of ecosystem based management has been provided because it establishes the context for the initiation of this project and the application of its results. Of particular interest is the management of human activities so as to maintain forest health or enhance it where it has been impaired.

It should be apparent even from such a brief overview that the implementation of ecosystem based management requires considerable knowledge about the "natural" state of the forest in terms of its patterns and processes at the landscape and site levels. To a large extent, landscape patterns are simply a summary of what has occurred on a multitude of sites. If we want to understand landscape patterns then information is required on how vegetation at the site level (i.e. the plant community) has responded to various types of disturbance. In particular, information is required on how vegetation responds to human disturbance so that forestry practices which most closely mimic the effects of natural disturbance on ecological processes can be applied.

Research on boreal vegetation dynamics has occurred throughout Canada (Bergeron and Dansereau 1993; Bergeron and Dubuc 1989; Brumelis and Carleton 1988, 1989; Carleton and MacLellan 1994; Carleton and Maycock 1978, 1980; Clayden and Bouchard 1983; De Grandpre et al. 1993; Dix and Swan 1971; Flinn and Wein 1988; Foster 1985; Hamilton and Yearsley 1988; Harvey and Bergeron 1989; Pare et al. 1993; Shafi and Yarranton 1973a, 1973b; Taylor et al. 1987; Walsh and Krishka 1991; Yang and Fry 1971; Zoladeski and Maycock 1990). Manitoba studies dealing with boreal vegetation (Anderson 1960; Mueller-Dombois 1964; Pedocan 1988, 1989; Ritchie 1956 and 1957; Rowe 1956 a; Wells 1987) have focused on the classification of forest types and, in some cases, related these to abiotic factors. Often the intended use has been the prediction of stand productivity. The studies completed elsewhere in Canada all focused on either lowland sites, post-fire dynamics, tree species only or forest ecosystems with parent material not common in the study area. No study has examined upland post-logging vegetation dynamics for the entire plant community beyond 14 years, a time period too short to assess resilience to logging. One other study (Brumelis and Carleton 1989) examined the response of lowland vegetation up to 56 years.

Given the focus of previous research, information regarding post-logging vegetation dynamics and community resilience to logging remains a research need. Reports on sustainable forestry consistently identify basic ecological research and research into ecosystem response to human disturbance as high priorities in the suite of prerequisites to the implementation of ecosystem based management (CCFM 1992; Grumbine 1994; OFPP 1993; Natural Resources Canada, CFS 1995; Thompson and Welsh 1993). An environmental impact assessment of the operations of the main commercial forestry operation in this project's study area (Synthen 1990) also identified this type of information as a research priority.

2.   Objectives and overview of this study.

In the context of the identified need to improve our understanding of and ability to use the boreal forest sustainably, the objectives of this project were to:

1) Determine how well naturally regenerating logged plant communities[5] in the southern part of the central Canadian boreal forest are recovering from the impacts of logging;

2) Describe how these post-logging plant communities differ from similar aged post-fire communities.

If logging is to be sustainable then post-logging communities should regenerate to a state typical of mature vegetation within an appropriate length of time (see Appendix C for a discussion and some qualifications). In other words, plant communities must be resilient to the effects of logging in much the same way as an elastic band is able to spring back after it is stretched. The choice of community resilience as the criterion of sustainability is based on ecological theory (Halpern 1988; Westman 1978; Westman and O'Leary 1986) and criteria developed at the international level for the sustainable use of forests (CCFM 1995; Maini 1993; Natural Resources Canada, CFS 1995; Poore 1993). The relevant international criteria are the "conservation of biodiversity" and the "maintenance and enhancement of forest ecosystem condition and productivity" (CCFM 1995; Natural Resources Canada, CFS 1995; Poore 1993).

To assess whether resilience is occurring, a description of the typical natural state must be provided. Fire has recurred throughout much of the boreal forest with an average return interval of approximately once every 100 years (Payette 1992). It is the major natural disturbance to which plant species in this region of the boreal forest are adapted[6] and was used as the standard of comparison for regenerating post-logging communities.

During the initial stage of regeneration, post-logging temporal pathways of species composition[7] are expected to differ from those of fire due to treatment[8] differences in the immediate effects of fire and logging. Nevertheless, the null hypothesis is that the species composition of post-logging communities will approximate a typical mature state within an appropriate length of time. The typical mature state is defined by the "mean" species composition of mature post-fire communities associated with the site conditions. The mature stage occurs for both upland and lowland post-fire communities during the period of 50 -100 years after disturbance (Ahlgren 1974; Van Cleve and Viereck 1981). During this stage, changes in species composition primarily involve small changes in relative abundances and not changes in the species which are present. The upper end of the mature stage is about the same number of years as the mean fire return interval for the study area and sets an upper time limit for resilience to occur. It should be kept in mind that resilience is a necessary but not a sufficient condition to establish the sustainability of logging since effects on ecological processes may not manifest themselves for more than 100 years or until a second rotation.

Descriptions of the typical natural state should group communities which are similar in terms of their time since disturbance (age), type of disturbance, species composition at the time of disturbance and site conditions since these are the factors which are expected to most strongly influence the species composition of a community at any point in time. We used pilot study data to

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[5]   A community is defined as a group of interacting plants located within an area which has relatively homogenous site conditions at a specified point in time. This concept will be discussed in more detail below.

[6]   Insect and disease outbreaks and windthrow can also occur on a large scale in the area. Their historical importance is more difficult to evaluate since they tend to increase the probability of a fire occurring and thereby eliminate some evidence of their occurrence.

[7]   These temporal pathways of species composition are often referred to as successional pathways. This term will be avoided as it can imply that temporal change involves a series of species replacements. The more general term, vegetation dynamics, will be used in its place.

[8]   Disturbance type is referred to as treatment. Although this is an observational study, the terminology developed for experiments will be used. Cochran (1983) points out that the principles of design are the same for both types of studies with the major difference being the inability to randomly apply a treatment in an observational study. A treatment unit is an area which has been either burned or logged once since 1900 but not otherwise disturbed. From this point onward, the term Block will be used to refer to treatment units.

create a site type classification which covered the range of soil conditions capable of supporting some form of forest cover. The classification was based on moisture regime and thickness of mineral and organic soil and is similar to the soil classification found in the Field Guide to the Forest Ecosystem Classification for Northwestern Ontario (NWO FEC) (Sims et al. 1989). Plots sampled within each burn or cutover were placed into one of the site type categories prior to statistical analysis to control for site factors and to increase the statistical power of hypothesis tests.

Although data were collected across the entire range of site conditions, this report includes results only for the site conditions represented in at least two replicate burns and cutovers and had at least three subsamples within each replicate[9]. These criteria led to the inclusion of the communities on organic soils (surface organic layer at least 20 cm thick) derived primarily from *Sphagnum* mosses and the communities on mineral soils with a depth to bedrock less than 100 cm. The communities found on mineral soils were divided into three groups based on increasing depth to bedrock.

An assessment of resilience to logging ideally involves measurement of the pre-disturbance species composition of a number of communities, logging or burning the communities and then monitoring them until they reach an age when they should have regenerated to a typical mature state. As noted above, this occurs from 50 - 100 years after disturbance. It is rarely possible to follow communities for such a long period of time. Consequently, a chronosequence approach to studying temporal change is often adopted (Pickett 1989). In this approach, post-fire or post-logging communities of different ages are sampled and then the sequence of communities ordered by age is assumed to represent how a particular type of community changes over time (i.e. the post-disturbance temporal pathway of species composition for the community type). We adopted this approach. The "mean" species composition of the communities found on each site type in 65 year old burns was assumed to represent the typical state of both pre-disturbance and mature communities for the site type. Examination of disturbance history information determined that only the 13 and 37 year old age classes had at least three replicates available for both burns and cutovers. Since suitable data for 65 year old post-logging communities were not available, direct comparisons of 65 year old post-fire and post-logging communities could not be made. Instead, resilience was assessed indirectly by seeing if the successional pathways suggested by 13 and 37 year old post-logging communities were headed toward the typical mature state.

The resilience criterion of sustainability requires indicators to measure its performance. We chose species composition (the list of species present in a community and their respective abundances[10]) and species richness (the number of species present in a community) as community level indicators of resilience vis-a-vis biodiversity conservation and forest ecosystem condition. Other community attributes could have been selected, however, given that this study needed to incorporate age class and site type replication, these seemed to be the most informative indicators for the amount of sampling effort available. Plants are synthetic indicators of environmental conditions (Gauch 1982; Klinka et al. 1989). A strategy using species composition and species richness as indicators will identify which, if any, community types or species are impacted by logging and merit further in depth research into ecological processes.

Species richness is an aspect of species composition which is reported separately since it is an important parameter in the conservation of species diversity (a form of taxonomic biodiversity). It is suggested that the maintenance of a natural level of native species richness maximizes a community's ability to adapt to global change or large scale human intervention (Maser 1994; Walker 1995). Many other measures, such as species diversity indices, have been developed to summarize species diversity. We did not employ any of these because they ignore species identities, the mathematical properties of some of them lead to ambiguous interpretations and most are highly

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[9] Most of the age class/ disturbance type/ site type combinations for which results are presented had four replicates and most of these replicates had at least 6 subsamples.

[10] Appendix B is a glossary of terms and abbreviations.

sensitive to sample size or require the circular assumption that a specific species abundance distribution is present (see Appendices C and D for a discussion).
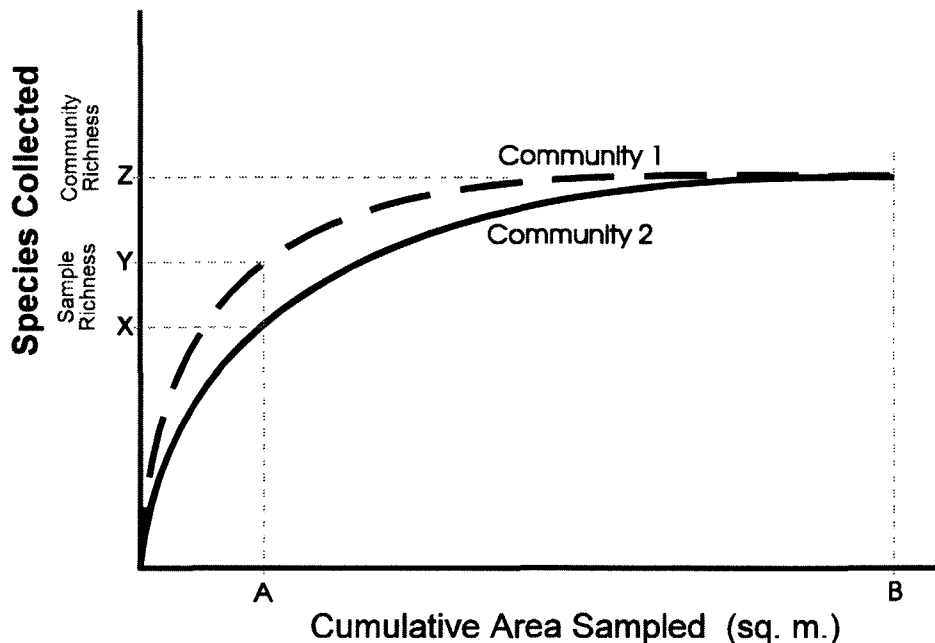
Figure 2.1. Collector curves for two communities with the same total species richness but different species abundance distributions.

Unfortunately, total species richness cannot be estimated from the small plot and sample sizes typical of plant ecology[11] (Baltanas 1992; Green 1979; Peet 1974; Section A.3 of Appendix C and Appendix D). Even with an adequate sampling design, many species in a community are not collected. These are predominantly the scarce[12] species. To see how this happens, imagine that two communities have the same total number of species but species are present in different amounts (i.e. the communities have different species abundance distributions). Figure 2.1 shows the theoretical collector, or species area curves, for the communities[13]. The sample taken from each community will collect the widespread, relatively abundant species plus some subset of the remaining ones. The size of that subset will be a function of the species abundance distribution in each community, the plot size and the sample size (total area sampled). As Figure 2.1 demonstrates, observed/ sample species richness is a biased estimate of total species richness[14] (see the area sampled equal to A). Even when the total species richness of both communities is the same, the number of species collected in each sample is expected to be different if the communities have different distributions of abundance. The problem is exacerbated when the total species richness of the two communities is different. In this situation, it is possible for the community with the lower observed richness to have the higher total richness. Therefore, observed/ sample species richness is an unreliable basis upon which to compare the total species richness of communities.

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[11] Other factors, such as variability in the size of individuals or spatial pattern, also affect estimates of species richness (see Appendix D). Sample size is focused on since it has such substantial effects which hold true even under idealized conditions.

[12] The distribution of a species can be described by two continua. One relates to the spatial distribution and has widespread and localized at its extremes. The other refers to the total amount of the species found in the community and it has abundant and scarce at its extreme. Thus, a community may contain localized, abundant species or widespread, scarce ones. Some conceptions of rarity would consider both types of species to be rare. Rabinowitz et al. (1992) recognize the potential confusion this might lead to and, consequently, delineate seven forms or rarity based on geographic range, habitat specificity and degree to which the species exists as a large local population as opposed to a number of small ones scattered throughout. This project's study area is large enough for geographic range to be a factor (Crescent Botanical Services 1994). This will increase the variance of treatment estimates.

[13] The theoretical collector curves are derived mathematically from the respective species abundance distributions (May 1975).

[14] This is true regardless of whether observed richness, jackknife estimates or rarefaction are used.

Moreover, unless the sample constitutes an impractically large proportion of the community, insufficient information exists to extrapolate observed richness to total richness or to fit a particular mathematical or statistical abundance distribution. If the species richness of communities is to be compared then it must use a parameter which can be estimated from the plot and sample sizes typical of plant ecology.

Appendix D discusses the sample size problem and a method for dealing with it. In short, it suggests that estimates of species richness be limited to those species which are expected to be collected by the plot size used in the study. The species expected to be collected are those with a relative abundance at some minimum level determined by a statistical relationship between a species' relative abundance and spatial distribution, the plot size and the consequent probability of collection. That is, each plot is expected to collect all species in the community which have a relative abundance of at least X% where X is a function of the plot size. Such species are referred to as Common species and they are the moderately to very abundant species in the community. The number of them in a community is referred to as Common species richness.

The study objectives are addressed in a number of steps beginning with a brief review of the boreal vegetation dynamics literature. That review indicates that although a theoretical model of vegetation dynamics is the essential foundation for empirical work (Green 1979; Levin 1989), plant ecology has not progressed to the stage where such a model exists. Consequently, the literature review includes a theoretical framework for a model of vegetation dynamics. The theoretical framework is used to structure the discussion of vegetation dynamics and to identify variables which must be controlled in the sampling design or measured in the field. A theoretical framework will ultimately be required for the development of predictive models and management prescriptions. Because research which has directly compared logged and burned communities older than 14 years is not available, we must postulate how post-fire and post-logging recovery will differ so that there is some basis for interpreting our results. Postulated pathways of recovery are based on previous research which has examined post-fire recovery, treatment differences in the initial stage of recovery and treatment differences in direct effects on the vegetation and the site. Interpretation of our results is based on these pathways as well as relevant sources, where available.

The literature review is followed by a description the study area, its disturbance history and the logging methods employed. After the study's methods are described, the results begin with a description of the site type categories created from pilot study data. For each site type, environmental conditions in post-fire and post-logging communities are compared to determine whether there were systematic differences other than treatment type which could lead to the detection of a spurious treatment effect. Next, the species composition of mature (65 year old) post-fire communities is described for each site type. These communities are then compared with the sequence of 13 and 37 year old post-fire communities using percentage dissimilarity to confirm that post-fire communities were regenerating towards the typical mature state and could be used as the standard for comparison with post-logging communities. Prior to making statistical comparisons of species composition, the "mean" species composition of post-fire communities found on each site type is described to provide an image of the typical natural state for that age class. MANOVA then made comparisons of the species composition of post-logging and post-fire communities to determine if it was significantly[15] different. Species composition differences in post-fire and post-logging communities were identified using four performance criteria (which identify a "treatment affinity") since no single method was adequate to do so. Results from each of the eight combinations of age class and site type are summarized and general patterns are discussed. Comparisons of Common species richness conclude the presentation of results and lead to a discussion of the project's findings regarding resilience and the nature of recovery in post-logging communities.

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[15] The term "significant" will always be used in its statistical sense.

3. Literature review- Ecological effects of fire and the expected differences from logging analyzed in the context of a theoretical framework for vegetation dynamics.

3.1 Controlling for substantial causal factors other than treatment- role for a theoretical framework for vegetation dynamics.

"Theory without data is sterile, while data without theory is uninterpretable."   (Levin 1989)

Before the impacts of logging can be fully evaluated, we must understand how fire affects species composition, ecological processes and vegetation dynamics and how these effects differ from those of logging. This requires an understanding of which factors cause change in the species composition of a community over time and how they do so.   In short, a theoretical model of vegetation dynamics is required.   Such a model identifies causal factors and specifies how they interact with each other to produce the observed vegetation and, when validated, is the essential foundation for operational plans.   Predictions or management prescriptions based solely on descriptions of previous disturbances are risky since new situations may easily involve different levels of some important factor that was not influential in the previous situations. The upshot for sustainable forestry is that we need to understand (as opposed to merely describe) how the effects of fire and logging differ if we are to change logging methods so that they do a better job of mimicking fire's effects on ecological processes and vegetation dynamics.

There are a multitude of causal factors which influence the species composition of a community, some of which are minor. Causal factors whose effects are large are termed substantial causal factors. Although causal factors which have small influences are of interest, they complicate analysis. Their inclusion in the design of field studies is usually precluded by constraints on total sampling effort. Site type (i.e. edaphic and micro-topographic factors) is one obvious example of a causal factor which can have a substantial influence on species composition.   To identify the remaining substantial causal factors, a theoretical model of vegetation dynamics is required[16].

Our knowledge of vegetation dynamics has not progressed to the point where there is a theoretical model which has been validated and generally accepted (McCook 1994; Pickett et al. 1987; Pickett and Kolasa 1989; Shipley and Keddy 1987; Smith and Huston 1989). Much debate still surrounds the mechanisms of community organization and the relative importance of biotic and abiotic factors (Keddy 1989, 1990). Nevertheless, there is sufficient consensus to construct a theoretical framework for vegetation dynamics[17]. The theoretical framework used in this study is a synthesis of the approaches of two groups of authors: Austin and Smith (1989) and Smith and Huston (1989) on the one hand (hereon referred to as Smith's group) and Pickett et. al (1987) and Pickett and Kolasa (1989) on the other (hereon referred to as Pickett's group). In the case of Smith's group, it is their approach more than the specific details which have been incorporated. Their major contribution to the framework is plant functional type. This concept summarizes how the mapping of resources into plant performance is constrained by the physiological possibilities dictated an individual's genotype. Whether or not their particular model of plant functional type is accurate is a moot point for our purposes. What is relevant is that a vegetation theoretical framework needs such a component.

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[16]   The spatial pattern of vegetation (i.e. species composition of a community) is merely a snapshot of a temporal process. Therefore, if we can predict temporal change we will also simultaneously describe spatial patterns.

[17]   The distinction being made between a theoretical framework and a general model is that the theoretical framework sets the spatial, temporal and analytical boundaries for the general model and identifies the hypothesized directions of direct and indirect causality, feedback and interaction. It is the first step towards a general model which will elaborate on the details by specifying the mechanisms involved in each interaction. A theoretical model provides a foundation for any study (Green 1979).

1. Species Performance
      Ecophysiology
            Germination requirements
            Assimilation rates
            Growth rates
            Population differentiation
      Life history strategy
            Allocation pattern
            Reproductive timing
            Reproductive mode
      Environmental stress
            Climate cycles
            Site history
            Prior occupants
      Competition
            Presence of competitors
            Identity of competitors
            Within-community disturbance
            Predators and herbivores
            Resource base
      Allelopathy
            Soil chemistry
            Soil structure
            Microbes
            Neighboring species
      Herbivory, predation and disease
            Climate cycles
            Predator cycles
2. Species Availability
      Dispersal
            Landscape configuration
            Dispersal agents
      Propagule pool
            Time since last disturbance
            Land use treatment
      Resource availability
            Soil Conditions
            Topography
            Microclimate
            Site history
3. Site Availability
      Disturbance
            Size
            Severity
            Time
            Dispersion

Figure 3.1. Hierarchy of Causes of Succession (after Pickett et al. 1987).

Pickett's group attempt to formulate a theoretical framework from which to develop vegetation models and mechanisms by summarizing generally accepted relationships in plant ecology. It is formulated at a higher and more general level than the approach of Smith's group while still preserving the essential requirement to model at the level at which the salient mechanisms operate. Pickett et al. (1987) start by asking the general question . . . "What causes succession?". The universal answers are that "(1) open sites become available, (2) species are differentially available at a site and (3) species have different, evolved or enforced capacities for dealing with a site and one another." If none of these conditions are present then there will be no temporal change in the vegetation regardless of the scale of analysis or observation. It should be noted that these three conditions cannot be considered to "cause" vegetation because they themselves are "caused" by other factors which are internal to the system we wish to understand. They simply group the conditions required for vegetation change into three categories. At least one of these categories is both necessary and sufficient for dynamics to occur. These categories can be further analyzed by hypothesizing what their "causes" may be.

Pickett et al. (1987) present a hierarchy of causes (Figure 3.1) in which more nested levels identify causes more ultimate in nature. A schematic representation of the theoretical framework generated by the synthesis of Pickett's group and Smith's group is presented in Figure 3.2. It illustrates the hierarchy of causes in the form of a causal diagram (Saris and Stronkhorst 1984) which specifies the links between causes and effects along with their mechanisms. It can be understood by beginning at its right-hand side. Here we find the variable which we wish to explain, namely, vegetation. From here we move left by asking 'what variables cause vegetation?'. Here we find the three categories of causes which are not causes themselves, that is, site availability, differential species availability and differential species performance. Next, a further step back is taken by identifying the causes of these three variables. This retrogressive process continues until we reach a set of causal variables whose causes are not of interest to the framework and will not affect its mechanisms. These variables are termed the ultimate causal variables. For example, Figure 3.2 shows that climate is a cause which influences vegetation in an indirect manner and, therefore, should be incorporated. On the other hand, for our objectives, we:
  1) are uninterested in what causes climate;
  2) believe the causes of climate do not affect variables in the theoretical framework to any substantial degree;
  3) believe the feedback effect of vegetation on climate at the plot level is insignificant.
Therefore, climate is one ultimate causal variable in our model (Saris and Stronkhorst 1984).

The effects of climate are complex and must be controlled for, regardless of which subsystem within the theoretical framework we might wish to study. For instance, plant competition cannot be studied without regard to climate. The same holds true for site type, disturbance type and landscape configuration.

A strength of the causal approach is in its identification of the multitude of interactions present in an ecological system. This appears to go against the view that the role of a model is to achieve a manageable simplification of reality. While some would argue that even this diagram is overly simplified, field ecologists will be more concerned with the impossibility of measuring all the specified variables. Here, causal theory plays a critical role in the simplification process. Proofs will not be provided, but it may seem intuitive that all the intervening variables (unshaded boxes in Figure 3.2) can be dropped from the empirical model without affecting our ability to identify and test the causal relations. Saris and Stronkhorst (1984) and Cook and Campbell (1979) provide the theoretical justification for the powerful result that complex causal relations can be understood using only a small subset of the explanatory variables (the "ultimate" causal variables). However, it must be recognized that parameter estimates for each "ultimate" causal variable include not only its direct effects on vegetation but also its indirect effects. Consequently, the internal mechanisms of the model cannot be tested unless additional information is gathered.
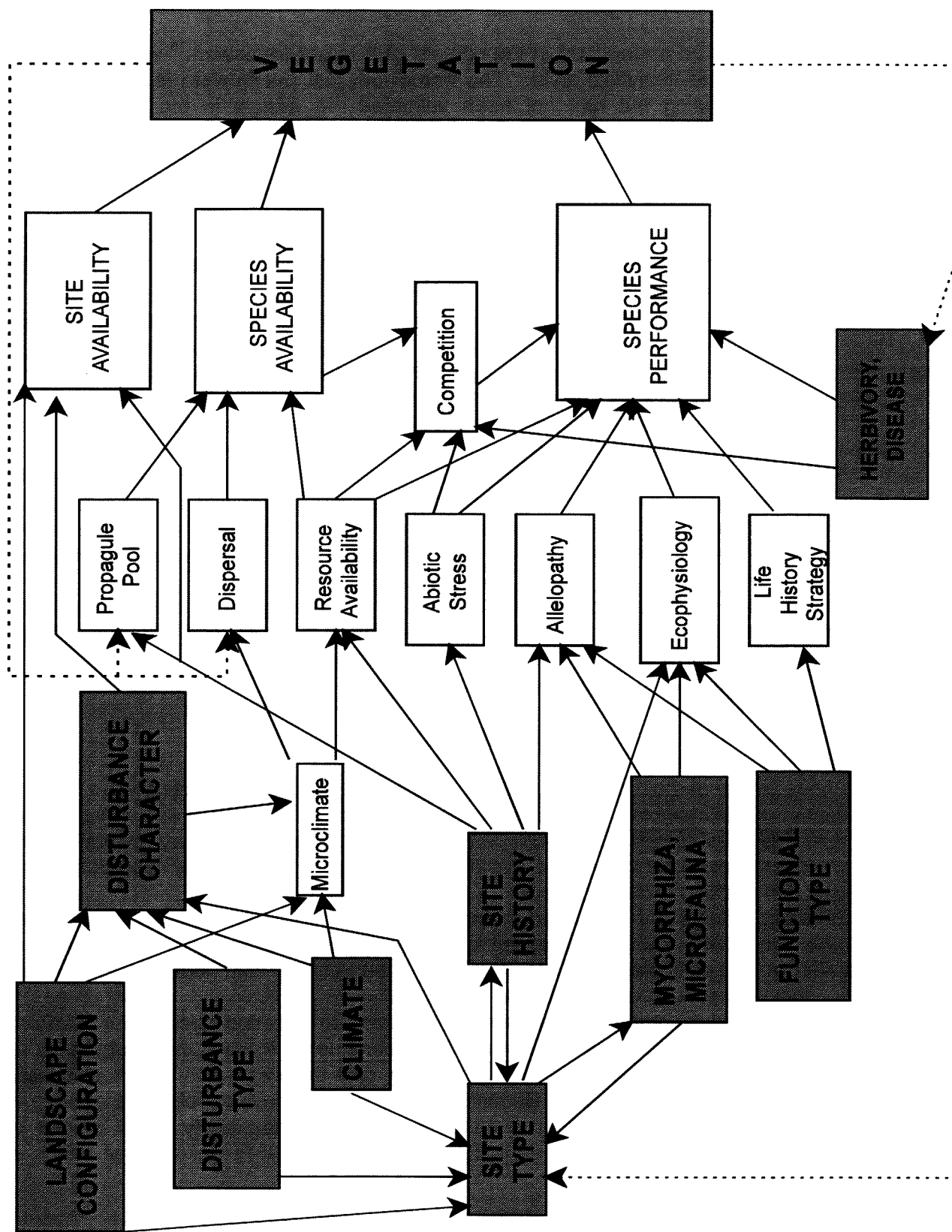
Figure 3.2. Vegetation theoretical framework. Shaded variable boxes identify "ultimate" causal variables (except vegetation). Arrows in the figure depict the hypothesized direction of cause and effect (not all are shown). Dotted lines indicate some of the feedback effects of vegetation.

Subsystems can only be understood in the context of a larger framework[18] which has been constructed at the appropriate analytical level. The framework just put forward is a summary of current ecological understanding but has not been validated. It assists in the formulation of hypotheses, predictive models, management prescriptions and identifies variables which have the potential to confound a test for treatment effects[19]. It also identifies which variables should be controlled and which others to incorporate into data collection.

3.2 Ecological effects of fire and the expected differences in post-fire and post-logging successional pathways.

The quotation at the beginning of this section (Levin 1989) and the comments just made emphasize that an analysis of any patterns suggested by this study's results must be conducted in the context of a vegetation theoretical framework. Such a theoretical framework can also be used to organize the findings of others on post-fire and post-logging vegetation dynamics and to postulate how we expect the effects of fire and logging on species composition may differ. Postulated temporal pathways of species composition take the place of unavailable comparable research and provide something with which our results can be compared. If there is a conflict between our results and the postulated pathways then it suggests that either the postulated pathways are not accurate or that the effects of logging on ecological processes are greater than projected or both. In the event that anomalies are found, the lack of relevant prior research will prevent us from eliminating either possibility.

The discussion which follows begins with a general review of vegetation dynamics and the implications for community resilience. This leads to a description of the expected differences in the immediate direct effects of fire and logging. That description assumes that:

1) The communities were mature[20] at the time of disturbance;
2) The communities are of fire origin;
3) Either fire or logging was the only form of disturbance;
4) Regeneration is natural;
5) Logging methods similar in their ecological effects to those applicable to this study were used;
6) Treatment differences in impacts are confined to the immediate differences in site variables and post-disturbance species composition. This implies that treatment differences in impacts on ecological processes are quickly absorbed so that the site's ability to eventually support a typical mature species composition is not impaired.

Immediate, direct effects are discussed in the context of the theoretical framework's three general factors- site availability, species availability and species performance. In the description of vegetation dynamics, emphasis is placed on 10 - 15 and 35 - 40 year old communities because age classes from these two time periods are included in this study.

A number of conceptual models have been put forward to describe succession (McCook 1994). They vary in the degree to which the community is considered to be a super-organism as opposed to a collection of independently acting individuals and the degree to which stochastic events determine the outcome of succession. Recent literature reviews have concluded that none of the models currently in use can serve as a general model which can apply to all stages of succession or for all species within a succession (McCook 1994; Miles 1987; Pickett et. al 1987). A

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[18] This is consistent with Eberhardt and Thomas' recommendation that ecology progress by using observational studies and experiments in a complementary fashion. Observational studies provide contrasts based on the larger system and experiments examine components.

[19] In the design of a study, experimental or statistical control of substantial causal factors prevents confounding their effects with those of treatment. Experimental control is achieved by selecting treatment units which are homogenous with respect to the factor; statistical control by incorporating replication for different levels of the factor.

[20] A mature community is one which has the physiognomy of a forest and is at a stage where species composition changes little. Post-fire communities in the study area are expected to be in this stage for the period of 50 - 100 years after fire.

model of vegetation dynamics must incorporate different mechanisms of change and different types of successional pathways for different groups of species. Two general types of successional pathways are sequential (McCook 1994) and direct (Miles 1987)[21]. In sequential succession, disturbance eliminates pre-disturbance species and is followed by a series of species replacements. If the community is resilient to the disturbance, a species composition typical for the site type is eventually restored. In direct succession, the species in the pre-disturbance community reappear immediately after disturbance and then persist until the next disturbance[22]. Changes in species composition in communities dominated by direct succession primarily involve redistributions of the relative abundances of species rather than species replacements.

Evidence suggests that a life history strategy which promotes direct succession also promotes community resilience (Abrams and Dickman 1982; Brumelis and Carleton 1989; Dix and Swan 1971; Halpern 1988; Nobel and Slatyer 1980; Ohmann and Grigal 1979; Outcalt and White 1981; Shafi and Yarranton 1973b). When a community has a high proportion of species which regenerate quickly from within it (regenerators), species composition quickly approximates pre-disturbance conditions[23]. These regenerators help the community withstand the invasion of colonizing species not found in the pre-disturbance community. The rapid growth characteristic of many herbaceous invaders causes a temporary, superficial change in the community's species composition which distracts attention away from the regenerators which are also present but less conspicuous (Cogbill 1985). However, the invaders eventually recede in importance due either to their life history characteristics (e.g. annuals or biennials) or changes brought about by regenerators (e.g. competition, shading, no available sites).

Boreal vegetation dynamics are typically dominated by direct succession but also incorporate a sequential component. Many boreal plant species are well adapted to frequent, catastrophic disturbance and contribute to direct succession (Rowe 1983). Adaptations include the ability to resprout from underground organs or possession of fire-resistant bark and cones. Jack pine is a good example. The bark of mature trees provides protection against light surface fires. A more severe or crowning fire will stimulate release of jack pine seeds which then germinate quickly without stratification and become rapidly growing seedlings (Sims et. al 1990).

Sequential succession is exhibited by species which can only establish in the conditions which exist shortly after fire (high light, less competition, exposed mineral soil) or which must wait until certain conditions have developed before they can establish themselves (e.g. shade). Examples of the former and latter types of species are *Polytrichum piliferum* and *Hylocomium splendens*. For some species such as *Abies balsamea*, the delay in establishment is due to the time it takes propagules to disperse into the burn from undisturbed areas outside it.

In addition to life history strategies, community resilience is influenced by chance events (e.g. spruce budworm outbreak), regional history and site history (Abrams and Dickman 1982; Brumelis and Carleton 1989; Dix and Swan 1971; Halpern 1988; Nobel and Slatyer 1980; Outcalt and White 1981). If any of these factors have led to the scarcity or absence of regenerating species which typically attain high relative abundance then the mature community may be atypical. For example, an especially severe fire or logging with significant soil disruption can result in the establishment and dominance of fast growing invaders which preempt the reestablishment of pre-disturbance species and lead to a long term alteration of species composition (Brumelis and Carleton 1989). Part of the reason that this occurs is that most boreal species have broad ranges of physiological tolerance and this enables them to take advantage of colonization opportunities. For example, soil moisture is a

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[21] Miles (1987) cites a number of terms used to refer to what McCook (1994) refers to as sequential succession. McCook's term is used because it names the pattern in an intuitive manner.

[22] This is similar to Egler's (1954) initial floristic composition. However, it also permits the entry of new species during intermediate stages of succession.

[23] It is assumed that pre-disturbance species composition is typical for the site type. A number of vegetation types may commonly be found on a particular site type. Certain others are atypical and may have resulted from severe fires or unusual historical events.

poor predictor of where a tree species might occur because most species are found across the entire range of soil moisture (Dix and Swan 1971; NWO FEC; Rowe 1956 b)[24].

Once the variability of site history and the broad physiological tolerances of species are considered, the upshot is that a model of vegetation dynamics should include a probabilistic element and such factors as the landscape characteristics which influence the probability that a new species will colonize a disturbed area (Frelich and Reich 1995; Rowe 1983). Ideally, probabilities are attached to the most likely, or typical, outcome and the other possible outcomes.

It is suggested that boreal post-fire dynamics are most predictable and communities are most resilient when fire does not eliminate regenerators typically present at the time of fire. Dynamics will then contain a strong direct component. Rowe (1983) provides support for this when he argues that the frequency, intensity and spatial patterns of fire are too variable to have produced boreal plant adaptations to particular levels of fire frequency and intensity. Fire adaptations should be found at the local ecosystem level. Three attributes important for survival at the local ecosystem level in a biome characterized by frequent fire are: mode of regeneration, competitive relationships and the time scale of critical life history events (Rowe 1983). Rowe places the greatest weight on mode of regeneration because there will be limited opportunities for competitive exclusion in a system with a high disturbance frequency and long-lived species which regenerate from within burns.

Rowe (1983) classified boreal species based on whether they were able to survive frequent fire by dispersal of propagules or vegetative regeneration. He subdivided these two classes further to account for more specific types of strategies to survive frequent fire. The resulting strategies are invaders, evaders, avoiders, resisters and endurers (Table 3.1). Some species employ more than one strategy. Jack pine evades fire with its serotinous cones and resists low intensity surface fires with its thick bark.

Table 3.1. Rowe's (1983) plant strategies to cope with frequent fire.

Strategy	Description
Disseminule- based, propagating primarily by diaspores.	
Invaders	Highly dispersive, pioneering fugitives with short-lived disseminules.
Evaders	Species with relatively long-lived propagules that are stored in soil or in canopy.
Avoiders	Shade-tolerant species that slowly reinvade burned areas; late successional, often with symbiotic requirements.
Vegetative- based, propagating primarily by horizontal and vertical extension.	
Resisters	Shade- intolerant species whose adult stages can survive low-severity fires.
Endurers	Resprouting species, shade- intolerant or tolerant, with shallow or deep perennating buds.

Species which can regenerate immediately from within a burned area (regenerators) have the greatest likelihood of remaining to become part of the mature community and thereby promote resilience. Consequently, we present a reorganization of Rowe's classification (Table 3.2) that emphasizes strategies that promote community resilience. Examples are given of species which exhibit each strategy. Strategies could be further subdivided based on preferred site conditions, the maximum fire severity a species can resist and shade tolerance.

A large proportion of boreal vascular plants, including all shade intolerant boreal tree species[25], are regenerators (Table 3.2; Abrams and Dickman 1982; Archibold 1979; Brumelis and

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[24] Despite the generally limited degree to which site conditions restrict where a particular species will be found, it can predict where certain species are most likely to be found (Bakuzis and Kurmis 1978; Bell 1991; Dix and Swan 1971; Jeglum 1971; Jones et. al 1983; Klinka et. al 1989; Ohmann and Grigal 1979; Rowe 1956 b). Consequently, site type is a useful grouping variable in an ecological study.

[25] Included in this group are jack pine, aspen, black poplar, white birch and tamarack. Notwithstanding their shade intolerance, these species are expected to be part of the canopy at the next occurrence of fire since their life expectancies are longer than the length of the fire rotation.

Carleton 1989; Dix and Swan 1971; Egler 1954; Halpern 1988, 1989; Nobel and Slatyer 1980; Ohmann and Grigal 1979; Outcalt and White 1981; Shafi and Yarranton 1973b; Van Cleve and Viereck 1981). In a study of vegetation and nutrient dynamics during the first five years following fire, Ohmann and Grigal (1979) found that all tall shrubs except *Prunus pennsylvanica* regenerated vegetatively. Most low shrubs regenerated in the same manner.

Trees deserve special emphasis in boreal vegetation dynamics due to their influence on understorey composition through their effect on light intensity and litter accumulation (Dix and Swan 1971; Rowe 1956 b). Litter can smother bryophytes, lichens and creeping plants, alter the chemical properties of soil and increase the thickness of the organic layer. A thicker organic layer leads to lower soil temperatures and increased soil moisture which in turn leads to a slower rate of decomposition which then leads to an even greater increase in the thickness of the organic layer. Fire arrests this process and resets soil temperature to a higher level by reducing or eliminating the organic layer and lowering the albedo of the soil surface (Bonan and Shugart 1989; Van Cleve et. al 1983 a, b).

The species composition of a mature tree canopy strongly influences understorey light intensity[26] and understorey physiognomy. Rowe (1956) constructs an understorey light intensity continuum based on overstorey composition which moves from pure aspen/ balsam poplar on to mixed aspen/ balsam poplar and upland black spruce and, finally, pure upland black spruce. Tall shrubs and herbs do not attain high cover values under a spruce canopy due to insufficient light. On the other hand, light penetration through a poplar canopy is adequate to permit the development of a tall shrub layer which suppresses tall herbs. An evenly mixed canopy of poplar and spruce simultaneously promotes tall shrub cover and maximizes tall and medium herb cover. Medium shrubs and low herbs are relatively unaffected by the patterns occurring in the tall shrubs and medium herbs.

As a reflection of the effects of a coniferous overstorey, mature boreal coniferous vegetation types are characterized by a coniferous overstorey and a feather moss ground cover with only a sparse amount of vegetation between these strata[27]. This stratification of vegetation develops over time, primarily in conjunction with tree dynamics.

Trees exert little influence in the stage immediately after fire because they regenerate more slowly than herbaceous species. By about 5 years of age, tree species will have overtopped herbs and shrubs and formed a dense canopy dominated by coniferous species (Ohmann and Grigal 1979). Tree sapling shade and coniferous litter will then influence which species can persist and establish. Self-thinning will occur over time and slower growing tree species (e.g. black spruce) will eventually join species with more rapid initial growth (e.g. jack pine, aspen) in the primary canopy.

Post-fire shrub dynamics are influenced by tree dynamics. Fire causes drastic changes in light intensity in the lower strata. Most species which resprout from underground organs are adapted to deal with both the shade characteristic of a closed spruce or fir canopy and the high light intensity present after canopy removal. Vegetative regeneration and the nutrient release produced by fire leads to a rapid increase in the cover of most shrub species until they are overtopped by trees. Shrub cover is then linked to the characteristics of the canopy formed by tree species whether it be at the sapling or mature tree stages. The dynamics of fire intolerant shrub species are initially influenced by dispersal, site availability and site conditions but later become an inverse function of the degree of canopy closure.

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[26] Trees can be arranged in order of increasing shade cast by mature individuals: jack pine, aspen, black poplar, birch, black spruce and balsam fir; white spruce varies greatly in the shade it casts (Dix and Swan 1971).

[27] Although a feather moss ground cover is a consequence of canopy closure, it does not develop under deciduous vegetation types for two reasons. Light intensity is higher and the heavy annual leaf litter accumulation smothers mosses and ground dwelling lichens.

Table 3.2. Classification of some boreal species based on the strategies which affect community resilience to fire.

	Regenerators (species which may be part of a direct succession)			Colonizers (species which may be part of a sequential succession)	
	Resisters (survive low severity fires)	**Endurers** (resprout from below-ground parts)	**Evaders** (protected propagules germinate)	**Avoiders** (require a specific condition before they can establish, e.g. a closed canopy)	**Invaders** (highly dispersed, pioneers)
Trees	Jack pine[a] Balsam poplar[b] Tamarack?[b]	Aspen[a b] Paper birch[b] Balsam poplar[b]	Jack pine[a b] Black spruce[a b]	Balsam fir[a] White spruce[a]	Aspen[a b] Paper birch[a b] Tamarack[b]
Shrubs		*Alnus crispa*[a] *Amelanchier* spp.[c] *Arctostaphylos uva.*[a] *Betula glandulosa*[a] *Cornus stolonifera*[c] *Corylus cornuta*[c] *Ledum groen.*[a] *Linnaea borealis*[d] *Lonicera villosa*[d] *Rosa acicularis*[c] *Rubus idaeus*[c] *Vaccinium angu.*[c] *Vaccinium myrt.*[a c d] *Vaccinium vitis.*[a]	*Cornus stolonifera*[a c] *Prunus pens.*[a c] *Ribes* spp.[a] *Rubus idaeus*[a c] *Shepherdia cana.*[a] *Symphoricarpos alb.*[a] *Viburnum* spp.[a]	*Linnaea borealis*[a]	*Salix bebb.*[a]
Herbs		*Anemone quin.*[d] *Apocynum andr.*[a] *Aralia nudicaulis*[a] *Clintonia borealis*[d] *Coptis trifolia*[d] *Cornus canadensis*[a d] *Epilobium angu.*[a] *Equisetum sylvaticum*[a d] *Gaultheria hispidula*[d] *Maianthemum cana.*[a d] *Mitella nuda*[d] *Petasites palmatus*[d] *Pteridium aquilinum*[a]	*Aralia hispida*[a] *Corydalis semp.*[a] *Geranium bick.*[a] *Geocaulon livi.*[a] *Polygonum cili.*[a]	*Circaea alpina*[a] *Corallorhiza* spp.[a] *Goodyera repens*[a] *Mitella nuda*[a] *Monotropa uniflora*[a]	*Cirsium arvense*[a] *Epilobium angu.*[a]
Graminoids	*Eriophorum vag.*[a]	*Calamagrostis cana.*[a]			*Calamagrostis cana.*[a]
Bryophytes		*Dicranum fuscescens*[d]		*Hylocomium splen.*[a]	*Ceratodon purp.*[a] *Polytrichum pili.*[a]
Lichens				*Peltigera aphthosa*[a]	

[a] Rowe (1983), [b] Sims et. al (1990), [c] Bell (1991), [d] Brumelis and Carleton (1989). Note contradictory finding for *Linnaea borealis*.

Herbs exhibit similar dynamics as shrubs but may be affected by tall shrub as well as tree cover. A light permeable aspen canopy may permit a dense tall shrub canopy (e.g. *Corylus cornuta*) leading to the same effect on the herb stratum in terms of light intensity as a spruce canopy. In general, tall shrub shading is not expected to be an important factor in herb dynamics since only a small proportion of vegetation types have a well developed tall shrub layer during any stage of their development (NWO FEC). As with trees, shading by tall shrubs will be relatively unimportant in the dynamics of herbs during the early stages following fire. Fire tolerant and intolerant pioneers will appear shortly after fire and quickly attain a high relative abundance. The seed bank is an important source of propagules for herb regeneration. Some species such as *Epilobium angustifolium* and *Agrostis scabra* reappear within a few weeks following fire (Bell 1991).

Ground stratum dynamics are linked with tree dynamics and typically go through a sequential succession from bare rock, mineral soil or organic material to increasing abundance of *Cladonia* lichens and pioneer mosses and lichens (e.g. *Ceratodon purpureus, Lecidea granulosa, Polytrichum* species) to the addition of feather mosses and *Cladina* lichens and then to increasing abundance of feather mosses (initially *Pleurozium schreberi* and then *Hylocomium splendens* and *Ptilium crista-castrensis*). Once a mature, closed tree canopy has developed, a continuous ground cover of feather mosses is formed. The moss layer of a mature forest affects ecosystem dynamics in several ways (Bonan and Shugart 1989; Van Cleve et al. 1983 a, b). By forming a continuous organic mat, mosses prevent the invasion of species requiring a mineral seedbed for germination or seedling survival. A moss layer is very effective at intercepting the moisture and nutrients from throughfall and precipitation. Mosses decompose at 10% of the rate of herbs (Oechel and Van Cleve 1983). In conjunction, these various effects lower soil temperature, raise soil moisture and slow down decomposition and the cycling of nutrients. The result is a nutrient build-up in the thickening organic layer (Bonan and Shugart 1989; Van Cleve et al. 1983 a, b).

3.2.1 Expected differences in the effects of logging in terms of the theoretical framework for vegetation dynamics.

These generalizations about vegetation dynamics and the attributes of boreal species which contribute to community resilience can now be used to postulate how the effects of fire and logging differ[28]. The analysis is couched in terms of the vegetation theoretical framework and loosely follows Pickett et. al's (1987) hierarchy of successional causes (Figure 3.1). Each process or condition contributing to a general cause (e.g. a site becomes available) is examined to identify differences in the immediate effects of fire and logging on boreal vegetation dynamics. In light of the limitations on prior research, the differences described are general and tentative. Postulated differences in post-fire and post-logging vegetation dynamics are summarized in a table which assists in the interpretation of our results.

3.2.1.1 Site availability.

Site availability following fire and logging differs greatly. Mosses and lichens usually comprise a large proportion of ground cover in mature post-fire communities on most of the site types included in this study (NWO FEC). Fire makes a large colonization area available and creates a greater variety of site characteristics than found in the pre-disturbance community because it removes most living ground cover and burns the organic layer down to the mineral soil or bedrock in

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[28] It is assumed in the following analysis that winter logging results in little soil compaction or disturbance except on haul roads. Plots landing on haul roads (generall only one per cutover) were skipped. Winter logging applied completely to the older age class and partially to younger.

some areas. Post-fire site availability will be strongly influenced by the intensity, severity and patchiness of the fire.

Logging creates sites when it disturbs the ground stratum or when plants are killed by logging equipment, slash deposition or the subsequent increase in light intensity[29]. Taking into consideration both the proportion of the area disturbed and the effects on the organic layer, site availability is expected to be altered much more by fire than logging (Zasada 1986). A lower number and variety of colonization opportunities are created in post-logging communities than in post-fire.

3.2.1.2 Species availability.

Treatment differences in species availability (species present as vegetation or propagules) are not expected to be present until immediately after disturbance because it is assumed that post-fire communities and post-logging communities have a similar disturbance history. In post-fire communities, most species are regenerators (Table 3.2). They are supplemented by invaders whose dispersal is accelerated if unburned or slightly burned patches are present (Archibold 1979; Flinn and Wein 1977). Invaders also arrive in cutovers but the lack of available sites limits their establishment.

With the possible exception of logged species, post-logging communities will have the same species available as post-fire plus two other types of species. The first type is species which can survive logging but not fire and reinvade slowly after fire (avoiders). This treatment difference in species availability is eliminated over time as the additional species endemic to the region disperse into post-fire communities also. The second type of species favored by logging are exotics that are transported into cutovers by humans on logging equipment or other means.

Not all species which survive overstorey removal (residual species) will regenerate in cutovers. Some species require fire to trigger dispersal or germination. Jack pine may be an example. If it is one of the species cut then the cones contained in logging slash may open if they are on the ground and exposed to the sun. However, even when this occurs, the number of seedlings produced is lower than after fire.

Even though many species will be common to both post-fire and post-logging communities, vegetation dynamics will be affected by differential availability of propagules. As just noted, fire triggers or enhances the dispersal of some species. Overstorey removal in post-logging communities may have a similar effect by stimulating some species to flower or by slightly warming the soil and triggering germination or suckering.

3.2.1.3 Species performance.

In the context of the theoretical framework for vegetation dynamics, species performance is a measure of how well a species has established, grown and persisted at a site. When a species performs well relative to others, its influence on measures of species composition increases. Ideally, performance is assessed using measures of growth and reproduction such as production of biomass and propagules. Because it is impractical to collect data for these measures in this type of study, cover, basal area and/ or frequency are used as indicators of performance.

Treatment differences in species performance are expected to result from differential effects on such factors as the identity of competitors, nutrient cycling, soil temperature, soil chemistry and light intensity. Fire reduces performance by complete elimination of some species and by killing the above-ground parts of others. It also enhances species performance through increased soil pH and

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[29] Light intensity is properly referred to as irradiance. Light intensity declines with downward movement through foliage to the ground stratum as irradiance is absorbed by leaves (Salisbury and Ross 1992). The difference between light and light intensity is analogous to the difference between total nutrients in the soil and available nutrients. Removal of foliage in any upper stratum will increase light availability.

temperature and the release of nutrients locked up in biomass (Ahlgren and Ahlgren 1960; Viro 1974). The resulting increase in nutrient availability can facilitate vigorous growth in plants which regenerate from below-ground parts or others which invade rapidly. In contrast, logging will favor species tolerant of the increase in light intensity created by overstorey removal since their above-ground parts will generally suffer little mortality relative to fire[30]. Light intensity at lower strata will decrease as a direct function of the degree that the tallest stratum containing residual vegetation is closed. A general increase in light intensity at all strata will occur if no one stratum has a dense layer of foliage. The degree to which understorey light intensity changes after logging will also be a function of the species composition of the pre-logging tree canopy.

Many boreal vascular plants are shade suppressed and are released by logging (Bell 1991; Sims et al. 1990; Viro 1974). The main energetic cost to high light tolerant residual plants in post-logging communities is the replacement of shade leaves with sun leaves. They still have a substantial advantage over post-fire species as they are not required to produce as much new stem tissue.

Residual understorey cover in post-logging communities affects light intensity by intercepting light and acting as an overstorey for the strata below it. It provides some shade for the ground stratum and this may facilitate the persistence of species intolerant of high light. This is expected to contribute to the maintenance of pre-disturbance floristics and species richness in post-logging communities. Whether or not this contribution to species richness results in higher richness in post-logging communities cannot be easily predicted. A number of species will be eliminated in post-fire communities but they will be replaced by a number of invading pioneers that take advantage of improved site availability in post-fire communities.

Light intensity in post-fire communities increases all the way to the ground stratum since foliage in all other overstorey strata is removed. Standing boles provide some shade which can be important for the survival of tree seedlings (Cayford and McRae 1983). Increased soil temperatures in post-fire communities are expected to enhance species performance over the short term (Ahlgren 1960; Ahlgren and Ahlgren 1960; Viro 1974), especially for soils undergoing paludification (Rowe and Scotter 1973). A decrease in growth rates may occur for fresh to moist soils if the increase in soil temperature is accompanied by a decrease in moisture availability. The latter effect may arise if the decrease in evapotranspiration from what has become standing dead plant material is more than offset by increased evaporation from the soil. Provided they are able to tolerate the drastic increase in light intensity and wind exposure, the established root system of regenerators in post-fire communities may confer on them a competitive advantage relative to invaders (Ahlgren 1960).

Nutrient availability, soil temperature and soil chemistry are not expected to be immediately affected by logging. Little is known about the long term effects on these parameters. Fire is thought to play an important role in arresting the declines in soil pH resulting from decomposition of coniferous litter (Ahlgren and Ahlgren 1960). However, a consensus is lacking on this question (Ohmann and Grigal 1979) and constitutes one important set of ecological processes which require further comparative research.

Competition it is not expected to be a major force immediately after logging because most understorey plants are light suppressed prior to disturbance. Total cover in the herb or shrub strata is generally much less than 100% except in some deciduous vegetation types. Competition in these strata will be probably be mainly below-ground and will be lessened in the short term by tree mortality. Only the ground stratum is expected to be substantially influenced by competition prior to disturbance since the cover of its living components often approaches 100%. Overstorey removal is expected to reduce the cover of feather mosses and increase that of reindeer lichens.

