Fire History and Secondary Vegetation Succession in the Forest-Tundra near Churchill, Manitoba

By

Kimberly M. M. Monson

A thesis
Submitted to the Faculty of Graduate Studies
of the University of Manitoba
in partial fulfilment of the requirements for the degree of
Master's of Science.

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

Of

MASTER OF SCIENCE

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Abstract

Concerns about increasing CO_2 in the global atmosphere and how this may affect climatic patterns and ultimately the structure, composition and distribution of the northern boreal forest prompted an examination of secondary succession in a segment of forest-tundra south of Churchill, Manitoba. Fire is the main disturbance in the boreal forest and climate change is expected to have an impact on the frequency of fire and the area burned in these forests. By reconstructing the fire history of these forests, we can evaluate the potential effects a change in fire activity will have upon this landscape. In addition to our lack of knowledge on fire in the forest-tundra of Manitoba, little is also known about the response of the vegetation and forest stand dynamics following fire.

The fire history of the Churchill, Manitoba forest-tundra was reconstructed following the determination of the time-since-last-fire (TSLF) dates from 119 locations using dendroecological methods. The dates were used to create a TSLF map. A bootstrapping procedure was used prior to the fire frequency analysis. The point data used for the bootstrap analysis was coded by forest type (black spruce, white spruce and eastern larch). Area data from the TSLF map and frequency data from the bootstrap analysis were converted into 25-year age classes and used to produce reverse cumulative area/frequency distributions to assess possible changes in the fire-cycle. The fire-cycle for homogenous fire periods was calculated using 1) natural fire rotation (area data) and 2) fire frequency analysis fitted to an negative exponential model (area and frequency data). All forest groupings showed a change in the fire-cycle in the AD 1700's to

a longer fire-cycle. Using the natural fire rotation (NFR) the fire-cycle has changed from 345 years to 558 years at AD 1725. For the fire-frequency analysis fit to an negative exponential model, the fire-cycle has changed from 58 years prior to AD 1775 to 588 years after AD 1775. The time-since-last-fire map showed that recent fires (<100 years old) may be related to human activity and are confined to areas along the railway line and roads. Removing the sites along the railway increased the fire-cycle from 588 years to 714 years after AD 1775.

Post-fire succession in vegetation and stand structure change was assessed using a chronosequence. A total of 81 vegetation sites and 82 forest stands were analyzed. Braun-Blanquet cover analysis was used to determine vascular plant composition and abundance for each sample site. Environmental data were collected for all sites. Using canonical correspondence analysis (CCA), the vegetation and structural data sets and the environmental data set, were analyzed to better understand the succession process and to identify the variables that control the pattern of vegetation and forest stand structure on the landscape.

A total of five vegetation and three structural clusters were identified in the forest-tundra. No vascular plant species replacement was observed in any of the identified clusters. Distribution of the plants and forest stands was not related to the age of the forest. Environmental variables such as substrate, depth of the active layer, aspect and distance from the Hudson Bay were the main factors controlling vegetation distribution and stand structure in the forest-tundra south of Churchill, Manitoba.

This study suggests that the forest-tundra south of Churchill, Manitoba is a self-perpetuating system in the absence of fire and that a shift to a longer fire-cycle will not adversely affect the vegetation or structural characteristics of this forest ecosystem. If the fire-cycle is shortened because of climatic warming as suggested in many studies, the impact on the inland black spruce and eastern larch forests may remain minimal. Increased paludification, due to continued isostatic rebound, and permafrost and peat degradation could make this wet landscape even wetter controlling the areal extent and severity of the fires in these forests. The degradation of the peat and permafrost may however, contribute further to the effects of climatic warming on the fire-cycle of this area. The affects of a shorter fire-cycle on the white spruce coastal and upland forests could be devastating. Evidence from northern Quebec indicates that these white spruce forests may disappear completely and be replaced by open tundra.

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my bear guard, my fundraiser, my editor, my conspirator, my strength, my shoulder to cry on, and most of all my best friend.

Dedication

I dedicate this thesis to grandmother, Elsie McLaughlin Hamill for her belief that I was capable of doing whatever I put my mind to. I wish you had lived to share in my journey. You would have loved Churchill.