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[30] This is especially true of the older post-logging communities in the study area when logging relied partially on horsepower and was carried out entirely during the period of November to March.

The identity of species in all but the ground strata will differ only marginally between treatments by 10 -15 years of age. Many of the species present before fire or logging will be there after disturbance due to the factors already outlined. Invaders in post-fire communities will have been largely eliminated by this age. Unless advance regeneration is adequate, logged softwood species are expected to perform more poorly in post-logging communities due to fewer released propagules and available sites. Survivors in post-logging communities will have a head start in cover over their conspecifics in post-fire communities. Consequently, comparisons across treatments are expected to show many species performing better in post-logging communities during the early stages of succession. This head start may not be maintained indefinitely since the development of a tree canopy will eventually lead to shade suppression in both treatments. Better tree performance in post-fire communities will lead to greater shading and make it difficult for an understorey species to overtake its conspecific (in terms of cover) in post-logging communities. For this reason, it is not expected that most vascular understorey species will still perform better in post-logging communities at 35 - 40 years of age. One factor which may lead to poorer performance are long term impacts on ecological processes.

As far as the ground stratum is concerned, lichens will reestablish and regain their pre-fire abundance more slowly than other plant groups; it may be a number of years before some species, such as reindeer lichens, even appear in post-fire communities (Foster 1985; Kershaw 1977). For instance, *C. stellaris* is thought to require particular soil conditions for establishment and these are generally not produced until about 25 years after fire (Kershaw 1977). Recent post-fire communities will contain some moss species which may not be present in post-logging communities of the same age. These are pioneer species such as the *Polytrichum* mosses which are scarce or absent under a closed canopy. Generalist mosses are expected to persist in post-logging communities and gain a cover head start. Therefore, it is expected that some lichens and generalist mosses will have affinities for post-logging communities shortly after disturbance. At the same time, pioneer bryophytes and lichens (e.g. some *Cladonia* species) are expected to perform better in post-fire communities.

Each treatment is expected to have species exclusive to it during the early stages of recovery since there are treatment differences in site availability and each treatment generally has conditions favorable to species confined to a different end of the light intensity gradient. Shade tolerant evaders (Table 3.2) which are also tolerant of the alteration in light intensity and microclimate will persist in post-logging communities (e.g. *Abies balsamea*). In post-fire communities, regenerators or colonizers intolerant of high light cannot establish. Most of the high light tolerant invaders which establish in post-fire communities are short-lived or poor competitors and are expected to have disappeared by 10 - 15 years of age. By 35 - 40 years of age, the additional time available for dispersal and reducing treatment differences in ecological conditions (assuming no long term impacts on ecological processes) is expected to reduce the number of species exclusive to a treatment.

These points are intended to highlight the main factors expected to contribute to treatment differences in boreal vegetation based on theory and the research of others. Table 3.3 synthesizes the trends described above for upland sites in the study area.

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Table 3.3. Postulated vegetation dynamics on upland sites for the two age classes included in this study.

<u>Pre- disturbance</u>	<u>10 -15 Years Later</u>	<u>35 - 40 Years Later</u>
Physiognomy on upland sites		
Dominant strata will be a coniferous overstorey and a feather moss- lichen ground cover.	Post-fire communities- dominant strata will be tree saplings in the shrub stratum and pioneer mosses; many standing dead trees. Post-logging communities - dominant strata will be saplings and deciduous shrubs in the shrub stratum and a feather moss- lichen ground cover.	Post-fire communities- dominant strata will be a jack pine dominated coniferous overstorey and a feather moss- lichen ground cover. Post-logging communities - dominant strata will be a mixed coniferous or mixedwood overstorey with *Vaccinium* conspicuous in the shrub stratum and a feather moss- lichen ground cover.
Summary of vegetation dynamics and the resulting species composition		
• Jack pine and black spruce overstorey either pure or mixed with each other and/ or aspen. Other tree species are a minor component. • Cover in the shrub and herb strata is generally sparse. • Ground cover is pre-dominantly lichen on the open jack pine plots and feather mosses on the others.	• Shrub stratum in post-fire communities is dominated by jack pine and black spruce; in post-logging communities by broad-leaved plants. • Fire has returned foliage cover in post-fire communities to zero. • Residual species in post-logging communities able to tolerate or benefit from overstorey removal will have a head start in cover. Shading and competition will determine which species will maintain the head start to 10 years. • The main opportunities for invading species will be for pioneers in post-fire communities. By 10 years, most of these species will have been eliminated. The exception will be the moderately shade tolerant, longer lived pioneer mosses or slow invading, high light intolerant species.	• Tree species in the shrub stratum will have moved from being part of the understorey to the overstorey. • Overstorey composition in post-fire communities will be similar to initial conditions unless fire has been atypical in its return interval or severity. The overstorey in post-logging communities will contain much less jack pine, somewhat less black spruce due to poorer regeneration and slightly more aspen. • When averaged over plots, light intensity will be higher in post-logging communities. • Shade intolerants will have been eliminated or reduced in abundance on treed plots. Scattered clumps of these species will occur on untreed plots or in gaps. • High light intolerants will be present in both treatments and slow invading, fire avoiders will have arrived in post-fire communities. • Ground stratum consists of feather mosses, reindeer lichens and litter. • Higher broadleaf litter accumulation in post-logging communities will eliminate some species relative to post-fire communities but create opportunities for other species. • Regenerators in post-fire communities may have caught up to their counterparts in post-logging communities. Their ability to do so will be limited by lower light intensity.
Anticipated treatment affinity patterns		
• Not applicable.	• Jack pine and black spruce reproduction will be favored by post-fire communities. • The cover head start will result in a high proportion of post-logging treatment affinities for vascular plants. • Pioneer mosses will have a post-fire affinity. • Reindeer lichens and generalist or later successional moss species will have a post-logging affinity. • Exclusive species in post-fire communities will be invaders and in post-logging communities they will be avoiders.	• A subset of the understorey species which maintained their cover head start to 10-15 years will still have post-logging affinities. This especially applies to slow growing species eliminated by fire such as reindeer lichens. • Fire and high light intolerants which prefer a deciduous ground layer will have post-logging affinities; species which prefer a coniferous canopy and feather moss ground cover will have post-fire affinities.

21

4. The study area.

4.1 Geology

The 900,000 ha study area (Figure 4.1) is located on the east side of Lake Winnipeg, Manitoba (96° 15' W) extending eastwards to the Ontario border (95° 7' W). From the Winnipeg River (50° 20' N) it extends north just beyond the Wanipigow River and includes an area on the north side of Wallace Lake (51° 5' N).

An east-west elevational gradient drops from approximately 335 m a.s.l. at the Ontario border to 217 m a.s.l at the Lake Winnipeg shoreline (Manitoba Surveys and Mapping Branch 1979). It reflects the Canadian Shield which is near the surface throughout the study area. Approximately 80% of the study area is bedrock (1:1,000,000 scale, Manitoba Dept. of Energy and Mines undated- b). The remaining 20% is evenly split between organic soils and deep lacustrine and glaciofluvial deposits which are concentrated along Lake Winnipeg where the Shield descends below the surface. A few large areas of organic or deep mineral deposits are also found elsewhere. Organic deposits not along Lake Winnipeg occur in areas of low elevation where drainage is impeded. The deep mineral deposits are primarily fine-textured lacustrine and border the major drainage routes (Manitoba Dept. of Energy and Mines undated- b).

There is considerable variability in surficial geology created by the Shield's morphology and the most recent glacial event. Acidic, intrusive bedrock was washed by waves from glacial Lake Agassiz to create a landscape of outcrops interspersed with basins of till and lacustrine deposits (Manitoba Dept. Energy & Mines undated- a). Localized sand and gravel deposits are also present.

4.2 Soils.

Parent material is derived primarily from deposition and reworking by the Wisconsin glaciation followed by further reworking and deposition by glacial Lake Agassiz (Manitoba Dept. of Energy and Mines undated- a and b). Outcrops typically lack mineral soil. Depressions between outcrops contain mineral soil which varies in texture from clays to coarse sands with high proportions of coarse fragments. Sandy loams predominate. Poorly drained depressions have developed organic soils and gleysols. Soils are primarily fibrisols, mesisols, dystric brunisols, gleysols and grey luvisols (Manitoba Dept. of Agriculture undated).

4.3 Climate.

The study area lies within the Subhumid Transitional Low Boreal Ecoclimatic Region (CCELC 1989). Winters are cold and relatively dry while summers are warm. Mean daily temperatures are -18.5 ° C in January and 20.0 ° C in July (Canada. Geography Division 1974). Average annual precipitation is 510 mm with 310 mm of that occurring from May to September. Warm summers and moderate precipitation combine to produce a moisture index just above the borderline for moisture deficit (Rowe 1972). The mean frost-free period is 120 days (Canada. Geography Division 1974).
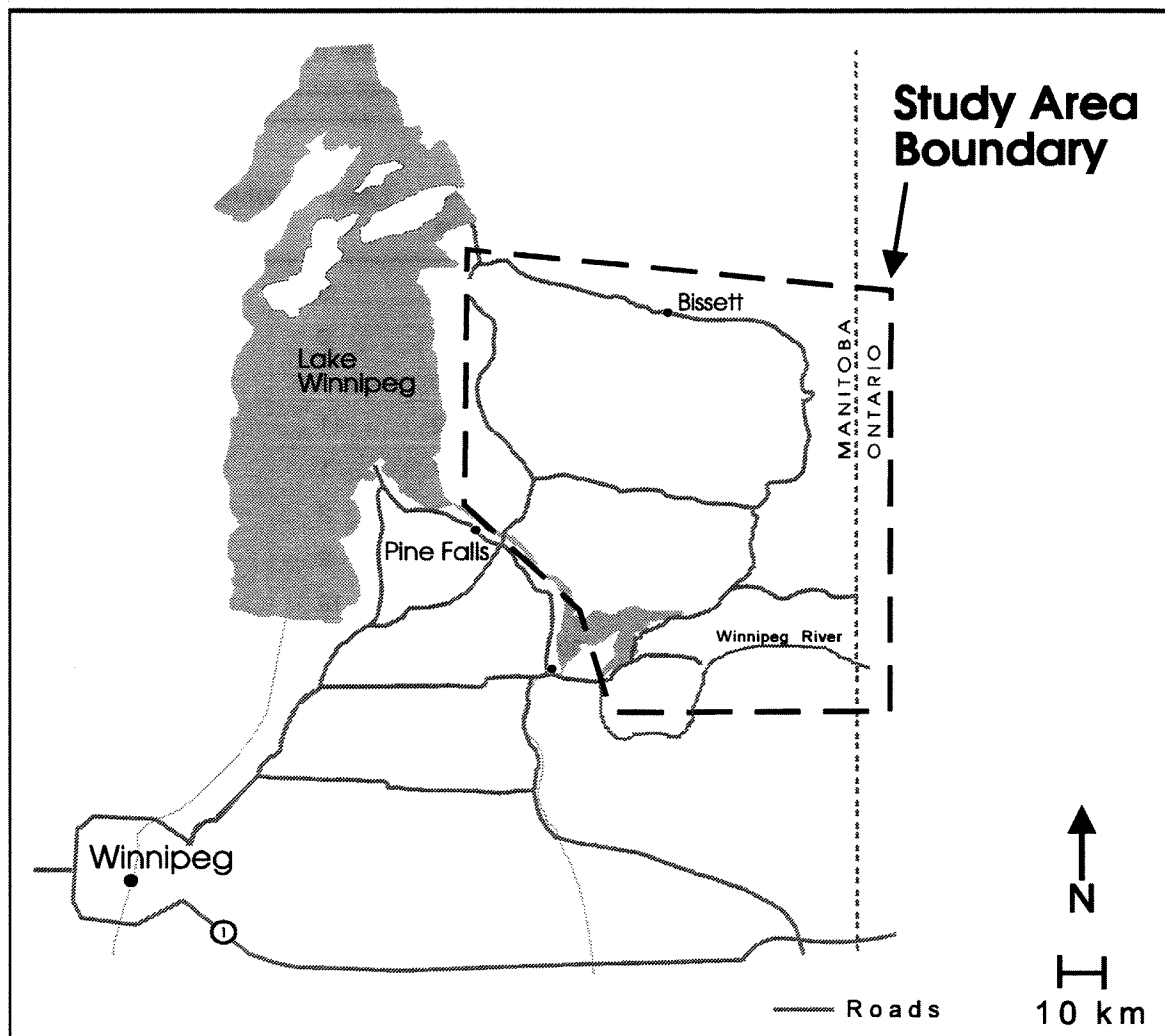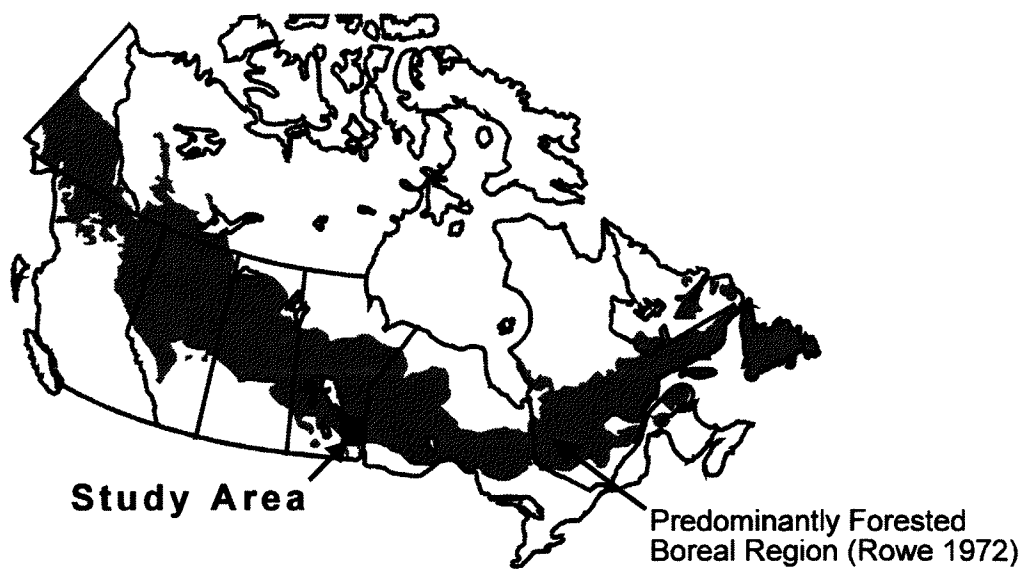
Figure 4.1. Location of study area (Source of digital base maps: Model Forest Gopher Server, URL-gopher://MF.NCR.Forestry.CA/).

4.4 Vegetation.

The Lower English River and the Northern Coniferous forest regions (Rowe 1972) meet in the study area. The boundary between them is established where the Shield ceases to dominate surficial geology. Vegetation of the two regions reflects this difference in surficial geology and the resulting depositional and drainage patterns.

According to the 1986 Forest Resource Inventory (FRI), jack pine, black spruce or aspen are either the primary or secondary species in 88% of treed stands (Table 4.1). A primary species is the canopy species having the highest relative cover in an FRI stand while the secondary species has the second highest relative cover. Black spruce appears as the primary or secondary species in 80% of stands, jack pine in 48% and aspen in 23%. Except on fine-textured soils, the species composition of upland sites typically consists of a jack pine/ black spruce overstorey, a sparse understorey and a feather moss/ reindeer lichen ground cover. The proportion of jack pine in the canopy declines with increasing age and soil moisture. Reindeer lichens are more abundant on the dry sites. Lowland sites typically have a moderately open to open black spruce overstorey, a fairly well developed low shrub stratum dominated by *Ledum groenlandicum* and a ground cover of *Sphagnum* mosses.

Table 4.1. Primary and secondary canopy species in the study area as indicated by the Forest Resource Inventory (1986). Figures indicate the number of stands the species occurs in.

Secondary Species in Stand	Primary Species in Stand								Total Number of Stands as Secondary Species
	Black Spruce	Jack Pine	Aspen	Tama-rack	Balsam Fir	White Spruce	Other	White Birch	
Black Spruce	1836	4644	860	922	154	110	3	0	8529
Jack Pine	1453	354	458	0	14	6	0	0	2285
Tamarack	1505	36	31	244	0	0	1	0	1817
Aspen	508	503	218	10	93	32	11	1	1376
Balsam Fir	358	17	512	1	2	77	1	1	969
White Spruce	114	19	295	0	40	0	2	0	470
White Birch	3	14	70	0	1	0	2	0	90
Other	6	0	48	0	0	0	19	0	73
Total number of stands as primary species	5783	5587	2492	1177	304	225	39	2	15609
Total number of stands as primary and/ or secondary species	12476	7518	3650	2750	1271	695	93	92	
Percentage of stands species occurred in	80	48	23	18	8	4	1	1	

Other = Balsam Poplar, Ash, Eastern White Cedar, Manitoba Maple

24

5. Disturbance history of the area and the logging methods applied to the cutovers.

Vegetation disturbance from commercial activities began around 1900 and spread throughout the area. Mining, pulp and sawmill operations have been the primary activities. Areas near mines were scoured for fuelwood and poles for mine shafts. Additional cutting for sawtimber and fuelwood occurred near towns and along the old winter road which cut across the study area from Pine Falls to Bissett before construction of the highway. Unfortunately, there is no historical record of many of these human activities and this presented problems when it came time to select sample areas. A number of candidate burns or cutovers had to be disqualified because during reconnaissance it became obvious that trees had been cut by humans at some point in the past.

5.1 Fire history: 1885 to 1989.

General descriptions of fire frequency for the boreal forest are found in Cogbill (1985), Foster (1983), Heinselman (1981) and Payette (1992). They suggest that the mean fire return interval for the region is 100 years. Descriptions for specific areas are also found in these works. However, no published descriptions of the fire history or mean return intervals were available for the study area. Historical maps (Section 6.1) indicated that approximately 80% of the study area burned at least once during the 104 year period between 1885 and 1989. Many areas burned several times.

5.2 Logging methods: 1950-1995.

Logging methods were relatively homogenous from 1953 to 1981. The earlier date coincides with the widespread introduction of the chainsaw and mechanized log removal and the later with whole tree harvesting. Documentation of logging methods was facilitated by a number of sources. Interviews with three PFPC employees, Harold Peacock, Julian Wilcott and Mike Retchuk, who had been involved in the logging operations. Harold Peacock also provided a brief summary of the logging history of the Pine Falls operation (Peacock unpublished) Photographs from PFPC's archives were also reviewed. Another interesting information source was Abitibi Price's company magazine which contained numerous photographs and articles going back prior to 1950. Of seemingly special interest to the magazine were new developments at each of its mills and woods operations, such as the elimination of horsepower.

Prior to 1953, all work in the bush was by hand and horse. Chainsaws were available but it was not until about this time that they were widely incorporated into woods operations in the study area. From about 1953 to 1978, cutting proceeded perpendicular to the logging road in strips 1 chain wide (20 m) and approximately 91 m deep. Trees were felled towards the edge of the strip and delimbed where they landed. Either a horse, farm tractor or D-6 crawler used a chain to drag the delimbed bole to the center of the strip. This was often difficult as the butt of the log dug into the snow and occasionally got hung up on stumps. In the center of the strip the bole was cut into 1.2 m (4 foot) lengths and stacked in 1 cord piles. This method of logging will be referred to as "strip cutting".

Some time after being stacked into piles, the wood was loaded by hand onto sleighs and hauled to the river or main haul road by horses or tractor. Wood hauled to the river was stacked on the ice to await the spring thaw. In earlier times, this was the only way to transport wood to the mill and it remained in use until 1958. If taken to a haul road, the wood was loaded by hand onto tractor trailers.

Between 1953 and 1981, logging operations took place almost exclusively between the beginning of November and the end of March. Cutting occurred on all site types where black spruce

stem sizes and volumes made operations economically viable. After 1954, all merchantable black spruce and jack pine was cut except those trees too small to be used by the mill or too large for a man to lift as a 1.2 m section. Jack pine was not utilized prior to 1955.

By 1979, logging had become fully mechanized with 1965 being the last year in which horses were used by PFPC in its woods operation. Trees were cut by mechanical fellers and delimbed at the stump. Mechanical skidders hauled numerous trees at one time to the roadside. The butts of these trees were lifted off the ground resulting in less damage to the ground than in strip cutting. The skidders weighed more and because they roamed over larger areas they may have caused greater damage to advance regeneration than horses which tended to follow a single trail down the center of the strip.

Cutting no longer took place in strips. Each skidder worked approximately 300 m perpendicular to the road and covered swaths much wider than 20 m. The greater power and maneuverability of skidders permitted the removal of larger trees than during the strip cutting era. Skidders dragged the entire bole to the roadside where it was bucked into 2.44 m (8 foot) lengths by chainsaw or mechanical slasher and then loaded onto a tractor trailer. This method of logging will be referred to as "cut and skid". Logging operations were conducted year round with workers being bussed daily to the bush.

From approximately 1986 to 1995, PFPC used a full tree logging system. A feller-buncher cut trees and laid them in piles. A skidder with a hydraulic grapple then picked up a bunch of trees and hauled them to the landing. There they were delimbed and cut into 2.44 m lengths by an hydraulic slasher and loaded onto tractor trailers with an hydraulic boom loader.

At present, PFPC is switching over to a cut-to-length system (FMG Timberjack) which may have effects similar to earlier methods. Trees are delimbed at the stump and the design of the equipment is thought to result in less soil disturbance than the full tree logging equipment. Season of cut will be one difference between the 37 year old and recent cutovers. Cutting now takes place year-round except occasionally for a period in the spring when the moisture content of the trees is too low.

6. Methods.

Numerous steps, each of which require decisions on methods or approach, are involved in the progression from the formulation of a question and objectives to the presentation of the results. It is important that the choices made at each step are explicit because many of them can determine which treatment impacts or whether any at all will be detected. This is not to imply that there is only one correct method for each of these steps. On the contrary, there are usually a number of alternatives, each of which has strengths and weaknesses relative to a study's objectives and the structure of the data. Although there are many works which thoroughly address some of these decisions (for instance, Cochran 1977, 1983; Eberhardt and Thomas 1991; Green 1979; Greig-Smith 1983; Harris 1985; Hurlbert 1984; Orloci 1978; Pielou 1984), there is no established protocol for community level observational studies which provides a guide for their design and analysis (Eberhardt and Thomas 1991). This report attempts to discuss and make explicit all the decisions involved in the evaluation of community resilience to logging and identification of the differences in the effects of fire and logging on species composition. Much of the discussion of alternative methods is confined to Appendix C since it will be of interest primarily to people working in plant ecology. This section will identify the issues involved at each step and indicate which methods were chosen by us.

6.1 Sampling design.

Considerable effort was devoted to reconstructing the disturbance history of the study area so that a map of all the suitable burns and cutovers could be created. Pine Falls Paper Co. (Pine Falls Division of Abitibi-Price at the time) made approximately 1300 maps available for this purpose. These maps were sorted and catalogued and are now stored in the offices of the Manitoba Model Forest. Disturbance history from approximately 500 of these maps was digitized to create a map which delineated all those areas which had been either burned or logged once but not otherwise disturbed since 1900. Some limited information going back to 1885 was available but its scale was too small to be of much use.

To qualify for study, areas must have been either burned or logged only once since 1900 and not otherwise disturbed. No vegetation homogeneity criteria were imposed on the burns or cutovers. Plots within a burn or cutover that had similar site conditions were grouped together.

Recent fire history was reconstructed from the maps made available by Pine Falls Paper Co. (PFPC), supplemented by records from the Manitoba Forestry Branch. Forestry Branch records are similar to those of PFPC until the 1970's when the former began to maintain detailed records. Even when information from both sources is combined, there are still large gaps within the study area. An additional problem involved in documenting fire history is that most of the area is covered with small scale information. Many portions of the burns shown on these maps were missed by the fire. This lack of information is acute in the northeast quadrant of the study area. Consequently, many areas which were identified as potential study burns had to be validated by a number of methods including database searches of the Forest Resource Inventory (1986) for applicable cutting classes and by ground truthing.

The ubiquity of fire made the task of selecting age classes extremely difficult. Initially the intention was to represent three or four age classes during the logging era with at least three replicates. Once the disturbance history had been digitized, it became obvious that this would not be feasible. A large proportion of potential burns and cutovers had subsequently burned. Others were subjected to some form of post-harvest treatment such as planting or drag chains. Ultimately, it was determined that only the 13 and 37 year old age classes had at least three replicate burns and cutovers. A map of all of the suitable burns or cutovers in a particular age class is the sampling frame for that combination.

The sampling design was three stage with random, blocked random and systematic sampling occurring at the successive stages (Figure 6.2). In the first stage of sampling, Blocks (i.e. a burn or cutover) were randomly selected from each of the sampling frames just described. Locations of sampled burns are shown in Figure 6.3 and cutovers in Figure 6.4. Second stage sampling involved subdividing the Block lengthwise into three equal sub-blocks to ensure adequate dispersion of plots within the Block. A transect was randomly located within each of these sub-blocks. Along each transect, subsamples in the form of plots were systematically located beginning from a random starting point at an interval which would yield at least 30 plots from each Block. Tree plots were centered on the understorey plots unless that would cause the tree plot to cross into a different site type. In that event, the tree plot was shifted to include only one site type. In some cases, site conditions necessitated changing the shape of the plot. However, in all cases the total area sampled remained constant and included all of the understorey plot.

The plots were classified into a site type category in the field. A minimum of six but up to seven plots per site type were sampled, if available. Representation of deep mineral soils was a particular problem because they are infrequent. Once quotas were met for a particular site type, subsequent plots of that type were skipped. If three transects did not yield an adequate number of plots for the site types present in the Block then an additional transect was randomly located in the Block. This sampling design permitted a treatment comparison of species composition and richness by age class and site type (Cochran 1977, 1983). Sampling took place during the summers of 1992 -1994. Most of the burns and cutovers sampled were accessed by mountain bike, canoe, float plane or helicopter.

Figure 6.2. Sampling design.
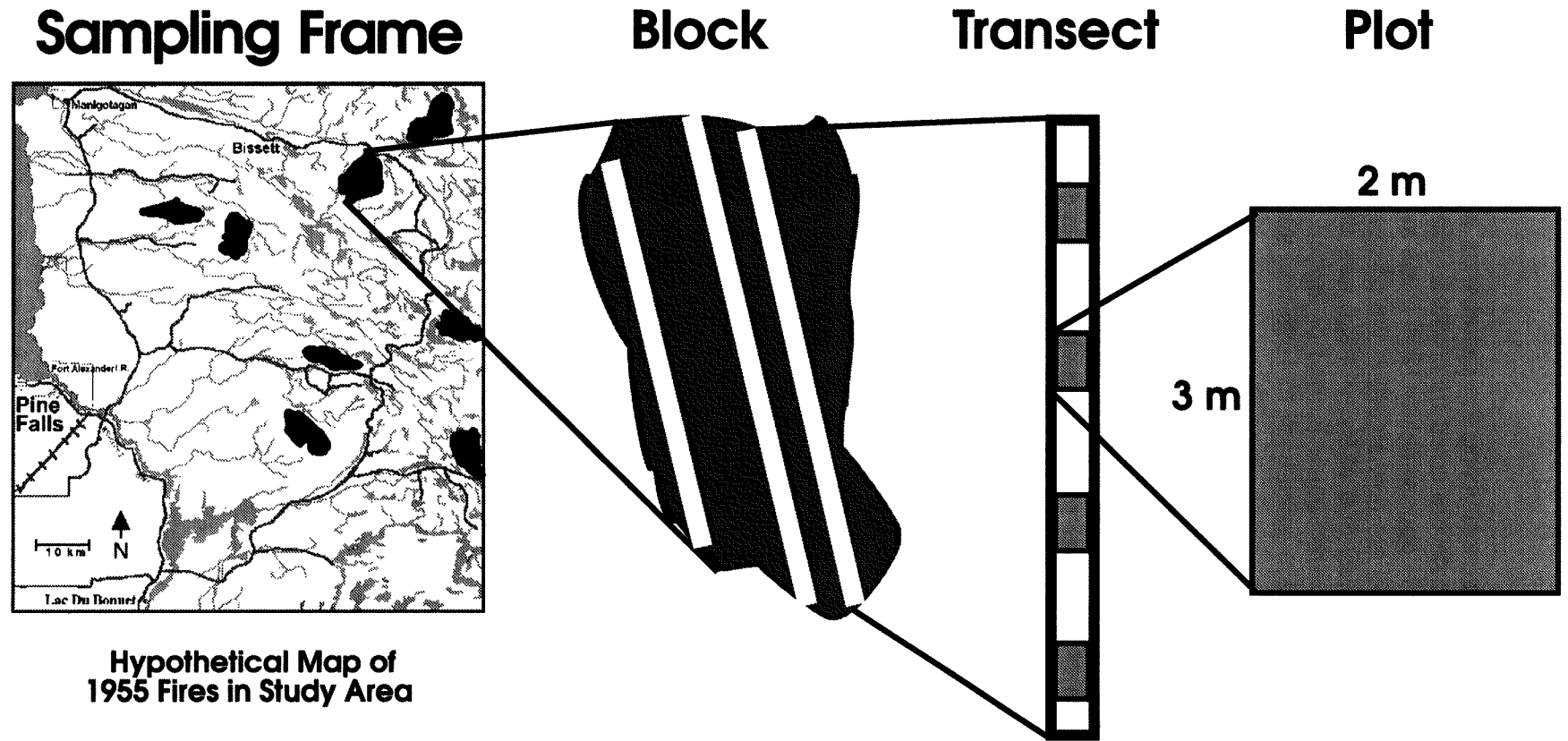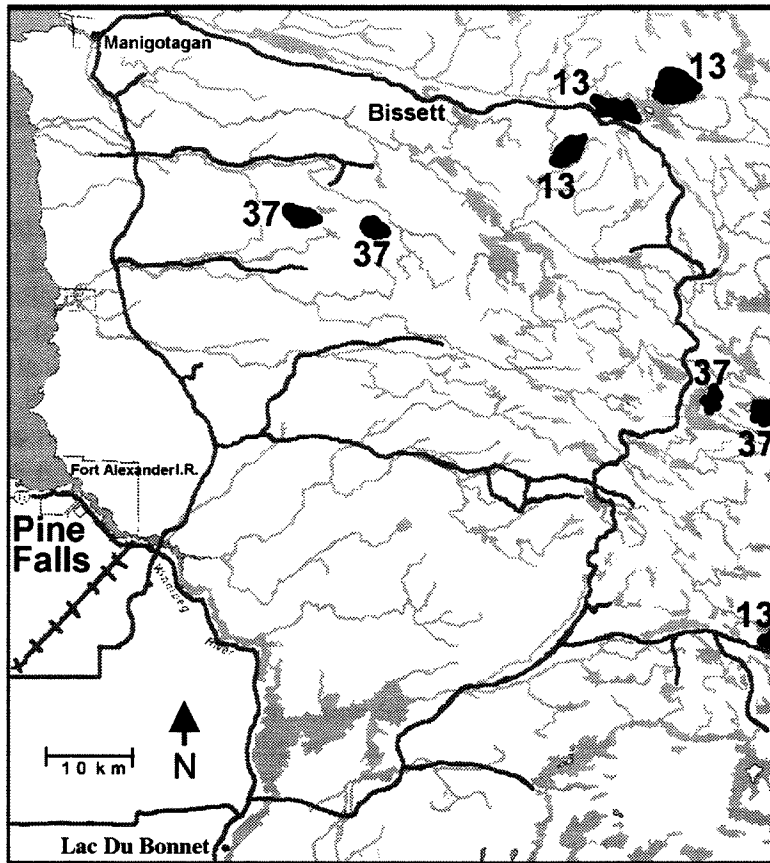
Figure 6.3. Blocks sampled from the 13 and 37 year old post-fire sampling frames. Size and shape of Block altered to render location more visible.
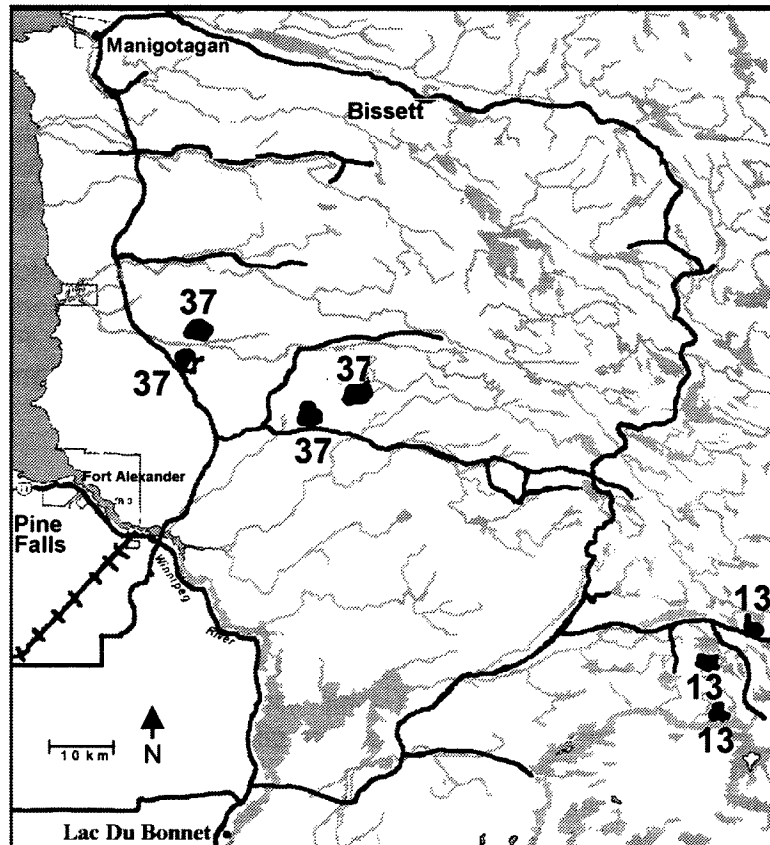
Figure 6.4. Blocks sampled from the 13 and 37 year old post-logging sampling frames. Size and shape of Blocks altered to render location more visible.

6.2 Pilot study to establish quadrat size, plot size, subsample size and site type categories.

Decisions regarding the number of replicates required, subsample size, plot size, quadrat size and site type categorization were based on a pilot study which sampled 136 plots in 1992. It employed the same sampling design as the balance of the study but included some additional sampling. The first task undertaken in the pilot study was the establishment of a quadrat and plot size for use during the pilot study. Percent cover was estimated in quadrats of various sizes to determine the largest quadrat size in which cover could be reliably estimated. The two individuals who completed the sampling that field season took turns estimating cover in a number of quadrats placed on various site types. Each person returned and estimated cover a second time for each quadrat. This provided data on the variability of cover estimates between sampling personnel and for the same person at different times. It was found that both variances rose dramatically once the quadrat size increased beyond 1m * 1m. Consequently, a 1 m^2 quadrat was used to estimate understorey percent cover. A plot consisted of a number of contiguous quadrats.

A 2m * 5m understorey plot was used in the pilot study and a 2m * 3m plot in the balance of the study. Percent cover was estimated for the first 9 quadrats within the 2m * 5m plot. Various plot areas and shapes (e.g. 1m * 1m, 2m * 3m, 1m * 5m) were analyzed to ascertain which one produced the lowest plot to plot variance. Since the site type classification could not be developed without data from the study area, all plots located by the sampling design were sampled during the first field season. Between the first and second field seasons, pilot study data was used to find the combination of a site type classification, plot size, subsample size (the number of plots to be sampled for each site type) and sample size which would maximize the precision of sample estimates subject to the total sampling effort available. Collector curve analysis (based on nested quadrats) and Sokal and Rohlf's (1981) and Kenkel and Podani's (1991) variance minimization methods were used to select plot, subsample and sample sizes. Only the latter two methods were used to construct the site type categories. For theoretical reasons, none of the methods is adequate to provide a solution for all four decisions. Optimum sizes and the site type classification were arrived at through iteration of the three methods. This approach suggested an optimum plot size of 2m * 3m, a minimum of 5 plots for each site type and at least three replicates for each age class, site type and treatment combination. Six 2m * 3m plots per site type were sampled in each Block, if available, during the second and third field seasons.

More than 6 plots were sampled for some site types during the first field season because the site type classification did not exist. Large imbalances in subsample sizes complicate data analysis so subsample sizes were reduced to 7 or 8 by randomly selecting plots. Plots within a burn or cutover which were missed by the disturbance were sampled but results from these plots are not included in this report.

6.3 Variables measured and data collected at each plot.

6.3.1 Measurement of ultimate causal variables.

Seven ultimate causal variables must be measured or controlled for (Figure 3.2). Of these, site type, disturbance type and climate have effects in many more causal pathways than the other variables and will require much greater care in their control and measurement. Climate was controlled for by selecting study area boundaries such that climate is relatively homogenous.

Site type incorporates relatively invariant edaphic and topographic characteristics which determine the availability of resources. It is discussed in more detail in the Section 7.1 and Appendix E. Site type is the only causal variable for which there was stratification in the sampling design.

Animal, including pathogen, effects were assumed to be homogenous between and within treatment units. Subjective field observations were made to confirm that this assumption held. In the event that evidence existed to suggest that a substantial difference was present, say a spruce budworm infestation, then the plot was skipped after its site type was recorded.

Plant functional type information was not collected in the field. To simplify matters, it was assumed that individuals of the same species are of the same functional type. Therefore, species is the finest taxonomic level used. The individuals of some species generally could not be identified to the species level in the field. Species were lumped into a broader taxon if they were either scarce and difficult to identify in the field without reproductive structures or they required a compound microscope or chemicals for identification. The largest taxa to receive such treatment were Moss species, *Salix* species and *Carex* species. Where feasible, taxa which represented ecologically similar aggregations of species within a genus were formed. For example, the taxon *Viola adunca* also contains *Viola conspersa*. Both species are characteristic of dry to fresh, open sites but we could not reliably distinguish between them. On the other hand, *Viola* spp. includes a number of additional species typically found in moist to wet, shaded conditions. When a species found in a plot presented identification uncertainties, it was collected and identified in the lab. Samples of flowering specimens were collected for other species encountered, when convenient. All specimens will be lodged in the University of Manitoba Herbarium (WIN).

Landscape configuration refers primarily to the spatial distribution of community types, surficial geology and degree of relief at the landscape level. Sand plains with ground water far below the surface will produce different vegetation than deep clays. Likewise, small bogs in a sea of outcrops will have different vegetation potentials than large bogs dotted with small outcrops. Topographic and reconnaissance level soil maps were used to ensure that the surficial geology of Blocks was similar[31]. An unpublished reconnaissance level soils map for the area was made available by Canada/ Manitoba Soils Survey (Veldhuis, unpublished). Areas which are predominantly organic soils or clay deposits were excluded from sampling since they cover a minor proportion of the study area (Section 4). In addition to not being representative, the incorporation of these areas would have meant that some Blocks would only have one or two site types included within them. Exclusion of these areas was the main form of control for this causal variable.

Plot level landscape configuration variables were recorded at each plot. They include items such as slope, slope position, slope length, upslope length and aspect along with a description of surrounding vegetation.

Site history and disturbance type presented the greatest challenges for control in sampling design and data collection. The further we go back in time, the less information that is available from written records and from the plot itself. In light of the steps taken in the study's design, it was assumed that systematic treatment differences in site history do not exist. Examples of steps taken include the exclusion of areas which have been disturbed more than once since 1885 and examination of the surroundings of each plot for evidence of atypical events. An attempt was made to detect subtle and local differences through observations on relevant plot and site variables. Even when precautions such as these are taken, a wide range of site histories may be incorporated within each treatment. This does not introduce a bias into the analysis but reduces the statistical power of the hypothesis tests by increasing overall variability (Appendix C).

Subtle differences in fire intensity and disturbance may substantially alter the vegetation found in an area, at least in the early stages following disturbance (Bonan and Shugart 1989; Flinn and Wein 1988). Site disturbance, distribution of slash and other effects associated with logging are also subject to variability which cannot be quantified *ex post*. Once again, the effect is to reduce the

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[31] Since the purpose of the study is to determine whether treatment results in differences in vegetation, aerial photographs and forest resource inventory maps are of limited applicability in establishing the similarity of vegetation in the Blocks unless they represent the vegetation prior to disturbance.

precision of parameter estimates and thereby the possibility of finding whatever treatment differences that are present.

Pre-disturbance vegetation is a causal variable which may exert a substantial influence of the pathways of vegetation dynamics. Limited information was available regarding the species composition of the pre-disturbance communities. FRI maps provided information on overstorey composition and they indicated that logged and burned areas were similar in that their pre-disturbance vegetation was dominated by a mixture of black spruce, jack pine and mixed black spruce/ jack pine stands.

6.3.2 Data collected at each plot.

This study attempted to follow the field procedures recommended by Luttmerding et al. (1990) and the field manual used by Sims et al. (1989). The latter source was given precedence because it is both comprehensive and the most comparable study to this one in terms of the vegetation studied and data collected.

Data or material collected at each plot included[32]:

1) An elevational drawing of the plot showing stratification of vegetation and degree of canopy closure;
2) Description of immediate surroundings of the plot;
3) Soil pit for soil profile description (Agriculture Canada Expert Committee on Soil Survey 1987), moisture regime, drainage regime and depth to carbonates, water table and bedrock;
4) Hand texture of each soil horizon;
5) Soil sample from top mineral horizon in each pit. Samples were taken of additional horizons at numerous representative pits and unusual pits. Samples were placed in labeled plastic bags, sealed and returned to the lab where they were dried. Chemical and textural analysis of selected soil samples was completed by Norwest Labs;
6) Aspect, shape, slope length (distance from crest to toe, maximum recorded length = 200m), upslope length (distance from crest to upper end of plot, maximum recorded length = 100m), percent slope and slope position of plot;
7) Density, height and circumference at breast height for trees (stems with CBH > 10 cm);
8) Percent canopy closure, visually estimated as percentage of a 10m * 10m area in the highest stratum over the plot with some form of cover;
9) Tree cores from at least 2 trees of each coniferous species. More than 2 cores were taken if there was a large range of CBH in the plot;
10) Notes on evidence of past disturbance, recruitment and any other significant items;
11) Percent cover of each understorey species.

Percent cover was estimated separately for each of the following understorey strata:
1) Tall shrub: vascular plant foliage occurring > 2.0 m in height unless it is from a tree; A tree is defined as a tree species having a CBH greater than or equal to 10 cm;
2) Low and medium shrub: vascular plant foliage occurring between 0.5 m and 2.0 m in height;
3) Herb: vascular plant foliage occurring < 0.5 m in height;
4) Ground-
   b) Living: mosses, lichens and liverworts.
   a) Other: includes rock, trunk, snag (dead tree), stump (base of a cut tree), water and various categories of litter.
   Cover in this stratum must add up to 100%. Foliose lichen growing on exposed rock

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[32] Data sheets and keys used in the field are available from the senior author on request.

was counted separately so that the total exceeds 100% for some plots[33]. Crustose lichens were ignored.

A tree species could be recorded as a seedling (under 0.5 m in height), a sapling (CBH < 10 cm) or a tree. Consequently, a tree species could appear more than once in a stratum. For example, cover from a *Picea mariana* tree and a *P. mariana* sapling could both be recorded in the low shrub stratum. Likewise, the same tree could appear in more than stratum. Tree cover was not recorded in the tall shrub stratum for two reasons. Firstly, it is very difficult to estimate percent cover in a stratum that extends from 2 m to the top of the canopy and, secondly, tree density and CBH was recorded in the tree plot.

6.4 Construction of site type categories.

Site conditions in the study area are variable. Consequently, vegetation variation within Blocks is likely to be as great as that between Blocks. To deal with this, the plots were grouped into seven site type categories which covered the range of site conditions capable of supporting some form of forest vegetation. The categories were constructed using pilot study data and were based on the following criteria:

1) Categories are relatively independent of treatment to avoid confounding;
2) The categories have an ecological interpretation consistent with previous work which has examined site type-vegetation type relationships;
4) The categories should minimize the variance of the cover values of their associated vegetation;
5) They should have the potential to be used by forest managers.

The procedure used to arrive at a site type classification was lengthy and peripheral to an evaluation of community resilience. Therefore, a description of the methods used and results leading up to the final classification is relegated to Appendix E. The site type classification is presented and discussed in Section 7.1.

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[33] The absence of soil severely restricts the number of species which can survive. Foliose lichen cover is not included in the summation of ground cover so that the cover of bedrock is not under-emphasized.

6.5 Data analysis.

This study expended much effort to ensure that, to the extent possible, plots were statistically independent and that factors expected to have a substantial influence on species composition were controlled for by the sampling design (e.g. subdividing each Block into three sub-blocks and randomly locating at least one transect within each sub-block) or statistically (e.g. subsampling within site type categories). Given this foundation, it is expected that species which occurred in only a few plots within a site type category were likely to be there as a result of accidental factors. On this basis, species which occurred in less than four plots within a site type category were deleted prior to initial data analysis. An exception were species which occurred in three plots within a single Block. If there were several species in a few plots in only one Block this may indicate that the Block was an outlier in terms of some unmeasurable factor such as ecological history.

6.5.1 Violations of the assumptions of the techniques employed.

Vegetation data rarely conform to the assumptions of the quantitative methods used in a study. The most common assumptions violated are normality and homogeneity of variances. When assumptions are violated, a bias may be introduced into the results, the power of statistical tests may be reduced or the true level of α may deviate from the specified one. Steps can be taken to reduce the degree of violations but often the data will still not conform to assumptions. Fortunately, some of the methods commonly employed have been shown to be quite robust to violations of certain of their assumptions. For example, t-tests and ANOVA are robust to violations of the assumptions of normality and homoscedasticity (Appendix C). A decision must still be made as to whether methods will be used which have either not yet been shown to be robust to violations or which are known to be affected by certain violations. Our approach was to use the method most suited to the data structure and study objectives as the primary method, provided that it is not highly sensitive to the violation of assumptions. Its results were corroborated by alternative methods which were not the optimal ones but which either were robust to a violation to which the primary method was somewhat sensitive, or which were likely to convey very different results from the primary method if the violation was distorting results.

A bias can be introduced when a linear method such as principal components analysis (PCA) is used to analyze non-linear multivariate data or to prepare it for further analysis. This potential bias was minimized in three ways: infrequent species were removed, plots were grouped by site type to split this composite environmental gradient into short lengths and the data were transformed prior to analysis.

Removal of infrequent species is justified by the sampling design. To the extent possible, plots were statistically independent and factors expected to have a substantial influence on species composition were controlled for by the sampling design (e.g. subdividing each Block into three sub-blocks and randomly locating at least one transect within each sub-block) or statistically (e.g. subsampling within site type categories). Species which occurred in one or two plots within a site type category were more likely there as a result of accidental factors. On this basis, species which occurred in less than four plots within a site type category were deleted prior to initial data analysis. An exception to this rule were species which occurred in three plots within a single Block since this might have been an indication that the Block was an outlier.

A data transformation can affect normality as well as non-linearity. Raw, square root transformed and natural log transformed (Ln{x + 1}) species data were tested for normality using the Shapiro-Wilk statistic (W). These results were used to calculate the percentage of species which had a frequency distribution not significantly different from normal. The species included were from the 37 year old age class and percentages of species with a normal distribution were calculated by site type. This percentage was compared for the raw, square root transformed and natural log

transformed data to determine which type of data were most consistent with the normality assumption.

Univariate homogeneity of variance was not tested since Bartlett's test is highly sensitive to small heteroscedasticity and non-normality.

6.5.2 Identification and treatment of outliers.

Univariate and multivariate approaches were used to identify outliers. The univariate approach calculated the mean of normalized species values[34] for each plot by site type and treatment. Any plot which had a mean of normalized species values greater than 2.0 was considered to be an outlier (Hair et al. 1987).

From the multivariate perspective, outliers were detected using non-hierarchical cluster analysis, centered principal components analysis (PCA) and correspondence analysis (CA) applied to the raw, square root transformed and natural log transformed data. Plots which were "distant" from the "swarm" of plots in an ordination scattergram were considered to be outliers. In cases where it appeared that the entire Block was an outlier because most of its plots were distant from the swarm, four criteria were used to identify species which performed better or worse in that Block relative to other Blocks in the same treatment. The criteria were:

1) If the species was ubiquitous it either had its maximum or minimum mean cover in the outlier Block (indicating affinity or repulsion, respectively);
2) If the species occurred primarily in the same treatment then it had its peak or minimum mean cover in the outlier Block;
3) The species was absent in the outlier Block but present in all other Blocks from the same treatment;
4) The species was found in three of four Blocks from the same treatment and its mean cover in the outlier Block was much higher than in the others.

CA was used to analyze outliers because it provides a visual means of quickly identifying which species had their peak cover in the outlier Block. The resemblance matrix on which it performs eigenanalysis leads to an ordination space such that species which are close to a plot in the biplot have their highest cover or probability of occurrence in that plot. CA also tends to position plots with high species richness or high numbers of frequent species near the origin of the scattergram. Conversely, blocks which are species poor or have a number of scarce species show up as outliers.

PCA was also used to identify and analyze outliers. In a PCA biplot (using species centered data i.e. covariance matrix), a line drawn from the species' position in the scattergram through the origin gives an indication of its cover value in the plot. Its mean cover occurs where the line passes through the origin and its maximum at the species point. The length of the species vector relative to those of other species gives an indication of the size of the species mean cover relative to the other species (Ter Braak 1987). The cover of a species in a particular plot can be inferred from the position of a perpendicular running from the species line to the plot. A perpendicular close to the species point indicates that the cover of that species is close to its maximum value in that plot. Inferring cover in this way has its limits since somewhat less than 100% of a species variation in cover is accounted for. In general, the cover of a species far from the origin is better represented than one close to it (Ter Braak 1987).

Outliers were removed from data analysis only if there was a strong justification for doing so.

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[34] That is, from each data value is subtracted the mean of the species it belongs to and then that result is divided by the standard deviation of that species.

6.5.3 Defining ecological distance in a manner compatible with study objectives.

Whenever comparisons of communities involve more than a few species, some measure of resemblance is required to summarize the species information. Numerous resemblance measures[35] are available and each provides a different representation of the pairwise distances of a group of plots. A resemblance measure should reflect a conception of ecological distance appropriate to the study's objectives; in this case a comparison of treatment effects (see Section C.6.4). Many resemblance measures, including some of the commonly used measures (e.g. Euclidean distance, variance in centered PCA), do not represent the relative distances of plots in a way that reflects ecological distance. An example of one inconsistency that some resemblance measures suffer from is that two plots which have all of their species in common can be found to be more distant than two plots which have no species in common. Figure 6.5 shows that the Euclidean distance between two plots which have no species in common (A and B) is less than that between two plots with both species in common (C and D). This makes little ecological sense. Equally undesirable results can occur even when the two pairs of plots have both species in common. This is a concern for any study but is especially important when a comparison of treatment effects is involved. Here, the objective is to preserve the matrix of pairwise plot resemblances in a lower dimensional space using an ecologically meaningful measure of resemblance.
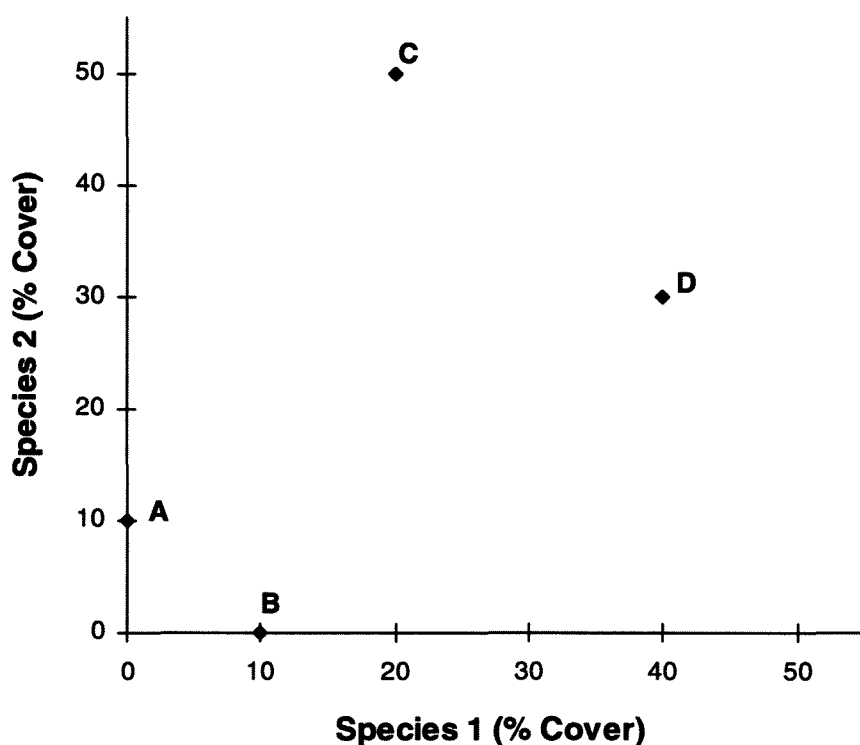
Figure 6.5. **Percent cover of 2 species in 4 plots. Diamonds indicate the percent cover of the two species in that plot (after Pielou 1977).**

The mathematical properties of a resemblance measure determine which ecological aspects of the data are emphasized. A resemblance measure should summarize species information in a

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[35] A resemblance measure is any measure of the similarity, dissimilarity or distance of two plots. The difference between a dissimilarity and a distance measure is that the former does not satisfy the triangle inequality.

manner consistent with the study's concept of "ecological distance" so that the relative distance between plots is not distorted and a bias introduced. Resemblance measures which may fail to detect a real treatment effect or find a spurious one should be avoided. Choosing a measure is complex because its use can be preceded by a data transformation and/ or standardization which also alters interplot distances. Many resemblance measures either implicitly or explicitly incorporate a data transformation or standardization or both. The choice of transformation, standardization and resemblance measure must be considered simultaneously and at two levels. The first level is at the pairwise comparisons of plots and the second when plots are grouped by treatment.