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1. Introduction

1.1 Climate change and forest fire

World-wide concern about climate change and how it may affect the forest landscape have had a profound impact on boreal forest studies. In light of Article 3.3 of the Kyoto Protocol (GCAP 2000) and its focus on carbon sinks, especially in forests, forest fire frequency has become a concern. In Canada it is agreed that climate change effects will vary at both regional and local scales, and it is also agreed that the most vulnerable regions and systems, such as the boreal forest, will undergo the greatest impact and have the least ability to adapt (Kasischke et al. 1995; CCPB 1998). Many believe that as our climate warms, as predicted by many of the General Circulation Models (GCMs), the fire-cycle length will shorten and fire frequency and/or the area burned will increase. Based upon predictions from the current climate models, an increased rate of forest disturbance (including fire), has been predicted (Clark 1989; Overpeck et al. 1990). Flannigan and Van Wagner (1991) predicted a possible 46% increase in burn area for the Canadian boreal forests under a 2 x CO_2 climate. This assumes that temperature will rise along with increasing CO_2 levels. A recent study by Weber and Flannigan (1997) has suggested that large regional variations are likely to occur and there is a danger in making sweeping generalizations. The boreal forest is expected to shift northward, under a 2 x CO_2 scenario (predicted by GCM) and it is also expected that the extent of the boreal forest in Canada will be significantly reduced (Rizzo and Wiken 1992). There is little information as to how the forest-tundra will be affected spatially other than suggesting that this

ecotone will be reduced in size. Predictions for Manitoba and Churchill are for longer warmer growing seasons, permafrost reduction, increased area burned due to changes in temperature and soil moisture and an overall increase in fire frequency (Weber and Flannigan 1997).

Instrumental data for Canada from 1948 to 2003 show a mean temperature increase of 0.8 °C and an overall increase in summer precipitation (Environment Canada 2003b). Data from the Churchill meteorological station showed an increase in mean temperature of 0.2 °C per decade since 1901 and of 0.4 °C per decade since 1976 (Environment Canada 2003a). This is in accord with the results presented by the Intergovernmental Panel on Climate Change (IPCC 2001).

Many proxy records in Canada showed a temperature increase since the end of the Little Ice Age (~AD 1850) (Kasischke and Stocks 2000), but surprisingly, the area burned in Canada showed a downward trend (Van Wagner 1988; Bergeron 1991; Bergeron and Dansereau 1993; Bergeron and Archambault 1993; Flannigan et al. 1998). Clark (1989) postulated that warming should have brought a decrease in the length of the fire-cycle, but studies from Quebec, Alberta and even Sweden are showing a general increase in the length of the fire-cycle over the last 150 years (Bergeron and Archambault 1993; Engelmark et al. 1994; Larsen 1997). This generally means that it takes more time to burn a surface equal to a reference area today than during the Little Ice Age. Bergeron and Archambault (1993) used tree-rings from northern white cedar (*Thuja occidentalis* L.) in the Lake Duparquet area in northwestern

Quebec, to reconstruct climate from the 1600's to present. The tree-ring data indicated slower growth rates between AD 1600 and AD 1850, followed by an upward trend for the next 100 years. Closer analysis of the dendrochronological record suggested a decrease in drought occurrence since AD 1850 and this seems to have had a profound affect on fire-cycle, mainly manifested in the absence of large catastrophic fires. This resulted in a change in the fire-cycle from 63 years before AD 1850 to 99 years after AD 1850 (Bergeron 1991; Bergeron and Archambault 1993). This pattern was also detected in Wood Buffalo National Park, northern Alberta by Larsen (1997). Again, using dendrochronology and calculating fire-cycle, Larsen (1997) found a change in fire-cycle in the past 300 years and, in particular, a significant change at AD 1860 to a longer fire-cycle (from 25-49 years to 59-89 years). This same pattern was detected in northern Sweden by Engelmark et al. (1994) in a study of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Pinus abies* Karst.). This study spanned 700 years and Engelmark et al. (1994) found a distinct increase in the length of the fire-cycle after AD 1870 (187 to 371 years). In all of these studies the possible relationship between the increase in fire-cycle and intentional fire suppression was ruled out, as the study sites were all in remote areas (Bergeron and Dansereau 1993; Engelmark et al.1994; Larsen 1997). The timing of the increase in fire-cycles in the boreal forests of northern Alberta, southern Quebec and in northern Sweden was attributed to synchronous climatic change occurring at the end of the Little Ice Age ~150 years ago (Larsen 1997).

Closer to the forest-tundra, Payette et al. (1989) studied fire in northern

Quebec and found that large fires were confined to the boreal forest proper while only small fires spread through the forest-tundra. Payette et al. (1989) found that the fire-cycle for the forest-tundra were very long (1460 years) and postulated that the natural fire-cycle length had changed markedly during the late Holocene from a shorter to a longer one induced in part by the decrease of shrub and conifer cover caused by climate change and fire.