Percentage difference, preceded by a square root transformation, was selected for use wherever a resemblance measure was required because, in combination, their representation of ecological distance is most appropriate in a comparison of treatment effects. Most importantly, they do the best job of representing abundant species relative to scarce ones, fidelity to one treatment, joint absences, equal abundances, different absolute abundances when relative abundances are the same and plot abundance (Appendix C).

6.5.4 Similarity of younger post-fire and post-logging communities to mature post-fire communities.

Resilience and relative rates of recovery were assessed through a comparison of 13 and 37 year old post-fire and post-logging communities with mature (65 year old) post-fire communities. The similarity of these communities was measured as percentage difference using percent cover of understorey species. Several steps were required. First, Block means for each species' percent cover were calculated by age class and site type. Treatment means were then calculated from Block means and the resulting values were grouped by site type. Percentage difference was calculated by site type from a matrix of treatment means from all three age classes.

6.5.5 Multivariate approach taken to describe post-fire communities and test for treatment differences in species composition.

Detailed examination of treatment differences in species composition followed the assessment of post-fire and post-logging recovery rates. First, the species composition of post-fire communities of each site type in the three age classes was characterized so as to create an image of the typical post-fire state. This was followed by a test of the null hypothesis that there was no treatment difference in species composition. A requirement of the statistical model used was that it incorporate Block as a random effect.

No single method or approach is the best one for these types of comparisons. Each has advantages and disadvantages which stem from its mathematical properties and assumptions. An approach was chosen which was most compatible with study objectives. Other methods were used to corroborate the results of the chosen method and address its weaknesses.

A major advantage of a multivariate approach is that it is sensitive to simultaneous changes in the abundance of species. That is, it considers the species composition of the community as a whole rather than on a species by species basis. A univariate approach ignores coordinated responses and requires a remedial measure, such as Bonferroni adjustments, to maintain the specified level of α for all comparisons. The disadvantage of a multivariate approach is that replication is rarely adequate for it to be applied directly to species data. Some form of variable (i.e. dimensionality) reduction is required.

Site type characterization was accomplished with a combination of methods which included canonical variates analysis, mixed model ANOVA, frequency and mean cover. A description of the approach used to characterize the post-fire communities found on each site type is reserved for

Section 6.5.6 since a similar approach was used to characterize treatment differences in species composition.

A multivariate approach was most consistent with the objective of testing for treatment differences in species composition and, given the number of species involved, was expected to have similar power to a univariate approach once Bonferroni adjustments were applied. Tests for differences in the species composition of communities were conducted by MANOVA. Its advantage over Hotelling's T^2 and canonical variates analysis is that it can model Block as a random effect and thereby evaluate within treatment variability. Canonical variates analysis also lacks an unbiased estimate of R^2 and a test for the statistical significance of the canonical correlations.

Too many species were involved (an average of 55 for each age class and site type combination) to apply MANOVA directly to the species composition data. Depending on the number of replicates available, the number of variables was reduced to either two, three or four using principal coordinates analysis (PCO)[36]. In other words, the information regarding ecological factors and treatment effects contained in about 55 species was summarized in about 3 principal coordinates. The assumption is that the principal coordinates extract the data structure which results from ecological factors and treatment effects in order of decreasing strength. If treatment type has a substantial influence on species composition, it is expected to appear on one or more of the first few components (Appendix C). The proportion of total variance accounted for by the first few components is reported but not emphasized since its value is a function of a number of factors, one of which is the number of species involved. PCO was used since it is the only linear ordination technique which allows the user to select the resemblance measure most appropriate to a study's objectives. Substantial non-linearities were not expected since infrequent species were dropped, the data were transformed and plots were stratified by age class and site type. PCO's representation of interplot relationships was compared with that of two non-linear techniques, hierarchical cluster analysis (Ward's method using percentage difference) and non-metric multi-dimensional (NMDS) using percentage difference) and two other ordination techniques correspondence analysis (CA) and centered principal components analysis (PCA). The results were not expected to be the same but the overall pattern conveyed by the four methods should be similar. If the patterns were different then this was a sign that non-linearities might be distorting the results. Results from PCO, CA and PCA are provided for many of the treatment comparisons to show that the detection of a treatment effect was not dependent on the use of PCO.

There were three situations where MANOVA could not adequately test for treatment differences in species composition apparently due to low statistical power. Low statistical power was a concern for treatment comparisons where there were less than four replicates, the replicates of at least one treatment were dispersed and the ordination scattergrams exhibited a treatment related separation of Blocks. In these situations, additional methods were required to corroborate the suspicion that statistical power was too low to detect a difference. Additional methods were also required to deal with the difficulties involved interpreting the results of MANOVA in terms of the input data (the principal coordinates of PCO). This is exacerbated by the fact that the principal coordinates of PCO cannot be interpreted directly in terms of the species. CA, PCA, NMDS, cluster analysis were used to corroborate the results of PCO[37]. These methods were complemented with other univariate and multivariate methods to interpret the results of MANOVA. They focused on highlighting the treatment differences in species composition. The resulting procedure is referred to as a treatment affinity analysis.

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[36] Unless stated otherwise, all quantitative methods were applied to square root transformed data.

[37] Appensix B is a glossary of terms and abbreviations.

38

6.5.6 Performance criteria used to characterize treatment differences in species composition or the communities of the site types- treatment and site type affinity analysis.

An approach was developed to characterize post-fire communities and treatment differences in species composition. Species which performed substantially better in one treatment relative to the other (for a given site type) based on at least one of four criteria were said to have a treatment affinity while species which characterized a site type were said to have site type affinity. For treatment affinities, the intention was to convey an image of what would stand out as being different if one were to compare post-logging communities from a particular age class and site type with similar post-fire communities. For site type affinities, the intention was to convey an image of which species one would expect to encounter in or around a plot situated within the site type. A species could have an affinity with more than one site type but not with more than one treatment.

The affinity approach took into account the strengths and weaknesses of traditional approaches to vegetation classification and several quantitative methods (Appendix C). One of the objectives was to address problems of inadequate statistical power due to the small sample sizes that might prevent appropriate species from being recognized. Four criteria were used to identify species which had either a site type or treatment affinity. Coordinated changes in species abundances were incorporated through the use of canonical variates analysis. Its drawbacks were addressed using ANOVA and mean cover and frequency at the plot and Block levels. For a particular site type and age class, a species was short-listed for the treatment affinity designation if it met one of the following performance criteria:

1) Had a high canonical structure correlation (>= 0.3 in absolute value) with a treatment;

2) Had a significant treatment difference at α = 5% when analyzed with mixed model ANOVA using Block as a random effect. Bonferroni adjustments were not applied;

3) Occurred in both treatments but with a much higher frequency or mean cover in one treatment (e.g. 60% frequency on outcrops in burns and 5% in cutovers). These species may be missed by the first two criteria if variability is high.

4) Was present in only one treatment and had an overall frequency of at least 50% and was present in at least 75% of Blocks in that treatment. Canonical variates analysis and ANOVA will identify species which meet this criterion. The problem is that they will also identify species with much lower frequencies than set out. When this occurs, it is possible that the species' absence in one treatment is an artefact of sampling and should not be considered to be an indicator of a treatment effect.

All four criteria had to be considered simultaneously since they were intended to complement each other. Species identified by one criterion might be disqualified by another.

Similar criteria were used to identify species with an affinity for a site type within an age class. Because frequency is a function of plot size (among other things), site type affinity was assessed at two strength levels. Species which were expected to be found in or adjacent to each plot from the site type are called characteristic species. Species which are less frequent or abundant than characteristic ones but still expected to occur in many plots or in a large area surrounding most plots are called associated species. A species was short-listed for the characteristic site type affinity designation if it:

1) Had a high canonical structure correlation (>= 0.3 in absolute value) with a site type;

2) Had a significant site type difference at α = 5% when analyzed with mixed model ANOVA using Block as a random effect. For species which were found to have a significant difference, this was followed by a Bonferroni adjusted comparison of means across site types to identify the site types in which the species had a significantly different mean cover;

3) Was present in only one site type or treatment and had an overall frequency of at least 50% and was present in at least 75% of Blocks in that site type;

4) Had an overall frequency of at least 75% and was present in at least 75% of Blocks.

Once again, all four performance criteria were considered simultaneously.

Associated species met criteria 1) and 2) but either had a lower frequency than in 3) or a much higher frequency or mean cover in one site type compared to all others (e.g. 60% frequency on outcrops and 0% - 5% on all others).

6.5.7 Tree data.

Tree results are not reported for the 13 year old age class since only a small proportion of individuals had reached the tree stratum by this age. For the site type characterizations, the affinity criteria were used to identify characteristic and associated species. Treatment affinity criteria were not applied for the treatment comparisons since the number of variables was small (only seven tree species). Mixed model ANOVA, which modeled Block as the random effect, identified species with treatment differences in mean basal area. Although MANOVA was expected to be less powerful than ANOVA for this number of species it was also used in the event that its sensitivity to coordinated changes in basal area might identify additional species affected by logging.

6.5.8 Chemical analysis of soils.

Chemical and textural analysis of soil samples was completed by Norwest Labs. Chemical analyses of pilot study soils included: $CaCl_2$ extractable nitrate nitrogen and sulphate sulphur, acetic fluoride extractable phosphorus and potassium, ammonium acetate extractable CA, Mg and Na, percent organic matter using the Wakeley/ Black method, pH and conductivity (1:2 soil:water ratio) and total extractable cations. Particle size analysis was by the hydrometer method.

Norwest Labs also chemically analyzed a random sample of soils from the second field season for nitrate nitrogen, total nitrogen (Kjeldahl method), potassium, sulphate sulphur, Ca, Mg, Na, total extractable cations, percent organic matter, pH and conductivity.

6.5.9 Testing for homogeneity of environmental conditions across treatments.

A subset of environmental variables was examined to determine whether any of them exhibited treatment differences which could lead to a spurious treatment effect. The variables examined were slope, position, aspect, plot shape, slope length, upslope length, thickness of mineral soil, moisture regime, percent stoniness of soil section, thickness of bedrock in soil section and thickness of gleying in soil section. Soil section refers to the 1m * 1m pit dug to a depth of 1m or lithic contact. A typical soil section consists of a litter (LFH) or organic (O) layer, one or more developed mineral layers, parent material and bedrock. Obviously, the presence and variation in thickness of each of these layers can differ greatly in the transition from outcrops to deep mineral soils to organic soils. "Thickness of" rather than "depth to" was used in data analysis to deal with the situations where the variable was not encountered in the pit. Otherwise, either a number larger than the depth of the pit, a negative number or a missing value are required. This made less sense than a zero value. For example, if bedrock was not encountered in the pit then a depth to bedrock value of 0 would not make sense. A missing value would exclude this plot and a value greater than 100 would involve an arbitrary choice. In contrast, thickness of bedrock in the soil profile would be zero in this case. This would treat environmental data in the same way as vegetation data. If we assume that the roots of most plants will be within the soil profile then a zero value is a true measure of the value of this variable and not an indication of absence.

Mixed model ANOVA, treating Block as a random effect, was used to detect treatment differences in environmental variables. It should be noted that the failure to detect a difference does not prove that it does not exist since statistical power may be too low. Multivariate tests were not

applied. Environmental variables present a problem not encountered with species data, that is, variable selection. The researcher must decide which of the environmental variables to include in the multivariate test. This choice of variables can determine whether or not a treatment difference is detected. The lack of a theoretical model of vegetation dynamics hinders the selection of appropriate variables and increases the risk that spurious results will be produced by the statistical problems which result from multicollinearity and redundant or inappropriate variables.

6.5.10 Evaluating ecological relevance in the event of statistical significance.

A statistically significant difference in species composition does not establish an ecologically relevant difference. The treatment affinity criteria were designed so that only substantial treatment differences in species composition would be recognized. Additional criteria taken to be indications of an ecologically relevant difference in species composition were:
1) An abundant species had a relatively large treatment difference in abundance;
2) A large number of scarce species had treatment affinities;
3) A species or group of species thought to contribute to ecological processes in an unusual or substantial manner had a treatment affinity;
4) A number of exotic species were present in post-logging communities.

7. Results.

7.1. Site type categories.

A description of the procedure used to develop the site type categories (Table 7.1) is contained in Appendix E. The classification covered the range of site conditions capable of supporting forest cover. It was based on moisture regime and depth of organic and mineral soil. All the criteria (Section 6.5.1) appropriate for a comparison of treatment effects are substantially met by the classification. The exception are organic soils vis-a-vis criterion 1). Organic soil depth can be affected by fire, especially a severe one. Since organic soil depth was used as an indicator of a wet moisture regime, the classification of plots was cross-checked against the depth to water table variable to ensure that water-logged soils are included in either the organic or deep mineral-moist class. No plots were borderline with respect to these dual criteria. Depth to water table was not used to classify plots as it can exhibit substantial seasonal and annual changes which are unrelated to treatment.

Validation of the site type categories was made by reference to the Field Guide to Forest Ecosystem Classification for Northwestern Ontario (NWO FEC) (Sims et al. 1989). Among other things, the NWO FEC classified sites[1] into 22 fine categories or 5 broad ones based on several soil and topographic variables. Coincidentally, the NWO FEC soil classification key is predominantly comprised of variables which are relatively unaffected by fire or logging. For example, depth of solum and texture of C horizon. Twenty-two soil types is a large number for operational and stratification purposes. The NWO FEC recommends that ecological groupings of soil types be made as a means of establishing treatment units which are more easily applied in the planning of forestry operations. The site type categories used in this study roughly correspond to the broad soil groups of the NWO FEC (pp. 92-93).

Table 7.1. Description of site type categories.

Site Type #	Category Name	Category Description
0	Outcrop	Partly exposed bedrock with an average of 3 cm or less of mineral material.
1	Shallow	Mineral soil depth > 3 cm and < 20 cm and Surface organic horizon < 20 cm thick. May have some exposed bedrock.
2	Moderately Deep	Mineral soil depth >=20 cm and <= 100 cm, Surface organic horizon < 20 thick.
3	Deep Mineral- Dry	Mineral soil depth > 100 cm, Surface organic horizon < 20 cm thick, moisture regime dry to fresh.
4	Deep Mineral- Moist	Mineral soil depth > 100 cm, Surface organic horizon < 20 cm thick, moisture regime moist to wet.
5	Organic- Bog	Surface organic horizon >= 20 cm in thickness. Peat derived primarily from *Sphagnum* mosses.
6	Organic- Nutrient Rich	Surface organic horizon >= 20 cm in thickness. Peat not derived primarily from *Sphagnum* mosses.

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[1] A site is an area delimited by relatively homogenous soil conditions. Site attributes change very slowly relative to vegetation. A number of stands (areas delimited by relatively homogenous vegetation) can occupy a single site and each of these stands will change vegetation types over time.

Table 7.2. Number of plots sampled by age class, treatment, Block and site type.

Age	Block	Number of Plots Sampled							Number of Plots Included in Data Analysis				
		Site type							Site type				
		Outcrop	Shallow	Mod. Deep	Deep Dry	Deep Wet	Organic	Total	Outcrop	Shallow	Mod. Deep	Organic	Total
13	Burn 1*	18	13	5	2		8	**46**	7	7	5	6	**25**
	Burn 2	5	7	6	4	7	7	**36**	5	7	6	7	**25**
	Burn 3	6	6	1			3	**16**	6	6		3	**15**
	Burn 4	6	6				7	**19**	6	6		7	**19**
	Cut 1*	10	9	5	3		4	**31**	7	7	5		**19**
	Cut 2	5	6	6	4	5	5	**31**	5	6	6	4	**21**
	Cut 3	5	5	6	4	6	4	**30**	5	5	6	4	**20**
37	Burn 1	7	6	7	6	7	7	**40**	7	6	7	5	**25**
	Burn 2	6	4	7		2	8	**27**	6	4	7	6	**23**
	Burn 3	9	5	7	3	6	6	**36**	9	5	7	6	**27**
	Burn 4	5	6	6		1	3	**21**	5	6	6		**17**
	Cut 1*	7	15	6		3	4	**35**	7	7	6	4	**24**
	Cut 2	6	5	7	4	3	9	**34**	6	5	7	8	**26**
	Cut 3	6	5	6	1	6	5	**29**	4	5	6	5	**20**
	Cut 4	6	6	6	4	5	6	**33**	5	5	6	5	**21**
65	Burn 1*	6	5	6	15	2		**34**	6	5	6		**17**
	Burn 2	7	6	5	3	1	8	**30**	7	6	5	6	**24**
	Burn 3	6	6	6			7	**25**	6	6	6	5	**23**
	Burn 4	6	6	5	7	3	6	**33**	6	6	5	5	**22**
	Total	**132**	**127**	**103**	**60**	**57**	**107**	**586**	**115**	**110**	**103**	**85**	**413**

* Sampled during the first field season.

Outcrop is not one of the NWO FEC broad soil categories but it appears as a fine one. It was included as an additional category due to its widespread occurrence in the study area and the results of Appendix E which indicate that it supports substantially different vegetation than shallow soils. Organic- nutrient rich soils are combined with organic- bog soils in the NWO FEC. They were treated separately here since the vegetation characteristic of them was quite different from that of organic- bog soils. For example, *Fraxinus nigra* was a frequent species and *Populus balsamifera* an occasional one. Organic-fen soils were rarely encountered and are not included in this report. Subsequent references to organic soils refer to organic- bog soils.

7.2. Summary of number of plots sampled and location of Blocks.

A total of 586 plots were sampled in 19 Blocks from three age classes (Table 7.2)[2]. Power tests conducted by the University of Manitoba Statistical Advisory Service following the second field season indicated that statistical power was too low to detect significant differences even if they were present. The power tests indicated that the most efficient way to increase power would be to obtain more replicates rather than more subsamples within the replicates already sampled. The third field season was spent sampling a fourth replicate for the 13 and 37 year old age classes and four 65 year old burns.

A site type within a Block must contain at least three subsamples (plots) for it to constitute a replicate. Only three of the ten deep mineral age class/ site type/ treatment combinations had three replicates. Consequently, deep mineral soils are not included in the comparisons of species composition or Common species richness.

More than 6 plots were sampled for some site types during the first field season because the site type classification did not exist. The last five columns of the table indicate how the 413 plots included in data analysis were distributed between site types and Blocks. Plots within a burn or cutover which were missed by the disturbance are included in the left hand side of Table 7.2.

7.3. Selection of a transformation to minimize violation of the assumption of normality.

One of the factors which contributes to non-normality is the percentage of zeros in a dataset. Even when the species which occurred in only one plot were ignored, the vegetation dataset contained approximately 75% zeros. This percentage was reduced slightly when species which occurred in less than four plots within a site type and treatment (infrequent species) were dropped (Table 7.3).

Table 7.4 summarizes the percentage of species whose frequency distribution of abundance was not significantly different from normal. When compared with the raw data, the logarithmic and square root transformations substantially increased the number of species with approximately normal distributions. Overall, the square root transformation produced the highest proportion of species with a normal distribution. This is expected when variances are proportional to means. Examination of variance to mean ratios indicated a ratio of approximately 1:1 for most site type/ Block combinations.

A square root transformation was selected for use in data analysis based on its effect on reducing the violation of the assumption of normality and its ability to alter the raw data so that it more closely represented the conception of ecological distance appropriate to the study's objectives. Even after a square root transformation, most species still had skewed distributions of abundance.

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[2] Only those plots which had been either logged or burned are included in the table. A field determination of whether or not a plot was treated was made. In cutovers, plots were not considered to be treated unless stumps were present in or near the plot. Treatment determination in 37 year old burns was more difficult due to the great variability in tree size by this age. Circumstantial evidence was corroborated with ages derived from tree cores. Cores were aged in the field and later in the lab.

This occurred primarily because all datasets had a large proportion of zeros even when infrequent species were removed. At best, only slightly more than one-half of the abundance values were not equal to 0 owing to the small number of species which had high frequencies. This is fairly typical of vegetation data.

Table 7.3. Number of species and percentage of zeros for each site type in the 37 year old age class.

Site Type	Number of Species	Percentage of Zeros
Outcrops	49	65
Shallow	67	69
Moderately Deep	70	70
Organic	41	61

Table 7.4. Percentage of species whose frequency distribution of abundance (based on the Shapiro-Wilk statistic) was not significantly different from normal ($\alpha = 0.05$) by site type (37 year old age class).

Site Type	Transformation			Total Number of Block/ Species Combinations
	None	Nat. Log	Square Root	
Outcrops	17.3	22.4	25.5	392
Shallow	13.8	18.7	22.0	536
Mod. Deep	10.2	15.2	19.8	560
Organic	18.9	22.3	27.4	328
MEANS	15.1	19.7	23.7	

7.4. Identification of outliers.

Five plots were identified as outliers during the construction of the site type categories following the second field season. Once replication was incorporated in the final data analysis, none of the plots were identified as outliers based on the univariate criterion due to the variability added by new Blocks. Ordination scattergrams placed certain plots distant from the clustering of the remaining plots in the Block. Examination of these outlier plots provided no justification for their removal.

7.5. Soil analysis.

Chemical and textural analysis of soils was performed on samples obtained during the first field season and a random sample from the second. Results from the chemical analyses were of limited use because within plot variability was as great as that between Blocks. This probably was a

result of our inability to dry soils in the field due to the remote conditions and wet summers and the higher within pit variability of boreal forest soils compared with agricultural soils (Timmer et al. 1983).

7.6. Comparison of site conditions across treatments in the 13 and 37 year old age classes to ensure similarity.

In the 13 year old age class, significant differences were not detected for any of the environmental variables which might indicate that substantial causal factors other than treatment differed between treatments. In fact, most comparisons had high probabilities (> 0.50) that a significant difference did not exist. Caution must be exercised when interpreting these results since, in a number of cases, they were derived from only two replicates[3] and statistical power is low.

Turning to the 37 year old age class, the only outcrop environmental variable which had a significant treatment difference was upslope length. It had a mean of 3.4 m in post-fire communities compared to 1.7 m in post-logging communities. Upslope length's main influence is on the amount of water which flows through the plot during and after a rainfall. On outcrops, soils are so thin and patchy that the amount of water percolating through a plot was expected to have a limited effect unless it was in a toe position. This small difference in length was not considered to be ecologically significant especially considering that no difference was observed in any other site variable.

Shallow soils showed significant differences for aspect and depth of mineral and organic soil in the soil section. Mean aspect in post-fire communities was east (Table 7.5) whereas it was south-southeast in post-logging communities. It is questionable whether this difference was ecologically significant, especially when there was no difference in slope and mean percent slope was only 6.6%.

Differences in the depth of soil can be ecologically important, especially when occurring together with differences in water availability because one of the main effects of shallow soil is a limitation on moisture availability. However, the difference in mean depth of mineral and organic soil was only 4 cm. This small difference in depth, when coupled with no significant difference in moisture regime or any other edaphic variable, was not considered to be ecologically significant.

Table 7.5. Means for shallow soil site variables in the 37 year old age class which had a significant treatment difference.

Community Type	Aspect (degrees)	Depth of mineral and organic soil in Soil Section (cm)
Post-fire	96	84
Post-logging	164	89

Aspect: -10 = none i.e. plot is level; otherwise, compass direction with 360 equal to due north.

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[3] There are a number of site variables for which the number of replicates used in the analysis is less than that used in the corresponding vegetation analysis. This occurs because data were not collected for these variables during the first field season. The variables include percent canopy closure, slope length, upslope length, drainage regime, percent stoniness in soil profile.

8.   Results for mature (65 year old) post-fire communities.

8.1.   Characterization of mature post-fire communities.

The ground stratum of 65 year old post-fire communities is dominant in terms of cover. A single lichen taxon had the highest mean cover on outcrops and a bryophyte on the other site types. The combined cover of either lichens or bryophytes was also dominant on each of the site types. Between the ground and the tree strata, the forest was fairly open. Cover in the tall shrub stratum was sparse. What was present consisted mainly of the foliage and saplings of selected tree species and scattered low shrubs. The exception to this was the low shrub stratum of organic soils. Basal area and understorey cover of tree species had a direct correspondence with increasing depth of mineral soil. Jack pine was ubiquitous and was the species with the highest basal area on mineral soils. Black spruce was a relatively important component of the understorey and tree canopy on all site types. Its basal area was highest on organic soils.

8.1.1. Trees.

The first step in characterizing the 65 year old post-fire communities found on each site type was a canonical variates analysis of the tree data. It detected significant site type differences in basal area for the overall model ($p = 0.0001$ for Wilk's Lambda) and the first two canonical variates ($p = 0.0001$ and 0.0064). Balsam fir, black spruce, jack pine and tamarack had canonical structure correlations greater than 0.3 (Table 8.1). Outcrops and organic soils are separated from shallow and moderately deep mineral soils on the first canonical variate (Figure 8.1) based on tamarack's high relative basal area on organic soils and jack pine's high relative basal area on shallow and moderately deep mineral soils (Table 8.2). Black spruce separated moderately deep and organic soils from outcrops and shallow soils on the second canonical variate. Balsam fir's presence only on shallow soils contributed to the separation of site types on both canonical variates.

No tree species had an affinity with outcrops since only 37% of plots had trees in them (Table 8.3). Jack pine was the only tree with a site type affinity with shallow soils where it was characteristic. Moderately deep mineral soils were characterized by jack pine and black spruce. Black spruce was a characteristic species on organic soils, tamarack was an associated species.
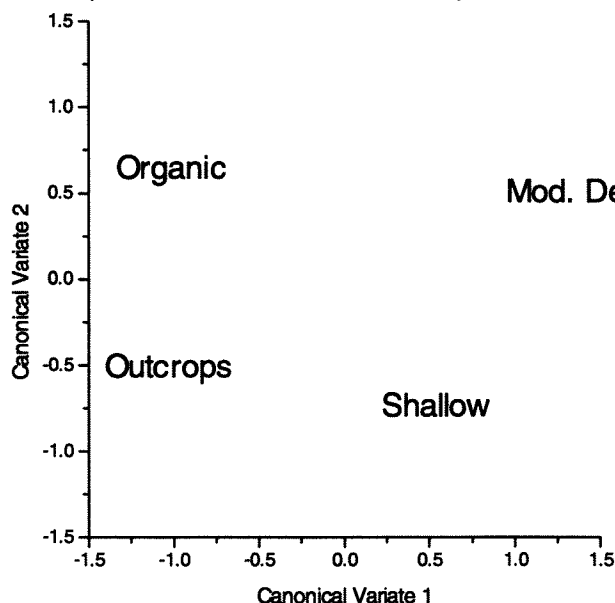
Figure 8.1. Site type means of plot scores from canonical variates analysis of trees in 65 year old post-fire communities.

Shallow soil plant communities were moderately closed (96% had trees and mean canopy closure was 20%) and often had small patches of exposed bedrock within them. Jack pine had its highest basal area on them. The understorey was fairly open with only the occasional tall shrub. Low shrubs and herbs had higher cover than tall shrubs but were still not abundant. Four shrubs had a site type affinity with shallow soils; *Vaccinium myrtilloides* was characteristic (C% = 2.0) and *Diervilla lonicera* (C% = 4.6), *Spiraea alba* (C% = 0.3) and *Vaccinium angustifolium* (C% = 2.6) were associated. *Maianthemum canadense* (C% = 2.0) was the only characteristic herb while *Lathyrus ochroleucus* (C% = 0.6) and *Potentilla tridentata* (C% = 0.5) were associated. Three grasses were associated with shallow soils. As with outcrops, the ground stratum had the dominant cover. *Pleurozium schreberi* (C% = 40.1), *Dicranum* species (C% = 8.5), *Cladina rangiferina* (C% = 5.6) and *Cladonia* species (C% = 0.3) were characteristic of shallow soil communities. The coniferous canopy was reflected Coniferous litter which had a cover of 20.4%. Other litter (C% = 13.6) was also high.

The improvement in tree performance with increasing mineral soil depth was demonstrated on moderately deep mineral soils by their having the highest degree of canopy closure (47%) and the highest basal area (39.3 m^2/ ha) (Table 8.2). Black spruce (11.1 m^2/ ha) and jack pine (21.9 m^2/ ha) were characteristic. Black spruce was also characteristic in the shrub stratum (mean cover = 5.7%) (Table 8.5). Recruitment data indicated that saplings (about 40,000 stems/ ha) and seedlings were present (about 12,500 stems/ ha). Associated shrubs consisted of aspen (C% = 0.3), *Linnaea borealis* (C% = 0.7) and *Vaccinium myrtilloides* (C% = 0.9). Herbs were also more abundant on moderately deep soils. *Maianthemum canadense* (C% = 0.9) and *Cornus canadensis* (C% = 3.2) were characteristic while *Clintonia borealis* (C% = 1.4) and *Rubus pubescens* (C% = 1.6) were associated. Bryophytes and lichens were still had high cover but less than on shallow soils. The decline in total bryophyte and lichen cover was approximately equal to the increase in Other litter. As was the case with shallow soils, *Pleurozium schreberi* (C% = 33.2) was the most abundant species and *Dicranum* species (C% = 5.5) was the second most abundant species. Lichens had much lower cover than on other mineral soil types. *Cladonia* species and Foliose lichen species were the only species with an affinity but their combined cover was only 0.3%.

Organic soils supported post-fire communities very different from those on mineral soils. Communities were moderately open, 94% had trees and mean canopy closure was 14%, with black spruce attained its highest frequency and basal area (Table 8.2). Tamarack was an associated species exclusive to organic soils. With the exception of black spruce saplings, tall shrubs were sparse. There was a well developed low shrub stratum dominated by Ledum groenlandicum (C% = 14.2). Chamaedaphne calyculata (C% = 3.4), Kalmia polifolia (C% = 0.2), Oxycoccus quadripetalus (C% = 0.2) and Vaccinium vitis-idaea (C% = 0.5) were found in most plots. Carex species (C% = 0.2) was the only graminoid with an affinity for organic soils and it was found in or around most plots. Bryophytes were more abundant on this site type than any other. Sphagnum species had a mean cover of 68.3% and Pleurozium schreberi 12.4%. Several other bryophytes were associated with organic soils (Table 8.5).

Table 8.4. Species in 65 year old post-fire communities with high canonical structure correlations (> |0.3|) when site type is the classification variable.

Species	Can Var 1	Can Var 2	Can Var 3
Sphag spp	0.93	-0.03	-0.05
Ledum gro	0.88	0.02	-0.04
Chama cal	0.83	0.02	-0.03
Oxyco qua	0.75	0.02	-0.03
Smila tri	0.74	0.02	-0.03
Vacci vit	0.72	0.02	-0.03
Kalmi pol	0.68	0.02	-0.03
Auloc pal	0.54	0.01	-0.02
Carex spp	0.48	0.15	-0.28
Polyt str	0.47	0.01	-0.02
Rubus cha	0.45	0.01	-0.02
Liver spp	0.35	0.01	-0.01
Betul gla	0.34	0.01	-0.01
Black spruce	0.30	-0.35	-0.04
Anemo qui	-0.09	-0.30	-0.09
Alnus cri	-0.09	-0.30	-0.09
Hyloc spl	-0.09	-0.31	-0.09
Paper birch	-0.09	0.06	0.35
Clint bor	-0.09	-0.32	-0.10
White spruce	-0.09	-0.32	-0.10
Lycop cla	-0.10	-0.34	-0.10
Arcto uva	-0.10	0.07	0.40
Spira alb	-0.11	0.08	0.41
Balsam fir	-0.11	-0.38	-0.11
Lathy och	-0.11	0.08	0.43
Goody rep	-0.11	-0.40	-0.12
Trien bor	-0.12	-0.40	-0.12
Vacci ang	-0.13	0.02	0.41
Aspen	-0.13	-0.47	-0.14
Woods ilv	-0.15	0.30	-0.28
Amela san	-0.15	-0.08	0.35
Coryd sem	-0.16	0.32	-0.30
Oryzo asp	-0.19	-0.09	0.46
Polyt pil	-0.19	0.36	-0.27
Arali nud	-0.19	-0.34	0.18
Agros hye	-0.20	0.40	-0.37
Pleur sch	-0.20	-0.26	0.36
Danth spi	-0.21	0.32	0.09
Poten tri	-0.21	0.26	0.36
Vacci myr	-0.22	-0.07	0.46
Dicra spp	-0.22	-0.13	0.31
Dierv lon	-0.22	-0.18	0.46
Polyt jun	-0.23	0.40	-0.13
Cornu can	-0.23	-0.34	0.01
Cladi ran	-0.24	0.35	0.11
Oryzo pun	-0.25	0.29	0.48
Moss_ spp	-0.29	-0.06	-0.31
Folio spp	-0.30	0.52	-0.36
Fruti spp	-0.33	0.59	-0.24
Maian can	-0.35	-0.11	0.38
Cladi mit	-0.36	0.57	-0.28

Species	Can Var 2
Aspen	-0.47
Trien bor	-0.40
Goody rep	-0.40
Balsam fir	-0.38
Black spruce	-0.35
Cornu can	-0.34
Arali nud	-0.34
Lycop cla	-0.34
White spruce	-0.32
Clint bor	-0.32
Hyloc spl	-0.31
Alnus cri	-0.30
Anemo qui	-0.30
Woods ilv	0.30
Danth spi	0.32
Coryd sem	0.32
Cladi ran	0.35
Polyt pil	0.36
Polyt jun	0.40
Agros hye	0.40
Folio spp	0.52
Cladi mit	0.57
Fruti spp	0.59

Species	Can Var 3
Oryzo pun	0.48
Dierv lon	0.46
Vacci myr	0.46
Oryzo asp	0.46
Lathy och	0.43
Spira alb	0.41
Vacci ang	0.41
Arcto uva	0.40
Maian can	0.38
Pleur sch	0.36
Poten tri	0.36
Amela san	0.35
Paper birch	0.35
Dicra spp	0.31
Coryd sem	-0.30
Moss_ spp	-0.31
Folio spp	-0.36
Agros hye	-0.37

See Appendix A for species codes. General format is first five letters of genus joined to first three letters of species.

Table 8.5. Understorey site type affinities, frequency and mean cover in 65 year old post-fire communities.

Site Type	Affinity[1] Char	Asso	Frequency in Plots (%) Outcrop	Shallow	Mod. Deep	Organic	Presence in Blocks Outcrop	Shallow	Mod. Deep	Organic	Mean Cover in Blocks (%) Outcrop	Shallow	Mod. Deep	Organic
N			25	23	22	16	4	4	4	3	4	4	4	3
Shrubs														
Aspen *		2	8	13	36	6	2	2	4	1	0.0	0.0	0.3	0.0
Balsam fir			4		23		1		2		0.1		3.1	
Black spruce *	5	2	20	26	50	94	1	4	4	3	0.5	1.5	5.7	5.0
Jack pine			20	22	14	13	3	3	3	2	0.1	0.1	0.1	0.1
Paper birch *			8	17	14		2	3	3		0.0	0.3	0.7	
White spruce				4	18			1	3			0.2	0.1	
Alnus cri				4	23			1	2			0.5	3.4	
Amela san			4	35	23		1	3	2		0.0	0.8	0.2	
Arcto uva			12	35	9		2	3	2		0.8	0.9	1.7	
Betul gla				4		19		1		1		0.0		0.1
Chama cal *	5E					81				3				3.4
Dierv lon *		1	12	70	36		3	4	3		0.1	4.6	3.1	
Kalmi pol *		5E				63				3				0.2
Ledum gro *	5E					94				3				14.2
Linna bor		2	12	43	59		1	3	4		0.1	0.4	0.7	
Oxyco qua *	5					75				3				0.2
Prunu pen			16	13			3	3			0.2	0.1		
Prunu pum			16	9			2	2			0.0	0.1		
Rosa_ aci *			8	30	27		2	3	4		0.0	0.4	0.2	
Salix spp				17	18	31		4	3	3		0.1	0.7	0.5
Spira alb *		1	12	26			2	3			0.0	0.3		
Vacci ang		1	4	39	27	6	1	4	4	1	0.0	2.6	0.1	0.0
Vacci myr *	1	2	24	78	59	38	3	4	4	3	0.4	2.0	0.9	0.1
Vacci vit *		5		4	9	69		1	2	3		0.0	0.6	0.5
Herbs														
Anemo qui				9	14			2	1			0.0	0.0	
Arali nud *			4	30	41		1	4	3		0.1	1.0	1.6	
Aster cil				17	5			2	1			0.1	0.0	
Campa rot *			16	13			3	3			0.0	0.0		
Chima umb			8	22	18		2	4	3		0.0	0.0	0.0	
Clint bor *		2		4	27			1	3			0.3	1.4	
Cornu can	2		16	30	73		1	3	4		0.7	1.6	3.3	
Coryd sem *		0E	36				4				0.0			
Fraga vir			8	30	23		2	3	3		0.0	0.1	0.2	
Gault pro				17				1				0.1		
Goody rep *			4	13	23		1	3	3		0.0	0.0	0.0	
Lathy och *		1		30	14			4	2			0.6	0.2	
Lycop cla			4	4	18		1	1	2		0.0	0.1	0.1	
Lycop obs			4	4	18		1	1	3		0.0	0.0	0.4	
Maian can *	1, 2		32	87	82	6	3	4	4	1	0.6	2.0	0.9	0.0
Melam lin			20	30	5	13	4	3	1	2	0.0	0.1	0.0	0.0

Site Type	Affinity[1]		Frequency in Plots (%)				Presence in Blocks				Mean Cover in Blocks (%)			
	Char	Asso	Outcrop	Shallow	Mod. Deep	Organic	Outcrop	Shallow	Mod. Deep	Organic	Outcrop	Shallow	Mod. Deep	Organic
N			25	23	22	16	4	4	4	3	4	4	4	3
Polyg cil		0E	16				3				0.4			
Poten tri *		1	44	61	9		3	4	2		0.1	0.5	0.0	
Rubus cha		5				25				2				0.3
Rubus pub		2		9	23	6		1	3	1		0.0	1.6	0.1
Smila tri *		5E				69				3				1.9
Trien bor *				4	27	6		1	3	1		0.0	0.0	0.1
Woods ilv		0E	36				3				0.4			
Graminoids														
Agros hye *		0	48		5		4		1		0.1		0.0	
Calam can					14	19			1	2			0.0	0.1
Carex spp	5	0	44	13	14	75	4	3	1	3	0.1	0.0	0.0	0.2
Danth spi *		0, 1	32	35			4	4			0.0	0.0		
Oryzo asp *		1	8	43	23		2	4	2		0.0	0.1	0.0	
Oryzo pun *		1	32	61	9		4	4	1		0.0	0.1	0.0	
Panic spp			16				2				0.0			
Schiz pur			12	22	5		1	3	1		0.0	0.0	0.0	
Bryophytes														
Auloc pal *		5	4	4	14	50	1	1	3	3	0.2	0.0	0.0	0.2
Dicra spp	0, 1, 2	5	88	96	86	69	4	4	4	3	2.4	8.5	5.5	2.4
Hyloc spl *		2	8	13	45	19	1	3	4	3	0.4	0.1	2.5	0.5
Liver spp			8	9	9	19	1	2	2	1	0.0	0.0	0.0	0.1
Moss_ spp *	0, 2	1	76	61	91	38	4	4	4	3	1.7	0.2	1.7	0.0
Pleur sch	1, 2, 5	0	64	96	91	81	4	4	4	3	15.1	40.1	33.2	12.4
Polyt com			20	26	41	31	4	3	4	3	0.5	0.8	1.4	1.5
Polyt jun *	0	1	80	48	14		4	4	2		1.1	0.2	0.1	
Polyt pil		0	60	17			4	3			0.4	0.0		
Polyt str *		5E				56				3				0.8
Selag den *		0E	24				3				0.0			
Sphag spp *	5			4	18	100		1	2	3		0.0	1.0	68.3
Lichens														
Cladi mit *	0	1	92	70	32	19	4	4	3	1	17.2	4.2	0.8	0.0
Cladi ran *	0, 1		88	87	32	38	4	4	3	3	4.7	5.6	1.0	0.9
Clado spp *	0, 1, 2	5	96	91	91	56	4	4	4	3	1.1	0.3	0.2	0.3
Folio spp *	0	1, 2	96	70	50	25	4	4	4	2	6.4	0.5	0.1	0.0
Fruti spp *	0	1	84	48	14	6	4	3	2	1	0.3	0.1	0.0	0.0
Other Ground														
Conifer litter*	0,1,2,5		100	100	100	100	4	4	4	3	10.6	20.4	21.6	3.4
Other litter *	0,1,2,5		100	100	100	100	4	4	4	3	6.4	13.6	27.5	6.4
Rock *	0	1	88	65	32		4	4	2		35.6	2.8	0.1	
Snag *			8	43	23	13	2	4	3	2	0.0	0.1	0.0	0.0
Trunk *	2, 5	1	4	57	73	81	1	4	4	3	0.0	0.3	0.6	0.2
Water				4		19		1		1		0.0		1.6
Wood litter *	0,1,2,5		100	96	100	100	4	4	4	3	0.8	2.1	2.9	0.5

Blank cell indicates absence; 0.0 means that mean cover was > 0 but less than 0.05.   * Significant site type difference in mixed model ANOVA at $\alpha = 5\%$ (after Bonferonni adjustment for number of pairwise site type comparisons) with Block as a random effect. [1] Char. = characteristic species, Asso. = associated species; 0 = affinity for outcrops, 1 = shallow, 2 = moderately deep, 5 = organic. E = exclusive to site type.

was a more important ground cover.

The 13 year old post-fire communities on moderately deep soils were characterized by a dense tall shrub stratum interspersed with dead trees and patches of *Polytrichum juniperinum*. Jack pine had the highest frequency and cover (F% = 91%, C% = 14.7). Aspen (F% = 82%, C% = 13.0) and black spruce (F% = 64, C% = 4.6) performed better here than on any of the other mineral site types. *Salix* species (C% = 6.7) was characteristic while *Rosa acicularis* (C% = 0.4), *Rubus idaeus* (C% = 0.3) and *Vaccinium myrtilloides* (C% = 3.7) were associated. *Epilobium angustifolium* (C% = 0.6) was the only species in the herb and graminoid strata with an affinity. Shrub stratum shade and litter production (Coniferous and Other litter had combined cover of 78.5%) appeared to affect ground stratum cover more than on the other mineral site types. Although *Polytrichum juniperinum* was still characteristic, its cover was only 8.1%. Four other bryophytes and lichens had a site type affinity. This was the only site type where the communities were not dominated by the cover of ground stratum species.

Organic soil communities were characterized by a sparse tall shrub stratum interspersed with dead trees that were surrounded by a well developed low shrub stratum and scattered herbs and graminoids. *Sphagnum* species (C% = 50.0) was the dominant ground cover. The same tree species which had affinities with the mineral site types also had them with organic soils. Jack pine (C% = 4.8) and black spruce (C% = 4.1) were characteristic and even aspen (C% = 0.5) was associated. *Salix* species (C% = 1.8) and *Vaccinium myrtilloides* (C% = 1.2) were once again present in the shrub stratum as associated species. The remaining shrubs with affinities were species typically found on organic soils. Associated species included *Alnus rugosa* (C% = 3.6), *Chamaedaphne calyculata* (C% = 2.4), *Gaultheria hispidula* (C% = 0.1) and *Kalmia polifolia* (C% = 0.1). *Ledum groenlandicum* (C% = 24.7) and *Vaccinium vitis-idaea* (C% = 3.9) were characteristic. Four herbs had an associated level affinity with organic soil communities. *Epilobium angustifolium* and *Maianthemum canadense* had affinities with the other site types while *Equisetum sylvaticum* and *Smilacina trifolia* had an affinity. *Carex* species was characteristic. This was the only site type where a graminoid taxon had an affinity. Moss species, *Pleurozium schreberi*, *Polytrichum strictum* and *Cladonia* species had affinities in ground stratum.

It is noteworthy that certain species not usually thought of as being found in bogs, such as *Epilobium angustifolium*, jack pine, aspen and *Vaccinium myrtilloides*, were present. All were ubiquitous throughout the site types. In contrast, organic soil was the only site type where some of the species with affinities were exclusive.
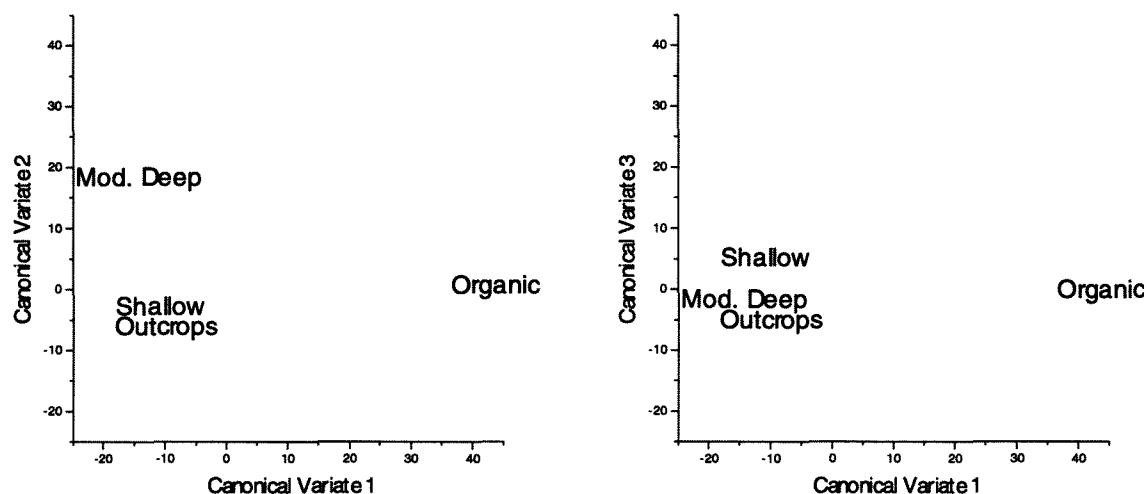
Figure 9.1. Understorey composition- site type means from canonical variates analysis.

Table 9.1. Species in 13 year old post-fire communities with high canonical structure correlations from a canonical variates analysis based on site type. Columns 1 - 4 contain all species which had a canonical structure correlation of at least 0.3 in absolute value with at least one of the first three canonical variates. Columns 5 and 7 show the subset of species which had high correlations with canonical variates 2 or 3.

Species Code	Can1	Can2	Can3	Species	Can2	Species	Can3
Sphag spp **	0.91	0.03	-0.02	Epilo ang	0.49	Jack pine	0.44
Ledum gro **	0.84	0.08	-0.03	Clint bor	0.47	Vacci myr	0.34
Oxyco qua **	0.73	0.03	-0.02	Rosa_ aci	0.42	Cladi mit	-0.36
Vacci vit **	0.59	0.02	-0.02	Rubus ida	0.39	Polyt pil	-0.42
Chama cal **	0.54	0.02	-0.01	Salix spp	0.39		
Equis syl **	0.53	0.13	-0.02	Aspen	0.38		
Kalmi pol **	0.50	0.02	-0.01	Alnus cri	0.37		
Polyt str **	0.49	0.02	-0.01	Dierv lon	0.30		
Carex spp	0.49	0.07	-0.06	Oryzo pun	-0.31		
Smila tri	0.48	0.02	-0.01	Polyt pil	-0.32		
Alnus rug	0.40	0.01	-0.01	Cladi mit	-0.32		
Gault his	0.34	0.01	-0.01				
Rubus cha	0.34	0.01	-0.01				
Eriop vag	0.32	0.01	-0.01				
Bl. spruce **	0.31	0.29	0.19				
Salix spp **	0.03	0.39	0.19				
Epilo ang **	-0.07	0.49	0.05				
Alnus cri	-0.10	0.37	-0.03				
Vacci myr **	-0.13	0.12	0.34				
Aspen **	-0.15	0.38	0.09				
Clint bor	-0.16	0.47	0.00				
Rosa_ aci **	-0.16	0.42	0.04				
Rubus ida **	-0.23	0.39	-0.12				
Cladi mit **	-0.26	-0.32	-0.36				
Polyt pil **	-0.29	-0.32	-0.42				
Dierv lon	-0.30	0.30	0.12				
Jack pine **	-0.31	0.06	0.44				
Oryzo pun	-0.32	-0.31	0.07				
Polyt jun **	-0.64	-0.15	0.02				

See Appendix A for species codes. The general format is first five letters of genus joined to first three letters of species.   ** = species that had a significant difference (mixed model ANOVA ; Block was a random effect; α = 5%) in mean cover on at least one site type.

Table 9.2. Species site type affinities, frequency and mean cover- 13 year old post-fire communities.

Site Type N	Affinity[1] Char	Asso	Frequency in Plots (%) Outcrop 24	Shallow 26	Mod. 11	Organic 23	Presence in Blocks Outcrop 4	Shallow 4	Mod. 2	Organic 4	Mean Cover in Blocks (%) Outcrop 4	Shallow 4	Mod. 2	Organic 4
Shrubs														
Aspen **	2	1, 5	38	50	82	48	3	4	2	4	0.3	2.3	13.0	0.5
Bl. spruce **	5	1, 2	29	58	64	100	4	4	2	4	0.3	1.8	4.6	4.1
Jack pine **	0,1,2,5		79	100	91	83	4	4	2	4	6.6	18.6	14.7	4.8
Alnus rug		5		4		30		1		4		0.0		3.6
Chama cal **		5E				48				4				2.4
Dierv lon		1	25	46	45		2	4	1		0.9	3.0	10.2	
Gault his		5E				26				2				0.1
Kalmi pol **		5E				39				4				0.1
Ledum gro **	5			8	9	96		2	1	4		1.1	1.3	24.7
Oxyco qua **	5E					70				4				0.5
Rosa_ aci **		2	8	8	27	4	2	2	2	1	0.0	0.0	0.4	0.0
Rubus ida **		2	17	12	45		2	2	2		0.1	0.0	0.3	
Salix spp **	2	1, 5	21	50	82	70	3	4	2	4	0.3	2.2	6.7	1.8
Vacci myr **	1	0, 2, 5	54	77	55	57	4	4	2	4	0.3	3.7	3.7	1.2
Vacci vit **	5			8		65		2		4		0.0		3.9
Herbs														
Clint bor				4	36	4		1	1	1		0.0	0.6	0.1
Epilo ang **	2	1, 5	29	62	100	52	2	4	2	4	0.1	0.1	0.6	0.1
Equis syl **		5		8	18	52		2	2	4		0.0	0.0	0.3
Maian can		1, 5	42	50	45	48	4	3	1	4	0.4	0.4	0.4	0.7
Poten tri		0	50	35	9		4	3	1		0.4	0.4	0.3	
Rubus cha						17				1				0.1
Smila tri		5E				48				3				0.4
Graminoids														
Carex spp	5		38	12	36	91	3	1	2	4	0.0	0.0	0.3	1.7
Eriop vag				4		17		1		3		0.0		0.2
Oryzo pun		0, 1	46	42			3	4			0.0	0.1		
Bryophytes														
Moss_ spp	0,1,2,5		88	92	91	30	4	4	2	4	1.5	1.1	2.9	0.9
Pleur sch		1,2,5	21	54	36	65	3	4	2	4	0.1	0.4	0.1	0.1
Polyt jun **	0,1,2		100	96	91		4	4	2		20.4	13.4	8.1	
Polyt pil **	0		79	46	18	22	4	4	2	3	11.8	0.9	0.1	0.1
Polyt str **		5E				52				4				1.0
Sphag spp **	5			12		96		2	1	4		0.1	0.0	50.0
Lichens														
Cladi mit **	0	1	79	65	18	26	4	4	1	3	0.6	0.1	0.0	0.0
Clado spp	0,1,2,5		92	100	91	83	4	4	2	1	2.5	1.2	1.1	1.4
Folio spp **	0	1, 2	71	77	73	26	4	4	2	3	0.8	0.2	0.1	0.1
Fruti spp		1	38	50	9	9	4	3	1	2	0.1	0.1	0.0	0.0
Other														
Confr litter **	0,1,2,5		100	100	100	96	4	4	2	4	12.1	45.5	23.9	6.4
Other litter **	0,1,2,5		100	100	100	100	4	4	2	4	11.4	18.1	54.6	29.3
Rock **	0,1,2		96	92	73	4	4	4	2	1	42.9	10.3	2.2	0.0
Snag		5	29	50	45	70	3	4	2	4	0.3	0.3	1.1	0.2
Trunk		2	8	46	64	13	2	3	2	1	0.0	0.1	0.1	0.0
Wood	0,1,2,5		100	100	100	100	4	4	2	4	3.1	3.9	2.6	4.3

[1] Char. = species had a characteristic afinnity for the site type listed; Asso. = species had an associated affinity with the site type; Site types: 0 = outcrops, 1 = shallow, 2 = mod. deep, 5 = organic. E = exclusive to site type. ** = significant at 5% level in nested ANOVA . See Appendix A for species codes.

Table 9.3. Characteristic and associated species in 13 year old post-fire communities.

	Site type			
	Outcrops	Shallow	Mod. Deep	Organic
Shrubs				
		Aspen [A]	Aspen [C]	Aspen [A]
		Black spruce [A]	Black spruce [A]	Black spruce [C]
	Jack pine [C]	Jack pine [C]	Jack pine [C]	Jack pine [C]
				Alnus rugosa [A]
				Chamaedaphne calyculata [A] **
		Diervilla lonicera [A]		
				Gaultheria hispidula [A] **
				Kalmia polifolia [A] **
				Ledum groenlandicum [C]
				Oxycoccus quadripetalus [C] **
			Rosa acicularis [A]	
			Rubus idaeus [A]	
		Salix species [A]	*S.* species [C]	*S.* species [A]
	Vaccinium myrtilloides [A]	*V. myrtilloides* [C]	*V. myrtilloides* [A]	*V. myrtilloides* [A]
				Vaccinium vitis-idaea [C]
Herbs				
		Epilobium angustifolium [A]	*E. angustifolium* [C]	*E. angustifolium* [A]
				Equisetum sylvaticum [A]
		Maianthemum canadense [A]		*M. canadense* [A]
	Potentilla tridentata [A]			
				Smilacina trifolia [A] **
Graminoids				
	Oryzopsis pungens [A]	*O. pungens* [A]		
				Carex species [C]
Bryophytes				
	Moss species [C]	Moss species [C]	Moss species [C]	Moss species [C]
		Pleurozium schreberi [A]	*P. schreberi* [A]	*P. schreberi* [A]
	Polytrichum juniperinum [C]	*P. juniperinum* [C]	*P. juniperinum* [C]	
	Polytrichum piliferum [C]	*P. piliferum* [A]		
				Polytrichum strictum [A] **
				Sphagnum species [C]
Lichens				
	Cladina mitis [C]	*C. mitis* [A]		
	Cladonia species [C]	*C.* species [C]	*C.* species [C]	*C.* species [C]
	Foliose lichens [C]	Foliose lichens [A]	Foliose lichens [A]	
		Fruticose lichens [A]		

[C] Species had a characteristic level affinity, [A] Species had an associated level affinity.   ** Species exclusive to the site type.

9.2. Outcrops- comparison of 13 year old post-fire and post-logging communities.

The presentation of results related to treatment differences in species composition follows the same general steps for each site type:

1) Exploratory data analysis to get a "feel" for the data, identify obvious patterns in the data which a multivariate technique should reproduce, determine whether PCA and CA corroborate the results of PCO and explore treatment patterns in an informal manner;

2) Test for treatment differences in species composition using MANOVA;

3) Highlight treatment differences using the performance criteria described in Section 6.5.6.

A principal coordinates analysis of outcrop plots distinctly separated 13 year old post-fire and post-logging communities (Figure 9.2). Eigenvalues for the first three principal coordinates accounted for 34.4% of the sum of all eigenvalues (Table 9.5). The treatment effect was strongly visible on the first principal coordinate but not at all on the second. Patterns similar to PCO were evident in scattergrams from PCA (Figure 9.3) and CA (Figure 9.4). Statistical analysis seemed redundant given the strong treatment based clustering but was undertaken to illustrate that point. PCA and CA scattergrams along with results from canonical variates analysis, mixed model ANOVA, frequency and mean cover results (Table 9.4) were examined for outliers or any other relevant patterns which might affect the outcome of hypothesis tests. None were detected.

The maximum number of principal coordinates which can be used in MANOVA is limited by the treatment with the smaller number of replicates. For outcrops that was three. However, given that it was apparent that the treatment effect was confined to the first principal coordinate and that inclusion of redundant principal coordinates reduces statistical power, only the first two were used in MANOVA[7]. As was anticipated by exploratory data analysis, MANOVA found highly significant differences (Table 9.6) for the overall test that there was no difference in the species composition of post-fire and post-logging communities notwithstanding high within treatment Block variability (Table 9.6).

Affinity analysis was used to characterize performance differences in the understorey species composition of post-logging communities relative to post-fire. In post-logging communities on outcrops, commercial tree species and haircap mosses (i.e. these species had a post-fire affinity) performed more poorly and reindeer lichens and a few shrubs and graminoids performed better. Black spruce was the only species with a treatment affinity that was exclusive to post-fire communities. Jack pine and black spruce had dramatically poorer performance in post-logging communities; jack pine was found in only one plot (Table 9.4). This could have important long-term effects on timber volumes and the dynamics of these communities. *Polytrichum juniperinum* (CD = -16.6) and *P. piliferum* (CD = -9.6) also performed more poorly in post-logging communities. *Amelanchier sanguinea* (CD = +0.6) and *Prunus pumilla* (CD = +0.5) were exclusive to post-logging communities. Species which had higher mean cover in post-logging communities included *Arctostaphylos uva-ursi* (CD = +6.2), *Spiraea alba* (CD = +0.4), *Agrostis hyemalis* (CD = +0.4), *Danthonia spicata* (CD = +0.1), *Dicranum* species (CD = +3.6), *Pleurozium schreberi* (CD = 8.0), *Cladina mitis* (CD = +12.6), *C. rangiferina* (CD = +9.4) and Foliose lichen species (CD = 2.2) (Table 9.4).

The largest treatment differences in cover were found in the ground stratum. Bryophytes and lichens compete for surface space. Lichens have slow growth and establishment rates relative to bryophytes (Kershaw 1977). Since both groups are usually consumed by fire, those species which remain after logging will gain a head start in their cover and a competitive advantage. This is suggested as the reason that the higher cover difference in post-logging communities of foliose and reindeer lichens and generalist bryophytes (CD = +35.8 for Foliose lichens, *Cladina mitis, Cladina rangiferina, Dicranum* species and *Pleurozium schreberi*) was largely offset by a reduction in the

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[7] MANOVA using three principal coordinates was still highly significant.

cover of pioneer bryophytes (CD = -26.2 for *Polytrichum juniperinum* and *P. piliferum*) (Table 9.4). Lichens dominated the successionally older ground stratum of post-logging communities whereas pioneer bryophytes dominated the younger ground stratum of post-fire communities.

Arctostaphylos uva-ursi (CD = +6.2) was the remaining species which had a large treatment difference in mean cover. It probably was a residual species in post-logging communities and gained a head start there.

When the cover of all species was combined, the treatment difference in total cover was not significant. Coniferous litter, Other litter and Rock had large treatment differences in mean cover but none were significant due to the high variability of their Block means.

It is worth reflecting back on the points made in Appendix C regarding the efficacy of ordination techniques at extracting interesting structure and ignoring "noise". In outcrop communities, MANOVA and the affinity analysis indicated that there were strong treatment related differences. The appearance of treatment on the first principal coordinate suggested that it was the strongest structuring force for this site type. Despite this, the first principal coordinate accounted for only 16.6% of the total variation in the dataset.
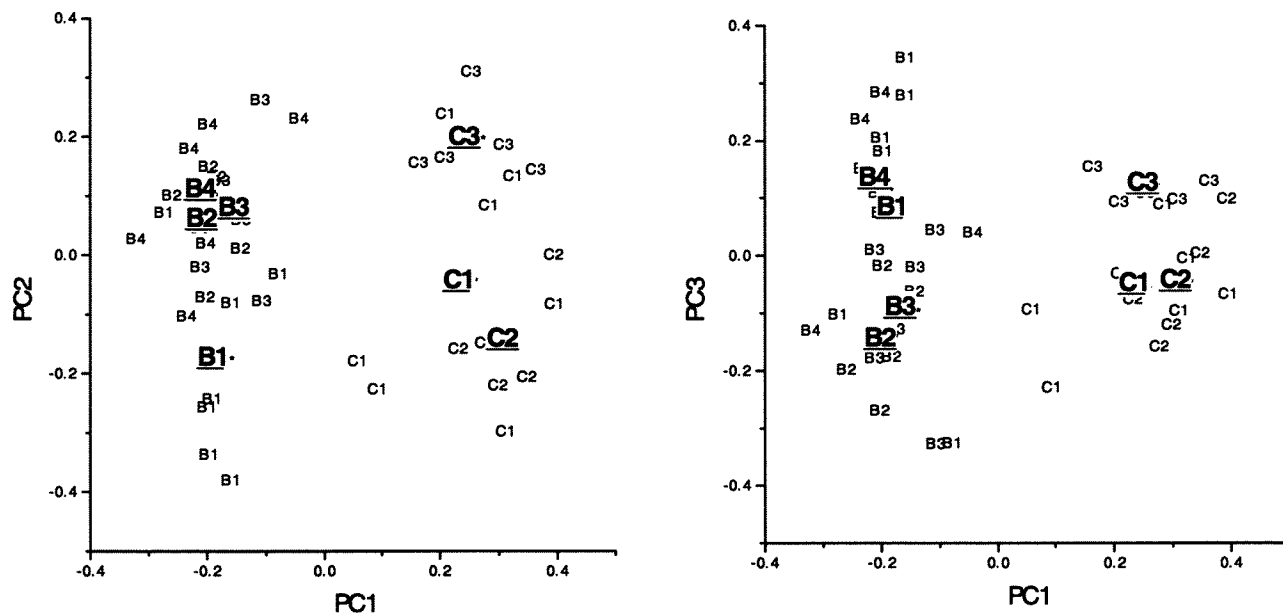
Figure 9.2. PCO scattergrams of plot scores for 13 year old communities on outcrops. Some plots are hidden. B= post-fire plot, C = post-logging plot. Labels with underscores are Block means.

Figure 9.3. PCA scattergrams of species and plot scores for 13 year old communities on outcrops. Some plots are hidden. B= post-fire plot, C = post-logging plot. Labels with underscores are Block means. Species codes in Appendix A.

Figure 9.4. CA scattergrams of species and plot scores for 13 year old communities on outcrops. Some plots are hidden. B= post-fire plot, C = post-logging plot. Labels with underscores are Block means. Species codes in Appendix A.

Table 9.4. Treatment affinities, canonical variates analysis, presence and cover results for 13 year old communities on outcrops.

Treatment	Affinity	CV	Diff. %	Blocks Presence Burn (4)	Blocks Presence Cut (3)	Blocks Cover Burn (4)	Blocks Cover Cut (3)	Plots Pres Burn1 (7)	Pres Burn2 (5)	Pres Burn3 (6)	Pres Burn4 (6)	Pres Cut1 (7)	Pres Cut2 (5)	Pres Cut3 (5)	Mean Cover Burn1 (7)	Cover Burn2 (5)	Cover Burn3 (6)	Cover Burn4 (6)	Cover Cut1 (7)	Cover Cut2 (5)	Cover Cut3 (5)
Shrubs																					
Aspen				3	2	0.3	0.2	1	3	1	4	1		1		0.2	0.1	0.8	0.4		0.4
Black spruce *	B*		-0.3	4		0.3		2	1	1	3				0.6	0.0	0.6	0.0			
Jack pine *	B	B	-6.5	4	1	6.6	0.1	6	3	6	5	1			19.9	1.1	2.2	3.1	0.4		
Paper birch				1	1	0.0	0.3	2						2	0.0						0.9
Amela san	C*	C	0.6		2		0.6						3	2						1.5	0.4
Arcto uva	C	C	6.2	3	2	2.0	8.2	1	1	1		6	4		0.6	4.2	3.3		13.7	11.0	
Dierv lon				2	3	0.9	0.2	5		1		1	1	2	3.7		0.1		0.1	0.1	0.4
Junip com				1	2	0.1	0.9	1				2	3		0.2				2.2	0.5	
Prunu pen				4	1	0.1	0.1	1	3	3	1	3			0.2	0.2	0.2	0.0	0.4		
Prunu pum **	C*	C	0.5		3		0.5					3	2	1					0.7	0.6	0.1
Prunu vir				2	1	0.0	0.2	2		1		1			0.1		0.1		0.7		
Rubus ida				1	1	0.1	0.0		4					1		0.3					0.0
Salix spp				3	1	0.3	0.0	1	2		2	1			0.7	0.2		0.1	0.1		
Spira alb ***	C	C	0.4	2	3	0.0	0.4	1		3		3	4	3	0.0		0.1		0.5	0.5	0.3
Vacci ang				2	2	2.2	0.5	7		2		5	2		8.7		0.1		0.8	0.8	
Vacci myr				4	2	0.3	0.5	3	1	5	4	3	3		0.4	0.1	0.2	0.6	1.2	0.3	
Herbs																					
Campa rot				1	2	0.0	0.0			2			4	1			0.0			0.1	0.0
Cornu can				2			0.4	3	2						1.2	0.3					
Coryd sem				2	2	0.0	0.0		1		1	3		3			0.0	0.0	0.0		0.0
Epilo ang				2	1	0.1	0.0	4	3					1	0.1	0.3					0.0
Fraga vir		C		1	1	0.0	0.1			1			4				0.0			0.2	
Gault pro				1	2	0.0	0.3	2				2	1		0.1				0.8	0.1	
Maian can				4	2	0.4	0.2	5	1	4	1	2	4		1.3	0.0	0.3	0.0	0.2	0.3	
Poten tri				4	3	0.4	1.4	4	1	5	2	5	5	2	0.4	0.2	0.9	0.1	0.4	3.5	0.3
Viola adu				3	2	0.0	0.0	1	1	2		2	1		0.0	0.0	0.0		0.0	0.0	
Woods iv				2	2	0.2	0.0	1		1		1	2		0.4		0.3		0.1	0.5	
Graminoids																					
Agrop tra					2		0.4						2	3						0.1	1.2
Agros hye **	C	C	0.4	1	3	0.0	0.4				1	3	4	5				0.0	0.0	0.5	0.8
Carex spp				3	3	0.0	0.1	2	3	5		3	2	3	0.0	0.1	0.1		0.1	0.1	0.0
Danth spi *	C	C	0.1	2	3	0.0	0.1	2		1		4	4	3	0.1		0.0		0.0	0.3	0.1
Oryzo asp				1	2	0.0	0.2			1			4	1			0.0			0.6	0.0
Oryzo pun				3	3	0.0	0.1	5		5	1	4	3	1	0.1		0.1	0.0	0.1	0.2	0.0
Schiz pur				2	2	0.0	0.0	2		1		1	3		0.0		0.0		0.0	0.1	
Bryophytes																					
Dicra spp **	C	C	3.6	3	3	0.0	3.6	2	1		2	6	5	3	0.0	0.0		0.0	5.2	5.5	0.1
Moss_ spp				4	3	1.5	0.2	6	5	6	4	6	5	5	0.5	4.9	0.4	0.1	0.1	0.3	0.1
Pleur sch	C	C	8.0	3	3	0.1	8.1	3	1		1	3	5	1	0.2	0.1		0.0	1.2	22.3	0.7
Polyt jun *	B	B	-16.6	4	3	20.4	3.8	7	5	6	6	6	5	5	36.4	30.1	10.3	4.9	1.1	8.5	1.9
Polyt pil *	B	B	-9.6	4	3	11.8	2.2	3	5	6	6	6	2	4	15.1	12.0	14.2	5.8	5.9	0.1	0.5
Selag den				3	2	0.0	0.1	1		1	2	2	1				0.0	0.1	0.1	0.1	
Lichens																					
Cladi mit ***	C	C	12.6	4	3	0.6	13.2	5	5	6	4	7	5	5	0.2	0.2	1.5	0.7	12.7	16.8	10.2
Cladi ran ***	C	C	9.4	2	3	0.0	9.4	1		2		7	5	5			0.0		11.3	11.8	5.1
Clado spp				4	3	2.5	2.1	7	5	6	4	7	4	5	3.4	4.4	1.5	0.6	4.5	0.5	1.3
Folio spp	C	C	2.2	4	3	0.8	2.9	5	5	4	3	6	5	5	0.1	0.8	0.9	1.3	1.4	0.4	7.0
Fruti spp				4	3	0.1	0.1	5	2	1	1	5	3	1	0.1	0.0	0.0	0.1	0.1	0.1	0.0
Other																					
Conifer litter				4	3	12.1	0.8								38.9	0.4	2.8	6.4	1.4	0.1	0.8
Other litter				4	3	11.4	16.8								1.7	30.8	9.6	3.6	19.6	20.3	10.6
Rock				4	3	42.9	35.1								26.7	12.7	58.2	73.9	32.5	7.7	65.2
Snag				3		1.0									0.2	3.8	0.1				
Wood				4	3	3.1	4.3								6.8	1.7	0.6	3.2	3.9	6.0	2.9

Affinity: B = Burn, C = Cut, * = exclusive to treatment.   CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks.
* = significant difference in ANOVA at α = .10, ** = .05, *** = .01.   Blank entry = not encountered, 0.0 = >0 and < 0.05   See Appendix A for species codes.

Table 9.5. Outcrops- cumulative percentage of eigenvalue total accounted for by first three principal coordinates of PCO, PCA and CA.

Technique	Principal Coordinate		
	1	2	3
PCO	16.6	26.2	34.4
PCA	30.3	46.6	60.2
CA	19.0	31.2	41.1

Table 9.6. MANOVA results for treatment and Block effects (p-value for Wilk's lambda) for 13 year old communities on outcrops.

	Effect	
	Treatment	Block
Overall Model	0.0001	0.0014
Principal Coordinate 1	0.0001	0.6114
Principal Coordinate 2	0.9181	0.0002

9.3. Shallow soils- comparison of 13 year old post-fire and post-logging communities.

Post-fire and post-logging communities were separated well by all three ordination techniques albeit not as clearly as for outcrops. PCO (Figure 9.5) and CA[8] separated them on the first principal coordinate, while PCA did so on a combination of the first two. The percentages of the total eigenvalues accounted for by the first three principal coordinates were 15.3%, 7.7% and 6.6% for a cumulative total of 29.6%. Exploratory analysis of the scattergrams and results for the affinity analysis (Table 9.8) did not identify any outliers. Plots from post-logging communities were more variable in their species composition than those from post-fire.

MANOVA detected a significant difference (p = 0.0394; Table 9.7) in the species composition of communities of burned and logged communities on shallow soils. Significant treatment differences were also found for the first principal coordinate and for the Block effect in all cases. Twenty-one species, most of which were probably present at the time of logging, performed better in post-logging communities; seven of these were exclusive. In contrast, only the post-fire pioneer species, jack pine (CD = -11.1) and *Polytrichum juniperinum* (CD = -11.0) performed better in post-fire communities. Black spruce did not meet the treatment affinity criteria due to a large mean cover value in one cutover, however, it was much more frequent in post-fire communities than post-logging (Table 9.8).

Vaccinium angustifolium (CD = +11.3) had the largest treatment difference in cover. *Amelanchier sanguinea* (CD = +0.9) and *Rosa acicularis* (CD = 0.2) were the other shrubs with treatment affinities. Herbs exclusive to post-fire communities were *Fragaria virginiana, Galium boreale* and *Lycopodium obscurum*. *Apocynum androsaemifolium, Clintonia borealis, Maianthemum canadense* and *Viola adunca* performed better but the differences in mean cover were also small. A large proportion of graminoids performed better. *Agropyron trachycaulum* and *Schizachne*

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[8] Ordination scattergrams from CA and PCA will only be provided when they are inconsistent with PCO or when they assist in the interpretation of other patterns of interest.

purpurascens were exclusive while *Agrostis hyemalis, Calamagrostis canadensis, Carex* species and *Oryzopsis asperifolia* had slightly higher mean cover.

The largest overall treatment differences occurred in the ground stratum. Ground stratum species with post-logging affinities had higher combined cover of 18.5% while that of *Polytrichum juniperinum* was 11.0% lower (Table 9.8). It is suggested that the poorer performance of *P. juniperinum* was due to logging's failure to make space available and smothering by Other litter (CD = 41.0). The generalist bryophytes which probably were present at the time of logging, *Dicranum* species (CD = +4.5) and *Pleurozium schreberi* (CD = +8.2), made up for the lower cover of *Polytrichum juniperinum*. Other residual ground species which had an affinity for post-logging communities included *Cladina mitis* (CD = +2.9) and *C. rangiferina* (CD = +2.3).

Species with an affinity for post-logging communities had a combined higher cover of 34.1% while those for post-fire had a combined lower cover of 22.1%. Nevertheless, a treatment difference in total cover was not detected.

Table 9.7. MANOVA results for treatment and Block effects (p-value from Wilk's Lambda) **for 13 year old communities on shallow soils.**

|	Effect	
	Treatment	Block
Overall Model	0.0394	0.0001
Principal Coordinate 1	0.0067	0.0001
Principal Coordinate 2	0.7072	0.0001
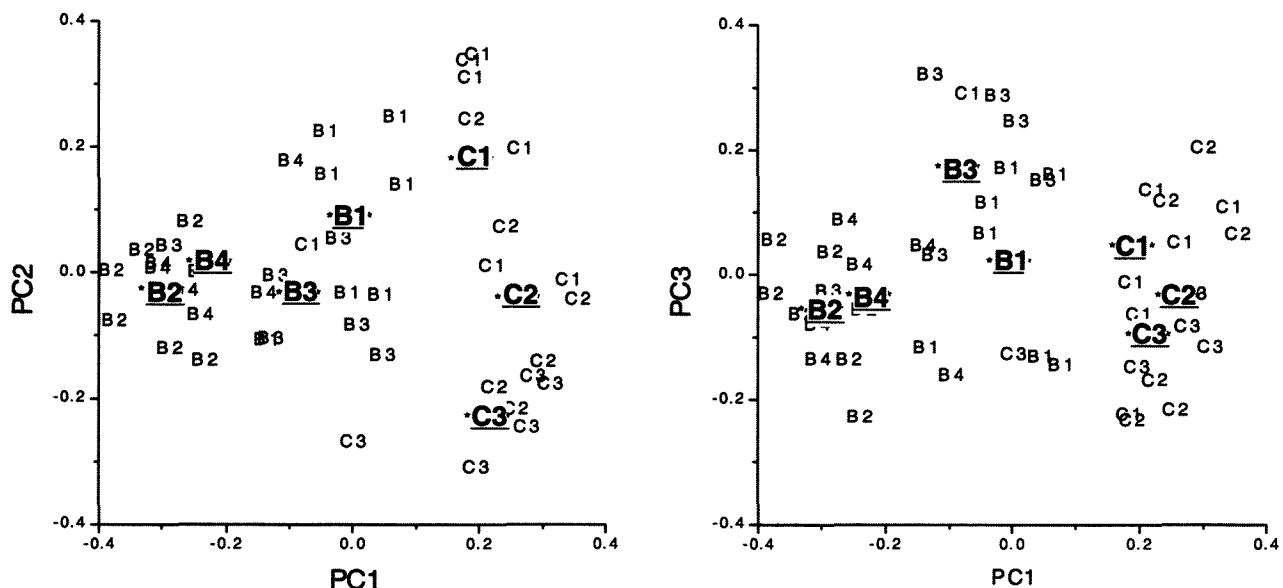
Figure 9.5. PCO scattergrams of plot scores for 13 year old communities on shallow soils.
Some plots are hidden. B= post-fire plot, C = post-logging plot. Labels with underscores are Block means.
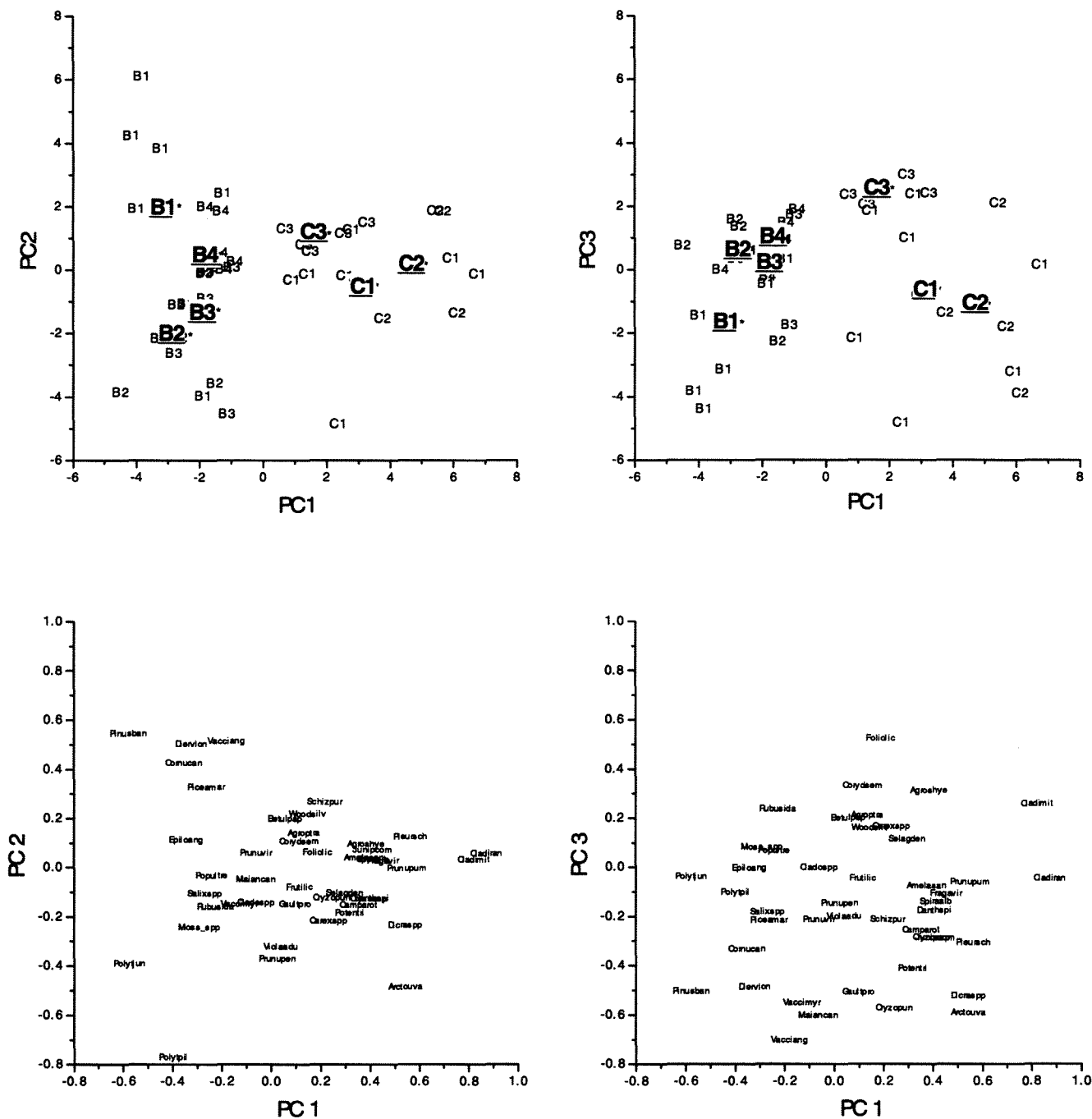
Table 9.8. Treatment affinities, canonical variates analysis, presence and mean cover results for 13 year old communities on shallow soils.

	Treatment	Affinity	CV	Diff. %	Blocks Presence Burns	Blocks Presence Cuts	Blocks Cover Burns	Blocks Cover Cuts	Plots Presence Burn 1	Burn 2	Burn 3	Burn 4	Cut 1	Cut 2	Cut 3	Plots Mean Cover Burn 1	Burn 2	Burn 3	Burn 4	Cut 1	Cut 2	Cut 3
	N				4	3	4	3	7	7	6	6	7	6	5	7	7	6	6	7	6	5
Shrubs	Aspen				4	3	2.3	0.2	3	4	3	3	3	2	3	7.9	0.7	0.2	0.3	0.2	0.5	0.0
	Balsam fir				1	1	0.2	0.6	1						3	0.7						1.7
	Black spruce				4	2	1.8	2.4	3	6	3	3	1	1		0.5	3.6	0.7	2.2	0.0	7.2	
	Jack pine **	B	B	-11.1	4	2	18.6	7.4	7	7	6	6	5	1		26.4	9.6	27.4	11.0	18.6	3.8	
	Paper birch				3	2	0.1	2.0	3		2	1		2	2	0.5		0.1	0.0		4.4	1.5
	White spruce				1	2	0.0	0.7			3		1	1				0.1		0.7	1.4	
	Amela aln				1	3	0.7	0.7	3				1	2	2	2.6				0.0	2.1	0.1
	Amela san ***	C	C	0.9	1	3	0.0	1.0				2	1	4	4				0.1	0.7	0.9	1.2
	Arcto uva				2	3	1.8	3.6	1		4		4	3	1	0.0		7.1		4.3	6.2	0.2
	Dierv lon				4	3	3.0	6.4	5	1	4	4	4	5	5	8.7	0.0	3.0	0.5	3.0	5.5	10.7
	Linna bor				2	1	0.5	0.1	1		5				2	0.0		2.2				0.3
	Prunu pen				2	2	0.0	0.3		3	3		2	1			0.1	0.0		1.0	0.0	
	Ribes gla				2	2	0.0	0.0	1		2		1	1	1	0.1		0.0			0.0	0.0
	Rosa_ aci *	C		0.2	2	3	0.0	0.2	1		1		2	2	1	0.0		0.1		0.3	0.0	0.3
	Rubus ida				2	2	0.0	0.1	2	1				1	2	0.0	0.0				0.2	0.2
	Salix spp				4	2	2.2	1.7	3	3	4	3	3	2		4.1	0.9	2.3	1.6	3.9	1.3	
	Spira alb				3	3	0.2	1.3	4		1	1	5	2	1	0.8		0.0	0.0	2.0	0.3	1.5
	Symph alb				1	2	0.0	0.0			1		2		1			0.1		0.0		0.0
	Vacci ang	C	C	11.3	4	3	4.7	15.9	5	3	2	1	7	3	3	17.0	0.9	0.3	0.5	41.6	5.3	0.9
	Vacci myr	C	C	11.3	4	3	3.7	5.1	7	4	4	5	6	6	5	7.0	1.4	1.8	4.7	0.9	11.0	3.4
Herbs	Apocy and *	C	C	0.1		2		0.1					1	3						0.0	0.4	
	Arali nud				2	1	0.2	1.0	4		4				3	0.5		0.5				3.1
	Aster cil		C		1	2	0.0	0.6	2				3	3		0.1				0.4	1.5	
	Clint bor *	C		0.1	1	3	0.0	0.1	1				3	1	1	0.1				0.0	0.2	0.1
	Cornu can				2	3	0.2	1.5	2		2		1	3	3	0.4		0.5		0.0	4.2	0.2
	Epilo ang				4	3	0.1	0.3	5	5	4	2	2	2	2	0.3	0.1	0.0	0.0	0.1	0.6	0.1
	Fraga vir ***	C*	C	0.7		3		0.7					1	3	2					1.1	0.8	0.1
	Galiu bor *	C*	C			3		0.3					1	2	2					0.1	0.8	0.0
	Gault pro				1	2	0.8	3.3	3				4	1		3.3				7.7	2.2	
	Hiera sca				1	1	0.0	0.0	2					2		0.0				0.1		
	Lathy och				2	3	0.0	0.1	3		1		2	3	1	0.1		0.0		0.0	0.2	0.0
	Lycop obs ***	C*	C	0.4		3		0.4					3	1	1					0.6	0.5	0.2
	Maian can	C	C	1.3	3	3	0.4	1.7	7		5	1	4	6	5	1.1		0.5	0.0	0.3	1.2	3.5
	Melam lin				1	3	0.0	0.0				3	2	1	3				0.0	0.1	0.0	0.0
	Poten tri				3	2	0.4	0.8	5		3	1	4	3		0.4		1.3	0.0	1.4	1.0	
	Solid his				2	1	0.1	0.0			4	1	1					0.4	0.0	0.0		
	Trien bor				2	2	0.0	0.0	1		1			1	2	0.0		0.0			0.1	0.0
	Viola adu **	C	C	0.0	1	3	0.0	0.0	3				2	3	2	0.0				0.1	0.0	0.0
Graminoids	Agrop tra ***	C*	C	0.0		3		0.0					2	1	1					0.0	0.0	0.0
	Agros hye	C	C	0.4	1	3	0.0	0.4				2	2	1	2				0.0	0.0	0.1	1.0
	Calam can **	C	C	0.1	2	3	0.0	0.1	2		1		3	2	2	0.1		0.0		0.1	0.1	0.2
	Carex spp **	C	C	0.1	1	3	0.0	0.1	3				2	2	2	0.0				0.0	0.1	0.1
	Danth spi				2	3	0.0	0.6	1		1		3	2	2	0.0		0.1		1.6	0.2	0.0
	Oryzo asp	C*	C	0.6		3		0.6					1	5	3					0.0	1.6	0.1
	Oryzo pun				4	3	0.1	0.1	4	1	4	2	6	4	2	0.1	0.0	0.2	0.0	0.1	0.2	0.1
	Panic spp				2	2	0.0	0.0	2		1		1	1		0.0		0.0		0.0	0.0	
	Schiz pur ***	C*	C	0.2		3		0.2					3	3	3					0.0	0.4	0.2
Bryophytes	Auloc pal				1	2	0.0	0.1		2			2	2			0.0				0.1	0.2
	Dicra spp ***	C	C	4.5	4	3	0.0	4.5	4	1	2	2	7	6	4	0.1	0.0	0.0	0.0	5.7	4.9	2.8
	Liver spp *	C*	C	0.1		2		0.1						2	2						0.4	0.1
	Moss_ spp				4	3	1.1	2.3	6	7	6	5	6	6	5	0.6	3.0	0.6	0.1	0.1	0.5	6.3
	Pleur sch ***	C	C	8.2	4	3	0.4	8.6	5	2	2	5	6	6	5	0.8	0.0	0.7	0.1	9.4	8.7	7.6
	Polyt com				3	2	4.1	0.6	3	1		4	4	1		3.2	0.3		12.9	1.6	0.3	
	Polyt jun ***	B	B	-11.0	4	3	13.4	2.5	7	7	6	5	6	6	5	9.8	19.3	7.3	17.2	4.1	0.3	3.0
	Polyt pil				4	2	0.9	0.1	4	3	2	3	1		2	1.9	0.4	0.0	1.2	0.1		0.2
Lichens	Cladi mit *	C	C	2.9	4	3	0.1	3.0	2	6	3	6	7	5	4	0.0	0.1	0.1	0.1	8.2	0.4	0.4
	Cladi ran **	C	C	2.3	3	3	0.0	2.3		1	1	3	7	5	3		0.0	0.1	0.0	5.7	0.7	0.4
	Clado spp				4	3	1.2	0.6	7	7	6	6	7	6	5	0.9	2.9	0.5	0.6	0.4	0.4	1.0
	Folio spp				4	3	0.2	0.3	7	5	5	3	7	2	5	0.3	0.1	0.1	0.2	0.1	0.0	0.9
	Fruti spp				3	3	0.1	0.1	7	3	3		6	1	1	0.2	0.0	0.0		0.2	0.0	0.0
Other	Confr litter ***	B		-37.3	4	3	45.5	8.3								46.4	47.3	48.4	40.1	21.3	1.2	2.3
	Other litter **	C		41.0	4	3	18.1	59.1								22.8	14.3	27.3	8.1	35.1	78.5	63.5
	Rock *	B		-6.2	4	3	10.3	4.1								4.5	9.3	12.1	15.3	4.3	0.9	7.2
	Snag **	B		-0.3	4	1	0.3	0.0								0.1	0.5	0.3		0.0		
	Wood				4	3	3.9	3.5								9.1	2.0	1.2	3.4	3.6	2.9	4.1

Affinity: B = Burn, C = Cut, * = exclusive to treatment.   CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks.   * = significant difference in ANOVA at a = .10, ** = .05, *** = .01.   Blank entry = not encountered, 0.0 = >0 and < 0.05 See Appendix A for species codes.

9.4. Moderately deep soils- comparison of 13 year old post-fire and post-logging communities.

Moderately deep soils presented a challenge as far as drawing inferences on treatment effects due to the small number of replicates- two for burns and three for cutovers. Four burns were sampled but Burn 3 had been logged up to its edge prior to the fire. No moderately deep site types were found in this burn. Burn 4 did not have enough moderately deep plots for it to qualify as a replicate.

While scattergrams from all three ordination techniques appear to exhibit treatment related differences (Figure 9.6 for PCO), MANOVA results indicate that neither the overall model nor the principal coordinates were significant at $\alpha = 5\%$ (Table 9.9). Principal coordinate 2 was significant at $\alpha = 10\%$. Our response to low statistical power was to proceed, as usual, to the affinity analysis and identify treatment differences in species composition. The large number of species with treatment affinities and the large treatment difference in mean cover of some species led us to conclude that there were treatment differences in species composition but they could not be detected due to low statistical power.

Twenty-four species had a treatment affinity on moderately deep soils (Table 9.10). The majority of these performed better in post-logging communities except jack pine, black spruce and a few species considered to be pioneers of recent burns such as *Epilobium angustifolium*. In the shrub stratum, black spruce (CD = -4.0), jack pine (CD = -9.8) and *Salix* species (CD = -5.0) had lower frequency and mean cover. Their lower cover was offset somewhat by the higher cover of paper birch (CD = +2.6), *Corylus cornuta* (CD = +6.0), *Ribes glandulosum* (CD = +0.2), *Vaccinium angustifolium* (CD = +5.0) and *V. myrtilloides* (CD = +1.3). *V. angustifolium* and *V. myrtilloides* had higher frequencies and generally higher mean cover values in post-logging communities. Ecologically, they are similar species. Their combined cover varied much less than their individual values (Table 9.10). Since low replication seemed to be the problem, they were designated with questionable affinities.

Epilobium angustifolium (CD = -0.3) was the only herb which performed more poorly in post-logging communities. *Aralia nudicaulis* (CD = +2.1), *Cornus canadensis* (CD = +2.6), *Fragaria virginiana* (CD = +0.5), *Maianthemum canadense* (CD = +1.2), *Rubus pubescens* (CD = +1.6) and *Viola adunca* (CD = +<0.05) all performed better. Differences in mean cover were strongly reinforced by differences in frequency (Table 9.10).

All graminoid treatment affinities were for post-logging communities; *Danthonia spicata* and *Oryzopsis pungens* were exclusive but had less than 0.2% cover. The other species with affinities were *Oryzopsis asperifolia* and *Schizachne purpurascens*. Bryophyte affinities were split between the treatments with the post-fire pioneers, *Polytrichum commune* (CD = -2.0) and *P. juniperinum* (CD = -5.6), performing more poorly while *Dicranum* species (CD = +1.5) and *Pleurozium schreberi* (CD = +6.3) did better. *Cladina rangiferina* (CD = +0.4) was the only lichen in the ground stratum to have a treatment affinity.

Species which met the affinity criteria and were exclusive to post-logging communities included *Corylus cornuta, Ribes glandulosum, Rubus pubescens, Viola adunca, Danthonia spicata,* and *Oryzopsis pungens* (Table 9.10). No species were exclusive to post-fire communities.

The higher number of species affected positively by logging belied the relatively small net difference in their total cover. The combined increase in cover of species positively affected by logging was 31.4% while those adversely affected declined by 22.5%. The difference would have been much less if jack pine had not been included. When all species included in data analysis were combined, a significant treatment difference in total cover was not detected.

Table 9.9. MANOVA results for treatment and Block effects (p-values for Wilk's Lambda) **for 13 year old communities on moderately deep soils.**

|	Treatment Effect	Block Effect
Overall Model	0.2776	0.0002
Principal Coordinate 1	0.2256	0.0006
Principal Coordinate 2	0.0817	0.4208
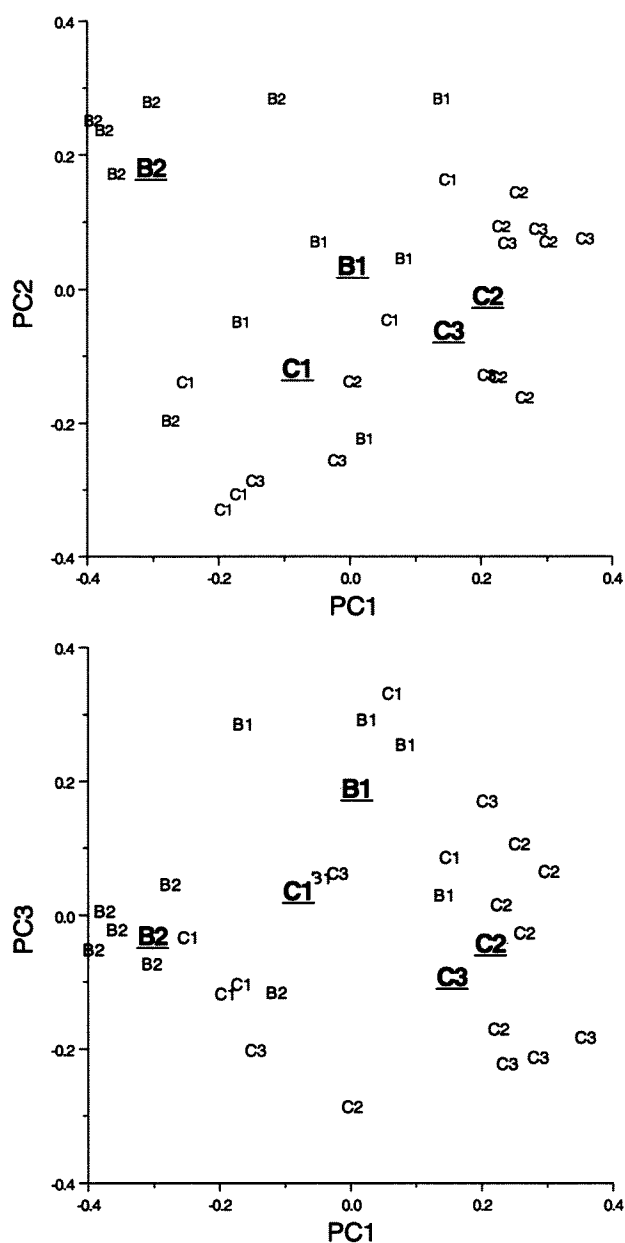
Figure 9.6. PCO scattergrams of plot scores for 13 year old communities on moderately deep soils. Some plots are hidden. B= post-fire plot, C = post-logging plot. Labels with underscores are Block means.

Table 9.10. Treatment affinities, canonical variates analysis, presence and cover results for 13 year old communities on moderately deep soils.

	Treatment N	Affinity	CV	Diff. %	Blocks Presence Burn 2	Blocks Presence Cut 3	Blocks Cover (%) Burn 2	Blocks Cover (%) Cut 3	Plots Presence Burn 1 5	Plots Presence Burn 2 6	Plots Presence Cut 1 5	Plots Presence Cut 2 6	Plots Presence Cut 3 6	Plots Mean Cover (%) Burn 1 5	Plots Mean Cover (%) Burn 2 6	Plots Mean Cover (%) Cut 1 5	Plots Mean Cover (%) Cut 2 6	Plots Mean Cover (%) Cut 3 6
Shrubs	Aspen				2	3	13.0	2.7	3	6	4	5	2	22.3	3.7	5.2	1.0	1.7
	Black spruce	B	B	-4.0	2	2	4.6	0.6	1	6		1	1	1.2	8.0		1.4	0.3
	Jack pine	B	B	-9.8	2	3	14.7	5.0	4	6	5	1	4	14.7	14.8	12.2	0.0	2.7
	Paper birch	C	C	2.6	1	3	0.6	3.3	2		2	4	4	1.2		1.7	3.6	4.5
	White spruce				1	3	0.3	0.1	1		1	1	1	0.5		0.0	0.0	0.1
	Alnus cri				1	2	3.0	0.9	2		2		1	6.0		2.6		0.1
	Amela san				1	2	0.9	1.0	1			4	4	1.8			1.7	1.2
	Cornu sto				1	2	0.0	0.4	1			1	3	0.0			0.7	0.4
	Coryl cor	C*	C	6.0		2		6.0				4	4				7.6	10.5
	Dierv lon				1	3	10.2	7.9	5		2	6	4	20.3		13.0	6.8	3.9
	Ledum gro				1	2	1.3	2.6		1	1	2			2.5	1.0	6.9	
	Linna bor				2	3	0.0	0.1	1	1	1	1	1	0.0	0.1	0.0	0.0	0.1
	Prunu pen				2	2	0.2	0.6	1	3	2		2	0.2	0.1	1.2		0.7
	Ribes gla *	C*		0.2		3		0.2			2	2	1			0.1	0.5	0.2
	Rosa_ aci				2	3	0.4	0.5	2	1	1	3	1	0.5	0.3	0.6	0.7	0.1
	Rubus ida				2	2	0.3	0.3	2	3	2	3		0.4	0.2	0.4	0.5	
	Salix spp ***	B	B	-5.0	2	3	6.7	1.7	3	6	2	2	1	7.7	5.7	1.3	3.2	0.5
	Spira alb				1	2	0.1	0.3	1			3	1	0.1			0.7	0.2
	Vacci ang	C?		5.0	2	3	6.9	12.0	3	2	5	4	3	7.6	6.3	19.9	1.3	14.7
	Vacci myr	C?		1.3	2	3	3.7	5.0	3	3	4	5	3	2.7	4.6	1.9	8.0	5.1
	Vacci spp				2	3	10.6	17.0						10.3	10.9	21.8	9.3	19.8
Herbs	Apocy and				1	2	0.0	0.1		1		2	1		0.0		0.2	0.0
	Arali nud	C	C	2.1	1	3	0.6	2.7	2		2	5	4	1.2		2.1	4.4	1.4
	Aster cil				1	3	0.0	0.3	1		2	3	1	0.1		0.0	0.8	0.0
	Clint bor				1	3	0.6	0.8	4		2	4	3	1.3		0.3	1.9	0.3
	Cornu can	C		2.6	2	3	0.9	3.5	4	1	5	4	4	1.4	0.4	1.7	1.7	7.0
	Epilo ang **	B	B	-0.3	2	3	0.6	0.3	5	6	4	4	2	0.5	0.8	0.1	0.3	0.4
	Equis syl				2	2	0.0	0.1	1	1	1	1	1	0.0	0.1	0.1		0.1
	Fraga vir	C	C	0.5	1	3	0.0	0.5	1		1	4	2	0.0		0.0	1.1	0.4
	Galiu bor					2		0.1				3	1				0.3	0.0
	Gault pro				1	2	0.1	1.1	2		1	2		0.2			2.9	0.5
	Lathy och				1	2	0.2	0.3	2		5	1		0.5			0.8	0.1
	Lathy ven					2		0.1			3	1					0.2	0.0
	Lycop obs				1	3	0.0	0.0	1		1	1	1	0.0		0.1	0.1	0.0
	Maian can	C	C	1.2	1	3	0.4	1.6	5		4	6	6	0.8		0.8	1.9	2.2
	Rubus pub **	C*	C	1.6		3		1.6			2	3	2			1.0	1.0	2.8
	Strep ros					2		0.1			3	1					0.1	0.3
	Trien bor				1	3	0.1	0.3	2		2	3	4	0.2		0.4	0.1	0.2
	Viola adu **	C*	C	0.0		3		0.0			2	1	1			0.0	0.0	0.0
Graminoids	Agrop tra		C			1		0.0				4					0.1	
	Calam can				1	3	0.3	0.3	3		1	4	3	0.6		0.3	0.4	0.1
	Carex spp				2	3	0.1	0.1	2	2	4	3	2	0.2	0.1	0.2	0.2	0.1
	Danth spi	C*	C	0.0		2		0.0			2	2				0.1	0.0	
	Oryzo asp	C	C	0.2	1	3	0.0	0.2	1		1	6	4	0.0		0.1	0.4	0.1
	Oryzo pun	C*	C	0.1		3		0.1			1	3	1			0.1	0.1	0.0
	Schiz pur	C	C	0.3	1	3	0.0	0.3	2		1	4	2	0.0		0.1	0.6	0.0
Bryophytes	Auloc pal				2	2	0.8	0.1	2	1	1		1	1.5	0.0	0.1		0.1
	Dicra spp	C	C	1.5	2	3	0.0	1.5	2	1	3	4	4	0.0	0.0	3.8	0.3	0.5
	Liver spp				1	2	0.0	0.0	1		2	1		0.0			0.0	0.1
	Moss_ spp				2	3	2.9	0.7	5	5	3	6	6	0.6	5.3	0.1	1.4	0.7
	Pleur sch **	C	C	6.3	2	3	0.1	6.4	3	1	5	5	5	0.3	0.0	8.1	7.9	3.2
	Polyt com ***	B	B	-2.0	2	2	2.0	0.1	2	2	2		1	1.8	2.3	0.1		0.1
	Polyt jun	B	B	-5.6	2	3	8.1	2.5	4	6	5	5	3	2.5	13.6	7.0	0.4	0.1
	Polyt pil				2	2	0.1	0.0	1	1		1	2	0.0	0.1		0.0	0.0
	Sphag spp				1	2	0.0	3.9		1	1		2			0.0	1.2	10.5
Lichens	Cladi mit				1	3	0.0	0.1		2	2	3	1			0.0	0.3	0.0
	Cladi ran	C		0.4	1	3	0.0	0.4	1		3	2	2	0.0		0.9	0.1	0.2
	Clado spp				2	3	1.1	0.6	4	6	4	6	6	0.3	1.9	1.0	0.6	0.2
	Folio spp				2	2	0.1	0.1	3	5		2	2	0.1	0.1		0.0	0.2
Other	Confr litter	B		-17.2	2	3	23.9	6.7						24.8	22.9	13.7	0.5	6.0
	Other litter	C?		15.4	2	3	54.6	70.0						61.8	47.4	60.6	81.6	67.9
	Rock				2	3	2.2	1.5						3.2	1.1	1.0	Rock	3.4
	Snag			-1.0	2	2	1.1	0.1						0.2	2.0		0.0	0.2
	Wood				2	3	2.6	4.9						2.8	2.5	2.5	7.6	4.7

Affinity: B = Burn, C = Cut, * = exclusive to treatment. CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks. * = significant difference in ANOVA at a = .10, ** = .05, *** = .01. Blank entry = not encountered, 0.0 = >0 and < 0.05. See Appendix A for species codes. Vaccispp = Vacciang + Vaccimyr

9.5. Organic soils- comparison of 13 year old post-fire and post-logging communities.

Statistical power also posed a problem for organic soils. While organic soils were represented in all Blocks, only two cutovers had an adequate number of subsamples to qualify as replicates. PCO[9] (Figure 9.7) and PCA weakly separated post-fire communities and post-logging communities on the first principal coordinate. Most plots from post-logging communities were confined to one area on the first two principal coordinates in each ordination. However, plots from post-fire communities were highly dispersed with some interspersed within the post-logging plots. MANOVA performed on the plot scores derived from the first two principal coordinates of PCO did not detect a significant overall or Block level treatment difference at $\alpha = 5\%$ (Table 9.11). The treatment effect was significant on the first principal coordinate at $\alpha = 10\%$. As with moderately deep soils, the number of treatment affinities and the magnitude of some of the differences in mean cover led us to conclude that a treatment difference in species composition probably existed but could not be detected due to low statistical power.

The treatment affinity pattern observed on the other site types was reversed on organic soils. More species had affinities for post-fire communities than for post-logging; four were exclusive to post-fire communities but none to post-logging. Tree species were less affected than on the other site types. Jack pine had 4.1% less cover but black spruce showed no difference (Table 9.12). *Linnaea borealis* had a treatment affinity and was exclusive to post-fire communities. *Maianthemum canadense* (CD = +0.2) and *Smilacina trifolia* (CD = -0.4) were the only herbs with treatment affinities while *Carex* species (+0.7%) was the only graminoid. The ground stratum had the most substantial differences. The treatment difference of *Sphagnum* species (CD = +19.0) was the largest found across all the site types. *Pleurozium schreberi* (CD = +1.6) was the only other ground stratum species with a post-logging affinity. *Dicranum* species (CD = -0.1), *Polytrichum piliferum* (CD = -0.1), *Cladonia* species (CD = -1.3) and Foliose lichens (CD = -0.1) all had post-fire affinities. Exclusive species in post-fire communities included Foliose lichens, *Linnaea borealis*, *Polytrichum piliferum* and *Smilacina trifolia*.