1.2 Secondary succession

In the boreal forest and forest tundra, fire is one of the most important factors controlling vegetation structure and driving secondary succession (Jasieniuk and Johnson 1982; Morneau and Payette 1989; Fortin et al. 1999; Larocque et al. 2000; Payette et al. 2000; Niklasson and Granstrom 2000; Asselin et al. 2001).

In boreal forests, time-since-last-fire is considered the prime factor determining the pattern of vegetation recovery (Morneau and Payette 1989). Black spruce (*Picea mariana* (P.Mill.) B.S.P) is a fire-adapted tree species and studies have found that seedling establishment can begin the first year after the fire and continues for several years. Wein (1975) found that, six years following a fire in Inuvik, 22% of the black spruce seedlings were four years of age and 35% were five years of age. Although usually killed in fires, black spruce have semi-serotinus cones and Wein (1975) found that seed-fall continued for at least eight years following a fire. Thin bark, shallow roots and the frequent occurrence of lichens on its lower branches make black spruce particulary susceptible to fire. It is only at the very edges of fires or where fires creep slowly through the moss

mat that spruce may survive and leave a fire scar record (Viereck 1983). Cyclical succession (the same species present before the fire reappear after the fire) is often observed when fire occurrence is high (fire intervals are short). Where fire occurrence is low, directional succession (replacement of pioneer species by late successional species) dominates (Larocque et al. 2000). However, this pattern is not usually observed in forest-tundra. Jasieniuk and Johnson (1982) found, in northern Saskatchewan, that fire does not significantly affect stand composition but does affect change in species abundance with stand age. Jasieniuk and Johnson (1982) found that many cladinea species recover rapidly and obtain a high abundance soon after fire. Sirois and Payette (1991) argued that the ecological role of fire is very different in the forest-tundra, and that fire, if severe enough can shift the vegetation from forest to tundra. Generally though, fires in the forest-tundra kills only the surface vegetation and is not severe enough to destroy the peat to any depth (Jasieniuk and Johnson 1982).

Little has been published on secondary succession in the Canadian forest-tundra biome. Succession studies have focused on primary succession i.e., the dynamics of the forest-tundra explained through processes including terrestrialization and paludification (Ritchie 1957, 1962; Brook 2001). Paludification refers to the creation of a peat-lands by the drowning or submergence of upland habitats (Brook 2001).

Two main patterns of succession follow fire in black spruce forests in northern boreal areas (Viereck 1983). The first pattern, applies to the black spruce - feather moss type of forest. The black spruce - feather moss forest

tends to be re-vegetated initially by a herb stage that lasts one to four years, depending on site and fire conditions. It is during this stage that black spruce seedlings become established, usually peaking at eight years post-fire. Shrubs form the next stage of succession and originate from sprouts and shoots from underground unburned roots. This shrub layer will quickly dominate the vegetation although the herb layer will continue to increase. Mosses begin to establish during the shrub stage but will often be limited if the shrub cover closes and leaf litter becomes abundant. It is also during this stage that the first lichens will begin to establish themselves. The shrub stage of succession usually occurs from six to 25 years. At about 25 years the tree canopy begins to close. Young stands (40-60 years) can be dense and the tall shrub layer may start to thin out as the spruce become taller, but the low shrub layer continues to expand and increase in cover. It is at this stage that feather mosses and/or sphagnum mosses start to invade and recolonize. These mosses may develop to 50% cover during this stage of succession. As the moss cover thickens, colder soil temperatures are created and the permafrost layer re-freezes on many sites. Once the tree canopy is well established, changes to the vegetation are slower and more subtle. A forest over 100 years is considered mature (Viereck 1983).

The second pattern of succession is observe in the black spruce - lichen woodland (Viereck 1983). Following fire, the first stage (1-20 years), is dominated by the establishment of pioneer mosses. Crustose lichens may cover up to 20% of the ground and in some areas vascular plants can be important. The second stage of succession commonly occurs from 10-60 years and is

characterized by the invasion of, and dominance of, fruticose lichens. Feather-moss and low ericaceous shrubs may also become important. Once the forest reaches 100 years of age there is a general shift in lichen species to domination by *Cladina alpestris* and *C. rangiferina.* Tree density generally increases during this stage resulting in an increase in feather mosses. Post-fire chronosequence studies conducted in forest-tundra of northern Quebec (Morneau and Payette 1989; Fortin et al. 1999), in the Northwest Territories (Johnson 1981), in northern Saskatchewan (Scotter 1964) and in Labrador (Foster 1985), followed the black spruce-lichen woodland model described above. Morneau and Payette (1989) found that most species within the black spruce-lichen woodland re-established within the first years after a fire disturbance and that the vegetation structure remained virtually unchanged even 250 years after fire and that this forest type can persist during a long fire-free period through the asexual reproduction (layering) of black spruce.

In general though, regardless of black spruce forest type, the most common occurrence after a fire in black spruce stands is direct replacement by another stand with similar species (Johnson and Rowe 1977; Brook 2001). Many authors suggest that the term succession should not be used to describe the re-vegetation of these northern forests (Payette and Morneau 1993; Fortin et al. 1999; Brook 2001). Although there are some examples of conversion of black spruce to hardwood forest types (Viereck 1983), little information is available about the conditions required for this type of succession especially in the forest-tundra. It was suggested that this last type of succession may occur after

particularly intense fires which destroy the black spruce cones and provide a mineral soil surface for hardwoods to become established (Viereck 1983). Sirois and Payette (1991) found that sustained depletion of tree populations following repeated fires was a key process in the development of the forest tundra and that the long-term maintenance and stability of the forest-tundra is dependant upon low frequency of fires and the ability of the forest to reproduce asexually (layering).

Secondary succession studies involving white spruce (*Picea glauca* (Moench) Voss) in the forest-tundra are rare. In the boreal forest, white spruce is considered a late-successional species, and tend to follow aspen and jack pine (Larsen 1997; Bergeron and Dubuc 1989). Foote (1983), working in boreal white spruce forests in Alaska, found a sequential dominance by herbs, shrubs, deciduous trees and finally white spruce after fire disturbance. Larsen and MacDonald (1998) reconstructed an 840-year record for fire and vegetation in a white spruce boreal forest near Rainbow Lake, Wood Buffalo National Park in northern Alberta. The vegetation dynamics from the study showed a predictable post-fire sequence of herbs to shrubs to deciduous trees and then to white spruce (Larsen and MacDonald 1998). A recent study by Parisien and Sirois (2003) along the James Bay coastline in northern Quebec where the white spruce forms a maritime tree-line, suggested that white spruce is the climax species in a primary succession sequence of colonization of the newly exposed land along the coast (a result of isostatic rebound). Parisien and Sirois (2003) considered the white spruce a relic feature and suggested that the persistence of

white spruce was due to low fire occurrence and favourable soil conditions.

No studies were found on secondary succession patterns in eastern larch (*Larix laricina* (Du Roi) K.Koch) in the northern or subarctic boreal forests of Canada.

1.3 Fire history concepts

Given the above studies it appears that the physiognomy of the boreal forest and the forest-tundra at any given time is a function of fire regimes [e.g. fire intensity, frequency, seasonality, size, type (crown versus surface), and severity (depth of burn)] (Weber and Flannigan 1997). It is therefore fire regimes, including fire frequency and size, that control the extent of the boreal forest and forest tundra (Sirois and Payette 1989, 1991) and drive secondary succession (Larocque et al. 2000; Asselin et al. 2001). Thus reconstruction of fire histories (fire dimensions and frequencies) for these northern biomes is an important step in documenting and interpreting the development of coniferous forests (Payette et al. 1989) and will provide a benchmark to analyze future impacts of climatic change.

In the boreal forest most trees become established within 8 years following a fire (Sirois and Payette 1989). This relationship allows the time-since-last-fire (TSLF) for a site to be inferred from the ages of the trees in a stand (Larsen 1996). By combining the TSLF and fire-related patterns on the landscape (through the use of aerial photos), a TSLF map can be created (Johnson and Gutsell 1994). The map is then used to extract the spatial information needed for the calculation of fire frequency and fire-cycle length.

These calculations allow characterization of the fire-cycle and allow for comparisons to other forested regions.

To understand how fire histories are reconstructed one needs to be familiar with fire history terminology. The definitions provided here are from Johnson and Gutsell (1994). Fire frequency is equal to the average annual probability of a site being burned. Fire-return interval is the number of years between two successive fire events at a specific site or an area of a specified size. The fire-cycle is a calculation of either, a fire-return interval calculated using a negative exponential (or Weibull) distribution and applied using the cumulative age-class distribution on the landscape or, an arithmetic average of all fire-return intervals for a specific study area, for a specific interval of time. The fire-cycle can also be described as the number of years required to burn an area equal in size to the study area (Johnson and Gutsell 1994).

Two basic mathematical models are usually used to characterize the fire-cycle of an area: 1) the negative exponential and 2) the Weibull models. Johnson and Van Wagner (1985) clearly outlined the difference between the models. The Weibull model includes a "shape parameter" that describes a 'hazard of burning' parameter. The Weibull model suggests that the hazard of burning increases with the age of the forest, while the negative exponential model contends that a forest of any given age has the same probability of burning (random selection). Its worth noting that when the shape parameter =1, the Weibull model is the same as the negative exponential model and thus the negative exponential model can be considered a special case of the Weibull model (Johnson and Van

Wagner 1985). Both the Weibull and negative exponential models apply to homogenous stochastic processes.