Total percent cover over all species did not differ significantly between treatments. The total cover of species with burn affinities was 6.2% lower while those with cutover affinities was 21.5% higher for a net increase of 15.3% largely due to *Sphagnum* species.

Table 9.11. MANOVA results for treatment and Block effects (p value for Wilk's Lambda) for 13 year old communities on organic soils.

| | Effect | |
	Treatment	Block
Overall Model	0.3669	0.0299
Principal Coordinate 1	0.1006	0.2204
Principal Coordinate 2	0.7842	0.0207

[9] Eigenvalues were 12.2%, 11.1% and 7.9% of the total of eigenvalues for a cumulative total of 31.2%.
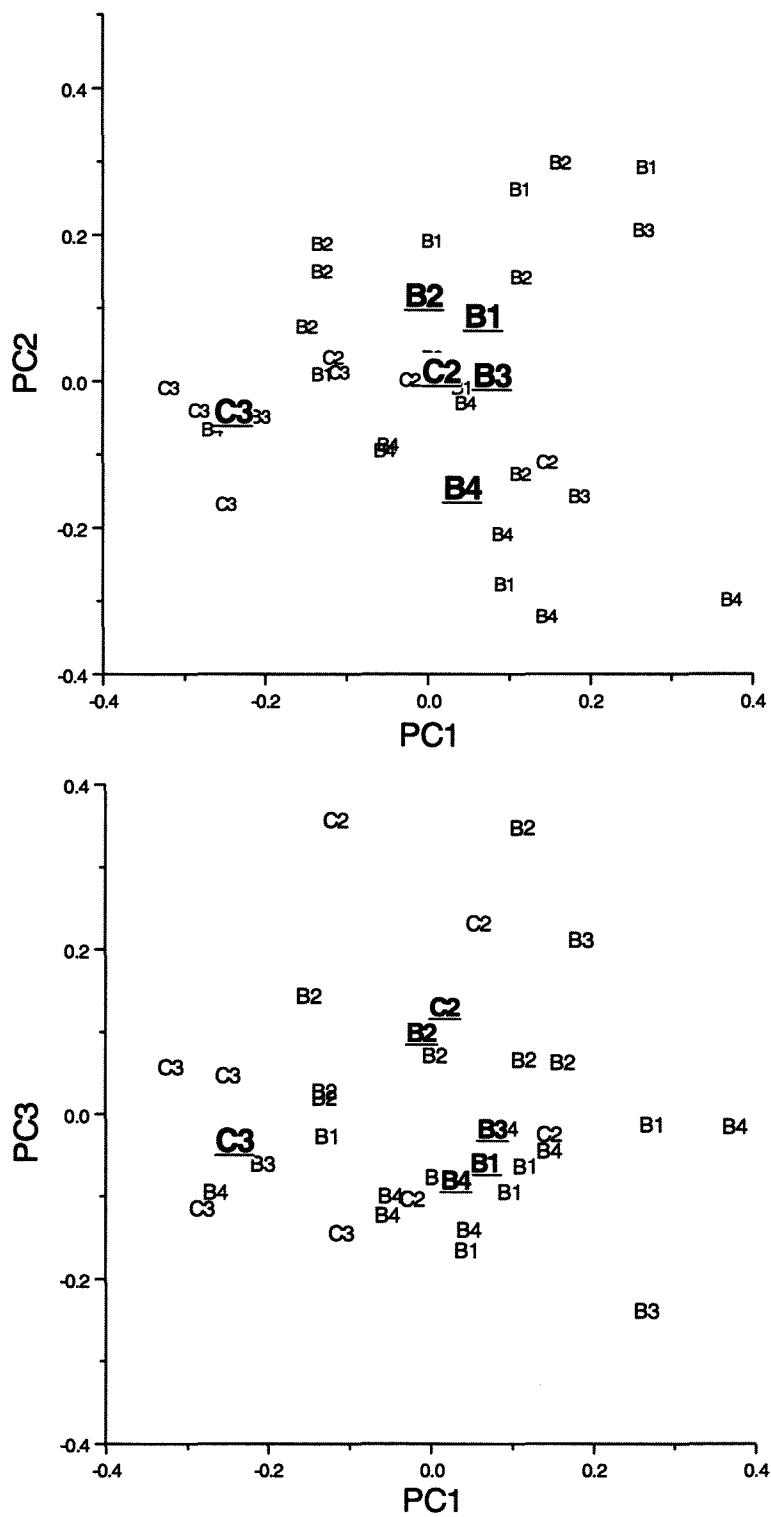
Figure 9.7. PCO scattergrams of plot scores for 13 year old communities on organic soils.
Some plots are hidden. B= post-fire plot, C = post-logging plot. Labels with underscores are Block means.

Table 9.12. Treatment affinities, canonical variates analysis, presence and cover results for 13 year old communities on organic soils.

	Treatment N	Affinity	CV	Diff. %	Blocks Presence Burns 4	Cuts 2	Cover (%) Burns 4	Cuts 2	Plots Presence Burn 1 6	Burn 2 7	Burn 3 3	Burn 4 7	Cut 1 4	Cut 2 4	Mean Cover (%) Burn 1 6	Burn 2 7	Burn 3 3	Burn 4 7	Cut 1 4	Cut 2 4
Shrubs	Aspen				4	1	0.5	0.6	2	2	2	5	3		0.0	1.1	0.1	0.9	1.1	
	Black spruce				4	2	4.1	3.4	6	7	3	7	3	4	1.0	8.4	4.4	2.5	2.6	4.2
	Jack pine *	B	B	-4.1	4	1	4.8	0.7	5	5	3	6	1		4.0	1.2	9.0	4.9	1.4	
	Paper birch				3	2	0.5	1.0	2	1		2	4	1	1.2		0.0	0.7	1.6	0.3
	Alnus rug				4	2	3.6	1.4	2	1	1	3	1	4	3.1	0.0	0.3	11.0	0.8	2.0
	Betul gla		C		1	1	0.0	0.7				1		3				0.2		1.4
	Chama cal				4	2	2.4	2.2	4	1	2	4	1	3	2.1	0.1	5.6	1.7	0.0	4.4
	Gault his		C		2	1	0.1	0.4		5	1		3			0.4	0.1		0.8	
	Ledum gro				4	2	24.7	17.3	6	6	3	7	4	4	43.9	21.3	20.3	13.3	25.2	9.4
	Linna bor				3		0.0			1	1	3				0.0	0.0	0.1		
	Oxyco qua				4	2	0.5	0.7	4	6	3	3	2	3	0.8	0.8	0.4	0.2	0.6	0.8
	Salix spp				4	2	1.8	1.5	2	5	3	6	3	4	0.9	1.6	2.4	2.4	1.4	1.5
	Spira alb				3	1	1.0	0.0	1		1	1	1		3.6		0.0	0.3	0.0	
	Vacci ang				4	1	0.8	0.4	2	3	2	1	1		0.6	1.6	0.9	0.0	0.8	
	Vacci myr				4	1	1.2	0.6	3	2	2	6	4		1.3	0.1	0.4	3.1	1.3	
	Vacci vit				4	1	3.9	3.8	4	7	1	3	4		7.0	5.5	2.7	0.2	7.6	
Herbs	Cornu can				3	1	0.5	0.5	2	3		4	3		0.4	0.1		1.5	1.0	
	Drose rot				2	2	0.0	0.0	1	2			1	1	0.0	0.0			0.0	0.0
	Epilo ang				4	1	0.1	0.1	2	3	2	5	2		0.1	0.1	0.1	0.2	0.1	
	Equis arv				3	1	0.1	0.0	1	2		1		1	0.4	0.0		0.0		0.0
	Equis syl				4	2	0.3	0.5	1	5	2	4	1	1	0.1	0.2	0.2	0.6	0.8	0.2
	Lycop ann		C		1	1	0.2	1.0	1				2		0.9				2.0	
	Maian can	C	C	0.2	4	2	0.7	0.9	1	5	3	2	4	4	0.0	0.1	2.7	0.1	1.4	0.5
	Rubus cha				1		0.1			4						0.3				
	Smila tri	B*	B	-0.4	3		0.4		5	1		5			1.2	0.0		0.4		
	Trien bor				3	1	0.1	0.1	1	2		3	3		0.1	0.1		0.1	0.3	
Graminoids	Calam can				3	2	0.1	0.3	2	3		4	3	1	0.1	0.1		0.1	0.5	0.1
	Carex spp		C	0.7	4	2	1.7	2.4	5	7	3	6	4	4	0.2	6.1	0.2	0.5	2.7	2.1
	Eriop vag				3	1	0.2	0.2	2	1	1		1		0.6	0.0	0.2		0.3	
Bryophytes	Auloc pal				4	2	1.9	0.1	1	2	2	4	2	1	0.0	0.5	6.9	0.1	0.2	0.1
	Dicra spp	B		-0.1	3	2	0.2	0.0	3	3		4	2	2	0.4	0.1		0.2	0.0	0.1
	Moss spp				4	2	0.9	0.4	3	6	3	5	3	4	0.1	2.8	0.7	0.2	0.5	0.2
	Pleur sch ***	C	C	1.6	4	2	0.1	1.7	4	6	1	4	2	3	0.1	0.2	0.0	0.1	2.1	1.3
	Polyt com				3	1	1.8	0.0	1		1	6		1	0.0		5.0	2.3		0.1
	Polyt pil	B*		-0.1	3		0.1		3	1		1			0.2	0.0		0.0		
	Polyt str				4	1	1.0	0.4	3	6	2	1	4		2.2	1.5	0.5	0.0	0.9	
	Sphag spp **	C	C	19.0	4	2	50.0	69.0	6	7	3	6	4	4	52.7	56.7	41.1	49.5	66.5	71.4
Lichens	Cladi mit				3	1	0.0	0.0	1	4		1	1		0.0	0.2		0.0	0.0	
	Clado spp	B	B	-1.3	4	2	1.4	0.1	4	7	2	6	3	2	2.4	2.4	0.4	0.2	0.1	0.0
	Folio spp	B*	B	-0.1	3		0.1		3	2	1				0.1	0.1	0.0			
	Fruti spp		B		2		0.0		3	2					0.1	0.0				
	Liver spp				2		0.0			2		1				0.0		0.0		
Other	Confr litter **	B		-6.0	4	2	6.4	0.4							0.9	0.5	7.4	16.6	0.6	0.1
	Other litter				4	2	29.3	25.6							28.0	30.7	33.8	24.5	25.8	25.3
	Rock				1		0.0											0.0		
	Snag	B		-0.3	4		0.3								0.3	0.5	0.2	0.1		
	Wood				4	2	4.3	1.5							5.8	3.9	2.1	5.5	3.1	0.0

Affinity: B = Burn, C = Cut, * = exclusive to treatment. CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks. * = significant difference in ANOVA at a = .10, ** = .05, *** = .01. Blank entry = not encountered, 0.0 = >0 and < 0.05. See Appendix A for species codes.

10. Results for the 37 year old age class.

10.1. Characterization of the 37 year old post-fire communities found on each of the site types.

Upland post-fire communities were characterized by a jack pine tree canopy whose degree of closure increased with increasing depth of mineral soil. Black spruce had not reached the canopy by this age and it was less frequent than jack pine. *Vaccinium myrtilloides* was the most common and abundant shrub. It was often accompanied by one or more of *Amelanchier sanguinea, Arctostaphylos uva-ursi, Diervilla lonicera, Linnaea borealis* or *Rosa acicularis*. *Maianthemum canadense* was ubiquitous on the upland site types. Several other herbs were frequently encountered in small amounts. As with 13 and 65 year old post-fire communities, 37 year old communities were dominated by the ground stratum. Reindeer lichen had the highest cover on outcrops while Schreber's moss dominated shallow and moderately deep soils. A number of other mosses also performed well in terms of frequency and cover.

Black spruce characterized the canopy of post-fire communities on organic soils. Jack pine was encountered more often than tamarack. *Ledum groenlandicum* was the most abundant vascular plant. It was found in every plot and was often accompanied by *Alnus rugosa, Chamaedaphne calyculata* and *Oxycoccus quadripetalus*. *Equisetum sylvaticum* and *Smilacina trifolia* were the only herbs found in slightly more than half the plots while *Carex* species and/ or *Calamagrostis canadensis* were found in most plots. As was the case in the 13 and 65 year old age classes, *Sphagnum* species was the most abundant species on this or any other site type. It was found in every plot.

10.1.1. Trees.

Canonical variates analysis of the trees found that the tree composition on site types was significantly different (p = 0.0001 for Wilk's Lambda) as were the first two canonical variates (p = 0.0001 for both). Canonical variate 1 separated the upland site types in order of increasing depth of mineral soil (Figure 10.1). Tamarack, balsam fir, aspen, white spruce and jack pine had high canonical structure correlations with the first canonical variate (Table 10.1). Jack pine's frequency and basal area were highest on shallow and moderately deep soils while those of balsam fir, aspen and white spruce were on moderately deep soils. Canonical variate 2 separated organic soils from the upland site types based on black spruce and tamarack. Black spruce also reinforced the separation on canonical variate 1 since its frequency and basal area was progressively higher in the transition from outcrops to moderately deep mineral soils to organic soils.

Jack pine, black spruce, white spruce, paper birch, aspen, balsam fir and tamarack were found in more than three plots in 37 year old post-fire communities. Jack pine and black spruce were ubiquitous with jack pine exhibiting peak performance on moderately deep soils and black spruce on organic soils (Table 10.2). Aspen and balsam fir were confined to moderately deep soils, tamarack to organic soils.

An affinity analysis of the trees found that jack pine was associated with outcrops and characteristic of shallow and moderately deep soils (Table 10.2). Black spruce accompanied jack pine as an associated species on moderately deep soils. It was characteristic of organic soils.

74
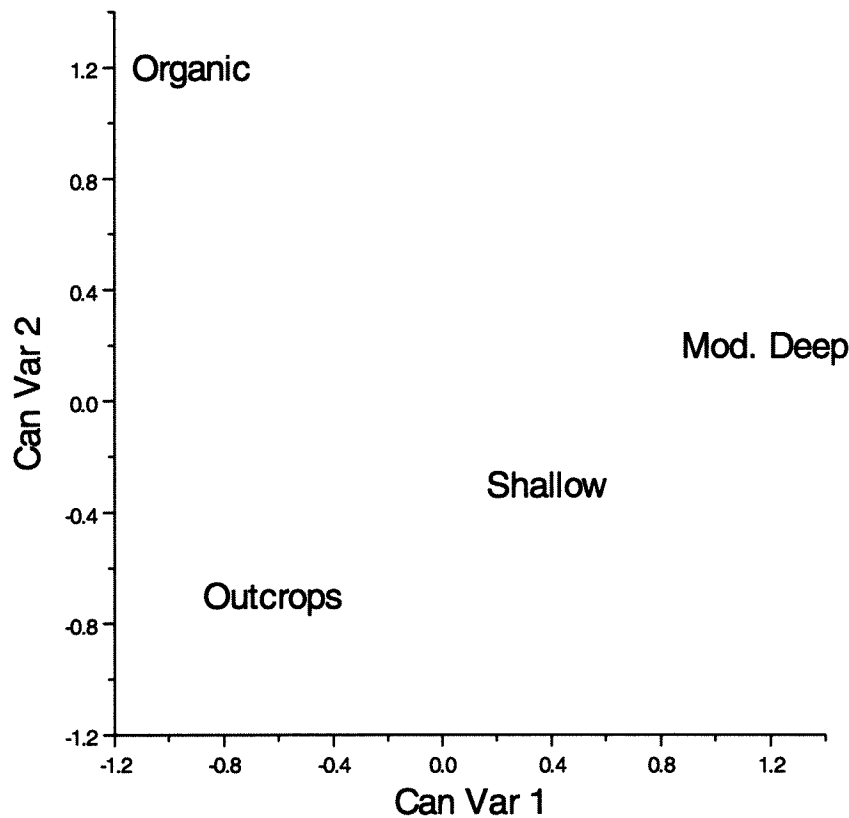
Figure 10.1. Site type means of plot scores from a canonical variates analysis of trees in 37 year old post-fire communities.

Table 10.1. Tree species with high canonical structure correlations from canonical variates analysis of site type in 37 year old post-fire communities.

Species	Can Var 1	Can Var 2	Species	Can Var 2
Tamarack	-0.23	0.41	Black spruce	0.92
Black spruce	0.18	0.92	Tamarack	0.41
Balsam fir	0.30	0.09	Jack pine	-0.17
Aspen	0.33	0.10		
White spruce	0.36	0.05		
Jack pine	0.73	-0.17		

Table 10.2. Tree species site type affinities, frequency and mean basal area in 37 year old post-fire communities.

Site Type		Plots				Blocks				Blocks			
		Outcrop	Shallow	Mod.	Organic	Outcrop	Shallow	Mod.	Organic	Outcrop	Shallow	Mod.	Organic
Canopy Closure (%)						7	18	40	18				
Plots with Trees (%)		44	90	100	94	48	90	100	94				
N		27	21	27	17	4	4	4	3	4	4	4	3

	Affinity[1]		Frequency in Plots (%)				Presence in Blocks				Mean Basal Area (m²/ha)			
	Char	Asso	Outcrop	Shallow	Mod.	Organic	Outcrop	Shallow	Mod.	Organic	Outcrop	Shallow	Mod.	Organic
Aspen					11				2				1.4	
Balsam fir					7				1				0.4	
Bl. spruce **	5	2	7	38	63	88	2	3	4	3	0.2	1.7	7.3	10.4
Jack pine **	1, 2	0	44	81	70	24	4	4	4	2	5.8	14.2	18.0	2.0
Paper birch			10	4			1	1			0.0	0.3		
Tamarack **						12				2				0.3
Wh. spruce				5	15			1	2			0.1	0.2	

** Significant site type difference in mixed model ANOVA at α = 5% (after Bonferonni adjustment) with Block as a random effect; * Difference significant at α = 10%. [1] Char. = characteristic species, Asso. = associated species, see Section 6.5.6 for a description of affinity criteria; 0 = affinity with outcrops, 1 = shallow, 2 = moderately deep, 5 = organic.

10.1.2. Understorey species composition.

Canonical variates analysis of understorey data revealed highly significant site type differences in species composition (p=0.0001 for the overall model using Wilk's lambda). Canonical variates 1 and 2 were significant (p=0.0001 and 0.0206) but canonical variate 3 was not. The differences between organic soils and the balance of the site types dominated the results; the first canonical variate accounted for 98.1% (based on eigenvalues) of the total variation in the data. Canonical variate 3 is shown for "exploratory" purposes only since the second canonical variate placed the outcrop and shallow site types in close proximity (Figure 10.2).

Prior to characterizing the vegetation of the site types based on the affinity analysis, some of the patterns extracted by canonical variates analysis will be discussed. It should be kept in mind that some apparent treatment differences will not show up as a site type affinity since they occurred as a result of the weaknesses of canonical variates analysis (Appendix C).

The top twelve positive correlations with canonical variate 1 were all taxa characteristic of wet sites and usually also acidic, organic soils (Table 10.3). *Sphagnum* species and *Ledum groenlandicum* had very high structure correlations. Fifteen of the eighteen species that had positive correlations with canonical variate 1 also had significant site type differences (α = 5%) in mean cover in mixed model ANOVA where Block was a random effect. Pairwise tests for site type differences in mean cover found that all these species with the exception of Liverwort species and black spruce had significantly higher cover on organic soils when compared with all other site types but no significant differences in any other pairwise site type comparison. This indicates that these species performed best on organic soils. In fact, many were exclusive to this site type. In addition to significantly higher cover on organic soils, Liverwort species and black spruce also had significantly different mean cover in comparisons of moderately deep plots with outcrops and shallow ones. This was not surprising for black spruce given its high correlation with canonical variate 2.

According to the site type affinity analysis (Table 10.4), seven species were characteristic of 37 year old post-fire communities on organic soils. In order of decreasing mean cover, they were

Sphagnum species (C% = 68.7[10]), *Ledum groenlandicum* (C% = 20.1), black spruce (C% = 8.7), *Salix* species (C% = 1.9), Moss species (C% = 1.8), *Carex* species (C% = 0.8) and *Oxycoccus quadripetalus* (C% = 0.7). Associated species were *Alnus rugosa* (C% = 6.9), *Chamaedaphne calyculata* (C% = 6.4), *Pleurozium schreberi* (C% = 4.9), *Equisetum sylvaticum* (C% = 2.0), *Smilacina trifolia* (C% = 0.9%), *Betula glandulosa* (C% = 0.5), *Polytrichum strictum* (C% = 0.4), *Vaccinium vitis-idaea* (C% = 0.4), *Calamagrostis canadensis* (C% = 0.2), *Gaultheria hispidula* (C% = 0.2), *Kalmia polifolia* (C% = 0.2), tamarack (C% = 0.2), *Aulacomnium palustre* (C% = 0.1) and *Cladonia* species (C% = 0.1). Six of the fourteen species with an affinity for organic soils were exclusive to organic soils. No other site type had an exclusive species with a treatment affinity.

Post-fire communities on organic soils had a moderately open black spruce tree canopy with small amounts of tamarack and a well developed shrub stratum (Table 10.5). Black spruce and *Alnus rugosa* were the main tall shrubs. *Ledum groenlandicum* was the most abundant vascular plant and was accompanied by *Chamaedaphne calyculata* and a number of other low shrubs. *Carex* species was the only herb or graminoid that had a characteristic level affinity. As with the 13 and 65 year old age classes, communities on organic soils were dominated by *Sphagnum* species. The understorey of post-fire communities on organic soils was very different from that found on the other site types.

Post-fire communities on outcrops presented a stark contrast to those found on organic soils. Jack pine trees grew where the lichen covered soil was more than a few centimeters deep. This led to a patchy, sparse canopy (canopy closure was only 7%; Table 10.2). Exposed bedrock (C% = 32.9) was surrounded by reindeer lichens and feather mosses. Reindeer lichens (*Cladina mitis* {C% = 16.0} and *C. rangiferina* {C% = 8.9}) dominated these communities. Between 13 and 37 years of age, feather moss cover had increased from 0.1% to 10.2% (*Pleurozium schreberi* {C% = 7.7} and *Dicranum* species {C% = 2.5}) and was higher than haircap moss cover (*Polytrichum juniperinum* {C% = 2.3} and *P. piliferum* {C% = 1.6}). No other understorey species performed well enough to attain a characteristic level of affinity. Graminoids associated with outcrops were *Agrostis hyemalis*, *Carex* species, *Danthonia spicata* and *Oryzopsis pungens*. *Maianthemum canadense* (C% = 0.5) and *Potentilla tridentata* (C% = 0.8) had an associated level affinity. *Vaccinium myrtilloides* (C% = 0.8) was the only shrub with an affinity. Other than the ground stratum, plant cover in post-fire communities on outcrops was confined to areas where soils were deeper than the maximum average depth of 3 cm.

Shallow soils supported better developed communities than outcrops. Jack pine was the only characteristic tree while a number of shrubs, herbs and graminoids had affinities. As with outcrops and organic soils, cover in the community was dominated by the ground stratum. *Vaccinium myrtilloides* (C% = 2.9) was the only characteristic shrub (Table 10.5). Shrubs with associated level affinities included *Amelanchier sanguinea* (C% = 0.2), *Arctostaphylos uva-ursi* (C% = 2.0), *Diervilla lonicera* (C% = 1.6), *Linnaea borealis* (C% = 1.5) and *Rosa acicularis* (C% = 0.5). In the herb stratum, *Maianthemum canadense* (C% = 1.5) was characteristic and *Cornus canadensis* (C% = 0.9), *Fragaria virginiana* (C% = 0.9), *Melampyrum lineare* (C% = 1.0) and *Potentilla tridentata* (C% = 0.6) were associated. Although they did not perform as well as *Pleurozium schreberi* (F% = 100 and C% = 39.1), *Dicranum* species (C% = 2.7) and *Cladina rangiferina* (C% = 4.6) both had frequencies of 95%. *Cladina mitis* (C% = 9.8), *Cladonia* species (C% = 1.4) and Moss species (C% = 0.9) were also characteristic while *Polytrichum juniperinum* (C% = 1.5), Foliose lichens (C% = 0.6) and Fruticose lichens (C% = 0.4) were associated.

The moderately deep site type was based on a soil depth between 20 and 100 cm and surface organic layer less than 20 cm thick. This incorporated a broad range of edaphic conditions related to soil volume, soil texture and moisture regime. For example, a 21 cm deep sandy soil on a

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[10] C% = mean percent cover, F% = frequency, CD = absolute difference in mean cover in post-logging communities relative to post-fire i.e. mean cover in post-logging communities minus mean cover in post-fire communities. A "+" indicates higher cover and "-" lower.

slope and a 95 cm deep gleyed, clay would both fall into this category. This category was not subdivided since the next step up in ecological resolution would have resulted in the addition of several rather than one more site type category. The implication for sampling effort (3 categories * 5 subsamples * 4 replicates * 2 treatments * 2 age classes = 240 additional plots) was not feasible. This site type also supported vegetation significantly different from the two site types most similar to it in ecological terms (see Appendix E).

Post-fire communities on moderately deep soils were more variable than those of the other site types due to the broad range of conditions incorporated within the site type. This was the only site type where the tree plots contained aspen or balsam fir (Table 10.2). These two tree species were always found with black spruce and sometimes jack pine, but never with each other. Communities were characterized by jack pine (18.0 m^2/ ha) in the upper canopy and black spruce (7.3 m^2/ ha) in the lower canopy. Black spruce (C% = 5.4) also had an associated level affinity in the shrub stratum. The characteristic understorey species were those typically found under a closed canopy, coniferous forest. They included *Maianthemum canadense* (C% = 1.4), *Dicranum* species (C% = 3.9), Moss species (C% = 1.1), *Pleurozium schreberi* (C% = 29.9), *Cladina rangiferina* (C% = 0.9) and *Cladonia* species (C% = 0.8). Once again, the ground stratum dominated the communities in terms of cover.

Thirteen species were associated with moderately deep soils (Table 10.5). Those which had mean cover greater than 1% were *Vaccinium myrtilloides* (C% = 3.2), *Linnaea borealis* (C% = 1.5), *Cornus canadensis* (C% = 2.1) and *Polytrichum commune* (C% = 2.9).
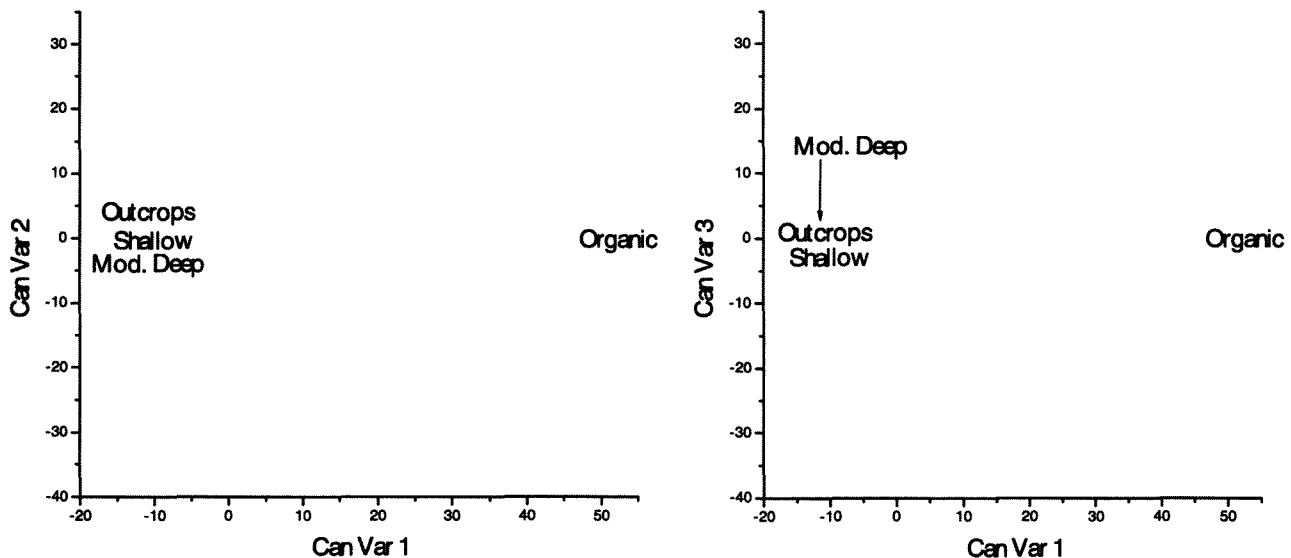
Figure 10.2. Site type means of plot scores from canonical variates 1, 2 and 3 for understorey of 37 year old post-fire communities.

Table 10.3. Species with high canonical structure correlations from canonical variates analysis of understorey species in 37 year old post-fire communities. (Species codes are found in Appendix A. The general rule for coding was to join the first 5 letters of the genus to the first 3 letters of the specific epithet.)

Species	Canonical Variate		
	Can 1	Can 2	Can 3
Sphag spp	0.97	-0.01	0.00
Ledum gro	0.90	-0.01	-0.05
Alnus rug	0.59	0.01	-0.01
Smila tri	0.58	-0.01	0.00
Chama cal	0.57	-0.01	0.00
Carex spp	0.55	0.10	0.14
Oxyco qua	0.54	-0.01	0.00
Equis syl	0.54	-0.02	0.01
Kalmi pol	0.52	-0.01	0.00
Calam can	0.45	-0.15	0.08
Gault his	0.45	0.00	-0.03
Salix spp	0.42	-0.27	0.07
Vacci vit	0.39	-0.10	0.07
Tamarack	0.38	0.00	0.00
Betul gla	0.38	0.00	0.00
Polyt str	0.37	0.02	0.02
Black spruce	0.35	-0.43	0.00
Liver spp	0.32	0.05	0.03
Rubus pub	0.09	-0.30	0.03
Polyt com	-0.05	-0.34	0.04
Lathy ven	-0.11	-0.01	-0.37
Coryd sem	-0.11	0.32	0.20
Clint bor	-0.13	-0.31	0.09
Amela san	-0.16	-0.07	-0.36
Arcto uva	-0.21	-0.06	-0.37
Campa rot	-0.22	0.31	-0.12
Agros hye	-0.22	0.40	0.20
Danth spi	-0.22	0.38	0.15
Polyt pil	-0.22	0.42	0.18
Fraga vir	-0.27	-0.18	-0.30
Folio spp	-0.29	0.54	0.25
Fruti spp	-0.30	0.37	-0.09
Oryzo pun	-0.32	0.19	-0.39
Pleur sch	-0.33	-0.38	-0.37
Cladi mit	-0.34	0.60	0.02
Maian can	-0.35	-0.22	-0.20
Oryzo asp	-0.35	-0.12	-0.25
Dicra spp	-0.36	-0.21	-0.02
Polyt jun	-0.36	0.37	0.01
Cladi ran	-0.36	0.42	-0.10
Clado spp	-0.40	0.18	0.04

Species	Can 2
Cladi mit	0.60
Folio spp	0.54
Cladi ran	0.42
Polyt pil	0.42
Agros hye	0.40
Danth spi	0.38
Polyt jun	0.37
Fruti spp	0.37
Coryd sem	0.32
Campa rot	0.31
Rubus pub	-0.30
Petas pal	-0.30
Clint bor	-0.31
Polyt com	-0.34
Pleur sch	-0.38
Black spruce	-0.43

Species	Can 3
Folio spp	0.25
Fraga vir	-0.30
Amela san	-0.36
Arcto uva	-0.37
Pleur sch	-0.37
Lathy ven	-0.37
Oryzo pun	-0.39

Table 10.4. Species site type affinities, presence and mean cover in 37 year old post-fire communities.

Site Type	Affinity[1] Char	Asso.	Frequency in Plots (%) Outcrop	Shallow	Mod. Deep	Organic	Presence in Blocks Outcrop	Shallow	Mod. Deep	Organic	Mean Cover in Blocks (%) Outcrop	Shallow	Mod. Deep	Organic
N			27	21	27	17	4	4	4	3	4	4	4	3
Shrubs														
Black spruce **	5	2	11	43	63	82	2	4	4	3	0.0	2.2	5.4	8.7
Tamarack **		5E				29				3				0.2
Alnus rug **		5	4	5	4	59	1	1	2	3	0.4	0.2	0.1	6.9
Amela san		1	7	48	15		2	3	2		0.0	0.2	0.1	
Arcto uva		1	22	48	15		3	3	2		0.2	2.0	1.0	
Betul gla **		5E				18				3				0.5
Chama cal **		5E				53				3				6.4
Dierv lon		1	33	67	44		3	4	3		1.1	1.6	1.1	
Gault his **		5		5		35		1		3		0.0		0.2
Kalmi pol **		5E				35				2				0.2
Ledum gro **	5			5	4	100		1	2	3		0.8	0.0	20.1
Linna bor		1,2	22	62	67	18	2	4	4	1	2.2	1.5	1.9	0.1
Oxyco qua **	5E					71				3				0.7
Rosa_ aci		1,2	22	43	48	6	3	4	4	1	0.5	0.3	0.5	0.1
Salix spp **	5		7	19	41	76	2	3	4	3	0.0	0.4	1.0	1.9
Vacci myr	1	0,2	52	81	70	29	4	4	4	3	0.8	2.9	3.2	0.1
Vacci vit **		5	4		7	41	1		2	3	0.0		0.1	0.4
Herbs														
Aster cil		2	22	24	52		3	2	3		0.1	0.1	0.2	
Campa rot			37	29	7		3	3	2		0.0	0.0	0.0	
Clint bor **		2		10	26			1	3			0.0	0.2	
Cornu can		1,2	26	48	63	41	3	3	4	3	1.1	0.9	2.1	0.3
Coryd sem			19				2				0.0			
Equis syl **		5			7	65			2	3			0.0	2.0
Fraga vir		1,2	30	62	67	6	3	3	4	1	0.2	0.9	0.5	0.0
Lathy ven **			4	19	7		1	3	1		0.0	0.1	0.0	
Maian can **	1,2	0	48	86	78	6	3	4	3	1	0.5	1.5	1.4	0.0
Melam lin		1	37	57	41		4	3	3		0.1	1.0	0.3	
Poten tri		0,1	44	48	15		4	3	1		0.8	0.6	0.3	
Rubus pub		2	19	38	44	24	2	3	4	2	0.1	0.2	0.9	1.0
Smila tri **		5E				53				3				0.9
Graminoids														
Agros hye **		0	48	19	11		3	2	2		0.1	0.0	0.0	
Calam can **		5			11	65			3	3			0.1	0.2
Carex spp **	5	0	52	14	26	94	4	2	4	3	0.1	0.0	0.1	0.8
Danth spi **		0	52	19	7		4	2	2		0.1	0.0	0.0	
Oryzo asp	1	2	33	76	56	6	4	3	4	1	0.1	0.1	0.1	0.0
Oryzo pun **	1	0	48	67	19		4	4	2		0.0	0.1	0.0	

Table 10.4. . . . continued

Site Type	Affinity[1] Char	Asso.	Frequency in Plots (%) Outcrop	Shallow	Mod. Deep	Organic	Presence in Blocks Outcrop	Shallow	Mod. Deep	Organic	Mean Cover in Blocks (%) Outcrop	Shallow	Mod. Deep	Organic
N			27	21	27	17	4	4	4	3	4	4	4	3
Bryophytes														
Auloc pal		5	19	10	22	59	3	2	4	3	0.1	0.0	0.5	0.1
Dicra spp **	0,1,2		78	95	96	35	4	4	4	3	2.5	2.7	3.9	0.3
Liver spp			4			18	1			2	0.0			0.0
Moss_ spp	0,1,2,5		85	81	96	71	4	4	4	3	0.7	0.9	1.1	1.8
Pleur sch **	0,1,2	5	78	100	100	65	4	4	4	3	7.7	39.1	29.9	4.9
Polyt com		2	4	33	41	18	1	2	3	2	0.0	0.9	2.9	0.5
Polyt jun **	0	1,2	93	67	67		4	4	3		2.3	1.5	0.4	
Polyt pil	0		78	19	15		4	2	2		1.6	0.3	0.1	
Polyt str		5				35				3				0.4
Sphag spp **	5		4			100	1			3	0.0			68.7
Lichens														
Cladi mit **	0,1	2	100	76	48	6	4	4	3	1	16.0	9.8	1.0	0.2
Cladi ran **	0,1,2		96	95	81	18	4	4	4	2	8.9	4.6	0.9	0.0
Clado spp	0,1,2	5	100	90	96	59	4	4	4	3	1.4	1.4	0.8	0.1
Folio spp **	0	1,2	89	62	59	18	4	4	3	2	5.3	0.6	0.2	0.0
Fruti spp	0	1	78	57	26		4	4	2		0.4	0.4	0.1	
Other Ground														
Conifer litter *	0,1,2,5		100	95	100	94	4	4	4	3	18.9	25.5	32.5	2.1
Other litter *	0,1,2,5		85	100	100	100	4	4	4	3	4.2	7.5	21.1	17.1
Rock ***	0	1	93	67	26	0	4	4	4	0	32.9	2.4	0.3	0.0
Snag *		2	4	33	56	12	1	4	4	1	0.0	0.0	0.1	0.1
Trunk ***	2	1,5	15	67	85	59	2	4	4	3	0.0	0.3	0.4	0.1
Wood litter *	0,1,2,5		89	90	100	94	4	4	4	3	1.2	1.4	3.1	1.2

[1] Char. = species had a characteristic level of affinity on the site types listed; Asso. = species had an associated level affinity; Site type codes: 0 = outcrops, 1 = shallow, 2 = moderately deep, 5 = organic. An "E" following a site type indicates that the species was exclusive to that site type.   See Appendix A for species codes.   ** Denotes species which had a significant difference ($\alpha = 5\%$) in mean cover in at least one site type by mixed model ANOVA.

Table 10.5. Characteristic and associated species of post-fire communities.

| | Site Type | | |
Outcrops	Shallow	Moderately Deep	Organic
Trees			
Jack pine [A]	Jack pine [C]	Black spruce [A] Jack pine [C]	Black spruce [C] Tamarack [A] **
Shrubs		Black spruce [A]	Black spruce [C] Tamarack [A] ** Alnus rugosa [A]
	Amelanchier sanguinea [A] Arctostaphylos uva-ursi [A]		
			Betula glandulosa [A] ** Chamaedaphne calyculata [A] **
	Diervilla lonicera [A]		
			Gaultheria hispidula Kalmia polifolia [A] ** Ledum groenlandicum [C]
	Linnaea borealis [A]	L.. borealis [A]	
			Oxycoccus quadripetalus [A] **
	Rosa acicularis [A]	R. acicularis [A]	
			Salix species [C]
Vaccinium myrtilloides [A]	V. myrtilloides [C]	V. myrtilloides [A]	
			Vaccinium vitis-idaea [A]
Herbs		Aster ciliolatus [A] Clintonia borealis [A]	
	Cornus canadensis [A]	C. canadensis [A]	
			Equisetum sylvaticum [A]
	Fragaria virginiana [A]	F. virginiana [A]	
Maianthemum canadense [A]	M. canadense [C]	M. canadense [C]	
	Melampyrum lineare [A]		
Potentilla tridentata [A]	P. tridentata [A]		
		Rubus pubescens [A]	
			Smilacina trifolia [A] **
Graminoids			
Agrostis hyemalis [A]			
Carex species [A]			Calamagrostis canadensis [A] Carex species [C]
Danthonia spicata [A]			
	Oryzopsis asperifolia [C]	O. asperifolia [A]	
Oryzopsis pungens [A]	O. pungens [C]		
Bryophytes			
			Aulacomnium palustre [A]
Moss species [C]	Moss species [C]	Moss species [C]	Moss species [C]
Dicranum species [C]	D. species [C]	D. species [C]	
		Polytrichum commmune [A]	
Polytrichum juniperinum [C]	P. juniperinum [A]	P. juniperinum [A]	
Polytrichum piliferum [C]			
			Polytrichum strictum [A]
Pleurozium schreberi [C]	P. schreberi [C]	P. schreberi [C]	
			Sphagnum species [C]
Lichens			
Cladina mitis [C]	C. mitis [C]	C. mitis [A]	
Cladina rangiferina [C]	C. rangiferina [C]	C. rangiferina [C]	
Cladonia species [C]	Cladonia species [C]	Cladonia species [C]	Cladonia species [A]
Foliose lichens [C]	Foliose lichens [A]	Foliose lichens [A]	
Fruticose lichens [C]	Fruticose lichens [A]		

See Appendix A for species codes. ** = Species exclusive to the site type.

10.2. Trees- comparison of 37 year old post-fire and post-logging communities for all site types.

Prior to a detailed examination of treatment differences by site type, an overview of tree results is provided for all site types (Table 10.6). Black spruce (F% = 41.9), jack pine (F% = 38.7), aspen (F% = 10.5), balsam fir, paper birch, tamarack and white spruce occurred in more than three plots in the 37 year old age class. Only the first three of these had a frequency of at least 5% over all site types. Black spruce and jack pine were found on all site types in both treatments. Jack pine had the highest basal area on the upland site types and black spruce on the organic soils. Jack pine mean basal area was substantially lower in upland post-logging communities. Black spruce's basal area appeared higher on organic soils (Table 10.6).

Table 10.6. Presence and basal area (m2/ ha) for tree species from 37 year old communities.

	Presence								Basal Area (m²/ ha)							
Site Type	Outcrops		Shallow		Mod. Deep		Organic		Outcrops		Shallow		Mod. Deep		Organic	
Treatment	Burns	Cuts	Burns	Cuts	Burns	Cuts	Burns	Cuts	Burns	Cuts	Burns	Cuts	Burns	Cuts	Burns	Cuts
Treed Plots (%)	23	27	90	63	100	72	94	95								
N	4	4	4	4	4	4	3	4	4	4	4	4	4	4	3	4
Aspen				1	2	4						1.0	1.4	3.0		
Balsam fir				1	1	2		1				0.2	0.4	0.9		0.1
Black spruce	2	2	3	3	4	3	3	4	0.2	0.6	1.7	3.5	7.3	4.6	10.4	19.0
Jack pine	4	2	4	3	4	3	2	2	5.8	2.5	14.2	4.3	18.0	5.6	2.0	3.0
Paper birch			1	1	1	1		2				0.1	0.3	0.3		0.6
Tamarack						1	2	3							0.3	1.7
White spruce			1	1	2	1				0.1	0.1	0.2	0.6			

* Shaded boxes denote treatment comparisons for which means were significantly different for p < = 0.05. A blank cell indicates that the species was not encountered.

Treatment differences in mean basal area (m²/ ha) were compared for black spruce, jack pine and aspen and total basal area for all seven tree species. ANOVA detected a significant difference for jack pine on shallow and moderately deep soils. Total basal area was substantially lower in post-logging communities on all the upland site types but the difference was significant only for moderately deep soils.

The failure to detect differences in means which appear large implies that Block to Block variability within treatments was high. MANOVA indicated that Block variability was significant for all the site types except shallow soils (Table 10.7). With only 4 replicates, it was not surprising that statistical power was low. One way to increase power without adding replicates would be to use a larger tree plot for this age class. Plot size was based on pilot study data which included only one Block from each age class/ treatment combination. If the two Blocks used in the plot size determination were not representative then it is possible that a larger tree plot size would increase power more than the addition of another replicate.

High Block to Block variability in trees also appeared to affect comparisons of the percentage of plots with trees on them. Although this percentage was substantially lower in the post-logging communities found on shallow and moderately deep soils, a significant difference was not detected. As will become apparent when the balance of the results are provided for each site type, the treatment affinity analysis suggests that treatment differences probably would have been detected in some cases had more replicates been available.

MANOVA was also applied so that coordinated changes among jack pine, black spruce and aspen might be detected. Probability values for this model are provided in Table 10.7 along with

those for the univariate comparisons. The multivariate approach detected significant treatment differences only for shallow soils. Once again, this may be a reflection of low statistical power.

Table 10.7. Treatment comparisons of basal area (m²/ ha) from 37 year old communities- probability values from MANOVA (Wilk's lambda) and ANOVA.

		Site Type			
		Outcrops	Shallow	Mod. Deep	Organic
MANOVA	Treatment	0.15	0.03	0.11	0.27
	Block	0.03	0.06	0.01	0.03
ANOVA	Jack Pine	0.32	0.01	0.03	0.85
	Black Spruce	0.57	0.76	0.50	0.16
	Aspen	n/a	0.14	0.14	n/a
	Total of black spruce, jack pine, aspen, balsam fir, white spruce, paper birch, tamarack	0.46	0.13	0.03	0.08

Shaded boxes denote effects or species that had significant treatment effects at p <= 0.05.

10.3. Outcrops- comparison of 37 year old post-fire and post-logging communities.

Most plots from the Burn 4 Block were somewhat separated from plots the other burns in the three dimensional space created by the first three principal coordinates (Figures 10.1 - 10.4). The suggestion by ordination scattergrams that this burn may be an outlier accords well with subjective impressions gained in the field. This Block had the lowest relief and outcrops tended to be smaller in area. They were generally partially to completely shaded for most of the day. Under these conditions, feather mosses are expected to be favored over reindeer lichens and other shade intolerant species characteristic of open, very dry conditions such as *Agrostis hyemalis, Polytrichum piliferum* and *Selaginella* species. Higher feather moss cover, in turn, aids in the more rapid accumulation and development of soil and provides establishment sites for more species than lichens do. The result over a long period of time is that the species composition of communities on these outcrops may be more similar to that found on shallow soils.

An analysis was undertaken to determine whether Burn 4 outcrop plots should be removed from further data analysis because the Block was an outlier. CA located most Burn 4 plots in the periphery of the scattergram. This was partly attributed to species richness patterns because CA locates species poor plots at the periphery of a scattergram. The number of species in a Block ranged from 25 to 43 with all but Burn 1 scattered between 25 and 35. Only Burn 1 plots had a large disparity in species richness. Burn 1 contained all the ubiquitous outcrop species whereas Burn 4 lacked more of them than any other Block. This accounted for the location of Burn 1 plots near the origin and those of Burn 4 at the periphery. It also suggested that the presence of infrequent outcrop species in Burn 4 may have contributed to its position as an outlier. Species which were close to Burn 4 on the second and third ordination axes included *Aster ciliolatus, Cornus canadensis, Diervilla lonicera, Epilobium angustifolium, Fragaria virginiana, Galium boreale, Linnaea borealis, Maianthemum canadense, Melampyrum lineare, Oryzopsis asperifolia, Pleurozium schreberi, Rosa acicularis, Rubus pubescens* and *Schizachne purpurascens.* All but two of these species were identified as having an affinity with Burn 4 by the affinity analysis. The two new species had peak relative frequency or cover in this Block but did not meet the affinity criteria.

PCA scattergrams confirmed Burn 4's outlier position. *Cladina rangiferina* was the Block 4 species with the greatest discriminatory power for treatment effects[11]. In the biplot of Figure 10.4, the perpendiculars to the *C. rangiferina* species line of all Burn 4 plots except one was on the same side of the origin as the species. *C. rangiferina* had much higher mean cover in post-fire communities. Most of the post-logging plot perpendiculars were also on the same side of the origin as the species point. *C. rangiferina* had a much higher cover in Burn 4 than the other post-logging communities. In fact, its mean cover in Burn 4 was also higher than that of 3 out of 4 post-fire communities. Consequently, Burn 4 appears on the same side of the origin as the post-fire communities. This reflects its similarity to them with regards to this strongly differentiating species but at the same time not within the post-logging plots in lieu of its dissimilarity to them based on other species such as *Aster ciliolatus* or *Fragaria virginiana*. The other species useful at discriminating Burn 4 from the other Blocks was *Pleurozium schreberi*. A number of the other species with affinities for Burn 4 were located near this species. Most Burn 4 plots were located in the biplot such that they implied a cover value which was above the site type average for either *Cladina rangiferina* or the *Pleurozium schreberi* group or both.

Species which performed better or worse in Burn 4 (Table 10.9) were identified using the criteria described in Section 6.5.2. Four of the nine species that performed more poorly in Burn 4 were previously identified as being characteristic or associated with burned outcrops (Section 10.1.2). Six of the 10 species with an affinity for Burn 4 but not outcrops were previously identified as being characteristic or associated with shallow or moderately deep soils. It appeared that the communities of Burn 4 outcrops were intermediate in species composition to those of outcrops and shallow soils.

Block means for various ecological variables from burns were examined using mixed model ANOVA to determine whether Burn 4 was anomalous in any way. Only percent canopy closure was significantly different and it was substantially higher in Burn 4. Previously it was indicated that subjective impressions were that outcrops in this Block were more shaded and this made the vegetation of outcrop plots more similar to that of shallow soil plots. Mean percent canopy closure was 7% and 29% in outcrops and shallow soils, respectively. Burn 4's mean percent canopy closure was 20%- a level much closer to that of shallow soils than outcrops (especially considering that the high value in Burn 4 has raised the overall mean in outcrops from 2.5% to 7%). One potential effect of greater shading was observed in ground cover. Mean percent cover of exposed Rock was only 0.8% in Burn 4 (Table 10.9) compared to a site type mean of 32.9%.

Burn 4 qualified as an outlier but it remains to be determined whether it should be excluded from analysis. In the case of CA, the results indicated that the outlier position was largely attributable to very high values for *Linnaea borealis* and *Rubus pubescens*. The remaining species with Burn 4 affinities also had unusually high frequencies or cover values in this Block but the differences in values were quite low. While PCO and PCA suggested that the vegetation Burn 4 differed from the other post-logging communities, unlike CA, they did not isolate the majority of the plots. There was no species unique to Burn 4 or no situation where a species occurred in at least 2 of 4 post-logging communities plus only Burn 4. Canopy closure was the only ecological variable for which Burn 4 was similar to shallow soil plots. In concert, the vegetation and ecological factors suggested that the communities on outcrops of Burn 4 were not so different that the burn was an ecological outlier but that the plots were moister and more shaded than those of the other post-logging communities and this led to a different species composition. In the absence of a convincing theoretical justification for removing it, Burn 4 was retained.

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[11] This is indicated by the length of a line from its point to the origin in the biplot of Figure 10.2. A biplot simply superimposes the plot ordination on the species ordination and rescales the axes so that one plot does not compress the other. The relative locations of plots and species are preserved.

The unusual nature of outcrops in Burn 4 could have affected the characterization of post-fire communities on outcrops. A review of the site type affinity analysis with Burn 4 excluded indicated that no additional species would be given an affinity but that *Agrostis hyemalis* would become characteristic and *Maianthemum canadense* would lose its associated level of affinity.

Turning to the evaluation of treatment effects, all three ordination techniques suggested that the species composition of post-fire and post-logging communities on outcrops differed. PCO did so on a combination of the second and third principal coordinates, CA on the second and third and PCA on the second only. The proportion of the total variance accounted for by the first three components of the PCO was 14.8%, 10.7% and 5.9% for a cumulative total of 31.4%.

MANOVA was performed on plot scores obtained from the first three principal coordinates of PCO. The Blocks within each treatment were significantly different from each other (Table 10.8) as anticipated in the exploratory analysis. Despite the variability of Blocks, there was a significant treatment difference ($\alpha=5\%$) in the species composition of communities on outcrops.

The treatment affinity analysis suggested that the main difference in the performance of species in post-logging communities relative to post-fire was poorer performance by herbs, graminoids and bryophytes and better performance by reindeer lichens. *Cladina rangiferina* was the only species with a large absolute difference in cover (CD = +11.6) (Table 10.4). Proportional changes in cover were substantial for most of the scarce species. *Aster ciliolatus*, *Fragaria virginiana* and *Aulacomnium palustre* were absent in post-logging communities. *Melampyrum lineare* (CD = -0.1), *Danthonia spicata* (CD = -0.1), *Oryzopsis asperifolia* (CD = -0.1), *Polytrichum piliferum* (CD = -1.5) and Fruticose lichen species (CD = -0.3) had lower cover in post-logging communities. *Polygonum cilinode* was the only herb that did better and it was exclusive to post-logging communities.

Reindeer lichens exhibited the greatest treatment differences. That of *Cladina rangiferina* has already been mentioned. *C. mitis* (CD = +10.6) also had substantially higher mean cover, but the difference was not significant due to an unusually high mean in one burn. Otherwise, its mean cover values in the remaining post-logging communities were all lower than the lowest value in post-fire communities. This suggested that the lack of significance was likely due to low statistical power. For this reason, it was given a questionable cutover affinity. *C. stellaris* (CD = +1.6) was also found in post-logging communities.