Fire history analysis using these models is based upon a number of assumptions (Johnson and Van Wagner 1985). The models assume that: 1) the whole study area had the same fire regime (fire frequency, size, and intensity) and 2) the fire regime, on average, was constant during the time span of the study (Johnson and Gutsell 1994). The first assumption is often compromised where there has been some level of fire suppression within the study area. This scenario would not fit any model that assumes stability of the fire regime. The easiest way around this problem is to partition the study area into suppressed and not-suppressed areas and/or time frames. The stability criteria is then met. The second assumption can be more problematic. The assumption that the fire regime has not changed, in light of what we know about climatic variation in the past, is often not true for study area unless the study confines itself to a short time frame (less than 400 years) (Johnson and Van Wagner 1985).

The process of creating a time-since-last-map, and the statistical models used in this project and other methodological and statistical processes, will be discussed later (see Methods).

1.4 Subarctic Manitoba

Little is known about the fire-cycle for the Churchill area (Sims et al. 1979). Most studies done on fire in the tundra-forest have been done in other areas such as Quebec (Payette et al. 1989; Parisien and Sirois 2003), Alberta (Larsen 1997), Alaska (Viereck 1983), North West Territories (Johnson and

Rowe 1977) and in northern Europe (Engelmark et al. 1994; Niklasson and Granstrom 2000). In Canada, black spruce forests have been highlighted as the most widely distributed stand type and most likely to burn (Viereck 1983). The natural fire regime of the boreal forest, in it's broadest sense, can be characterized as one of high-intensity crown fires. The fires are usually large due to the types of forest, continuity of fuels and the climatic conditions. The fire rotation time is relatively short, 50-100 years, in much of Alaska and western Canada but may increase to 500 years or more in the wetter section of eastern Canada (Viereck 1983). This general estimate of fire-cycle may hold true for many areas in northern Manitoba, such as Thompson, where the fire-cycle maybe 70 years (personal communication, C. Elliot, wildlife manager, Manitoba Conservation, June 2001). The fire-cycle for the Churchill area is unknown.

Regarding plant succession, Shelford and Twomey (1941) spent time in the Churchill region examining plant communities and developing a model of succession where all the lands in the area eventually developed into bogs. This model has been since dismissed as it does not explain the presents of climax fens, tundra or forest found in the region (Scott 1998). Ritchie (1957) also worked on succession in the Churchill area, but his work was confined to the tidal flat areas of the Hudson Bay. Brook (2001) looked at succession on a broad landscape level and concluded that there was a strong moisture-nutrient gradient related to the spatial distribution of fens, bogs and upland vegetation types. Brook (2001) also concluded that the moisture-nutrient gradient was controlled by isostatic rebound and distance from the Hudson Bay coast.

1.5 Objectives

This study addressed two broad questions. The first question focused on fire history. Little is known about the fire history of the Churchill area and even less is known about the potential impacts of climate change on the fire-cycle for this area. This study will determine the fire-cycle of the study area, and compare it to other boreal and forest-tundra areas of Canada. The study looked for the well-documented decrease in fire frequency found in northern hemispheric forests at the end of the Little Ice Age (~1850 AD) (Bergeron 1991; Dansereau and Bergeron 1993; Engelmark et al. 1994; Larsen 1996, 1997; Bergeron et al. 1998; Niklasson and Granstrom 2000). The second question focused on secondary forest succession. Our objective was to determine whether there were significant changes in vegetation and/or forest structure along a post-fire chronosequence.

There were two main objectives to this study:

1. To reconstruct the fire history of the forest-tundra immediately south of Churchill, Mb.
2. To characterize the post-fire vegetation and structural succession occurring in this forest-tundra.

It was predicted that:

a) there was an increase in the length of the fire-cycle at the end of the Little Ice Age (AD ~1850) consistent with what Bergeron et al. (2001) in Ontario and Quebec, Payette et al. (1989), in northern Quebec, Larsen (1997) in northern Alberta, and Engelmark et al. (1994) and Niklasson and

Granstrom (2000) in Sweden, have found in the boreal forest.

b) there was no change in vegetation structure and composition with increased stand age. It was expected that the succession pattern in the forest-tundra in Churchill area would not differ from the patterns observed in the forest-tundra by Jasieniuk and Johnson (1982) in the Northwest Territories, Payette et al. (1989) in northern Quebec and Brook (2001) in northern Manitoba.

To date, little is known about the fire history and secondary succession in the forest-tundra of this region. This study will add much-needed knowledge about secondary succession in the white spruce, black spruce and eastern larch forests of the Hudson Bay lowlands and the role fire disturbance plays in these forest-tundra communities. This study also provides bench-mark information for the land managers of the area, upon which future change can be monitored.

2. Methods

2.1 Study area

The study area is located in subarctic Manitoba about 1007 km north of Winnipeg. The focus of the study is the forest tundra south of Churchill, Manitoba, 58^0 20' to 58^0 40' N and 93^0 20' to 94^0 20' W (Figure 1). The study area lies within the Hudson Plain ecozone on the western coast of the Hudson Bay, referred to as the forest-tundra (Zoladeski et al. 1995). The forest-tundra forms a transitional boundary between the true boreal forest to the south and the tundra to the north (Ritchie 1962).

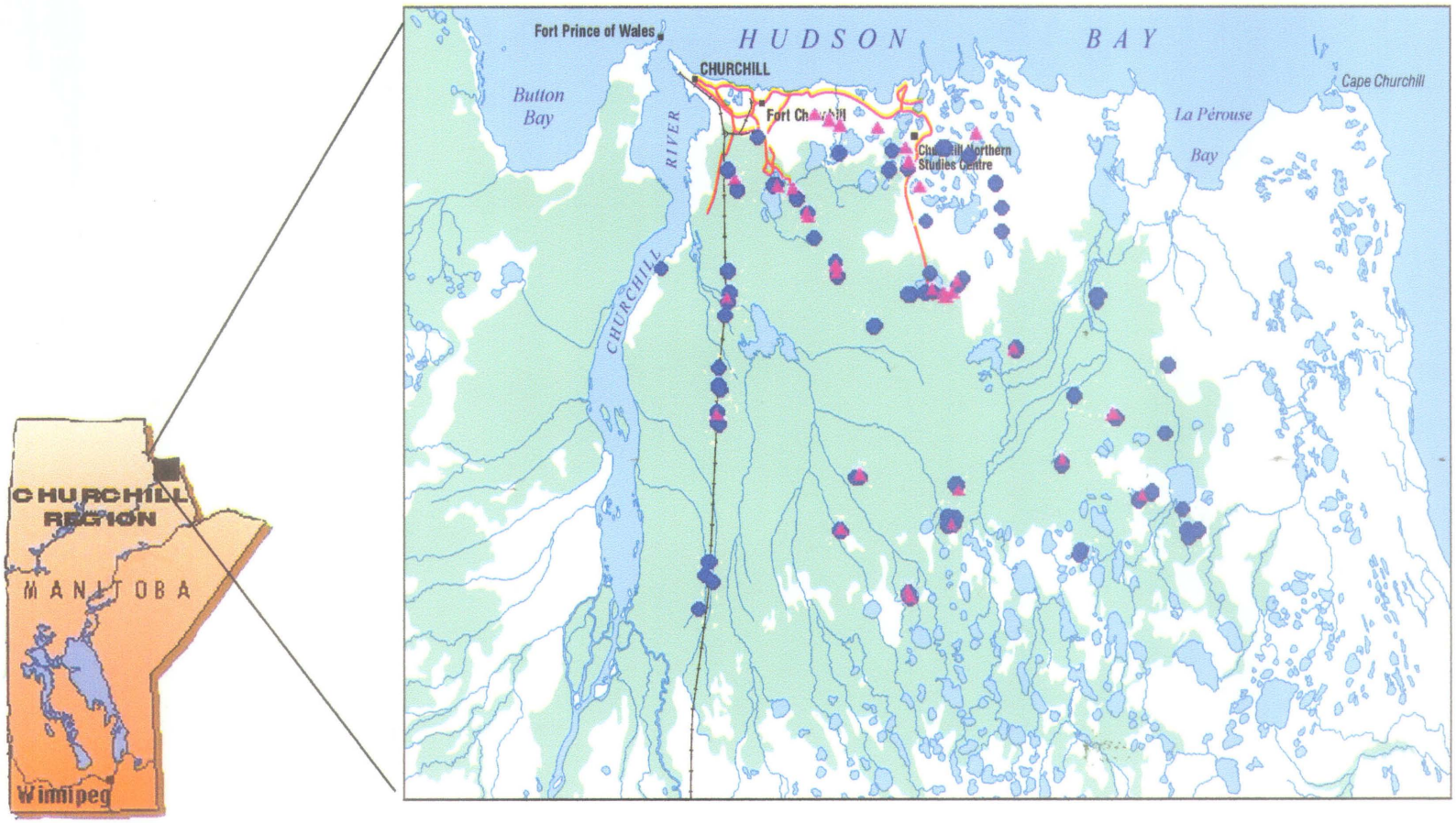

Figure 1. Map of the study area, south of Churchill, Manitoba. The blue circles indicate sample sites and the pink triangles indicate checkpoints. Roads are represented by red lines and the railway by a black line.The forest-tundra is green. The white areas indicate non-forested lands.