The large increase in the cover of reindeer lichens did not seem to have been at the expense of any other species or group of species[12]. Another consequence of higher reindeer lichen cover might be reduced other ground cover. The treatment difference in the cover of exposed bedrock (CD = -10.5) was not significant, however, examination of the Block data indicated that bedrock suffered from the same problem as *Cladina rangiferina*. The unusually low value in Burn 4 led to inadequate statistical power. Therefore, Rock was given a questionable treatment affinity. Coniferous litter (CD = -15.5) and Wood litter (CD = -3.1) had significantly lower cover. The combined decrease in Coniferous litter, Wood litter and Rock (CD = -29.1) more than offset the increase in the reindeer lichens (CD = +23.1).

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[12] A large difference in mean total cover of all understorey species was not significant due to the large within treatment variability.

Table 10.8. MANOVA results (p-values from Wilk's lambda) from the test for treatment and Block effects for 37 year old communities on outcrops.

	Treatment Effect	Block Effect
Overall Model	0.001	0.0001
Coordinate 1	0.996	0.0006
Coordinate 2	0.055	0.0009
Coordinate 3	0.044	0.6420
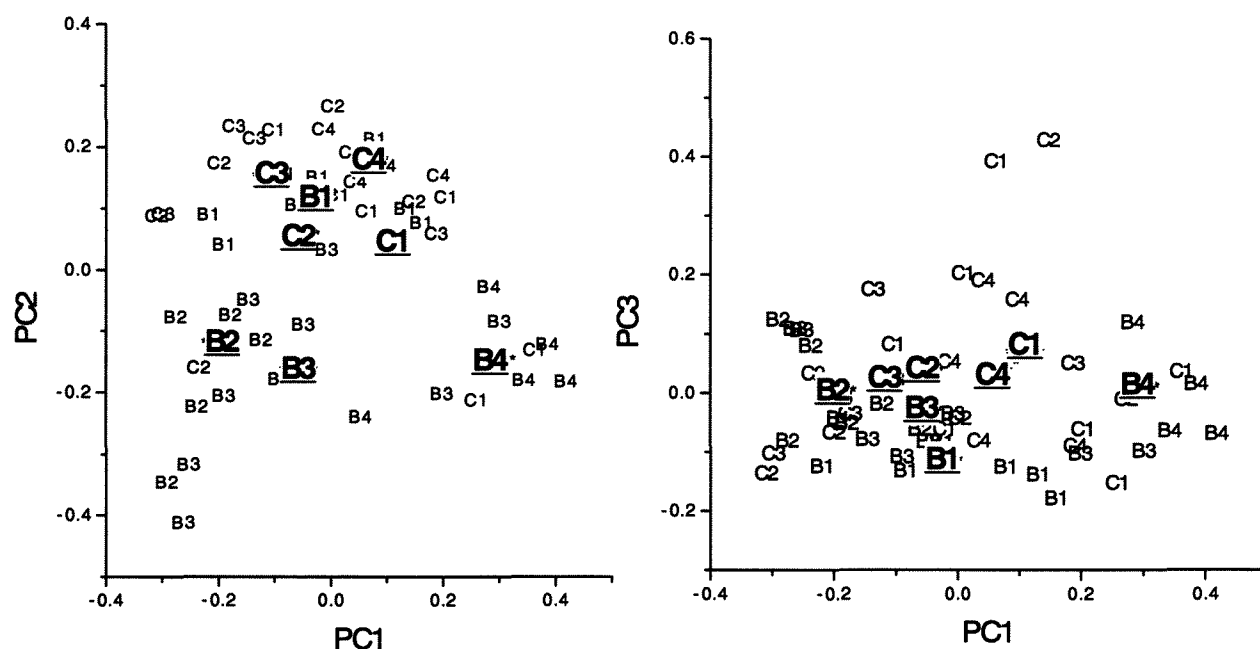
Figure 10.1. PCO scattergrams of plot scores for 37 year old communities on outcrops.
B = post-fire communities, C = post-logging communities. Underlined labels are Block means of plot scores. Some plots are hidden.

87
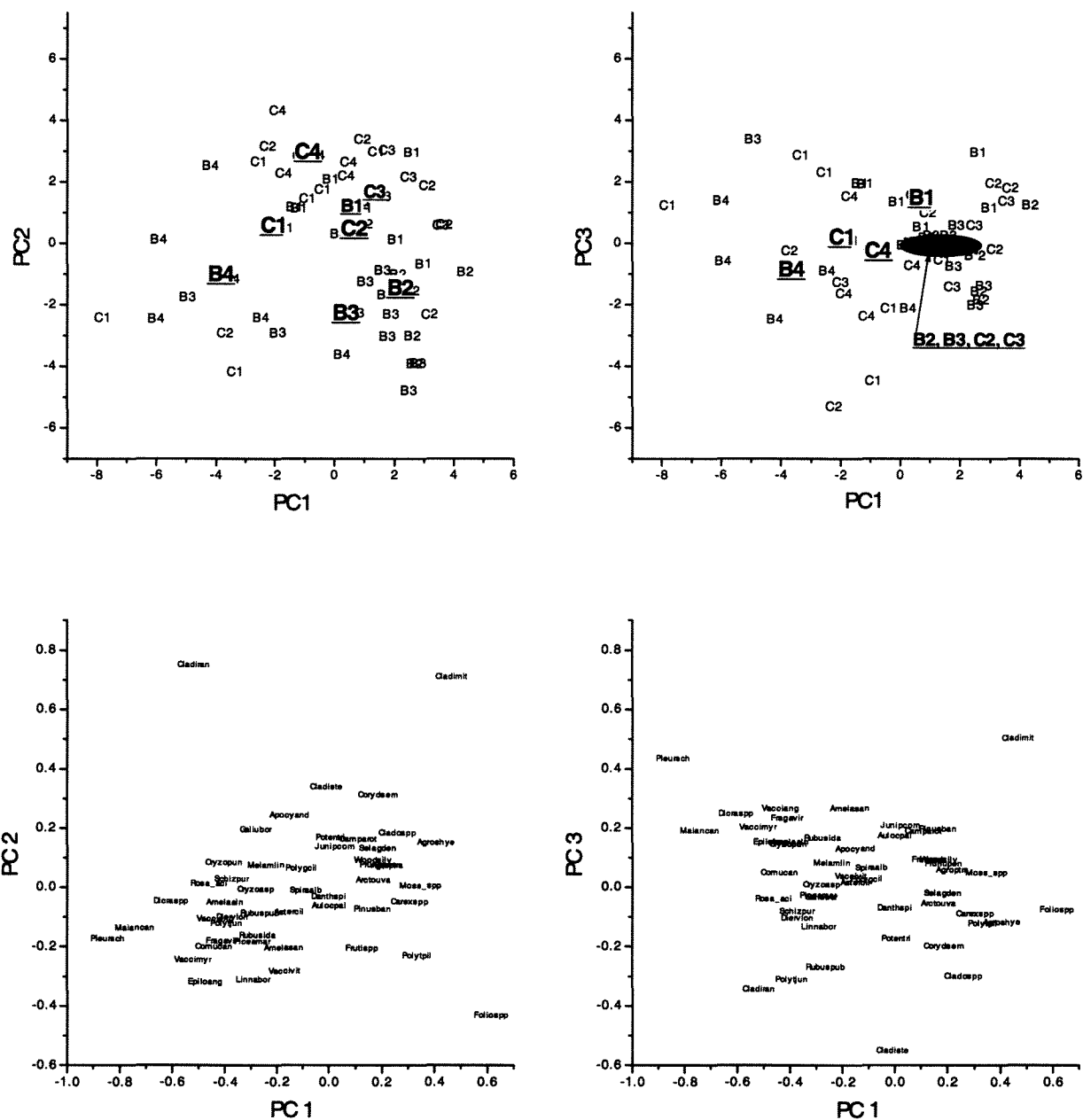
Figure 10.2. PCA scattergrams of plot and species scores for 37 year old communities on outcrops. B = post-fire communities, C = post-logging communities. Underlined labels are Block means of plot scores. Some plots are hidden. See Appendix A for species codes.

Figure 10.3. CA scattergrams of plot and species scores for 37 year old communities on outcrops. Note difference in axis scales. Underlined labels are Block means of plot scores. Some plots are hidden. See Appendix A for species codes.

Table 10.9. Treatment affinities, canonical variates analysis, frequency and cover results for 37 year old communities on outcrops.

Treatment	Affinity	CV	B4	Diff. %	Blocks Presence Burns	Blocks Presence Cuts	Blocks %Cover/Basal Burns	Blocks %Cover/Basal Cuts	Pres Burn1	Pres Burn2	Pres Burn3	Pres Burn4	Pres Cut1	Pres Cut2	Pres Cut3	Pres Cut4	Cover Burn1	Cover Burn2	Cover Burn3	Cover Burn4	Cover Cut1	Cover Cut2	Cover Cut3	Cover Cut4
N					4	4	4	4	7	6	8	5	7	6	4	5	7	6	8	5	7	6	4	5
Trees																								
Bl. spruce					2	2	0.2	0.6			1	1	1	1					0.1	0.5	0.4	1.8		
Jack pine					4	2	5.8	2.5	1	2	4	5	3	2			3.1	0.5	4.1	15.6	3.0	6.9		
Shrubs																								
Bl. spruce					2	1	0.0	0.3			2	1	2						0.2	0.0		1.0		
Jack pine			-		3	2	1.0	0.4	1	3	2		3	1			0.0	3.6	0.5		1.5	0.1		
Amelasan					2	2	0.0	0.3	1		1		1			1	0.0		0.0		1.1			0.2
Arctouva					3	3	0.2	0.1	2	1	2		1	1		1	0.3	0.1	0.3		0.0	0.0		0.5
Diervlon		B	+		3	2	1.1	0.0	1		4	4	1			1	0.2		0.8	3.5	0.0			0.0
Junipcom					2	1	0.8	0.1	3		1				1		3.2		0.0				0.5	
Linnabor			+		2		2.2						2	4					0.1	8.7				
Prunupen			-		3	3	0.1	0.2	1	1	3			2	2	3	0.0	0.1	0.4			0.4	0.1	0.3
Rosa_aci			+		3	1	0.5	0.0	1		1	4				1	0.2		0.0	1.7				0.1
Rubusida					2	2	0.0	0.1	2			2	1	1			0.2			0.0	0.1	0.2		
Spiraalb			-		3	3	0.1	0.4	5	2	1		3	1		2	0.2	0.0	0.0		0.4	0.6		0.4
Vacciang		C			2	3	0.0	3.2	1			3	5	2		3	0.0			0.1	12.7	0.0		0.3
Vaccimyr					4	4	0.8	0.9	1	2	8	3	3	2	1	2	0.1	0.9	0.9	1.3	2.2	0.0	0.0	1.3
Vaccivit					1	2	0.0	0.1				1	1	2						0.0	0.1	0.2		
Herbs																								
Apocyand					1	2	0.0	0.1	1				3			1	0.0				0.2			0.0
Astercil	B*	B	+	-0.1	3		0.1		2		1	3					0.1					0.0	0.1	
Camparot					3	2	0.0	0.0	7	2		1			1	1	0.1	0.0		0.0			0.1	0.0
Cornucan		B	+		3	1	1.1	0.0	1		2	4	1				0.1		0.3	3.9	0.0			
Corydsem					2	4	0.0	0.1	3		1		3	1	4	1	0.0		0.0		0.2	0.0	0.1	0.0
Epiloang			+		2	1	0.1	0.0	2			4	2				0.1			0.2	0.1			
Fragavir *	B*			-0.2	3		0.2		2		2	4					0.0		0.4	0.2				
Galiubor					2		0.0		2		2						0.0			0.1				
Maiancan			+		3	4	0.5	0.6	2		6	4	5	1	1	4	0.2		0.3	1.5	1.5	0.0	0.6	0.3
Melamlin **	B		+	-0.1	4	3	0.1	0.0	3	1	4	2	3		1	3	0.1	0.1	0.2	0.2	0.0		0.0	0.0
Polygcil **	C*	C		0.3		3		0.3					3		1	1					0.1		0.8	0.3
Potentri					4	3	0.8	0.4	3	3	5	1	3	1		4	0.2	1.2	0.3	1.6	0.5	0.1		0.9
Rubuspub			+		2		0.1		1			4					0.0			0.2				
Woodsilv					1	1	0.1	0.0	5						1		0.3						0.0	
Graminoids																								
Agroptra					2	1	0.0	0.0	4	1			1				0.1	0.0			0.0			
Agroshye			-		3	4	0.1	0.1	5	3	4		3	2	4	3	0.1	0.1	0.1		0.0	0.0	0.3	0.2
Carexspp					4	4	0.1	0.1	5	5	2	2	5	4	2	2	0.1	0.3	0.0	0.1	0.1	0.1	0.2	0.0
Danthspi	B?			-0.1	4	3	0.1	0.0	5	4	3	1	3		1	2	0.2	0.0	0.1	0.0	0.0		0.0	0.0
Oryzoasp	B	B	+	-0.1	4	1	0.1	0.0	2	1	1	5				1	0.1	0.0	0.0	0.2				0.0
Oryzopun					4	4	0.0	0.1	4	1	5	3	5	2	1	4	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.0
Schizpur			+		2	2	0.1	0.0	1			2	2			3	0.0			0.3	0.1			0.1
Bryophytes																								
Aulocpal **	B*		-	-0.1	3		0.1		1	1	3						0.1	0.1	0.0					
Dicraspp			+		4	4	2.5	2.2	6	5	6	4	7	6	1	5	3.7	0.4	1.5	4.3	1.7	4.6	1.9	0.7
Moss_spp			-		4	4	0.7	0.9	6	5	7	4	5	3	4	5	0.9	0.5	1.1	0.4	0.4	0.5	2.4	0.3
Pleursch			+		4	4	7.7	4.6	6	2	8	5	6	4	1	5	4.1	0.3	10.0	16.4	11.8	2.5	0.7	3.4
Polytjun					4	4	2.3	3.1	5	6	8	5	5	6	4	3	0.5	2.8	1.9	4.0	6.2	3.0	0.6	2.4
Polytpil	B	B	?	-1.5	4	4	1.6	0.1	5	6	7	2	1	1	1	3	0.3	4.9	0.8	0.3	0.0	0.2	0.3	0.0
Selagden			-		3	4	0.1	0.4	2	1	1		1	2	2	2	0.2	0.0	0.0		0.0	0.1	0.3	1.1
Lichens																								
Cladimit	C?			10.6	4	4	16.0	26.7	7	6	8	5	7	6	4	5	34.4	16.6	9.7	3.4	18.2	28.8	31.3	28.3
Cladiran *	C	C		11.5	4	4	8.9	20.5	6	6	8	5	7	6	4	5	8.8	2.7	2.3	22.0	20.5	15.3	13.4	32.6
Cladiste ***	C*	C		1.6		4		1.6					2	4	3	1					1.9	2.0	2.0	0.3
Cladospp			-		4	4	1.4	1.5	7	6	8	5	7	6	4	5	1.5	1.0	3.0	0.3	1.5	2.4	1.6	0.7
Foliospp			-		4	4	5.3	3.1	7	6	7	3	7	5	4	4	1.5	10.7	8.8	0.1	3.2	6.1	2.3	0.7
Frutispp *	B	B		-0.4	4	4	0.4	0.1	4	6	7	4	6	3	1	1	0.3	0.8	0.5	0.1	0.2	0.0	0.0	0.0
Other																								
Confr litter *	B			-15.5	4	4	18.9	3.4									6.2	8.6	22.7	38.3	5.3	5.3	1.5	1.6
Other litter					4	4	4.2	7.6									6.4	0.9	2.7	6.6	13.4	2.0	9.4	5.6
Rock	B?			-10.5	4	4	32.9	22.4									31.0	58.8	41.1	0.8	15.6	29.9	29.0	15.2
Snag					1		0.0													0.0				
Trunk					2		0.0														0.0	0.1		
Wood **	C			3.1	4	4	1.2	4.3									0.7	0.3	1.4	2.4	2.8	3.1	3.9	7.3

Affinity: B = Burn, C = Cut, * = exclusive to treatment. CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks. * = significant difference in ANOVA at a = .10, ** = .05, *** = .01. Blank entry = not encountered, 0.0 = >0 and < 0.05 See Appendix A for species codes.
B4 = species with an affinity or repulsion for Burn 4; + = affinity, - = repulsion.
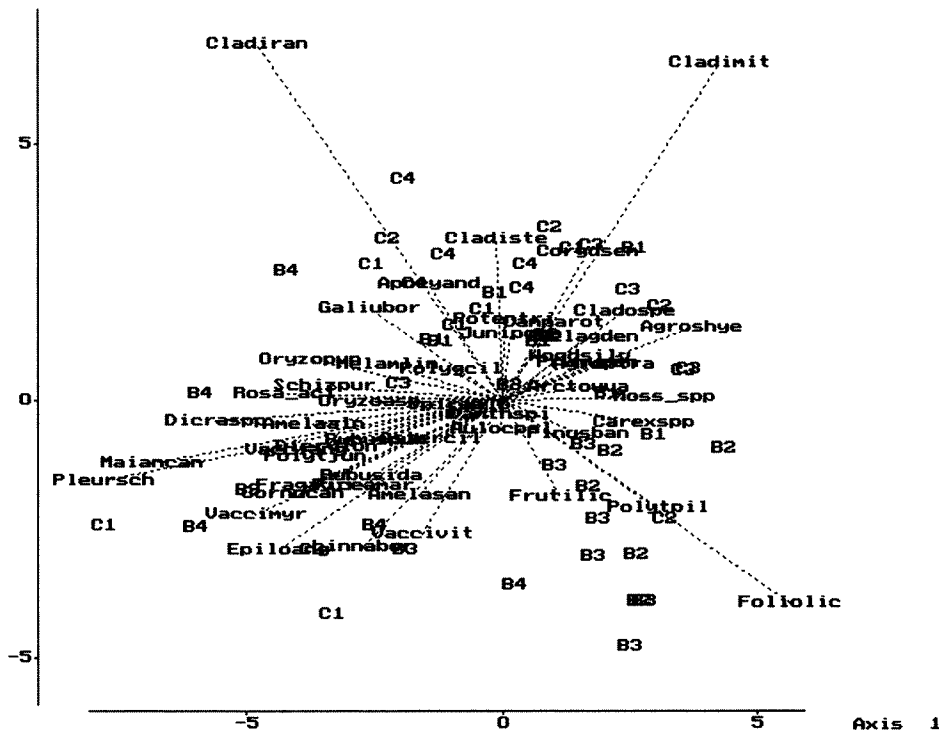
Figure 10.4. PCA biplot for 37 year old communities on outcrops.

10.4. Shallow soils- comparison of 37 year old post-fire and post-logging communities.

In the shallow soil ordination scattergrams, CA identified one plot in Cutover 1 as a potential outlier. Examination of the species scattergram from CA indicated that *Amelanchier sanguinea, Clintonia borealis, Corylus cornuta, Ledum groenlandicum* and *Populus tremuloides* were the species contributing to the position of this plot. Each of these species had much higher mean cover in Cutover 1 than the other cutovers (Table 10.11). Since the plot's outlier position was not carried over to PCO (Figure 10.5) or PCA, it was not removed from further analysis.

PCO applied to square root transformed plot data yielded eigenvalues for the first three principal coordinates which accounted for 11.9%, 9.4% and 8.3% (a cumulative total of 29.6%) of the total for all eigenvalues. As with outcrops, the variance incorporated in the first axis was low because there was a high degree of variability in the data. For example, *Pyrola secunda* was encountered in only one Block (Table 10.11).

All three ordination scattergrams suggested a treatment effect in terms of species composition. The effect was quite distinct on the second principal coordinate of CA and the third of PCO. In the case of PCA, the effect seems to be represented as a linear combination of principal coordinates 1 and 3. Apart from treatment effects and the one potential outlier Block, exploratory data analysis did not reveal other patterns which required further exposition.

MANOVA detected a significant treatment difference (p = 0.006) in the species composition of the communities found on shallow soils (Table 10.10). Block to Block variability was also significant (p = 0.0001) which indicated that Blocks within a treatment were significantly different from each other. Notwithstanding this, the differences between treatments were still greater than those between Blocks. Only principal coordinate 3 exhibited a significant treatment difference (p = 0.001).

Treatment differences in species composition in post-logging communities on shallow soils (Table 10.11) consisted of lower jack pine basal area (-10 m^2/ ha) and lower cover for a number of

shrubs, herbs, graminoids and bryophytes. This was accompanied by higher cover for reindeer lichen and two *Vaccinium* species. Of the shrubs, *Rosa acicularis* (CD = -0.3) was not encountered in post-logging communities and *Linnaea borealis* (CD = -1.4%) performed more poorly. *Vaccinium angustifolium* (+15.6) had the largest cover difference for vascular plants. *V. vitis-idaea* (CD = +1.3) was exclusive to post-logging communities. *Lathyrus ochroleucus* (CD = < -0.05), *Potentilla tridentata* (CD = -0.5) and *Oryzopsis pungens* (CD = -0.1) were the only herbs and graminoid with a treatment affinity. *Lathyrus ochroleucus* was absent in post-logging communities. The largest differences were in the ground stratum. *Pleurozium schreberi* (CD = -17.0), *Polytrichum juniperinum* (CD = -1.3) and *P. piliferum* (CD = -0.3) performed more poorly than in post-fire communities. Lower bryophyte cover was offset by higher *Cladina rangiferina* (CD = +14.2) and *C. stellaris* (CD = +3.1)[13] cover. An additional consequence of the high within-treatment variances of these two *Cladina* species was that the treatment difference in the combined of all species was not significantly different.

Table 10.10 Probability values (p) for a significant difference in the species composition of communities on shallow soils.

	Treatment Effect	Block Effect
Overall Model	0.006	0.0001
Principal Coordinate 1	0.718	0.0005
Principal Coordinate 2	0.174	0.4276
Principal Coordinate 3	0.001	0.1040
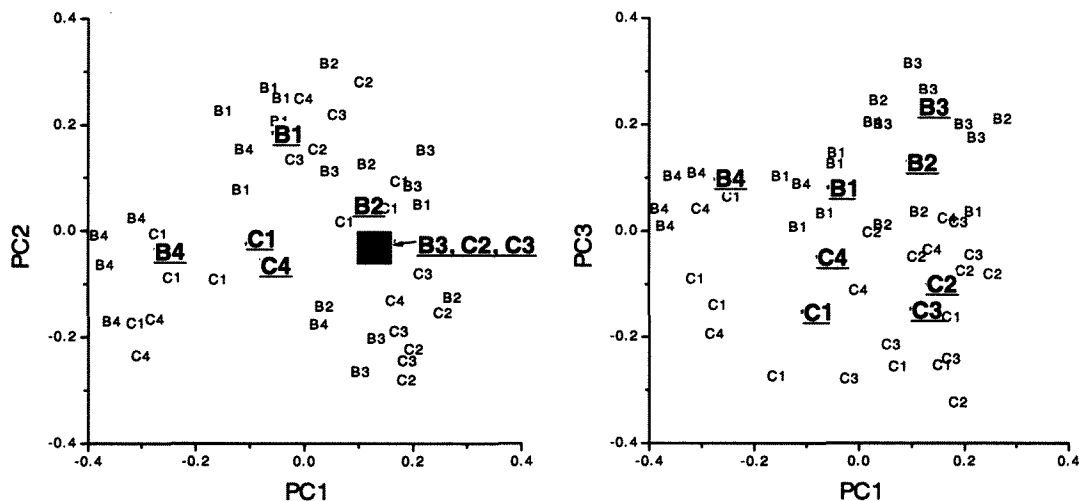
Figure 10.5. PCO scattergrams of plot scores for 37 year old communities on shallow soils. B = post-fire communities, C = post-logging communities. Underlined labels are Block means of plot scores. Some plots are hidden. See Appendix A for species codes.

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[13] The large cover differences of *Cladina rangiferina* and *Pleurozium schreberi* were not significant due to a very large value in one Block. For both species, three of their four values in one treatment were higher than their largest value in the other treatment which suggested that there may be "true" differences in mean cover which could have been detected with more subsamples or replicates. *Cladina rangiferina* was given a cutover affinity as canonical variates analysis attached a high structure correlation to it. *Pleurozium schreberi* barely missed the canonical variates criteria so it was given a questionable treatment affinity.

Table 10.11. Treatment affinities, canonical variates analysis, frequency and cover results for 37 year old communities on shallow soils.

Treatment / N	Affinity	CV	B4	Diff. %	Blocks Presence Burns	Presence Cuts	% Cover/Basal Area Burns	Cuts	Plots Presence Burn 1	Burn 2	Burn 3	Burn 4	Cut 1	Cut 2	Cut 3	Cut 4	Mean Cover (%)/Basal Area Burn 1	Burn 2	Burn 3	Burn 4	Cut 1	Cut 2	Cut 3	Cut 4
N					4	4	4	4	7	6	8	5	7	6	4	5	7	6	8	5	7	6	4	5
Trees																								
Bl. spruce					2	2	0.2	0.6			1	1	1	1					0.1	0.5	0.4	1.8		
Jack pine					4	2	5.8	2.5	1	2	4	5	3	2			3.1	0.5	4.1	15.6	3.0	6.9		
Shrubs																								
Bl. spruce					2	1	0.0	0.3			2	1	2						0.2	0.0	1.0			
Jack pine			-		3	2	1.0	0.4	1	3	2		3	1			0.0	3.6	0.5		1.5	0.1		
Amela san					2	2	0.0	0.3	1		1		1			1	0.0				1.1			0.2
Arcto uva					3	3	0.2	0.1	2	1	2		1	1		1	0.3	0.1	0.3		0.0	0.0		0.5
Dierv lon		B	+		3	2	1.1	0.0	1		4	4	1			1	0.2		0.8	3.5	0.0			0.0
Junip com					2	1	0.8	0.1	3		1				1		3.2		0.0				0.5	
Linna bor			+		2		2.2						2	4						0.1	8.7			
Prunu pen			-		3	3	0.1	0.2	1	1	3			2	2	3	0.0	0.1	0.4			0.4	0.1	0.3
Rosa_ aci			+		3	1	0.5	0.0	1		1	4				1	0.2		0.0	1.7				0.1
Rubus ida					2	2	0.0	0.1	2			2	1	1			0.2			0.0	0.1	0.2		
Spira alb			-		3	3	0.1	0.4	5	2	1		3	1		2	0.2	0.0	0.0		0.4	0.6		0.4
Vacci ang	C				2	3	0.0	3.2	1			3	5	2		3	0.0			0.1	12.7	0.0		0.3
Vacci myr					4	4	0.8	0.9	1	2	8	3	3	2	1	2	0.1	0.9	0.9	1.3	2.2	0.0	0.0	1.3
Vacci vit					1	2	0.0	0.1			1		1	2					0.0		0.1	0.2		
Herbs																								
Apocy and					1	2	0.0	0.1	1				3			1	0.0				0.2			0.0
Aster cil	B*	B	+	-0.1	3		0.1		2		1	3					0.1		0.0	0.1				
Campa rot					3	2	0.0	0.0	7	2		1			1	1	0.1	0.0		0.0			0.1	0.0
Comu can		B	+		3	1	1.1	0.0	1		2	4	1				0.1		0.3	3.9	0.0			
Coryd sem					2	4	0.0	0.1	3		1		3	1	4	1	0.0		0.0		0.2	0.0	0.1	0.0
Epilo ang			+		2	1	0.1	0.0	2			4	2				0.1			0.2	0.1			
Fraga vir *	B*			-0.2	3		0.2		2		2	4					0.0		0.4	0.2				
Galiu bor					2		0.0		2		2						0.0			0.1				
Maian can			+		3	4	0.5	0.6	2		6	4	5	1	1	4	0.2		0.3	1.5	1.5	0.0	0.6	0.3
Melam lin **	B		+	-0.1	4	3	0.1	0.0	3	1	4	2	3		1	3	0.1	0.1	0.2	0.2	0.0		0.0	0.0
Polyg cil **	C*	C		0.3		3		0.3					3		1	1					0.1		0.8	0.3
Poten tri					4	3	0.8	0.4	3	3	5	1	3	1		4	0.2	1.2	0.3	1.6	0.5	0.1		0.9
Rubus pub			+		2		0.1		1			4					0.0			0.2				
Woods ilv					1	1	0.1	0.0	5						1		0.3						0.0	
Graminoids																								
Agrop tra					2	1	0.0	0.0	4	1			1				0.1	0.0			0.0			
Agros hye			-		3	4	0.1	0.1	5	3	4		3	2	4	3	0.1	0.1	0.1		0.0	0.0	0.3	0.2
Carex spp					4	4	0.1	0.1	5	5	2	2	5	4	2	2	0.1	0.3	0.0	0.1	0.1	0.1	0.2	0.0
Danth spi	B?			-0.1	4	3	0.1	0.0	5	4	3	1	3		1	2	0.2	0.0	0.1	0.0	0.1		0.0	0.0
Oryzo asp	B	B	+	-0.1	4	1	0.1	0.0	2	1	1	5				1	0.1	0.0	0.0	0.2				0.0
Oryzo pun					4	4	0.0	0.1	4	1	5	3	5	2	1	4	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.0
Schiz pur			+		2	2	0.1	0.0	1			2	2			3	0.0			0.3	0.1			0.1
Bryophytes																								
Auloc pal **	B*		-	-0.1	3		0.1		1	1	3						0.1	0.1	0.0					
Dicra spp			+		4	4	2.5	2.2	6	5	6	4	7	6	1	5	3.7	0.4	1.5	4.3	1.7	4.6	1.9	0.7
Moss_ spp			-		4	4	0.7	0.9	6	5	7	4	5	3	4	5	0.9	0.5	1.1	0.4	0.4	0.5	2.4	0.3
Pleur sch			+		4	4	7.7	4.6	6	2	8	5	6	4	1	5	4.1	0.3	10.0	16.4	11.8	2.5	0.7	3.4
Polyt jun					4	4	2.3	3.1	5	6	8	5	5	6	4	3	0.5	2.8	1.9	4.0	6.2	3.0	0.6	2.4
Polyt pil	B	B	?	-1.5	4	4	1.6	0.1	5	6	7	2	1	1	1	3	0.3	4.9	0.8	0.3	0.0	0.2	0.3	0.0
Selag den			-		3	4	0.1	0.4	2	1	1		1	2	2	2	0.2	0.0	0.0		0.0	0.1	0.3	1.1
Lichens																								
Cladi mit	C?			10.6	4	4	16.0	26.7	7	6	8	5	7	6	4	5	34.4	16.6	9.7	3.4	18.2	28.8	31.3	28.3
Cladi ran *	C	C		11.5	4	4	8.9	20.5	6	6	8	5	7	6	4	5	8.8	2.7	2.3	22.0	20.5	15.3	13.4	32.6
Cladi ste ***	C*	C		1.6		4		1.6					2	4	3	1					1.9	2.0	2.0	0.3
Clado spp			-		4	4	1.4	1.5	7	6	8	5	7	6	4	5	1.5	1.0	3.0	0.3	1.5	2.4	1.6	0.7
Folio spp			-		4	4	5.3	3.1	7	6	7	3	7	5	4	4	1.5	10.7	8.8	0.1	3.2	6.1	2.3	0.7
Fruti spp *	B	B		-0.4	4	4	0.4	0.1	4	6	7	4	6	3	1	1	0.3	0.8	0.5	0.1	0.2	0.0	0.0	0.0
Other																								
Confr litter *	B			-15.5	4	4	18.9	3.4									6.2	8.6	22.7	38.3	5.3	5.3	1.5	1.6
Other litter					4	4	4.2	7.6									6.4	0.9	2.7	6.6	13.4	2.0	9.4	5.6
Rock	B?			-10.5	4	4	32.9	22.4									31.0	58.8	41.1	0.8	15.6	29.9	29.0	15.2
Snag					1		0.0													0.0				
Trunk					2		0.0													0.0	0.1			
Wood **	C			3.1	4	4	1.2	4.3									0.7	0.3	1.4	2.4	2.8	3.1	3.9	7.3

Affinity: B = Burn, C = Cut, * = exclusive to treatment. CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks. * = significant difference in ANOVA at a = .10, ** = .05, *** = .01. Blank entry = not encountered, 0.0 = >0 and < 0.05 See Appendix A for species codes.

10.5. Moderately deep soils- comparison of 37 year old post-fire and post-logging communities.

During exploratory data analysis, CA (Figure 10.8) suggested that two plots were outliers; one in Burn 2 and the other in Burn 3. The position of both plots was attributable to a very large mean cover for one species, *Spiraea alba* in Burn 2 and *Vaccinium caespitosum* in Burn 3. Since the other techniques did not suggest the presence of outlier plots (Figure 10.6 and Figure 10.7), none were excluded from data analysis.

Another pattern evident in the ordination scattergrams was the similarity of Cutover 2 to post-fire communities. Perusal of Table 10.13 indicates that, for a number of species with an affinity, this Cutover either had a low mean cover compared with a species with a post-logging affinity or a high mean cover for a species that had a post-fire affinity. Examples include *Amelanchier sanguinea, Pleurozium schreberi,* black spruce, aspen, *Vaccinium angustifolium* and *Viola* species. The similarity of Cutover 2 to post-fire communities made it less likely that a significant treatment difference would be detected even though all three ordinations suggested that post-fire communities, in general, differed from post-logging communities in their species composition. All three ordinations suggested that the first principal coordinate incorporated a treatment effect. CA did so on principal coordinates 1 and 2.

MANOVA was performed on the plot scores obtained from the first three principal coordinates of PCO. The percentage of the total eigenvalues accounted for by the first three principal coordinates of PCO (12.9%, 8.1% and 5.3% for a cumulative total of 26.3%) were lower than those from outcrops and shallow soils due to the larger number of species involved. Treatment effects were detected for the overall model at the 6% level (Table 10.12), principal coordinates 1 and 2 at the 5% level and principal coordinate 3 at the 10% level. Block effects were detected for the overall model (p = 0.011). Although it was very close, the overall model was not significant at the prescribed error rate of 5%. In light of the effect of Cutover 2 on statistical power, it must be determined whether the absence of a significant difference for the overall model represented the "true" situation or low statistical power[14]. Mixed model ANOVA can assist in this evaluation by testing for treatment effects at the univariate level. It found significant differences for 4 species at α = 5% and 2 species at α = 1%. The general pattern exhibited by the ordinations, the effect of Cutover 2, ANOVA results and the significance of the first two principal coordinates led to the conclusion that a significant treatment difference in the species composition of communities on shallow soils appeared to exist but could not be established due to inadequate statistical power.

Many treatment differences in species composition were identified by the affinity analysis (Table 10.13). Trees were more affected than on the other site types. Jack pine had a large decline in basal area (-12.4 m^2/ ha). Black spruce's decline in basal area was small in absolute terms (-2.7 m^2/ ha) but large in relative (-37%). Aspen's performance was slightly better in post-logging communities in absolute terms (+1.7 m^2/ ha) and much better proportionately (+121%). A similar pattern was observed for black spruce (CD = -2.4) and aspen (CD = +0.5) in the shrub stratum. Most of the remaining species with treatment affinities performed more poorly in cutovers. Some of the exceptions were familiar from communities on shallow soils. The largest differences in terms of cover were for blueberries (CD = +15.8) and *Pleurozium schreberi* (CD = -12.5).

Linnaea borealis (CD = -1.4) performed more poorly in post-logging communities. Shrubs which performed better included *Amelanchier sanguinea* (CD = +0.5), *Ledum groenlandicum* (CD = +5.4), *Vaccinium angustifolium* (CD = +10.3), *V. myrtilloides* (CD = +5.2) and *V. vitis-idaea* (CD = +0.8). *V. angustifolium* and *V. vitis-idaea* had affinities with shallow and organic soils but this is the only site type for which *V. myrtilloides* had a treatment affinity. Most herbs performed more poorly in

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[14] It is possible to calculate statistical power of the test, however, this is problematic for two reasons. Firstly, the formulae are complex and require the input of a statistician. Secondly, one must specify the minimum difference to be detected. This is difficult because it is the differences between the principal coordinate vectors and not species which must be specified.

post-logging communities: *Aster ciliolatus* (CD = -0.1), *Equisetum arvense* (CD = < -0.05), *Mitella nuda* (CD = -0.2), *Pyrola secunda* (CD = < -0.05), *Rubus pubescens* (CD = -0.7) and *Viola* species (CD = -0.1). *Equisetum arvense* and *Pyrola secunda* were not found in post-logging communities. *Apocynum androsaemifolium* (CD = +0.7) and *Clintonia borealis* (CD = +0.9) performed better. *Schizachne purpurascens* (CD = +0.2) was the sole graminoid with a treatment affinity. Bryophytes generally did more poorly. *Pleurozium schreberi* (CD = -12.5), *Polytrichum commune* (CD = -2.9), *Polytrichum juniperinum* (CD = -0.3) and *Ptilium crista-castrensis* (CD = <0.05) all had lower cover. Moss species (CD = +1.7) was the exception to the bryophyte pattern. No lichens had a treatment affinity.

Species adversely affected by logging had a combined reduction in mean cover of 20.5% while those which benefited had an increase of 25.9% for a net increase of 5.4% in post-fire communities. Mean total understorey cover for all species in post-logging communities C% = 75.5) differed significantly from that in post-fire communities (C% = 91.3).

Treatment differences in the tree and shrub strata were reflected by inanimate ground cover. Coniferous litter was 20.1% lower in post-logging communities and Other litter was 33.1% higher. Wood litter (+1.2%) was also higher.

Table 10.12. MANOVA results (p-values from Wilk's Lambda) for treatment and Block effects for 37 year old communities on moderately deep soils.

	Treatment Effect	Block Effect
Overall Model	0.059	0.011
Principal Coordinate 1	0.050	0.444
Principal Coordinate 2	0.019	0.014
Principal Coordinate 3	0.088	0.172

Figure 10.6. PCO scattergrams of plot scores for 37 year old communities on moderately deep soils. B = post-fire communities, C = post-logging communities. Underlined labels are Block means of plot scores. Some plot are hidden.

Figure 10.7. PCA scattergrams of plot and species scores for 37 year old communities on moderately deep soils. Underlined labels are Block means of plot scores. B = post-fire communities, C = post-logging communities. Some plots are hidden. See Appendix A for species codes.
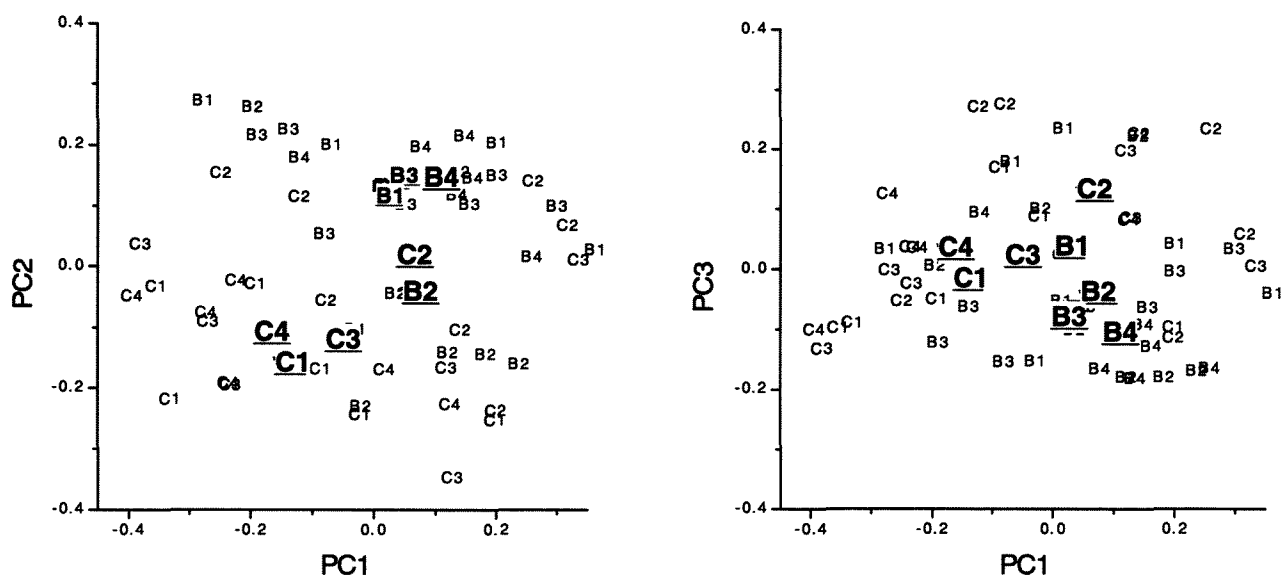
Figure 10.8. CA scattergrams of plot and species scores for 37 year old communities on moderately deep soils. B = post-fire communities, C = post-logging communities. Underlined labels are Block means of plot scores. Some plots are hidden. See Appendix A for species codes.
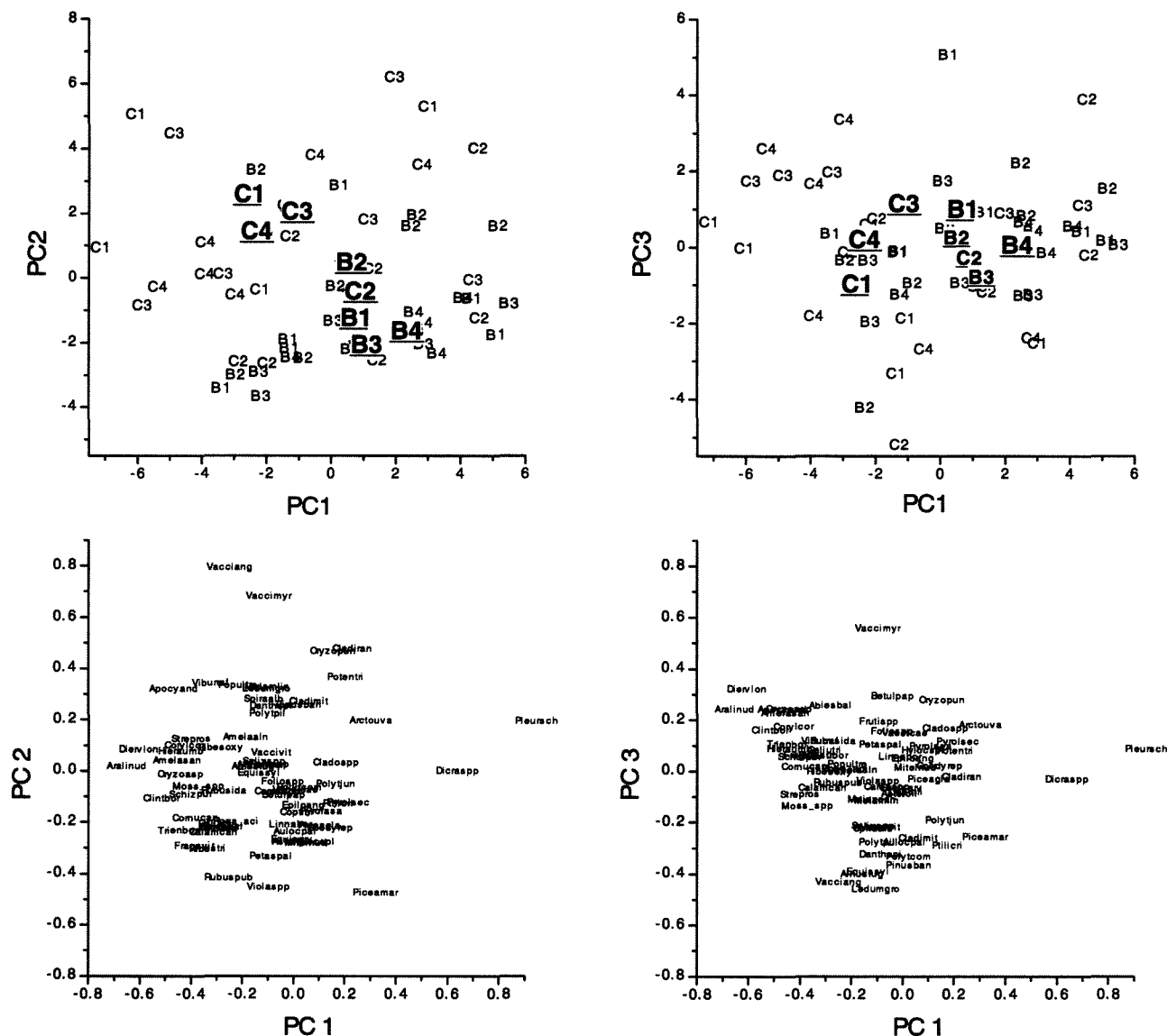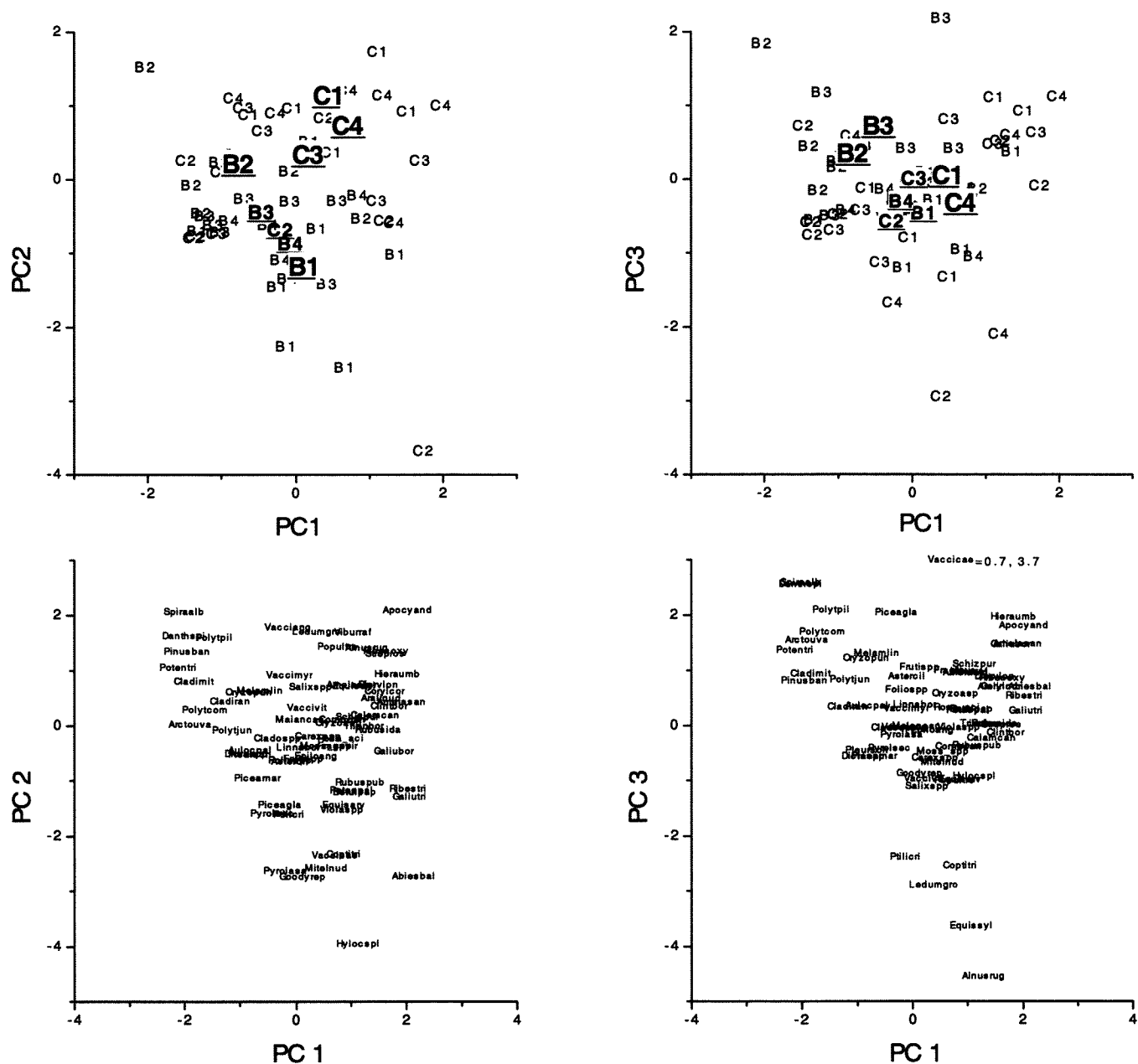
Table 10.13. Treatment affinities, canonical variates analysis, frequency and cover results for 37 year old communities on moderately deep soils.