Ancient bedrock of the Precambrian, Ordovician, and Silurian underlies the entire study area (Dredge and Nixon 1992). These bedrocks are covered by glacial tills of the Pleistocene age or by marine deposits from the Holocene.

During the Pleistocene epoch the study area was covered by the Wisconsin glacier, which was 1.5-3 km thick. The weight of the glacier depressed the Hudson Bay Lowlands region by approximately 600 vertical meters (Dredge and Nixon 1992). Following deglaciation (approximately 7800 years ago), the entire study area was covered by the Tyrell Sea. The land rapidly began emerging from the sea, immediately following deglaciation, rising approximately 0.5 m per century due to isostatic uplift creating a landscape of shallow inland peat-lands separated by "fossil" beach ridges, which once occurred on the shores of Hudson Bay.

The entire study area is uniformly low (<50 m elevation) and flat, forming a vast wetland adjacent to Hudson Bay (Dredge and Nixon 1992). The relief has been significantly affected by post-glacial marine submergence and up-warping of its surface, resulting in an extensive pattern of raised beaches. All rivers drain eastward through this area into the Hudson Bay and have little affect on the local drainage. Drainage over most of the landscape is extremely poor and chaotic in pattern, controlled partly by relief and partly by the continuous permafrost that in many places is more than 80 m deep (Dredge 1992). Organic cryosols occur on fibric sphagnum peat plateaus and organic mesisols are associated with fens. The poorly drained areas support sedge-moss-lichen covers, while the better-drained sites are covered by open coniferous woodlands.

Hudson Bay has a dominant influence on the marine subarctic climate of the region (Rouse 1991). The closest meteorological station is Churchill, MB, immediately north of the study area. The 1971-2000 mean annual temperature for the Churchill area was -6.9^0 C (Environment Canada 2003). Annual precipitation was 431.6 mm at Churchill, with about 40% of the precipitation occurring as snow (Environment Canada 2003). The prevailing winds are from the northwest year round. The Hudson Bay is usually ice-free from mid-June to mid-November (Dredge 1992).

Ritchie (1962) originally mapped and described the plant communities of the Hudson Bay Lowlands using a combination of air photos and ground survey. Recent studies have since refined the vegetation communities (Rubec and Pollet 1980; Zoltai and Vitt 1995; Brook 2001). The study area is dominated by three tree species: white spruce, black spruce and eastern larch, which are associated with different communities of arctic, subarctic and boreal shrubs and herbs.

White spruce communities are found exclusively on well-drained sand or gravel ridges in the forest-tundra or, at the junction of sand and rock at the northern tree-line of the study area (Johnson and Fryer 1987). Other than descriptions of the associated shrubs and herbs, there is little in the literature dealing with fire history or secondary succession in white spruce stands. Brook (2001) suggested that the white spruce forest undergoes a somewhat unique burn and regeneration process due to its mineral, rather than organic, substrate. Brook (2001) stated that this type of forest is highly susceptible to fire with its open-canopy, erect, woody, shrub and often-dry lichen cover. Brook (2001)

suggested the forest is dominated by pioneering herb species such as *Epilobium angustifolium* (L.), *Corydalis sempervirens* (L.) Pers. and *Calamogrostis neglecta* (Ehrh.) Gaertn, along with low shrubs such as *Ledum groenlandicum* (Oeder) and *Betula glandulosa* Michx. in the first five years after a burn.

The black spruce communities are referred to as "black spruce muskeg" by Ritchie (1962) and "heath treed bog" by Brook (2001). Black spruce is the predominant tree species of the study area. The ground cover is dominated by sphagnum moss over peat deposits. The shrub cover is usually composed of *Ledum groenlandicum* and *Ledum decumbens* (Ait.) Lodd. with *Rubus chamaemorus* (L.) as the dominant herb. The black spruce forests are highly susceptible to fire. Fire kills the surface vegetation but usually does not burn into the peat. Post-fire regeneration is not well documented although Brook (2001) suggested that the succession is in the form of regrowth of the original vegetative cover, starting with the shrubs, followed by sphagnum. Black spruce starts to re-colonize after 10 years.