	Treatment N	Affinity	CV	Diff. %	Presence Burns 4	Presence Cuts 4	% Cover/Basal Area Burns 4	Cuts 4	Bum 1 7	Bum 2 7	Bum 3 7	Bum 4 6	Cut 1 6	Cut 2 6	Cut 3 6	Cut 4 6	Cover Bum 1 7	Bum 2 7	Bum 3 7	Bum 4 6	Cut 1 6	Cut 2 7	Cut 3 6	Cut 4 6
Trees	Aspen	C?		1.7	2	4	1.4	3.0	2	1			3	1	2	3	5.1	0.3			2.6	3.6	1.5	4.5
	Black spruce	B?		-2.7	4	3	7.3	4.6	7	1	5	3	1	5		2	13.9	0.1	11.1	4.0	1.6	14.8		1.9
	Jack pine **	B	B	-12.4	4	3	18.0	5.6	2	7	4	6	2	1		2	12.5	19.5	12.4	27.6	7.0	3.1		12.3
Shrubs	Aspen	C?		0.5	3	3	0.1	0.6	3	1	1		3		3	2	0.3	0.0	0.0		0.3		1.0	1.0
	Balsam fir				2	3	0.2	2.3	4		1			2	3	2	0.4		0.4			5.0	1.9	2.4
	Black spruce	B?		-2.4	4	4	5.4	3.1	5	2	6	4	1	6	3	4	5.0	2.6	8.7	5.4	0.0	8.8	3.1	0.3
	Jack pine				2	3	0.3	0.5		2	1			1	2	2		1.1	0.1			0.2	0.1	1.5
	Paper birch				4	3	0.2	0.3	2	1	1	2	1		2	1	0.1	0.0	0.0	0.6	0.0		0.1	1.0
	White spruce				2	2	0.9	0.1			3	1	1	1					3.1	0.7	0.1	0.4		
	Alnus rug				1	2	0.1	0.9				1			1	2				0.5		1.8		1.8
	Amela aln				3	2	0.1	0.4	1		1	1	2		1		0.0		0.0	0.2	1.4		0.1	
	Amela san *	C		0.5	3	4	0.1	0.6	1		2	1	1	1	1	3	0.2		0.0	0.0	0.6	0.5	0.1	1.3
	Arcto uva				2	2	1.0	1.1		1	3			1		1		2.5	1.4			3.6		0.7
	Coryl cor				2	3	0.3	3.2	2		2		4		4	2	0.9		0.1		1.6		11.2	0.1
	Diery lon				4	3	1.1	5.3	3	3	3	3	3		2	5	2.3	0.8	0.6	0.6	12.4		1.5	7.2
	Ledum gro ***	C	C	5.4	1	4	0.0	5.4				1	2	3	2	4				0.0	5.2	3.6	2.9	10.1
	Linna bor	B	B	-1.4	4	3	1.9	0.5	4	5	4	5	6	1		4	0.5	1.3	4.3	1.5	0.8	0.6	0.7	
	Ribes tri				2	2	0.2	0.2	2	1				1	2		0.3	0.4			0.5	0.3		
	Rosa aci				4	4	0.5	0.4	3	1	5	4	2	2	1	1	0.2	0.1	0.6	1.1	1.0	0.3	0.1	0.3
	Rubus ida				1	4	0.0	0.1				2	2	1	1	1				0.1	0.1	0.0	0.1	0.1
	Salix spp				4	4	1.0	1.7	2	3	5	1	2	1		2	0.1	2.0	1.2	0.6	3.1	0.2	0.3	3.3
	Spira alb				2	1	0.1	0.0		2	1				1		0.5	0.0				0.1		
	Vacci ang **	C	C	10.3	3	4	1.1	11.4		4	2	1	6	4	6	5		4.3	0.1	0.1	25.5	2.7	7.6	9.8
	Vacci cae				2	2	1.0	0.0			1	1		1		1		3.9	0.0		0.0			0.0
	Vacci myr *	C	C	5.2	4	4	3.2	8.4	3		5	4	6	2	6	6	8.5	4.3	0.2	0.1	3.7	6.4	17.6	6.1
	Vacci vit **	C	C	0.8	1	4	0.0	0.9		2			3	4	3	2			0.4		0.3	1.9	1.2	0.1
	Vibur raf					2		0.2					2		2						0.2		0.7	
Herbs	Apocy and *	C		0.7	1	3	0.0	0.7	1				2		3	1	0.1				1.9		0.6	0.5
	Arali nud				4	4	0.5	2.3	3	1	3	3	4	3	3	5	0.8	0.1	0.8	0.5	5.0	0.6	0.7	3.0
	Aster cil	B	B	-0.1	4	2	0.2	0.0	2	3	5	4	2		2		0.1	0.0	0.4	0.2	0.0		0.1	
	Clint bor	C	C	0.9	4	4	0.2	1.1	3	1	1	2	4	1	3	6	0.5	0.1	0.1	0.0	0.3	0.5	0.7	3.0
	Copti tri				2	1	0.0	0.0	2			1				1	0.1			0.0				0.1
	Cornu can				4	4	2.1	2.0	4	2	6	5	4	3	4	5	0.7	3.0	2.0	2.8	2.8	0.2	1.2	3.7
	Epilo ang				3	3	0.2	0.1		3	1	4		3	1	3		0.2	0.0	0.4		0.3	0.0	0.1
	Equis arv *	B*		0.0	3		0.0		1	1		2					0.0	0.0		0.0				
	Equis syl				2	3	0.0	0.2	1	1			1	2		1	0.0	0.0			0.0	0.6		0.0
	Fraga vir				4	4	0.5	0.3	3	3	6	6	3	2	2	3	0.2	0.1	1.5	0.1	0.6	0.1	0.4	0.1
	Galiu bor				2	3	0.0	0.0			2	1	1	1		1			0.0	0.0	0.0	0.1		0.0
	Galiu tri				2	2	0.0	0.0	1	1			1	1			0.0	0.0			0.0	0.0		
	Goody rep		B		2		0.0		1			4					0.0			0.0				
	Hiera umb				1	2	0.0	0.0			2		2		1				0.1		0.1		0.0	
	Maian can				4	4	1.4	0.9	6	5	4	6	5	3	4	5	0.3	1.0	2.5	1.6	2.3	0.5	0.6	0.4
	Melam lin				4	3	0.3	0.2	1	3	5	2	5		4	3	0.0	0.7	0.6	0.0	0.1		0.6	0.2
	Mitel nud	B	B	-0.2	2	1	0.2	0.0	3			3			1		0.2			0.5			0.0	
	Petas pal				4	4	0.1	0.1	2	1	1	4	1	1	1	1	0.0	0.0	0.0	0.4	0.0	0.1	0.2	0.0
	Poten tri				2	3	0.3	0.1	1	3			1	1		1	0.0	1.0			0.0	0.4		0.0
	Pyrol asa				3	1	0.1	0.0	2		1	1			1		0.1			0.0	0.2		0.0	
	Pyrol sec ***	B*	B	0.0	4		0.0		1	1	1	2					0.0	0.0	0.0	0.0				
	Rubus pub	B		-0.7	4	4	0.9	0.2	3	1	3	5	2	2	2	2	0.7	0.1	0.3	2.3	0.2	0.1	0.3	0.2
	Strep ros				2	3	0.1	0.2	1			1	1		1	3	0.1			0.1	0.3		0.0	0.3
	Trien bor				4	4	0.1	0.1	2	1	2	3	2	1	3	4	0.0	0.0	0.1	0.2	0.2	0.0	0.1	0.1
	Viola spp *	B	B	-0.1	3	2	0.1	0.0	3		2	4	2	1			0.1		0.1	0.1	0.0	0.0		
Graminoids	Calam can				2	3	0.1	0.0			1	2	1		2	2			0.1	0.2	0.0		0.0	0.1
	Carex spp				4	3	0.1	0.0	1	1	2	3	1	1	3		0.0	0.0	0.0	0.2	0.0	0.0	0.1	
	Danth spi				2	2	0.0	0.0		1	1			1		1			0.0	0.0			0.0	0.0
	Oryzo asp				4	4	0.1	0.3	6	1	4	4	3	1	4	5	0.2	0.0	0.1	0.1	0.1	0.2	0.4	0.4
	Oryzo pun				2	4	0.0	0.0		3	2		1	1	4	1		0.1	0.0		0.0	0.0	0.0	0.0
	Schiz pur *	C		0.2	2	4	0.0	0.2			5	1	3	1	3	5				0.1	0.1	0.6	0.1	0.1
Bryophytes	Auloc pal				3	2	0.5	0.0		2	3	1		2	1			0.1	1.9	0.2		0.1	0.0	
	Dicra spp				4	4	3.9	4.8	7	7	6	6	4	6	5	4	6.0	1.3	2.0	6.3	3.8	10.2	2.8	2.3
	Hyloc spl				3	2	0.7	0.5	4		2	1		2	1		2.7		0.0	0.0		1.7	0.1	
	Moss spp **	C		1.7	4	4	1.1	2.7	6	7	7	6	5	5	6	6	1.4	0.3	1.6	1.0	3.1	3.3	2.9	1.6
	Pleur sch **	B		-12.5	4	4	29.9	17.5	7	7	7	6	6	7	6	5	26.8	28.5	26.7	37.8	14.2	21.3	21.0	13.3
	Polyt com	B	B	-2.9	3	1	2.9	0.0		4	6	1	1					5.9	5.9	0.0	0.0			
	Polyt jun	B	B	-0.3	4	4	0.4	0.1	1	6	7	4	2	2	2	1	0.0	0.3	0.7	0.5	0.2	0.0	0.1	0.1
	Polyt pil				2	1	0.1	0.0		1	3		1					0.3	0.1		0.1			
	Ptili cri	B		0.0	4	1	0.1	0.1	3	1	1	2		2			0.2	0.0	0.0	0.1		0.2		
Lichens	Cladi mit				4	4	1.0	0.4	1	5	4	3	2	3	2	2	0.0	3.8	0.0	0.1	0.1	1.2	0.3	0.0
	Cladi ran				4	4	0.9	1.2	4	7	6	5	5	4	5	5	0.1	2.8	0.2	0.4	0.2	2.2	2.0	0.4
	Clado spp				4	4	0.8	0.7	7	6	7	6	5	7	6	5	0.8	0.4	1.2	0.7	0.2	0.8	1.3	0.4
	Folio spp				4	4	0.2	0.2	4	4	4	4	2	4	2	1	0.2	0.2	0.2	0.3	0.4	0.7	0.2	0.1
Other	Conifr litter **	B		-20.1	4	4	32.5	12.4									20.2	46.2	20.1	43.7	19.0	15.5	4.1	11.0
	Other litter **	C		33.1	4	4	21.1	54.1									38.3	6.6	34.2	5.1	54.5	37.4	58.3	66.3
	Snag				4	2	0.1	0.1									0.3	0.0	0.1	0.0		0.3	0.1	
	Trunk				4	4	0.4	0.3									0.4	0.4	0.2	0.0	0.1	0.7	0.2	0.1
	Wood **	C		1.2	4	4	3.1	4.2									2.5	2.9	3.9	2.9	4.2	3.8	5.1	3.8

Affinity: B = Burn, C = Cut, * = exclusive to treatment.   CV = species with high structure correlations in canonical variates analysis. Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks.   * = significant difference in ANOVA at a = .10, ** = .05, *** = .01.   Blank entry = not encountered, 0.0 = >0 and < 0.05   See Appendix A for species codes.

10.6. Organic soils- comparison of 37 year old post-fire and post-logging communities.

Organic plots had weaker Block and treatment patterns than those of the other site types. Ordinations (Figure 10.9) indicated that, while there was a weak separation of burned and logged plots, there was also a good deal of interspersion. Only Burn 2's plots were located in a cluster.

PCO's eigenvalues for the first three principal coordinates accounted for 16.3%, 10.0% and 7.1% of the total eigenvalues for a cumulative total of 33.4%. MANOVA did not detect a significant treatment effect for the overall model or for any of the principal coordinates. A Block effect was detected only on the third principal coordinate (p = 0.014). On the upland site types, Block effects were generally significant for the overall model and for the principal coordinates which did not incorporate a treatment effect. High within Block plot variability was a potential cause for the lack of a Block effect on organic soils that was supported by the scattergrams. This was especially true for plots from post-logging communities and may have resulted from one or more factors. The first was that the immediate effects of fire and logging were more variable on organic soils. Another potential cause of high within Block plot variability was plot size. Most of the characteristic and associated species of organic soils differed from those of the other site types. Hummock microtopography facilitates the presence of different species along the crests, slopes and hollows. If the plot size was too small for the microtopography of organic soils then the precision of species' cover estimates would be lower than that of a larger plot. It is possible that the plot size was efficient for some site types but not others since the most efficient size is determined by the patch sizes of individuals and species within the communities on each site type, all other things being equal. A different scale of microtopography in organic soils would necessitate a larger plot size to attain the same level of precision as was obtained in the other site types.

It was concluded that a treatment difference in the overall species composition of organic soils was not present. Given the high plot variability, it was not clear whether this was a reflection of the actual state or problems related to plot size or control of substantial causal variables, among other things. Examples of substantial causal variables include pH, nutrient status or water table level (Jeglum 1971). The treatment affinity analysis suggested that treatment differences were present for a number of species. This was the only site type where *Pleurozium schreberi* did not reverse its affinity from post-logging communities after 13 years to post-fire by 37 years (Table 10.15). *Sphagnum* species reversed its affinity and in a dramatic way. Its cover in 13 year old post-logging communities was 19% higher than in 13 year old post-fire communities but the same as in 65 year old post-fire communities. By 37 years of age, its cover had dropped 20% in post-logging communities while in post-fire its cover had risen to the same level as in 65 year old post-fire communities. In other words, *Sphagnum* cover in post-logging communities declined over time from its level in typical mature communities while in post-fire communities its cover increased over time back to its level in typical mature communities.

Pleurozium schreberi and *Sphagnum* species provide contrasting site moisture indications which would be consistent with the 37 year old results. A treatment comparison of depth to water table found that the mean depth of 19 cm in 37 year old post-fire communities was not significantly different from the mean depth of 62 cm in post-logging communities (p = 0.11) due to high cutover Block to Block variability. All four cutover Block mean depths to water table were higher than the lowest burn Block mean which suggested that this should be examined more closely. Two other species with substantial differences in mean cover which might corroborate the suggestion that the organic soils of post-logging communities were drier are *Alnus rugosa* (CD = -4.9) and *Chamaedaphne calyculata* (CD = -4.8). They give similar depth to water table indications (40 - 79 cm) but opposite nutrient indications (Jeglum 1971). The reliability of estimates of depth to water table derived from a single measurement at each plot is not good. It is a parameter which fluctuates

seasonally and in response to heavy rains. No clear indications are available on treatment differences in the wetness of organic soils.

Salix species (CD = -0.8) also performed more poorly in post-logging communities whereas *Vaccinium angustifolium* (CD = +0.5) and *V. vitis-idaea* (CD = +0.5) performed better once again. In the herb stratum, *Maianthemum canadense* (CD = +0.2) performed better and *Smilacina trifolia* (CD = -0.8) more poorly as in the 13 year old communities. *Calamagrostis canadensis* (CD = -0.2) was the only graminoid with an affinity. Bryophytes exhibited large treatment differences. *Sphagnum* species was reduced by 19.8% while cover for *Dicranum* species (CD = +2.0) and *Pleurozium schreberi* (CD = +5.0) increased.

Table 10.14. MANOVA results (p-values from Wilk's Lambda) for treatment and Block effects for 37 year old communities on organic soils.

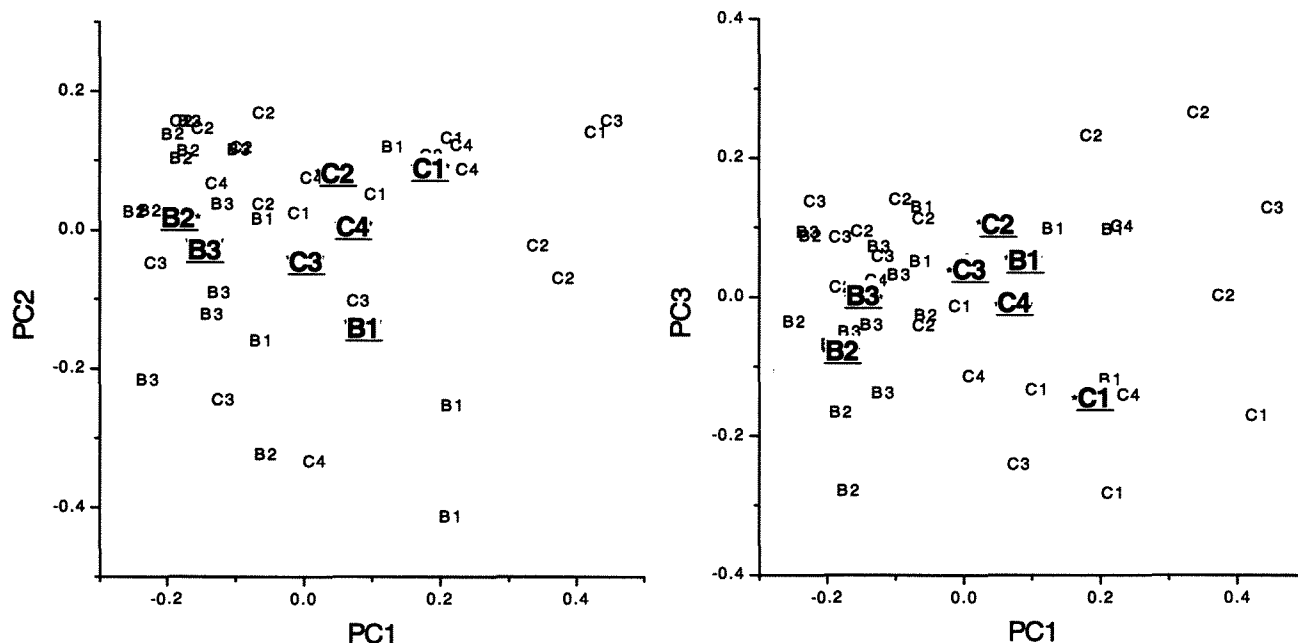|	Treatment	Block
Overall Model	0.542	0.260
Principal Coordinate 1	0.111	0.104
Principal Coordinate 2	0.193	0.355
Principal Coordinate 3	0.951	0.014

Figure 10.9. PCO scattergrams of plot scores for 37 year old communities on organic soils.
B = post-fire communities, C = post-logging communities. Underlined labels are Block means of plot scores. Some plots are hidden

100

Table 10.15. Treatment affinities, canonical variates analysis, frequency and cover results for 37 year old communities on organic soils.

Treatment	Affinity	CV	Diff. %	Blocks Presence Burns	Cuts	Blocks %Cover/Basal Area Burns	Cuts	Plots Presence Burn 1	Burn 2	Burn 3	Cut 1	Cut 2	Cut 3	Cut 4	Plots Mean Cover Burn 1	Burn 2	Burn 3	Cut 1	Cut 2	Cut 3	Cut 4
N				3	4	3	4	5	6	6	4	8	5	5	5	6	6	4	8	5	5
Trees																					
Black spruce				3	4	10.4	19.0	5	4	6	4	7	5	4	16.9	3.9	10.2	22.5	18.4	26.7	8.2
Jack pine				2	2	2.0	3.0	1	3		2			2	2.3	3.8		8.8			3.3
Tamarack				2	3	0.3	1.7	1	1		2		1	3	0.1	0.9		2.1		0.5	4.4
Shrubs																					
Balsam fir				1	2	0.0	0.7	1			2			1	0.0				2.7		0.1
Black spruce				3	4	8.7	6.3	3	6	5	4	5	5	5	1.9	13.5	10.9	7.0	4.0	6.3	8.0
Paper birch				1	2	0.1	0.1		1			2	2			0.3			0.0	0.4	
Tamarack				3	2	0.2	0.1	2	1	2		1	2		0.7	0.0	0.0		0.2	0.2	
Alnus rug	B	B	-4.9	3	4	6.9	2.0	3	2	5	1	1	4	2	9.8	3.9	7.1	0.0	0.0	6.4	1.6
Chama cal *	B		-4.8	3	3	6.4	1.6	2	4	3		5	2	1	6.3	6.5	6.4		2.3	4.0	0.0
Gault his				3	3	0.2	0.3	3	1	2		7	2	2	0.5	0.0	0.1		0.7	0.3	0.2
Kalmi pol				2	2	0.2	0.1		3	3		3	1			0.2	0.2		0.1	0.2	
Ledum gro				3	4	20.1	21.2	5	6	6	3	7	5	5	12.3	16.9	31.1	6.5	26.6	25.5	26.2
Linna bor	B			1	1	0.1	0.0	3						1	0.2						0.0
Oxyco qua				3	3	0.7	0.2	3	4	5		6	2	1	0.1	1.7	0.4		0.4	0.2	0.0
Salix spp	B	B	-0.8	3	4	1.9	1.1	1	6	6	2	1	1	2	0.1	3.7	1.9	0.9	0.0	1.1	2.3
Vacci ang	C	C	0.5	2	4	0.0	0.5		1	2	4	1	1	3		0.0	0.0	0.7	0.0	0.1	1.2
Vacci myr				3	4	0.1	0.4	3	1	1	2	2	1	4	0.2	0.0	0.1	0.2	0.0	0.1	1.4
Vacci vit *	C	C	0.5	3	4	0.4	0.8	2	1	4	4	7	5	3	0.1	0.4	0.7	1.0	1.3	0.9	0.2
Herbs																					
Cornu can				3	4	0.3	0.3	3	2	2	2	2	1	4	0.5	0.3	0.2	0.1	0.5	0.0	0.8
Equis arv				2	2	0.0	0.1		1	1		1	2			0.1	0.0		0.0	0.5	
Equis syl				3	4	2.0	0.6	1	5	5	3	2	1	3	0.6	0.4	4.9	0.5	1.5	0.2	0.3
Maian can	C	C	0.2	1	3	0.0	0.2		1		3	5		2		0.1		0.0	0.6		0.1
Rubus pub				2	2	1.0	0.1	3	1				1	1	2.6	0.3				0.2	0.1
Smila tri *	B	B	-0.8	3	3	0.9	0.0	4	3	2		1	1	3	1.7	0.9	0.1		0.0	0.0	0.2
Trien bor				3	2	0.1	0.0	2	1	2			2	2	0.0	0.1	0.0			0.0	0.1
Viola spp				3	1	0.1	0.0	1	1	1				1	0.1	0.3	0.0				0.1
Graminoids																					
Calam can ***	B	B	-0.2	3	2	0.2	0.0	3	5	3			1	1	0.4	0.1	0.1			0.0	0.0
Carex spp				3	4	0.8	0.4	4	6	6	1	8	4	4	1.8	0.3	0.2	0.0	0.3	0.9	0.2
Bryophytes																					
Auloc pal				3	4	0.1	0.1	3	5	2	3	5	3	1	0.1	0.1	0.2	0.2	0.2	0.1	0.0
Dicra spp **	C		2.0	3	4	0.3	2.4	4	1	1	4	5	4	4	0.9	0.0	0.1	1.9	2.0	5.1	0.6
Hyloc spl				2	1	0.3	0.2	2		1		1			0.8		0.0		0.9		
Liver spp				2	3	0.0	0.0	2	1			1	1	1	0.1	0.0			0.0	0.1	0.0
Moss_ spp				3	4	1.8	2.3	5	3	4	4	6	5	5	4.4	0.7	0.2	2.9	0.8	1.8	3.6
Pleur sch	C		5.0	3	4	4.9	9.8	5	3	3	3	8	3	5	12.9	0.4	1.3	4.8	13.1	11.9	9.5
Polyt com				2	3	0.5	0.0		2	1	1	1		1		0.5	1.1	0.0	0.0		0.1
Polyt str				3	3	0.4	0.1	1	3	2	1	2		1	0.0	1.0	0.0	0.3	0.1		0.0
Ptili cri				1	3	1.5	0.0	1			1	1		1	4.6			0.0	0.1		0.1
Sphag spp	B	B	-19.8	3	4	68.7	48.8	5	6	6	3	8	4	5	44.0	86.3	75.7	32.4	60.5	51.4	51.0
Lichens																					
Cladi mit				1	2	0.2	0.0			1	2		1				0.5		0.0		0.0
Cladi ran *	C	C	0.1	2	4	0.0	0.1	1		2	2	4	2	5	0.0		0.1	0.1	0.2	0.0	0.2
Clado spp ***	C	C	0.2	3	4	0.1	0.3	3	4	3	4	8	4	4	0.1	0.0	0.2	0.2	0.4	0.3	0.3
Folio spp				2	3	0.0	0.1		1	2	2	2	1				0.0	0.0	0.2	0.0	0.0
Other																					
Conifr litter	C?		6.3	3	4	2.1	8.4								1.3	4.6	0.4	48.4	5.4	12.0	7.7
Other litter				3	4	17.1	17.1								28.7	5.3	17.3	3.4	14.0	12.7	24.6
Snag				1	2	0.1	0.0										0.2		0.0	0.0	
Wood				3	4	1.2	1.4								2.0	0.1	1.6	1.3	0.6	1.5	2.0
Trunk				3	4	0.1	0.2								0.2	0.1	0.0	0.5	0.5	0.2	0.0
Water				2	1	0.6	0.3									0.8	1.0		0.9		

Affinity: B = Burn, C = Cut, * = exclusive to treatment.   CV = species with high structure correlations in canonical variates analysis.   Diff. = mean cover in post-logging Blocks minus mean cover in post-fire Blocks.   * = significant difference in ANOVA at a = .10, ** = .05, *** = .01.   Blank entry = not encountered, 0.0 = >0 and < 0.05   See Appendix A for species codes.

101

10.7. Do the younger post-fire communities appear to be regenerating into typical mature communities?

Results from the 13 and 37 year old communities were taken to be representative of the typical natural state for these age classes. The chronosequence formed by these two age classes along with 65 year old communities indicated that immature post-fire communities were regenerating towards the typical mature state. On all the site types, the difference between the species composition of the 13 year old communities and 65 year old communities was much greater than that between 37 and 65 year old communities (Figure 10.10). Dissimilarity to 65 year old communities decreased by about 40% from 13 to 37 years of age. We have no data for the first few years after fire but based on the research of others we expect that 1-2 year old communities were more dissimilar to 65 year old communities than 13 year old ones. Post-fire invaders not found in mature communities would be present and regenerators would be recovering from having their cover reduced to zero. When the 2, 13 and 37 year old age classes were linked together, it appeared that the post-fire communities found on the four site types were regenerating towards a typical mature state.

An interesting pattern was exhibited when the post-logging communities were compared with recovering post-fire communities. Thirteen year old post-logging communities found on all the site types were more similar to 65 year old post-fire communities than comparable 13 year old post-fire communities. However, at 37 years of age, the situation had reversed. The post-fire communities on mineral soils were more similar to 65 year old communities than post-logging communities. Post-logging communities on shallow soils were more different at 37 years of age than the same communities were at 13 years of age. On organic soils, post-logging communities were less dissimilar at 13 years of age than post-fire communities but by 37 years of age there was no difference. This pattern suggested that, although logging had a lower initial impact on species composition than fire, logged communities recovered more slowly than burned ones. Slower recovery creates the possibility that resilience might not be achieved within the time span of the fire rotation.
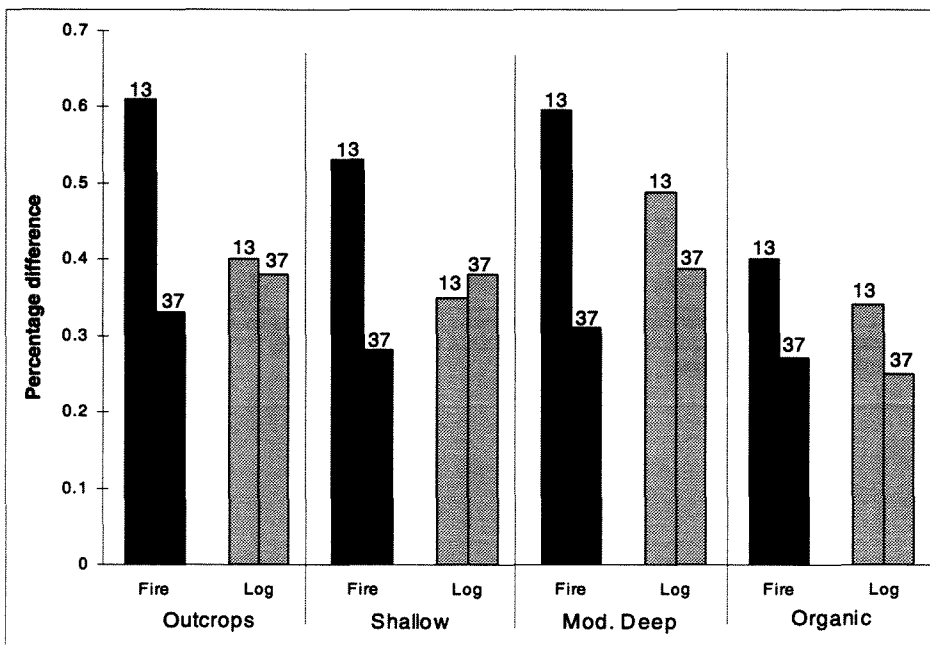

Figure 10.10. Dissimilarity of 13 and 37 year old communities to typical mature post-fire communities. A percentage difference equal to 0 indicates that the communities had the same species composition while a value of 1 indicates that there were no species in common.

11. Comparison of species composition in 13 and 37 year old post-fire and post-logging communities.

MANOVA detected a significant treatment difference in the species composition of post-fire and post-logging communities in 5 of the 8 age class/ site type combinations (Table 11.1). The corroborative methods suggested treatment differences for two of the remaining three combinations. Statistical power was a problem for many of the comparisons since within treatment Block variability was high (Table 11.2). High Block variability was generally the result of an atypical Block within each treatment (Table 11.2). Thirty-seven year old communities on organic soils was the only comparison where the Block effect was not significant and this was due to high plot variability within Blocks.

The species affected by logging (i.e. those species which, based on the performance criteria of Section 6.5.6, were given a treatment affinity) are identified in Table 11.3. With the exception of *Sphagnum* species, taxa which represent aggregations of species are not included in the summary because there is no way of knowing whether the observed differences reflect treatment effects or normal Block variation in the species encountered. Mean cover data for species with a treatment affinity on at least one site type is presented (Table 11.4). For a given species, a treatment difference in performance was considered to be present only on those site types where the species had a treatment affinity (Table 11.3). The number of understorey treatment affinities is summarized by growth form (Table 11.5) because species or groups of species within a growth form have somewhat distinct roles in vegetation dynamics. Two examples previously discussed are the tree canopy and bryophyte ground cover.

Table 11.1. Age class/ site type combinations for which MANOVA found a significant treatment difference in the species composition of communities at p = 0.05 (Wilk's lambda).

	13 Years Old			37 Years Old		
	N		Significant	N		Significant
Site Type	Post-Fire	Post-Log		Post-Fire	Post-Log	
Outcrop	4	3	**Yes**	4	4	**Yes**
Shallow	4	3	**Yes**	4	4	**Yes**
Moderately Deep	2	3	**?**	4	4	**Yes***
Organic	4	2	**?**	4	3	**No**

* = significant at p = 0.06.   ? = significant difference not detected but low statistical power was a concern.

Table 11.2. Comparisons for which the main type of within treatment Block variability is one outlier Block.

	13 Years Old					37 Years Old			
	Outcrop	Shallow	Mod. Deep	Organic		Outcrop	Shallow	Mod. Deep	Organic
Block Effect Significant?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	No
Is One Block Atypical?	Yes	Yes	Yes	Maybe		Yes	Yes	Yes	Yes

Table 11.3. Species which had a post-fire (B) or post-logging (C) affinity by age class and site type.

Age Class / Site Type	13 years				37 years			
	Outcrop	Shallow	Mod Deep	Organic	Outcrop	Shallow	Mod Deep	Organic
Trees								
Aspen							C?	
Black spruce							B?	
Jack pine						B	B	
Tree species in understorey								
Aspen							C?	
Black spruce	B*		B				B?	
Jack pine	B	B	B	B				
Paper birch			C					
Shrubs								
Alnus rugosa								B
Amelanchier sanguinea	C*	C*					C	
Arctostaphylos uva-ursi	C							
Chamaedaphne calyculata								B
Corylus cornuta			C*					
Ledum groenlandicum							C	
Linnaea borealis				B*		B	B	
Prunus pumila	C*							
Ribes glandulosum			C*					
Rosa acicularis		C				B*		
Spiraea alba	C							
Vaccinium angustifolium		C	C?			C	C	C
Vaccinium myrtilloides			C?				C	
Vaccinium vitis-idaea						C*	C	C
Herbs								
Apocynum androsaemifolium		C*					C	
Aralia nudicaulis			C					
Aster ciliolatus					B*		B	
Clintonia borealis		C					C	
Cornus canadensis			C					
Epilobium angustifolium			B					
Equisetum arvense							B*	
Fragaria virginiana		C*	C		B*			
Galium boreale		C*						
Goodyera repens							B*	
Lathyrus ochroleucus						B*		
Lycopodium obscurum		C*						
Maianthemum canadense		C	C	C				C
Melampyrum lineare					B			
Polygonum cilinode					C*			
Potentilla tridentata						B		
Pyrola secunda							B*	
Rubus pubescens			C*				B	
Smilacina trifolia			B*					B
Viola adunca		C	C*					
Viola species							B	
Graminoids								
Agropyron trachycaulum		C*						
Agrostis hyemalis	C	C						
Calamagrostis canadensis		C						B
Danthonia spicata	C		C*		B			
Oryzopsis asperifolia		C*	C		B			
Oryzopsis pungens			C*			B		
Schizachne purpurascens		C*	C				C	
Bryophytes								
Aulacomnium palustre					B*			
Pleurozium schreberi	C	C	C	C		B?	B	C
Polytrichum commune			B				B	
Polytrichum juniperinum	B	B	B			B	B	
Polytrichum piliferum	B			B*	B	B		
Ptilium crista-castrensis							B	
Sphagnum species				C				B
Lichens								
Cladina mitis	C	C			C			
Cladina rangiferina	C	C	C		C		C	C
Cladina stellaris					C*	C		
Other Ground								
Coniferous litter		B	B	B	B		B	C?
Other litter		C	C?				C	
Rock		B			B?			
Snag		B		B				
Wood					C		C	

* = species exclusive to this treatment in this site type and age class;   ? = questionable affinities.

104

Table 11.4. Mean cover values for understorey species/ basal area for trees in 13 and 37 year old communities.
A blank denotes absence in the Block, 0.0 = mean cover < 0.05%.

Age Class / Site Type / Treatment	13 Years Old Outcrops Burn	Cut	Shallow Burn	Cut	Mod. Deep Burn	Cut	Organic Burn	Cut	37 Years Old Outcrops Burn	Cut	Shallow Burn	Cut	Mod. Deep Burn	Cut	Organic Burn	Cut
N	4	3	4	3	2	3	4	2	4	4	4	4	4	4	3	4
Trees																
Aspen			0.0	0.2	1.3	1.6							1.4	3.0		
Black spruce							2.7	0.0	0.2	0.6	1.7	3.5	7.3	4.6	10.4	19.0
Jack pine	0.6	0.1	4.8	0.8	5.1	1.5	1.2	0.4	5.8	2.5	14.2	4.3	18.0	5.6	2.0	3.0
Tree species																
Aspen	0.3	0.2	2.3	0.2	13.0	2.7	0.5	0.6			0.0	1.3	0.1	0.6		
Black spruce	0.3		1.8	2.4	4.6	0.6	4.1	3.4	0.0	0.3	2.2	3.9	5.4	3.1	8.7	6.3
Jack pine	6.6	0.1	18.6	7.4	14.7	5.0	4.8	0.7	1.0	0.4	1.4	0.4	0.3	0.5		
Paper birch	0.0	0.3	0.1	2.0	0.6	3.3	0.5	1.0			0.0	1.7	0.2	0.3	0.1	0.1
Shrubs																
Alnus rugosa							3.6	1.4					0.1	0.9	6.9	2.0
Amelanchier sanguinea		0.6	0.0	1.0	0.9	1.0			0.0	0.3	0.2	0.5	0.1	0.6		
Arctostaphylos uva-ursi	2.0	8.2	1.8	3.6					0.2	0.1	2.0	4.4	1.0	1.1		
Chamaedaphne calycu.							2.4	2.2							6.4	1.6
Corylus cornuta						6.0						2.1	0.3	3.2		
Ledum groenlandicum					1.3	2.6	24.7	17.3			0.8	0.9	0.0	5.4	20.1	21.2
Linnaea borealis			0.5	0.1	0.0	0.1	0.0		2.2		1.5	0.1	1.9	0.5	0.1	
Prunus pumila		0.5														
Ribes glandulosum			0.0	0.0		0.2										
Rosa acicularis			0.0	0.2	0.4	0.5			0.5	0.0	0.3		0.5	0.4		
Spiraea alba	0.0	0.4	0.2	1.3	0.1	0.3	1.0	0.0	0.1	0.4	0.0	0.7	0.1	0.0		
Vaccinium angustifolium	2.2	0.5	4.7	15.9	6.9	12.0	0.8	0.4	0.0	3.2	0.0	15.7	1.1	11.4	0.0	0.5
Vaccinium myrtilloides	0.3	0.5	3.7	5.1	3.7	5.0	1.2	0.6	0.8	0.9	2.9	3.3	3.2	8.4	0.1	0.4
Vaccinium vitis-idaea							3.9	3.8	0.0	0.1		1.3	0.1	0.9	0.4	0.8
Herbs																
Apocynum androsaem.				0.1	0.0	0.1			0.0	0.1			0.0	0.7		
Aralia nudicaulis			0.2	1.0	0.6	2.7					0.4	0.7	0.5	2.3		
Aster ciliolatus			0.0	0.6	0.0	0.3			0.1		0.1	0.0	0.2	0.0		
Clintonia borealis			0.0	0.1	0.6	0.8					0.0	0.1	0.2	1.1		
Cornus canadensis	0.4		0.2	1.5	0.9	3.5	0.5	0.5	1.1	0.0	0.9	0.5	2.1	2.0	0.3	0.3
Epilobium angustifolium	0.1	0.0	0.1	0.3	0.6	0.3	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.1		
Equisetum arvense							0.1	0.0					0.0		0.0	0.1
Fragaria virginiana	0.0	0.1		0.7	0.0	0.5			0.2		0.9	0.5	0.5	0.3		
Galium boreale				0.3		0.1			0.0		0.0	0.0	0.0	0.0		
Goodyera repens									0.0				0.0			
Lathyrus ochroleucus			0.0	0.1	0.2	0.3			0.0							
Lycopodium obscurum				0.4	0.0	0.0			0.0	0.0						
Maianthemum cana.	0.4	0.2	0.4	1.7	0.4	1.6	0.7	0.9	0.5	0.6	1.5	1.0	1.4	0.9	0.0	0.2
Melampyrum lineare			0.0	0.0					0.1	0.0	1.0	0.3	0.3	0.2		
Polygonum cilinode										0.3						
Potentilla tridentata	0.4	1.4	0.4	0.8					0.8	0.4	0.6	0.0	0.3	0.1		
Pyrola secunda											0.0		0.0			
Rubus pubescens						1.6			0.1		0.2	0.0	0.9	0.2	1.0	0.1
Smilacina trifolia							0.4								0.9	0.0
Viola adunca	0.0	0.0	0.0	0.0		0.0					0.0	0.0				
Viola species													0.1	0.0	0.1	0.0
Graminoids																
Agropyron trachycaul.		0.4		0.0		0.0			0.0	0.0	0.0	0.0				
Agrostis hyemalis	0.0	0.4	0.0	0.4					0.1	0.1	0.0	0.0				
Calamagrostis cana.			0.0	0.1	0.3	0.3	0.1	0.3					0.1	0.0	0.2	0.0
Danthonia spicata	0.0	0.1	0.0	0.6		0.0			0.1	0.0	0.0	0.0	0.0	0.0		
Oryzopsis asperifolia	0.0	0.2		0.6	0.0	0.2			0.1	0.0	0.1	1.1	0.1	0.3		
Oryzopsis pungens	0.0	0.1	0.1	0.1		0.1			0.0	0.1	0.1	0.0	0.0	0.0		
Schizachne purpurascens	0.0	0.0		0.2	0.0	0.3			0.1	0.0		0.2	0.0	0.2		
Bryophytes																
Aulacomnium palustre			0.0	0.1	0.8	0.1	1.9	0.1	0.1		0.5	0.0			0.1	0.1
Pleurozium schreberi	0.1	8.1	0.4	8.6	0.1	6.4	0.1	1.7	7.7	4.6	39.1	22.0	29.9	17.5	4.9	9.8
Polytrichum commune			4.1	0.6	2.0	0.1	1.8	0.0			0.9	0.0	2.9	0.0	0.5	0.0
Polytrichum juniperinum	20.4	3.8	13.4	2.5	8.1	2.5			2.3	3.1	1.5	0.2	0.4	0.1		
Polytrichum piliferum	11.8	2.2	0.9	0.1	0.1	0.0	0.1		1.6	0.1	0.3	0.0	0.0	0.0		
Ptilium crista-castrensis											0.0		0.1	0.1	1.5	0.0
Sphagnum species					0.0	3.9	50.0	69.0							68.7	48.8
Lichens																
Cladina mitis	0.6	13.2	0.1	3.0	0.0	0.1	0.0	0.0	16.0	26.7	9.8	2.7	1.0	0.4	0.2	0.0
Cladina rangiferina	0.0	9.4	0.0	2.3	0.0	0.4			8.9	20.5	4.6	18.8	0.9	1.2	0.0	0.1
Cladina stellaris										1.6	0.0	3.1				
Other Ground																
Coniferous litter	12.1	0.8	45.5	8.3	23.9	6.7	6.4	0.4	18.9	3.4	25.5	6.7	32.5	12.4	2.1	8.4
Other litter	11.4	16.8	18.1	59.1	54.6	70.0	29.3	25.6	4.2	7.6	7.5	28.7	21.1	54.1	17.1	17.1
Rock	42.9	35.1	10.3	4.1	2.2	1.5	0.0		32.9	22.4	2.4	2.2				
Snag	1.0		0.3	0.0	1.1	0.1	0.3		0.0	0.0	0.0	0.3	0.1	0.1	0.1	0.0
Wood	3.1	4.3	3.9	3.5	2.6	4.9	4.3	1.5	1.2	4.3	1.4	1.8	3.1	4.2	1.2	1.4

Table 11.5. Number of understorey species with a treatment affinity by growth form.

	13 Year Old Communities				37 Year Old Communities			
	Outcrop	Shallow	Mod. Deep	Organic	Outcrop	Shallow	Mod. Deep	Organic
Tree Species								
Post-Fire	2	1	2	1	0	0	1	0
Post-Logging	0	0	1	0	0	0	1	0
Shrubs								
Post-Fire	0	0	0	1	0	2	1	2
Post-Logging	4	3	4	0	0	2	5	2
Herbs (except graminoids)								
Post-Fire	0	0	1	1	3	2	6	1
Post-Logging	0	7	6	1	1	0	2	1
Graminoids								
Post-Fire	0	0	0	0	2	1	0	1
Post-Logging	2	5	4	0	0	0	1	0
Bryophytes								
Post-Fire	2	1	2	1	2	3	4	1
Post-Logging	1	1	1	2	0	0	0	1
Lichens								
Post-Fire	0	0	0	0	0	0	0	0
Post-Logging	2	2	1	0	3	2	0	1

An overview of treatment differences in species composition begins with the tree canopy since its composition has a strong influence on the understorey through its effects on such factors as light intensity, microclimate, the chemical composition of litter and litter accumulation. A tree canopy was not present in 13 year old communities but tree saplings formed an overstorey in the shrub stratum which developed into the tree canopy of 37 year old communities.

Jack pine had much higher mean cover in 13 year old post-fire communities on all four site types. This was expected as it is a pioneer species of burned sites (Sims et al. 1990). Seed dispersal is limited in the absence of fire since jack pine's cones are serotinous. Any seeds which are dispersed have a higher probability of survival on exposed mineral sites. These were generally limited to roads in post-logging communities.

Black spruce had a post-fire treatment affinity on outcrops and moderately deep soils after 13 years. Its poorer performance in post-logging communities may indicate that either seedling establishment and survival was poorer or a large proportion of advance regeneration was destroyed or both. Black spruce cones are semi-serotinous; those growing on a tree open over several years. Seedling establishment and survival will be limited in post-logging communities by less exposed mineral soil (Sims et al. 1990).

Paper birch had a post-logging affinity on moderately deep soils. There were no treatment affinities for trees on organic soils.

Some tree species which had treatment affinities in the shrub stratum at 13 years of age also had them in the tree stratum at 37 years of age. Jack pine had the highest basal area and frequency in upland post-fire and post-logging communities. Jack pine also performed substantially better in upland post-fire communities than in post-logging communities on shallow and moderately

deep soils. On moderately deep soils, black spruce also had a post-fire affinity while aspen had a post-logging affinity.

Comparisons of total basal area over time or across treatments can be misleading as this measure combines information on density and mean basal area per tree. Upland post-logging communities had fewer trees than post-fire communities (747 stems/ ha compared with 3,013 stems / ha) but their trees were larger on average (128 cm^2 basal area at breast height/ tree compared with 60 cm^2/ tree). The trees in post-logging communities were often the ones left after logging. Jack pine and black spruce were not being replaced to the same extent in post-logging communities as they were in post-fire communities.

Generalizations about treatment differences in the overstorey composition of 37 year old communities are also influenced by the proportion of plots that had no trees. On upland site types, only 54% of plots in post-logging communities had trees compared with 71% of plots in post-fire communities. The combination of poorer tree regeneration and a greater proportion of treeless plots in post-logging communities is expected to have led to higher mean understorey light intensity there.

Whereas the basal area of the pioneer tree species (jack pine, aspen and birch) generally increased between 13 and 37 years, their understorey cover declined. This indicated that the trees in the fire cohort or the unlogged trees in cutovers had entered the tree stratum but were not being completely replaced in the lower strata by continued regeneration. The exception was black spruce which is a slower growing, shade tolerant species. Its basal area and understorey percent cover increased from the younger to the older age class on all site types except outcrops.

Jack pine and black spruce in the shrub stratum had 6 post-fire affinities in the younger age class compared with 1 in 37 year old communities. The decline in the number of affinities is probably the result of saplings becoming trees, self-pruning of lower branches and a lack of continuous establishment rather than a treatment effect. Many individuals were at the sapling or small tree stage at 13 years old. Height growth and self-pruning had generally removed lower branches from the understorey by 37 years of age. Trees comprised a negligible component of understorey cover at 37 years except on open plots where adequate light delayed self-pruning. Seedlings and saplings that did not belong to the cohort arising from the major disturbance accounted for most of the understorey cover from tree species.

In the shrub stratum, there were 11 post-logging affinities in the 13 year old age class. *Vaccinium angustifolium* and *V. myrtilloides* were the only shrub species for which the higher cover in 13 year old post-logging communities appears to have led to higher cover at 37 years (i.e. a treatment affinity occurred for both age classes on the same site type). It is noteworthy that all three widespread *Vaccinium* species performed better in post-logging communities by 37 years of age. Overstorey removal and fire both generally stimulate the growth of *V. angustifolium* and *V. myrtilloides* (Bell 1991). Better performance by these species in 13 year old post-logging was attributed to the cover head start. By 37 years of age, a tree canopy had developed on treed sites and shade intolerant species were expected to have their performance impaired. Apparently, *Vaccinium* species in post-logging communities were not affected by increasing canopy closure or any other ecological effects since their cover generally remained about the same or increased over time. In post-fire communities, the denser shade probably prevented the *Vaccinium* species from attaining a cover similar to that in post-logging communities.

The higher proportion of untreed plots in post-logging communities may account for the affinity of *Ledum groenlandicum* and *Amelanchier sanguinea* for post-logging communities on moderately deep mineral soils. *Ledum groenlandicum* is moderately shade tolerant and roots only in the organic layer (Bakuzis and Kurmis 1978; Bell 1991). An alternative explanation for the treatment affinities of *Amelanchier sanguinea* is that its distribution was quite patchy and the observed difference was a sampling artefact. *A. sanguinea* is singled out because of the high variability of its Block frequency.

Rosa acicularis was the only shrub species exclusive to post-fire communities in the older age class where it was found on shallow mineral soils. It is a shade-intolerant shrub which requires moderately rich nutrient conditions (Bakuzis and Kurmis 1978; Bell 1991). Given that plots in post-logging communities on shallow soils were more open, its absence in them may indicate that logging had an adverse impact on nutrient status relative to fires.

Chamaedaphne calyculata and *Alnus rugosa* both have an affinity with post-fire communities on organic soils and give somewhat different indications as far as nutrient status is concerned. *C. calyculata* is characteristic of very wet, nutrient poor sites while *A. rugosa* prefers a somewhat higher nutrient status and has been found to perform well on nutrient rich sites (Brumelis and Carleton 1989; Jeglum 1971). *Alnus rugosa* responds well to both fire and logging (Bell 1991). *Chamaedaphne calyculata* is shade intolerant (Carleton and Maycock 1981) and *Alnus rugosa* performs better in the open (Bell 1991). The lack of a significant treatment difference in percent canopy closure (apparently due to inadequate statistical power) precludes the use of shade as an explanation for the post-fire affinities. Conflicting indications for other ecological factors also prevent them from being suggested as potential causes.

Linnaea borealis was the remaining shrub with an affinity for post-fire communities on shallow and moderately deep soils. *L. borealis* typically grows on a feather moss ground cover under a coniferous canopy (Baldwin and Sims 1989). It is a small, creeping shrub whose performance will be adversely affected by the heavy leaf litter of a deciduous canopy. The higher aspen component and light intensity in post-logging communities may have contributed to its lower abundance there.

There were 14 herb treatment affinities in 13 year old communities. Of these, only *Epilobium angustifolium* and *Smilacina trifolia* had post-fire affinities. *Epilobium angustifolium* exists as scattered individuals even in mature stands, reproducing quickly from roots and seed following fire or logging (Bell 1991). Its nutrient preferences are somewhat higher than typical for a boreal species. *E. angustifolium* benefits from the large increase in available sites and the nutrient flush produced initially by fire (Klinka et al. 1989).

Smilacina trifolia was exclusive to organic soils in the younger post-fire communities and retained an affinity with them in the older age class. It also had a frequency of 68% in the 65 year old post-fire communities. This suggested that some factor important in the ecology of this species was present in post-fire but not post-logging communities.

There was a dramatic reversal in herb treatment affinities from the 13 to the 37 year old age classes. Most herbs in the 37 year old age class had an affinity for post-fire communities. In fact, many of these herbs were exclusive to post-fire communities. This was not consistent with the postulated successional pathways of species composition (Table 3.1) which suggested that the cover of species in post-fire communities would catch up to post-logging species in the older age class but should not overtake them due to the limiting effects of shade on species cover[1]. Potential causes of this anomaly are examined in Section 13.

All 11 graminoid treatment affinities at 13 years were for post-logging communities. By 37 years this had reversed and 4 out of 5 graminoid affinities were for post-fire communities. As with the other herbs, the pattern of graminoid treatment affinities at 37 years was not predicted by the postulated pathways.

The bryophyte treatment affinity pattern is best understood by subdividing the taxa into pioneer and later successional species. All the *Polytrichum* species are post-fire pioneers and they performed more poorly in post-logging communities in both age classes. On outcrops and shallow mineral soils, the most important influence on *Polytrichum* cover was probably space competition and allelopathy from *Cladina* species. The primary form of competition between bryophytes is for space (Okland 1994). This is also true for lichens since the main source of water and nutrients for

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[1] Other important ecological factors, such as soil temperature, were expected to follow the trend in shading.

both groups is precipitation and throughfall. Chemicals produced by some of the *Cladina* species have been found to inhibit germination of moss spores (Kershaw 1985). On moderately deep mineral soils, the space competition was between *Polytrichum* species and generalist bryophytes such as *Pleurozium schreberi.* Lower *Polytrichum* cover was probably also a result of treatment differences in overstorey composition (i.e. less jack pine and more aspen in post-logging communities) and the consequent difference in shade and litter conditions.

The post-logging affinity of *Pleurozium schreberi* for all site types at 13 years was due to its head start in cover. By 37 years of age, the affinities switched to post-fire communities on shallow and moderately deep mineral soils. This was attributed to higher Other litter cover and the competitive effects of reindeer lichens through space preemption and allelopathic inhibition in post-logging communities.

Lichens were favored by logging in both age classes. They are slow growing species which are usually completely destroyed by fire. The combined mean cover of *Cladina rangiferina* and *C. mitis* was less then 1% in 13 year old post-fire communities on each of the site types. *C. stellaris* usually does not appear until 25 years after fire (Clayden and Bouchard 1983).

Certain generalizations can be made about differences in the species composition of upland post-fire and post-logging communities in both age classes. Jack pine abundance in the shrub and tree strata is roughly 3 times higher in post-fire communities. Most site types had one or two shrub species which performed much better in post-logging communities. *Vaccinium angustifolium* was one of these shrubs on shallow and moderately deep soils. The ground stratum was most affected on all site types. In the 13 year old age class, two pioneer mosses, *Polytrichum juniperinum* and *P. piliferum,* performed much more poorly in post-logging communities. Reindeer lichens and *Pleurozium schreberi* had higher cover in post-logging communities after 13 years. The treatment disparity in the performance of reindeer lichens was maintained to 37 years of age on moderately deep soils while that of *Pleurozium schreberi* was reversed on all upland site types.

Thus far, the focus has been on specific differences in species composition. A further way of assessing the ecological relevance of differences in species composition, especially when scarce species are involved, is to calculate the proportion of species that were affected by logging. When applied to the 13 year old age class, it is expected that there will still be a number of treatment affinities due to treatment differences in direct effects. However, if resilience is occurring then the proportion of species with affinities should decrease between 13 and 37 years and become 0 by age 65. Across all the site types, an average of 35% of the species encountered had treatment affinities after 13 years compared with an average of 27% after 37 years (Table 11.6). Although the percentage of species with treatment affinities had declined from 13 to 37 years, a substantial proportion still had not recovered from the effects of logging by 37 years. On organic soils, the percentage of species affected increased over the same time period.

A strong indication of a treatment effect is provided when a species has both an affinity with and is exclusive to a treatment. This means it occurred in no Blocks of one treatment and at least 75% of the Blocks in the other treatment. An even stronger indication of an ecologically relevant treatment effect is provided when a number of treatment affinities involve exclusive species. On the upland site types, the number of treatment affinities which involved exclusive species was higher in post-logging communities after 13 years (15 post-logging versus 5 post-fire) (Table 11.7). This changed to post-fire communities after 37 years (3 post-logging versus 8 post-fire). On organic soils, exclusive species were found only in 13 year old post-fire communities. Exclusive species were less numerous in the older age class on all site types except outcrops.

Another criterion set out in Section 6.5.10 for evaluating the ecological relevance of the effects of logging related to a determination of whether the species was exotic. It turned out that this was not a concern. Seven exotic species were encountered (Crescent Botanical Services), but none in more than three plots within a site type. The species were *Agropyron repens, Bromus inermis,*

Cirsium arvense, Poa compressa, Sonchus arvensis, Taraxacum officianale and *Vicia cracca.* These species were found in post-fire communities more often than in post-logging communities. The surprisingly low number of exotic species probably reflects the distance of Blocks from roads.

Treatment differences in total understorey cover were significantly different only for 37 year old communities on shallow soils where total cover was 88% in post-fire communities and 108% in post-logging. Age class differences in total cover were not detected for any treatment/ site type combination. Because both sets of results suffered from low statistical power, the indication that logging generally had no impact on total understorey percent cover should be interpreted cautiously.

Table 11.6. Number of understorey species and percentage with treatment affinities by age class and site type.

Species	13 Years Old					37 Years Old				
	Mean	Outcrop	Shallow	Mod. Deep	Organic	**Mean**	Outcrop	Shallow	Mod. Deep	Organic
Total Number	51	44	60	58	43	56	48	65	70	41
Percentage with Affinities	35	34	38	41	26	27	25	20	31	32

Table 11.7. Number of understorey treatment affinities where the species was exclusive to a treatment by age class and site type.

Community Type	13 Years Old					37 Years Old			
	Outcrop	Shallow	Mod Deep	Organic		Outcrop	Shallow	Mod Deep	Organic
Post- Fire	1	0	0	4		3	2	3	0
Post- Logging	2	8	5	0		2	1	0	0
Total	3	8	5	4		5	3	3	0

12. Comparisons of species richness for Common species.

Common species had a relative cover of at least 1%. The minimum relative cover was determined separately for each age class and site type combination using the method in Appendix D. It was very close to 1% for all site types except for outcrops where it was $0.7\%^2$. A minimum relative abundance of 1% was adopted for all site types so that comparisons across site types would show how Common species richness differs for various types of communities. A 1% relative cover translated into an absolute cover of about 2%, depending on the site type.

The mean number of Common species was 12 in 13 year old communities and 14 in 37 year old communities (Table 12.1). Common species richness was significantly higher in 13 year old post-logging communities on outcrops at α = 5% (Table 12.2) where it was 10.3 species per 6 m^2 in post-logging communities compared with 8.0 per 6 m^2 in post-fire communities. On shallow mineral soils, thirteen year old post-logging communities had significantly higher Common species richness at α =10% (9.3 species/ 6 m^2 in post-logging versus 7.7 in post-fire). Statistical power was a concern for this latter comparison and for that of 37 year old communities on outcrops.

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[2]   Note that the previous tables show absolute and not relative abundance.

In the 13 year old post-logging communities, mean Common species richness was approximately 30% higher on outcrops and 21% higher on shallow mineral soil than in post-fire communities. Examination of the outcrop results (Table 9.4) indicates that *Amelanchier sanguinea* was the only Common species (Table 12.3) exclusive to outcrops in post-logging communities while no Common species was exclusive to post-fire communities. One possible explanation for the higher Common species richness of post-logging communities on outcrops is that some of the species eliminated by fire require more than 13 years to reestablish themselves to a relative abundance of 1%. This appears to be the case for the *Cladina* species and Foliose lichens. However, time elapsed is not expected to be the constraint on the remaining Common species (Table 12.3). For them, competition and differences in light intensity at the ground level may be involved. Logging left the low shrub layer largely intact and created a scattered tall shrub canopy on parts or all of the outcrops and shallow soils (Section 9). The surviving low shrubs provided shade and a more sheltered microenvironment which may have allowed other species to persist under them and attain a cover high enough to be a Common species. At the same time, jack pine cover and litterfall in post-fire communities would have limited the growth of species to a greater extent there.

To reiterate points made in Appendix D, these results tell us nothing about total species richness. It may be higher in post-fire communities or post-logging communities. To address this question, a study would have to be designed with the estimation of total species richness as its objective.

Table 12.1. Mean richness of Common species by site type and age class (species/ 6 m²) and total number of Common species in both treatments.

	13 Year Old Communities				37 Year Old Communities			
	# of Species		Mean Richness of Common		# of Species		Mean Richness of Common	
Site Type	Total	Common	Fire	Log	Total	Common	Fire	Log
Outcrop	44	14	8.0	10.3	48	16	10.6	9.0
Shallow	60	12	7.7*	9.3*	65	15	10.1	9.5
Mod. Deep	58	13	8.0	8.7	70	15	10.0	9.7
Organic	43	10	7.4	7.5	41	11	7.1	7.8
Mean	51	12			56	14		

Shaded boxes denote comparisons which are significantly different at $\alpha = 5\%$. * = significant at $\alpha = 10\%$.

Table 12.2. Significance levels (p-values) of richness comparisons at the treatment and Block levels using mixed model ANOVA.

Site Type	Age Class			
	13 Years Old		37 Years Old	
	Treatment	Block	Treatment	Block
Outcrop	0.028	0.083	0.155	0.003
Shallow Soils	0.060	0.074	0.337	0.408
Moderately Deep Soils	0.546	0.093	0.752	0.018
Organic Soils	0.841	0.269	0.370	0.055

Dark shaded boxes denote effects significant at $\alpha = 5\%$, light shaded boxes denote effects significant at $\alpha = 10\%$

Table 12.3. Common species by age class and site type. "X" denotes site types where the species met the Common species criteria.

	Age Class							
	13 Years Old				37 Years Old			
	Site Type				Site Type			
	Outcrop	Shallow	Mod. Deep	Organic	Outcrop	Shallow	Mod. Deep	Organic
Aspen			X					
Black spruce		X	X	X		X	X	X
Jack pine	X	X	X	X	X			
Alnus rugosa				X				X
Arctostaphylos uva-ursi	X					X		
Chamaedaphne calyculata				X				
Diervilla lonicera	X	X	X		X		X	
Juniperus communis						X		
Ledum groenlandicum				X				X
Linnaea borealis					X	X	X	
Salix species			X	X				X
Vaccinium angustifolium	X	X	X		X	X	X	X
Vaccinium myrtilloides		X	X			X	X	
Vaccinium vitis-idaea				X				X
Aralia nudicaulis			X					
Clintonia borealis							X	
Cornus canadensis			X		X		X	
Equisetum sylvaticum								X
Fragaria virginiana						X		
Maianthemum canadense		X	X	X	X	X	X	
Potentilla tridentata	X							
Rubus pubescens							X	
Carex species				X				
Dicranum species	X	X			X	X	X	X
Moss species	X	X	X		X	X	X	X
Pleurozium schreberi	X	X	X		X	X	X	X
Polytrichum commmune							X	
Polytrichum juniperinum	X	X	X		X			
Polytrichum piliferum	X				X			
Sphagnum species				X				X
Cladina mitis	X				X	X		
Cladina rangiferina	X	X			X	X	X	
Cladonia species	X	X			X	X	X	
Foliose lichen species	X				X	X		
Fruticose lichen species					X			

13. Discussion.

13.1. Replication.

Replication is a key element in any study which intends to examine treatment effects, species composition or vegetation dynamics. This is especially true in an observational study. A myriad of ecological factors are involved in producing the vegetation observed in a particular area even when site and disturbance conditions are similar (Section 3.1, Appendix C). Without replication, it is impossible to know whether the area sampled is typical of the conditions under investigation. In this study, it was initially hoped that three replicates for each age class/ treatment type combination would be adequate to draw inferences regarding treatment effects and vegetation recovery. However, data analysis following the second field season indicated that Block to Block variability was too high. Generally, the high variability was caused by one replicate whose species composition was atypical in some way (Table 11.2). It is quite possible that an unreplicated study would draw its inferences from unrepresentative data.

13.2. Comparison of the species composition of post-fire and post-logging communities.

Statistical tests (Sections 9 and 10) detected significant differences in the species composition of post-fire and post-logging communities for five of eight site type and age class comparisons. Two of the remaining three comparisons appeared to have differences which could not be detected due to low statistical power. For all comparisons, univariate tests indicated that certain species had significant treatment differences in mean cover and this was corroborated by the other univariate and multivariate techniques applied.

Differences in species composition were identified using the treatment affinity analysis which was based on four performance criteria (Section 6.5.6, Appendix C). Some strong patterns consistent with the postulated pathways of vegetation dynamics on upland site types (Table 3.1) emerged when understorey species with a treatment affinity were grouped by growth form and age class (Table 11.3). As predicted, the younger age class had a high proportion of species with an affinity for post-logging communities (80%). The 11 post-fire affinities involved species considered to be pioneers of or regenerators in recent burns and included jack pine and black spruce. All the species involved in the 47 post-logging affinities were expected to have been present at the time of logging in enough plots to create the post-logging affinity observed at 13 years of age[3]. Logging favored understorey species present at the time of disturbance and disfavored species which cannot establish without conditions similar to those present during or immediately after fire.

One of the conspicuous differences in 13 year old post-logging communities, when compared with post-fire communities, was the poorer performance of black spruce and jack pine. This is consistent with the well documented difficulties which softwoods have regenerating naturally in cutovers (Brumelis and Carleton 1988, 1989; Carleton and MacLellan 1994; Cayford and McRae 1983; Harvey and Bergeron 1989; Jeglum 1983; Yang and Fry 1981; Zasada 1986). Pioneer

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[3] We do not have data which indicated which species were present in the particular communities at the time they were disturbed so we used information which allowed us to infer which species were likely to have been present. The first is our results from 65 year old communities which were used to describe the typical mature state. Another is the Field Guide to the Forest Ecosystem Classification for Northwestern Ontario (NWO FEC). It sampled approximately 2100 plots in stands which were generally at least 50 years old. Fact sheets for each vegetation type list those species occurring with high frequency in the vegetation type. The vegetation types potentially present in high proportions on mineral soils at the time of disturbance include V4, V17 - V20, V28 - V33. Data collected for the NWO FEC study from the area of Ontario adjacent to the study area was kindly provided by the Ontario Ministry of Natural Resources (Peter Uhlig, pers. comm.) and used as an additional source. This area is considered to be ecologically similar to the study area. An intermediate draft of the Forest Ecosystem Classification Guide being produced for Manitoba was referred to during interpretation to determine whether it encountered substantially different understorey vegetation than any of the other sources.

mosses face similar regeneration difficulties in post-logging communities. Logging does not create the conditions necessary for the increase in their abundance and distribution that is observed during the early stages of post-fire vegetation dynamics. Pioneer mosses are unable to find suitable colonization sites or, if they do, to survive when subject to heavy deciduous leaf litter.

In contrast with its effects on pioneers, logging appeared to benefit many of the species which were thought to be present at the time of disturbance. Such species existed in a suppressed state, presumably due to limitations on light, moisture and nutrient availability (Brumelis and Carleton 1989; Sims et. al 1990; Viro 1974). The direct effects of logging equipment and overstorey removal generally include only limited mortality of individual plant parts from physical damage and slash deposition (Brumelis and Carleton 1989; Rowe 1983; Zasada 1986). Desiccation in the more exposed post-logging microenvironment reduces the cover of species such as *Hylocomium splendens* or *Ptilium crista-castrensis,* but for many other species the net effect is an increase in cover even though they may need to replace shade leaves with sun leaves (Bell 1991; Brumelis and Carleton 1989). Species able to tolerate or benefit from the change in conditions will have a substantial head start in cover compared with their conspecifics in burns. Fire generally removes plant cover and this is not replaced until plants sprout from disseminules or under-ground parts and produce stem tissue. The head start conferred by logging is especially important for slow growing species such as reindeer lichens (*Cladina mitis, C. rangiferina* and *C. stellaris*) which are eliminated by fire. The pattern observed in 13 year old communities suggests that post-fire pioneers were not able to establish to the same degree in post-logging communities but many species present at the time of logging were able to tolerate the change in light intensity and microclimate and attain a cover head start that was maintained for at least 13 years.

The cover head start was reflected in higher Common species richness in 13 year old post-logging communities on outcrops and shallow mineral soils (Section 12). By 37 years of age, there were no treatment differences in the number of Common species.

Some of the treatment affinity patterns observed in the 37 year old age class (Table 11.3) were anticipated from the postulated pathways of vegetation dynamics (Section 3.2.1, Table 3.3). In the tree stratum, jack pine and black spruce continued to perform more poorly in post-logging communities. Jack pine performed better in the understorey of 13 year old post-fire communities on all 4 site types and black spruce did so on outcrops. There was no treatment difference in the performance of these species by 37 years of age. In jack pine's case, this reflected its transition from sapling to tree and its inability to become established for more than a few years after fire. Jack pine's poorer performance in post-fire communities was partly offset by other shrubs. All five of the new post-fire affinities involved species present in the younger post-logging communities. *Linnaea borealis,* which had two 37 year old post-fire affinities, is usually found creeping on a moss layer under a coniferous canopy (Baldwin and Sims 1989). A moss layer and a coniferous canopy characterized 37 year old post-fire communities on shallow and moderately deep mineral soils. Performance differences in the moss layer and canopy also characterized two of the three major differences in the species composition of upland post-fire and post-logging communities. The third major difference was that post-fire communities had lower reindeer lichen cover. *Cladina* species had treatment affinities only for post-logging communities and this was attributed to their cover head start.

The large number of post-fire treatment affinities for bryophytes, graminoids and other herbs at 37 years of age was not anticipated by the postulated pathways of vegetation dynamics. It was postulated that the cover of herbs and graminoids in post-fire communities might have caught up to their conspecifics in post-logging communities by 37 years. However, it was also suggested that shading and other conditions associated with a closed canopy would prevent many species in post-fire communities from surpassing the performance of their conspecifics in post-logging communities enough to qualify for post-fire affinities. While some species were expected to perform better under

the closed, coniferous canopy (and associated conditions) in post-fire communities, at the same time, some species were expected to perform better in the more open and deciduous nature of post-logging communities. The latter expectation was not fulfilled. Even some of the species expected to have post-logging affinities had post-fire affinities instead (*Aster ciliolatus, Fragaria virginiana, Lathyrus ochroleucus, Melampyrum lineare, Potentilla tridentata* and *Oryzopsis pungens*).

Predictions were not made regarding the distribution of bryophyte affinities between treatments. It was expected that the abundance of pioneer bryophytes in post-fire communities would be reduced by 37 years of age as a result of less light and competition with other bryophytes and lichens. The more open nature of post-logging communities might create a sufficient number of microsites to favor the performance of pioneer bryophytes there relative to post-fire communities. The net effect was expected to be a reduction in the number of treatment affinities. There was no change in the number of bryophyte affinities from 13 to 37 years but, by 37 years, 10 of 11 affinities were with post-fire communities. Although this pattern was not predicted it could still be consistent with the projected differences in the overstorey and shrub stratum.

There are two potential explanations for the anomalous treatment affinity pattern in the graminoids and other herbs[4]. The first is that the postulated pathways of upland vegetation dynamics are inaccurate. This is quite possible since they are based on knowledge regarding differences in the direct effects of fire and logging and the comparative research of others which only deals with the initial stages of post-disturbance vegetation dynamics. The studies that have compared the species composition of burned and logged upland boreal communities beyond the first 14 years after disturbance included only trees (Yang and Fry 1981) or trees and shrubs (Carleton and MacLellan 1994). The anomalies we observed occurred after this age. Postulations about direct effects were based primarily on the consequences of a more open, less coniferous canopy in post-logging communities and the head start gained by species which survived logging.

The second potential explanation for the anomalies is that there were indirect effects beyond the direct effects proposed. That is, logging had long term effects on ecological processes that were not revealed until after 13 years of age. For example, fire generally reduces the thickness of the surface organic layer and lower its albedo. This can raise soil temperature for anywhere from 10 to 25 years (Brown 1983; Van Cleve et al. 1983 a, b; Viereck 1983) with consequent effects on decomposition, nutrient cycling and productivity. Logging does not directly reduce the thickness of the organic layer (although it may disturb it) or its albedo. Canopy removal permits more sunlight to reach the forest floor but not as much as after fire. The living ground cover and organic layer act as an insulator between the increased sunlight and the soil. Due to the combined effects of greater shading and an intact ground cover, logging is not expected to mimic fire by arresting the long term decline in soil temperature and elevate it back to a higher level. Plant growth, decomposition and nutrient cycling are influenced by soil temperature. There may have been a continued decline in soil temperature and this indirect effect was not manifested in the species composition of communities until 37 years later.

Direct effects which might have contributed to the anomalies in upland communities include:

1) Better shrub performance in post-logging communities produced more deciduous litter than expected and this smothered bryophytes (Van Cleve et al. 1991). This could help explain the bryophyte affinity pattern but not the herb and graminoid. While some herbs and graminoids might be affected by smothering, others would benefit from the more open and deciduous nature of the communities. More post-logging affinities should have occurred if this was the responsible factor.

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[4] There is a third possibility which affects any study. That is, the degree of control for substantial causal factors was not adequate to ensure that the burns and cutovers were comparable and that the observed differences are spurious. This was considered to be less likely than the typical situation in view of the explicit recognition of other substantial causal factors and attempts to control for them, replication and statistical tests which failed to detect ecologically significant treatment differences in environmental variables.

2) Logging slash may have adversely affected herb and graminoid regeneration, especially that of creeping species. If that had occurred then these species should have performed more poorly in 13 year old post-logging communities also. That was not the case.

3) On outcrops and shallow mineral soils, herb and graminoid performance may have been adversely affected by higher reindeer lichen cover. Reindeer lichens provide a less hospitable seed bed and nurse site for seedlings than organic material or mosses (Foster 1985). Although this may have contributed to the anomaly on outcrops and shallow mineral soils, the cover of reindeer lichens was too low on moderately deep soils for this to be a factor.

There are many potential differences in indirect effects which could affect ecological processes, some of which are:

1) Logging did not reverse the successional decline in soil temperature and pH or the increase in soil moisture which results from a thickening organic layer (Ahlgren and Ahlgren 1960; Bonan and Shugart 1989; Van Cleve et al. 1983 a, b; Viro 1974). Declining soil temperature reduces nutrient availability, plant productivity and the rate of decomposition.

2) Better shrub performance led to a thicker organic layer, lower soil temperatures and higher soil moisture. Although lower soil temperatures are a concern in these soils, their shallow nature implies that higher soil moisture should be beneficial.

3) A reindeer lichen and feather moss ground cover has a similar effect on soil processes as the organic layer (Bonan and Shugart 1989; Viro 1974). It also intercepts moisture and nutrients from precipitation and throughfall (Ahlgren and Ahlgren 1960; Taylor et al. 1987). Fire removes the living ground cover. The negative effects of the surviving ground cover in post-logging communities may be counteracted by the concomitant increase in soil moisture. One study which examined the effects of a lichen mat on trees (Cowles in Kershaw 1985) found that the net effect of the mat was an increase in productivity. This was attributed to the increase in soil moisture since it probably is a limiting factor in the shallow upland soils of the study area.

4) Reindeer lichens may also inhibit the growth of shallow rooted graminoids and other herbs by exuding allelopathic chemicals (Kershaw 1985). If lichens had such an effect then an explanation must be advanced as to why the effect does not appear in the younger age class.

5) Fire may neutralize allelopathic chemicals exuded into the soil by reindeer lichens (Auclair 1983). The heat from fire may chemically alter the solubility of the exudates and render them more susceptible to leaching or may convert them to non-toxic forms.

6) Fire releases the nutrients bound up in the organic layer and the biomass (Ahlgren and Ahlgren 1960; MacLean et al. 1983; Viro 1974).

7) Logging removes nutrients from the site and these may not be replenished by 37 years of age. This problem would be exacerbated if the intact organic layer lowered soil temperatures and pH. Decomposition is retarded and a higher proportion of the nutrients are unavailable (Viro 1974). Two important influences on the extent of nutrient removal are the type of logging and length of the rotation. Nutrient removals are higher when the entire tree is removed (Timmer et al. 1983). Long term projections based on the distribution of nutrients between soils and vegetation at the time of logging suggest that the boreal communities found on certain soil conditions will be able to recover from the nutrient depletion of a single, long rotation bole-only harvest (Foster and Morrison 1976; Timmer et al. 1983). Shallow soils, which characterize the study area, are expected to have difficulties recovering.

The degree to which mosses, graminoids and other herbs performed more poorly in 37 year old post-logging communities on upland site types is striking. Whereas 75% of species with treatment affinities after 13 years performed better in post-logging communities, 85% performed more poorly after 37 years. The anomalies within this reversal of affinities appear to lack an

explanation in terms of treatment differences in direct effects. That is, modification of the postulated pathways of species composition to reflect our results is not adequate to explain the anomalies in the herbs and graminoids. Potential differences in the indirect effects of fire and logging on ecological processes is another possibility. Van Cleve et al. (1983 a, b) argue that the organic layer, through its effect on soil temperature, is the most important factor controlling vegetation dynamics in upland black spruce stands in the taiga. Logging has little effect on the organic layer and, therefore, may fail to reset the successional cycle of soil temperature. This is only one of the ways in which logging's long term effects on ecological processes may differ from those of fire which serve to rejuvenate the ecosystem (Heinselman 1973, 1981; MacLean et al. 1983; Viereck 1983). Therefore, the possibility is raised that one or more ecological processes were altered in a way that could not be absorbed by the ecosystem and this was not revealed until some time between 13 and 37 years after logging. There is a need for research on the long term effects of logging on ecological processes.

On organic soils, treatment differences in species composition were suggested for the 13 but not the 37 year old age class. Consistent with the findings of Brumelis and Carleton (1989), our results suggested that the most abundant species in post-logging communities were from among those present at the time of logging. The cover head start of these species led to the treatment differences observed after 13 years. Although there was no detectable treatment difference in species composition on organic soils by 37 years of age, there were some noticeable patterns of treatment affinities for individual species. *Pleurozium schreberi* reversed its affinity from post-logging communities at 13 years to post-fire communities at 37 years on shallow and moderately deep soils but retained its post-logging affinity on organic soils. *Sphagnum* species also reversed its affinity. Its cover was 19% higher in post-logging communities after 13 years but dropped to 20% lower after 37 years. When concerns about low statistical power were pursued, it was still not clear whether the affinity patterns of these two taxa could be associated with treatment differences in soil moisture. Brumelis and Carleton (1989) related stand differences in post-logging species composition to site nutrient regime and degree of ground disturbance. In the post-logging communities we sampled, little evidence of ground layer disturbance was visible at the time of sampling other than main haul roads through the Blocks. Cutting and hauling in the 37 year old communities occurred when the ground was frozen and hence the minimal amount of ground disturbance[5]. Plot to plot differences in the degree of disturbance may have occurred but were too small to be apparent when sampled. If there was such within disturbance variability then this could account for the high plot to plot variability in species composition. In depth research is required for communities on organic soils to shed light on the causes of low statistical power and large differences in the cover of certain species.

13.3. Community resilience.

An assessment of the sustainability of logging ultimately involves a test for community resilience (Section 6.1, Appendix C). When the species composition of 13 and 37 year old communities was compared with the typical mature state (65 year old communities), the species composition of post-logging communities on upland sites was less affected at 13 years of age than similar post-fire communities. Nevertheless, by 37 years of age, post-fire communities had become more similar to typical mature ones. In other words, species composition was initially less affected by logging than by fire and then recovered more slowly.

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[5] In the cutovers we sampled, little evidence of ground layer disturbance was visible at the time of sampling other than main haul roads through the Blocks. Undoubtedly, some ground layer disturbance occurred as a result of skidding. However, no long term effects in the form of ruts or ridges were apparent. This is consistent with the findings of others (Zasada 1986) and attributed to the types of soils involved, season of cut and haul, the logging methods employed and haul route selection. Summer logging on organic or fine textured mineral soils is expected to result in greater ground disturbance.

Appendix A- **Species List and Species Codes**

A total of 216 "species" were encountered in this project. Certain broader taxons were referred to with a species name. This occurred for 19 of the "species" in this list. An additional 11 "species" were forms of ground cover such as coniferous or wood litter. Nomenclature follows Cody and Britton (1989) for ferns and allies, Scoggan (1978) for remaining vascular plants, Hale (1979) for lichens and Ireland (1982) for mosses.

Species Code	Scientific Name	Authority	Common Name	Additional Species Included in the Taxon
Abiesbal	*Abies balsamea*	(L.) Mill.	Balsam Fir	
Acer_spi	*Acer spicatum*	Lam.	Mountain Maple	
Achilmil	*Achillea millefolium*	L.	Common Yarrow	
Actaerub	*Actaea rubra*	(Ait.) Willd.	Red Baneberry	
Agroprep	*Agropyron repens*	(L.) Beauv.	Couch Grass	
Agroptra	*Agropyron trachycaulum*	(Link) Malte	Slender Wheatgrass	
Agroshye	*Agrostis hyemalis*	(Walt.) BSP.	Hairgrass	
Alliucer	*Allium cernuum*	Roth	Nodding Onion	
Alnuscri	*Alnus crispa*	(Ait.) Pursh	Green Alder	
Alnusrug	*Alnus rugosa*	(Du Roi) Spreng.	Speckled Alder	
Amelaaln	*Amelanchier alnifolia*	Nutt.	Saskatoon	
Amelasan	*Amelanchier sanguinea*	(Pursh) DC.	Eastern Serviceberry	
Anaphmar	*Anaphalis margaritacea*	(L.) Clarke	Pearly Everlasting	
Andropol	*Andromeda polifolia*	L.	Bog-Rosemary	
Anemocan	*Anemone canadensis*	L.	Canada Anemone	
Anemoqui	*Anemone quinquefolia*	L.	American Wood Anemone	
Antendio	*Antennaria dioica*	(L.) Gaertn.	Common Pussy-Toes	
Apocyand	*Apocynum androsaemifolium*	L.	Spreading Dogbane	
Aquilcan	*Aquilegia canadensis*	L.	Columbine	
Aralihis	*Aralia hispida*	L.	Bristly Sarsaparilla	
Aralinud	*Aralia nudicaulis*	L.	Wild Sarsaparilla	
Arctouva	*Arctostaphylos uva-ursi*	(L.) Spreng.	Bearberry	
Asarucan	*Asarum canadense*	L.	Wild Ginger	
Astercil	*Aster ciliolatus*	Lindl.	Lindley's Aster	
Asterlae	*Aster laevis*	L.	Smooth Aster	
Asterpun	*Aster puniceus*	L.	Purple-Stemmed Aster	
Astersim	*Aster simplex*	Willd.	Small Blue Aster	
Asterumb	*Aster umbellatus*	Mill.	Flat-Topped White Aster	
Athyrfil	*Athyrium filix-femina*	(L.) Roth	Lady Fern	
Aulocpal	*Aulacomnium palustre*	(Hedw.) Schwaegr	Ribbed Bog Moss	
Betulgla	*Betula glandulosa*	Michx.	Dwarf Birch	
Betulpap	*Betula papyrifera*	Marsh.	Paper Birch	
Botryvir	*Botrychium virginianum*	(L.) Sw.	Rattlesnake Fern	
Bromucil	*Bromus ciliatus*	L.	Fringed Brome	
Bromuine	*Bromus inermis*	Leyss.	Awnless Brome	

Calamcan	*Calamagrostis canadensis*	(Michx.) Nutt.	Blue-joint	*C. inexpansa, C. lapponica, C. neglecta*
Camparot	*Campanula rotundifolia*	L.	Harebell	
Carexspp	*Carex species*		Sedges	
Chamacal	*Chamaedaphne calyculata*	(L.) Moench	Leatherleaf	
Chimaumb	*Chimaphila umbellata*	(L.) Barton	Prince's Pine	
Chrysvil	*Chrysopsis villosa*	Ell.	Golden Aster	
Cinnalat	*Cinna latifolia*	(Trev.) Griseb.	Slender Wood Grass	
Circaalp	*Circaea alpina*	L.	Small Enchanter's-Nightshade	
Cirsiarv	*Cirsium arvense*	(L.) Scop.	Canada Thistle	
Cirsimut	*Cirsium muticum*	Michx.	Swamp-thistle	
Cladimit	*Cladina mitis*	(Sandst.) Hale & Culb.	Yellow Reindeer Lichen	*C. arbuscula*
Cladiran	*Cladina rangiferina*	(L.) Harm.	Reindeer Lichen	
Cladiste	*Cladina stellaris*	(Opiz) Brodo	Reindeer Lichen	
Cladospp	*Cladonia species*			
Clintbor	*Clintonia borealis*	(Ait.) Raf.	Blue-bead Lily	
Comanumb	*Comandra umbellata*	(L.) Nutt.	Bastard Toadflax	
Confrlit	Conifer litter			
Coptitri	*Coptis trifolia*	Salisb.	Goldthread	
Coraltri	*Corallorhiza trifida*	Chat.	Early Coral-root	
Cornucan	*Cornus canadensis*	L.	Bunchberry	
Cornusto	*Cornus stolonifera*	Michx.	Red Osier	
Corydsem	*Corydalis sempervirens*	(L.) Pers.	Pale Corydalis	
Corylcor	*Corylus cornuta*	Marsh.	Beaked Hazelnut	
Cypriaca	*Cypripedium acaule*	Ait.	Stemless Lady's-slipper	
Danthspi	*Danthonia spicata*	(L.) Beauv.	Poverty Grass	
Dicraspp	*Dicranum species*		Broom Mosses	
Diervlon	*Diervilla lonicera*	Mill.	Bush Honeysuckle	
Droserot	*Drosera rotundifolia*	L.	Round-leaved Sundew	
Dryopcar	*Dryopteris carthusiana*	(Vill.) H.P. Fuchs	Spinulose Wood Fern	
Epiloang	*Epilobium angustifolium*	L.	Fireweed	
Epilopal	*Epilobium palustre*	L.	Marsh Willowherb	
Equisarv	*Equisetum arvense*	L.	Common-Horsetail	
Equisflu	*Equisetum fluviatile*	L.	Water-Horsetail	
Equishye	*Equisetum hyemale*	L.	Scouring-rush	
Equispra	*Equisetum pratense*	Ehrh.	Meadow-Horsetail	
Equissci	*Equisetum scirpoides*	Michx.	Dwarf Scouring-rush	
Equissyl	*Equisetum sylvaticum*	L.	Wood-Horsetail	
Eriopspp	*Eriophorum species*			
Eriopvag	*Eriophorum vaginatum ssp. spissum*	(Fern.) Hult.	Sheathed Cotton-Grass	
Foliospp	Foliose lichen species not included in another taxon			

Pyrolasa	*Pyrola asarifolia*	Michx.	Pink Pyrola	
Pyrolell	*Pyrola elliptica*	Nutt.	Shinleaf	
Pyrolsec	*Pyrola secunda*	L.	One-sided Pyrola	
Pyrolvir	*Pyrola virens*	Schweigger	Greenish-Flowered Wintergreen	
Quercmac	*Quercus macrocarpa*		Bur Oak	
Rhamnaln	*Rhamnus alnifolia*	L'Her.	Alder-leaved Buckthorn	
Rhus_gla	*Rhus glabra*	L.	Smooth Sumac	
Ribesame	*Ribes americanum*	Mill.	Wild Black Currant	
Ribesgla	*Ribes glandulosum*	Grauer	Skunk-Currant	
Ribeslac	*Ribes lacustre*	(Pers.) Poir.	Bristly Black Currant	
Ribesoxy	*Ribes oxyacanthoides*	L.	Bristly Wild Gooseberry	*Ribes oxyacanthoides var. hirtellum*
Ribestri	*Ribes triste*	Pallas	Red Currant	
Rock	Exposed Bedrock			
Rosa_aci	*Rosa acicularis*	Lindl.	Prickly Rose	
Rubuscha	*Rubus chamaemorus*	L.	Baked-apple-berry	
Rubusida	*Rubus idaeus*	L.	Red Raspberry	
Rubuspub	*Rubus pubescens*	Raf.	Dwarf Raspberry	
Salixspp	*Salix* species		Willows	
Sanicmar	*Sanicula marilandica*	L.	Snakeroot	
Saxifvir	*Saxifraga virginensis*	Michx.	Early Saxifrage	
Schizpur	*Schizachne purpurascens*	(Torr.) Swallen	False Melic-Grass	
Selagden	*Selaginella densa*	Rydb.		*Selaginella rupestris*
Shephcan	*Shepherdia canadensis*	(L.) Nutt.	Soapberry	
Smilatri	*Smilacina trifolia*	(L.) Desf.	Three-Leaved Solomon's-Seal	
Snag	Snag			
Solidcan	*Solidago canadensis*	L.	Canada Goldenrod	
Solidgig	*Solidago gigantea*	Ait.	Late Goldenrod	
Solidhis	*Solidago hispida*	Muhl.	Pale Goldenrod	
Solidspp	*Solidago* species not included in another taxon			
Soncharv	*Sonchus arvensis*	L.	Field-Sow-Thistle	
Sorbudec	*Sorbus decora*			
Sphagspp	*Sphagnum* species			
Spiraalb	*Spiraea alba* var. *latifolia*	(Ait.) Ahles	Meadow-sweet	
Spirarom	*Spiranthes romanzoffiana*	Cham.	Hooded Ladies'-tresses	
Stelllon	*Stellaria longipes*	Goldie	Northern Stichwort	
Strepamp	*Streptopus amplexifolius*	(L.) DC.	Liverberry	
Strepros	*Streptopus roseus*	Michx.	Rose Mandarin	
Stump	Stump			
Symphalb	*Symphoricarpos albus*	(L.) Blake	Snowberry	
Taraxoff	*Taraxacum officianale*	Weber	Common Dandelion	
Taxuscan	*Taxus canadensis*	Marsh.	American Yew	

126

Thaliven	*Thalictrum venulosum*	Trel.	Veiny meadow-Rue	
Tofieglu	*Tofieldia glutinosa*	(Michx.) Pers.	Sticky Asphodel	
Trienbor	*Trientalis borealis*	Raf.	American Star-flower	
Trunk	Trunk			
Vacciang	*Vaccinium angustifolium*	Ait.	Low Sweet Blueberry	
Vaccicae	*Vaccinium caespitosum*	Michx.	Dwarf Bilberry	
Vaccimyr	*Vaccinium myrtilloides*	Michx.	Velvet-leaf-blueberry	
Vaccivit	*Vaccinium vitis-idaea*	L.	Rock-Cranberry	
Viburedu	*Viburnum edule*	(Michx.) Raf.	Squashberry	
Viburopu	*Viburnum opulus var. americanum*	L.	Guelder-Rose	
Viburraf	*Viburnum rafinesquianum*	Schultes	Downy Arrow-wood	
Viciaame	*Vicia americana*	Muhl.	American Vetch	
Viciacra	*Vicia cracca*	L.	Tufted Vetch	
Violaadu	*Viola adunca*	Sm.	Early Blue Violet	*V. conspersa*
Violaspp	*Viola* species		*V. canadensis var. rugulosa, V. palustris, V. pubescens, V. renifolia, V. selkirkii, V. soraria*	
Water	Water			
Wood	Wood			
Woodsilv	*Woodsia ilvensis*	(L.) R. Br.	Rusty Woodsia	

Appendix B- **Glossary of Abbreviations and Terms**

Words in bold type represent terms which are defined elsewhere in the glossary.

Term	Definition
Abundant species	A species having a high cover or basal area in a **community**. Opposite of a **scarce species**.
Affinity	A close relationship between a species and a **site type** or a **treatment**. Species with affinities are used to characterize the post-fire vegetation of the site types or **treatment** differences in **species composition**. For the characterization of site types, affinity is assessed at two levels (see **associated species, characteristic species**). Species with treatment affinities are presumed to be indicators of treatment effects.
ANOVA	Analysis of variance.
Associated species	A species considered to typify the communities of a particular site type and age class because it meets at least one of the four performance criteria in Section A.6.5.6. Less frequent than a **characteristic species**.
Avoider	Shade tolerant species that are eliminated by fire and reinvade slowly. They often cannot establish until the conditions associated with a mature closed tree canopy are present.
Block	A burn or cutover. The Block is the treatment unit/ replicate in this study.
C%	Mean percent cover.
CA	Correspondence analysis.
CD	Cover difference. Mean percent cover of a species in post-logging communities minus its cover in post-fire communities.
Characteristic species	A species considered to typify the communities of a particular site type and age class because it meets at least one of the four performance criteria in Section A.6.5.6. For the given site type, it has a high frequency, its cover or basal area is substantially higher and/ or it is part of a group of species whose cover or basal area differ in a coordinated way. See also **associated species**.
Colonizer	A species which is eliminated by fire and reestablishes from outside the burn. Includes **avoiders** and **evaders**.
Common species	A species that is expected to be collected by the plot size provided its distribution is not **localized** in the **community** based on its relative cover.
Common species richness	Number of **Common species** present in a **community**.
Community	The plants found within specified spatial and temporal boundaries.
Coniferous litter	Coniferous needle litter.
Cut and skid logging	The logging method used in the study area from about 1979 to 1986. Cutting was done by mechanical fellers. Skidders ranged widely up to 200 m from the haul roads. Trees were cut to length at the roadside.

128

Direct succession	A pattern of succession in which the species in the pre-disturbance community regenerate immediately after disturbance from within the disturbed area and then persist until the next disturbance. Direct succession will generally apply only to a portion of the species in the community. see also **sequential succession.**
Ecological distance	A representation of plots in Euclidean space such that the straight line distances between the plots reflects their ecological dissimilarity.
Endurer	A species which can resprout within a burn from shallow or deep underground organs. May be shade tolerant or intolerant.
Evader	A species which can regenerate from within a burn due to relatively long-lived propagules stored in the soil or the canopy.
Exclusive species	A species found in only one **site type** when site types within **treatments** are compared or in one treatment when treatments are being compared.
F%	**Frequency.**
Forest ecosystem type	A classification unit in the Northwestern Ontario Forest Ecosystem Classification which combines **vegetation type** and **soil type**.
Frequency	Percentage of **plots** from a given site type within a **Block** in which a species occurs.
FRI	Forest resource inventory. Forest cover maps digitized from ariel photography. Year flown depends on the area in question. Most of the study area was flown in 1986.
Invader	A species not present in a pre-fire community that has highly dispersive, short-lived propagules. Often present only during the initial stage of post-fire recovery.
Localized species	A species which occurs in only one part of either a community, Block, or the study area. Opposite of a **widespread species**.
MANOVA	Multivariate analysis of variance.
NMDS	Non-metric multi-dimensional scaling.
NWO FEC	Northwestern Ontario forest ecosystem classification guide. Sims et al. (1989).
Observed species richness	The number of species collected in a sample from a **community** whose boundaries have been precisely defined.
Other litter	Ground stratum cover category. Exposed F and/ or H horizons and litter not included in **coniferous** or **wood litter**.
PCA	Principal components analysis.
PCO	Principal coordinates analysis.
Performance	see **species performance**.
PFPC	Pine Falls Paper Company. Formerly Abitibi-Price, Pine Falls Division.
Plot	The **sampling unit**. A 2 m * 3 m understorey plot is nested within a 5 m * 5 m tree plot.
Quadrat	The surface area used to estimate percent cover for understorey species. Six contiguous 1 m * 1 m quadrats formed the understorey **plot**.

Regenerator	A species present prior to fire which regenerates from within the burn either from underground organs, the seed bank or protected above-ground propagules. Includes **endurers, evaders** and **resisters**.
Resilience	A disturbed **community's** ability to return to a typical mature **species composition** for the **site type** after an appropriate length of time.
Resister	A shade intolerant species whose adult stages can survive a low severity fire.
Sample	The group of **plots** sampled in a **community**.
Sampling unit	The **plot**.
Scarce species	A species having a low abundance in a **community**. Opposite of an **abundant species**.
Sequential succession	Disturbance results in the elimination of pre-disturbance species. Subsequent vegetation dynamics involve a series of successive species replacements.
Site	A mapping unit in which topographic influences and soils are relatively homogenous. In this study, **site type** is the classification unit.
Site conditions/ characteristics	Soil and topographic variables which influence species composition.
Site type	The soil and topographic classification unit used in this study.
Snag	Standing dead tree.
Soil type	The soil classification unit used in the **NWO FEC**.
Species composition	The list of species found in a **community** and their respective abundances (e.g. percent cover, basal area).
Species density	The number of species collected in a **plot** of a fixed area within a precisely defined **community** (e.g. 12 species/ 6 m^2).
Species performance	A measure of how well a species has established, grown and reproduced in a community. This study measured performance using criteria which incorporated cover or basal area, frequency and coordinated species responses. Each criterion had strengths but also addressed some of the weaknesses of the other criteria. see Section 6.5.6 for details.
Species richness	Strictly speaking, it is the number of species per fixed number of individuals (or other measure of abundance; e.g. 16 species/ 2 m^2 of plant cover). To be consistent with common usage, we use it in the more general sense of the total number of species present in a **community**, i.e. **total species richness**. See also **Common species richness** and **observed species richness**.
Stand	A vegetation mapping unit in which the **vegetation type** is relatively homogenous throughout. Often refers to trees only.
Strip cutting	The logging method used in the study from about 1953 to 1978. Cutting was accomplished by chainsaws, horses and tractors in 1 chain wide strips extending about 91 m perpendicular to haul roads. Trees were cut to length on the strips.
Stump	Ground stratum cover category. Base of a cut tree.

Substantial causal factor　　An ecological variable thought to have a substantial influence on **species composition** or **vegetation dynamics**.

Total species richness　　The number of species present in a **community** whose boundaries have been precisely defined.

Treatment type　　Type of disturbance such as a burn or cutover.

Treatment unit　　An area which has been either burned or logged once but not otherwise disturbed since 1900. It is the replicate in the study and is generally referred to as a **Block**.

Ultimate causal variables　　Causal variables whose causes are not of interest to the **vegetation theoretical framework** and will not affect its mechanisms. For a given set of objectives, an ultimate causal variable is one: 1) whose causes are not of interest; 2) whose causes do not affect other variables in the framework to any substantial degree; 3) which does not experience feedback effects from vegetation at the plot level.

Vegetation dynamics　　Temporal change in **species composition**. Sometimes referred to as succession.

Vegetation theoretical framework　　A description of the ecological variables thought to have a substantial influence on vegetation and how they are linked together.

Vegetation type　　A vegetation classification unit in the **NWO FEC** based on overstorey and understorey composition.

Widespread species　　A species which occurs throughout a region, Block or community. Opposite of a **localized species**.

Wood litter　　Wood (incl. twigs) that have not decomposed to the point where they crumbles easily.

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Errata

1. Reference to Table 10.4 on page 86 should read Table 10.9.

2. The table on page 93 should be replaced with the following table.

Table 10.11. Treatment affinities, canonical variates analysis, presence and mean cover for 37 year old communities on shallow soils.

	Treatment	Affinity	CV	Diff. %	Blocks Pres. Burns	Blocks Pres. Cuts	Blocks Cover Burns	Blocks Cover Cuts	P Burn1	P Burn2	P Burn3	P Burn4	P Cut1	P Cut2	P Cut3	P Cut4	C Burn1	C Burn2	C Burn3	C Burn4	C Cut1	C Cut2	C Cut3	C Cut4
N					4	4	4	4	6	4	5	6	7	5	5	5	6	4	5	6	7	5	5	5
Trees	Aspen				1	2		1.0					2			2					1.7			2.2
	Bl. spruce				4	3	1.7	3.5	1		1	6	2	3	1		0.8		0.1	5.7	7.6	6.1	0.3	
	Jack pine **	B	B	-10.0	4	3	14.2	4.3	4	4	3	6	3	2		1	20.2	16.8	5.9	14.0	8.3	1.3		7.6
Shrubs	Aspen				1	3	0.0	1.3	1				2	1		1	0.0				3.5	0.6		1.1
	Bl. spruce				4	4	2.2	3.9	1	1	2	5	1	4	3	2	0.2	2.0	0.2	6.6	1.8	4.6	4.8	4.3
	Jack pine				4	3	1.4	0.4	1	1	2	1	2	2	1		5.5	0.2	0.0	0.0	0.1	1.2	0.3	
	Paper birch				3	1	0.0	1.7	1	1		2	1				0.2		0.0		1.1	0.0	5.7	
	Amela aln				1	2	0.0	0.5	1				4		1		0.0				1.5		0.5	
	Amela san				3	4	0.2	0.5	6		3	1	2	2	1	2	0.6		0.1	0.0	1.4	0.2	0.2	0.4
	Arcto uva				3	3	2.0	4.4	5	1	4		1	4		3	3.6	0.3	3.9		1.2	13.5		3.0
	Cornu sto				2		0.1		2			2					0.5			0.1				
	Coryl cor					2		2.1					3			1					8.1			0.4
	Dierv lon				4	2	1.6	1.1	4	2	5	3	2			2	1.9	0.2	1.0	3.2	3.0			1.6
	Junip com				2	1	0.2	2.5	2		1				3		0.9		0.0					10.1
	Ledum gro				1	3	0.8	0.9	1				2		1	1	3.1				2.1		0.4	1.0
	Linna bor **	B	B	-1.4	4	2	1.5	0.1	5	2	1	5	5			2	1.0	1.3	0.3	3.3	0.4			0.0
	Prunu pen				3	1	0.1	0.8	1		2	1			2	3	0.0		0.3	0.1			2.0	1.2
	Rosa aci **	B*	B	-0.3	4		0.3		3	1	2	3					0.5	0.0	0.3	0.4				
	Rubus ida				1	2	0.1	0.0				2		1		1				0.3		0.1		0.0
	Salix spp				3	3	0.4	0.4	1		1	2	2		1	1	1.4		0.1	0.0	0.7		0.3	0.8
	Spira alb				2	3	0.0	0.7	2		3		1		2	1	0.0		0.1		0.1		0.9	1.8
	Vacci ang **	C	C	15.6	2	4	0.0	15.7		1	3		6	2	4	5		0.1	0.1		31.5	10.2	12.9	8.0
	Vacci myr				4	4	2.9	3.3	6	4	5	2	7	2	4	5	1.9	7.0	2.7	0.1	1.5	2.5	4.6	4.8
	Vacci vit **	C*	C	1.3		4		1.3					3	1	2	2					0.1	1.0	0.7	3.3
Herbs	Arali nud				2	2	0.4	0.7	5			6	4			3	0.6			1.1	1.1			1.8
	Aster cil				2	2	0.1	0.0			1	4	1			1			0.0	0.3	0.0			0.0
	Campa rot				3	1	0.0	0.0	2	2	2					1	0.0	0.0	0.0					0.1
	Clint bor				1	3	0.0	0.1				2	3		1	1				0.1	0.4		0.1	
	Cornu can				3	2	0.9	0.5	3		1	6				2	0.4		0.0	3.1	1.7			0.1
	Cypri aca				1	3	0.0	0.0	1				1	1	1		0.0				0.0	0.0	0.0	
	Epilo ang				3	4	0.1	0.1	1	1		4	1	2	2	1	0.0	0.0		0.2	0.1	0.3	0.0	0.1
	Fraga vir				3	2	0.9	0.5	5		2	6	1			2	0.4		0.7	2.4	1.0			1.0
	Galiu bor				2	1	0.0	0.0	2			1				1	0.1			0.0				0.1
	Goody rep				3		0.0		1	1		2					0.0	0.0		0.1				
	Lathy och **	B*	B	0.0	3		0.0		2		2	2					0.1		0.0	0.1				
	Lathy ven				3	1	0.1	0.0	1		1	2				1	0.2		0.0	0.1				0.0
	Maian can				4	4	1.5	1.0	5	3	4	6	7	4	3	4	1.4	3.0	0.6	1.1	2.8	0.6	0.4	0.3
	Melam lin				3	3	1.0	0.3	6	1	5		4		3	4	0.3	0.0	3.7		0.1		0.8	0.3
	Poten tri	B	B	-0.5	3	2	0.6	0.0	2	3	5		1			2	0.4	0.6	1.2		0.0			0.1
	Pyrol asa				3	1	0.0	0.0	1		1	1				1	0.0		0.0	0.1				0.1
	Rubus pub				3	1	0.2	0.0	1		1	6	2				0.0		0.0	0.7	0.1			
	Solid his				3	1	0.1	0.0	1		2	1			1		0.0		0.3	0.0		0.0		
	Trien bor				2	4	0.1	0.1	2			2	2	1	1	1	0.1			0.2	0.1	0.1	0.1	0.0
	Vicia ame				2		0.0				3	1										0.0	0.0	
	Viola adu				2	1	0.0	0.0		2	2					1		0.0	0.0					0.1
Graminoids	Agrop tra				2	1	0.0	0.0	1	1			2				0.0	0.0			0.0			
	Agros hye				2	3	0.0	0.0			1	2	1		1	1	0.0	0.0			0.0		0.0	0.0
	Carex spp				2	2	0.0	0.0		1	2		1		1		0.0	0.0			0.0		0.1	
	Danth spi				2	1	0.0	0.0	2		2					1	0.0		0.1				0.0	
	Oryzo asp				3	3	0.1	1.1	5		5	6		2	1	4	0.2		0.1	0.1		0.0	0.0	4.4
	Oryzo pun *	B	B	-0.1	4	3	0.1	0.0	4	2	5	3	1	3	2		0.1	0.1	0.2	0.1	0.0	0.1	0.0	
	Schiz pur				3	2	0.0	0.2	2		3	2	5			3	0.1		0.0	0.0	0.3			0.5
Bryophytes	Dicra spp	C		4.1	4	4	2.7	6.8	6	4	4	6	7	5	4	3	6.3	2.1	0.9	1.7	10.6	5.0	6.9	4.6
	Hyloc spl				2	1	0.7	0.0	3			4	1				2.5			0.1	0.1			
	Moss spp				4	4	0.9	1.4	6	2	4	5	6	2	3	5	0.3	0.1	0.6	2.6	1.9	2.3	0.1	1.4
	Pleur sch	B?		-17.0	4	4	39.1	22.0	6	4	5	6	6	5	5	5	66.9	30.1	40.6	18.6	17.7	29.2	26.1	15.1
	Polyt com				2	1	0.9	0.0			3	4				1		3.5	0.3					0.1
	Polyt jun *	B	B	-1.3	4	4	1.5	0.2	2	4	5	3	2	3	3	1	0.0	1.0	2.9	1.9	0.2	0.2	0.3	0.0
	Polyt pil *	B	B	-0.3	2	1	0.3	0.0		2	2		1					0.9	0.3		0.0			
	Ptili cri				2		0.0				1	3									0.0	0.0		
Lichens	Cladi mit				4	4	9.8	2.7	4	4	5	3	4	4	5	4	0.7	8.5	27.0	2.9	0.6	0.8	6.7	2.6
	Cladi ran	C	C	14.2	4	4	4.6	18.8	6	4	5	5	6	5	5	4	4.8	6.0	5.4	2.3	3.4	50.6	11.6	9.5
	Cladi ste	C		3.1	1	3	0.0	3.1	1				1	3	5		0.0				0.0	2.5	10.0	
	Clado spp				4	4	1.4	0.5	5	3	5	6	7	3	5	4	0.1	1.1	1.7	2.7	0.3	0.5	0.3	1.0
	Folio spp				4	4	0.6	0.3	1	4	5	3	7	3	2	3	0.0	1.2	0.7	0.3	0.5	0.1	0.2	0.4
	Fruti spp		B		4	4	0.4	0.0	3	4	4	1	6	1	2	1	0.1	0.2	1.2	0.0	0.1	0.0	0.0	0.0
Other	Confr litter				4	4	25.5	6.7									6.9	38.2	7.0	49.9	10.9	1.6	1.9	12.4
	Other litter				4	4	7.5	28.7									9.8	2.7	4.7	13.0	45.1	3.5	18.1	47.9
	Rock				4	4	2.4	2.2									0.6	2.8	5.4	1.0	0.7	0.3	5.5	2.3
	Snag *				4	3	0.0	0.3									0.0	0.1	0.0	0.0	0.3	0.2		0.5
	Trunk				4	4	0.3	0.2									0.5	0.4	0.1	0.3	0.6	0.0	0.0	0.1
	Wood				4	4	1.4	1.8									0.4	1.0	1.6	2.6	2.3	1.0	3.0	1.1

Affinity: B = burn, C = cut, * = exclusive to treatment. CV = species with high structure correlations in canonical variates analysis; MANOVA for trees. Diff. = mean cover/ basal area in post-logging Blocks minus mean cover/ basal area in post-fire Blocks. Species with significant differences in ANOVA; * = .10, ** = .05, *** = .01. See Appendix A for species codes. 0.0 <= 0.05, blank = not encountered.

SUMMARY

Sustainable use of the boreal forest requires that, among other things, logged areas recover to a species composition typical for the site conditions and that ecological processes are not adversely affected over the long term. To date, few studies have examined the long term impacts of logging on an entire plant community. The objective of this study was to determine how well naturally regenerating plant communities in the southern part of the central Canadian boreal forest recover from logging when compared with fire.

Sixty-five year old post-fire communities were taken to represent the typical mature state. Differences in species composition (species present and their abundances) were described for 13 and 37 year old communities on site types that included rock outcrops, shallow and moderately deep mineral soils and organic soils. Post-disturbance pathways of recovery were constructed by comparing the species composition of 13 and 37 year old post-fire and post-logging communities with 65 year old post-fire communities.

Four replicate burns or cutovers were randomly selected for all but one (where only 3 were available) of the five combinations of disturbance type and age class. Plots were located within each replicate using a combination of random and systematic methods. Quadrat, plot, subsample and sample sizes, along with site type categories, were established based on the results of a pilot study conducted during the summer of 1992. Information relating to understorey vegetation, trees, soils, topography and disturbance history was collected at each plot (2m * 3m understorey plot nested within a 5m * 5m tree plot). Each of the 413 plots sampled was placed in a site type category so that comparisons could be based on vegetation from similar site conditions.

Tests for treatment differences in species composition were conducted using MANOVA after the number of species was reduced by principal coordinates analysis. Percentage difference was used as the resemblance measure in principal coordinates analysis and to compare the species composition of 13 and 37 year old communities with 65 year old communities. Total species richness was not estimated due to concerns about sample size effects. The number of common species (species with a relative cover of at least 1%) was used to make treatment comparisons of species richness.

Many of the species present at the time of fire or logging are known to regenerate shortly thereafter. We found that, by the time the communities were 13 years old, most species which performed better in one treatment did so in post-logging communities. This was expected based on the research of others and was attributed to the less destructive effect that logging generally has on plants when compared with fire. Pioneer mosses (*Polytrichum* spp.), *Epilobium angustifolium*, *Smilacina trifolia*, jack pine and black spruce were the only species which performed better in 13 year old post-fire communities. An average of 12 common species was found across the four site types (14 in 37 year old communities). The number of Common species was higher in the 13 year old post-logging communities found on outcrops and shallow mineral soils.

By 37 years of age, most species performed better in post-fire communities. Reindeer lichens and several species of *Vaccinium* were the main exceptions. Logging resulted in different species being the most abundant.

The extent to which grasses and other herbs performed better in 37 year old post-fire communities (16 of 21 situations) was not expected and could not be explained. Logging may have had long term impacts on ecological processes which then led to differences in species composition by 37 years of age. The pattern of post-disturbance recovery supports this suggestion. That is, even though the species composition of communities was initially less affected by logging than fire, subsequent recovery appeared to be slower in post-logging communities. The well known difficulties which trees have regenerating in cutovers appears to also be true of some understorey species. Forest management planning should allow for the fact that post-logging recovery will be different from that after fire.