Eastern larch grows freely throughout the study site in association with both black and white spruce. Pure eastern larch forests are confined to the fen areas with water levels at or near the surface. The trees are usually found on hummocks that form in this type of landscape (Ritchie 1962). Brook (2001) suggested that fire is not a significant disturbance factor in these forests.

The study area is unique in that it has only been minimally impacted by human activities and this activity is limited to hunting and trapping. This area is not commercially logged, most fires are naturally caused (by lightning) and no

fire suppression is practiced.

2.2 Study site layout and sampling site selection

The study area was divided into a systematic grid, based upon UTM squares, providing eighteen 10 x 10 km cells. Air photos were reviewed to choose the sites within each cell. A helicopter survey was used to refine site selection. Sites were specifically chosen that showed visible signs of structural change (height and species), indicating possible changes in the age of the forest (Payette et al. 1989). Site selection also had to be adapted to areas the helicopter was able to safely land. At each site, samples were collected for fire history reconstruction and succession analysis. Checkpoint sites were sampled contiguous to or between the sites to help determine if there was a change in forest age. Where there was a distinct change in forest age, another site was sampled. Locations, determined by a hand-held GPS (Garmen III Plus®), were recorded for each site and checkpoint. A total of 83 sites and 36 checkpoints were sampled over two field seasons (Figure 1). Site and checkpoint locations were highly influence by access and weather.

2.3 Fire history data collection

For each of the 83 sites selected, tree cores and disks were collected to reconstruct fire history (Payette et al. 1989; Engelmark et al. 1994; Bergeron et al. 2001) and to support the vegetation succession portion of this study.

At each site, 8-10 trees were sampled within 50 metres of the vegetation quadrat (see section 2.5). Cores were collected using increment borers. Two cores were removed from the base of each tree, as close to the ground as

possible and perpendicular to each other on the tree trunk. The cores were stored in straws and labeled. When appropriate, whole disks were collected from living trees to ensure whole tree-circuits can be traced to better identify missing rings and to better date fire scars. Disks and cores were removed from the base of the tree, to limit improper age interpretation (DesRochers and Gagnon 1997). Fire-scarred trees were preferentially sampled when present, because they provided an absolute date for past fires. Fire scars occur when heat kills part of the tree cambium and are easily recognized by a triangular-shaped scar at the tree base (Arno and Sneck 1977).

The area within ~100 m of the site was then searched for snags (dead standing trees) and for carbonized wood. Snags, often the result of previous fires (especially if they are charred), can potentially help extend the master tree-ring chronology and fire history, for time periods pre-dating living trees (Payette et al. 1989). Carbonized wood, not only provides evidence of fire but, when crossdated and aged can also provide approximate fire dates.

A series of checkpoints were sampled to help extend information on the forest age. Checkpoints were often sampled contiguous to sample sites or between two sites (whenever there was a change in vegetation or stand structure). Two to five living trees and one to two snags were collected from each checkpoint. A visual inspection of tree cores and disks in the field would provide an estimated age of the checkpoint. If there appeared to be a distinct change in stand age, a full site was designated and a vegetation quadrat was set up and sampled. The number of cores and disks would then be increased accordingly

(minimum 8 living trees in total). Tree cores and disks from snags were collected from all 83 sites and 36 checkpoints.

2.4 Dendrochronological data

2.4.1 Construction of chronologies

All cores and cross-sections were prepared following standard dendrochronological methods (Stokes and Smiley 1968). Cores were glued into core holders, allowed to dry and then sanded using progressively finer grits of sandpaper (80, 150, 210, 320, 400, and 600). All the tree cores and cross-sections were aged by tree-ring counts and visual crossdating using a binocular microscope. Crossdating is the procedure of matching ring-width variations and other structural characteristics among trees that have grown in nearby areas, allowing the identification of the exact year in which each ring was formed. To facilitate the crossdating of cores and cross-sections collected in the first field season, an initial set of standardized reference chronologies were constructed using tree-ring data collected by Schweingruber (2003) from the Churchill region for black spruce, white spruce and eastern larch. This data was available on line from the International Tree Ring Data Bank web site. Skeleton plots were also constructed for each species by visually crossdating the tree cores and disks using a method adapted from Yamaguchi (1991) to identify pointer years, such as light, wide or narrow rings. Crossdating was facilitated by the presence of many pointer years, in particular light rings in both black and white spruce (Filion et al. 1986). The most notable pointer years were 1815,1817 (Figure 2), and 1836. It was rare to find light rings in the eastern larch and the crossdating of

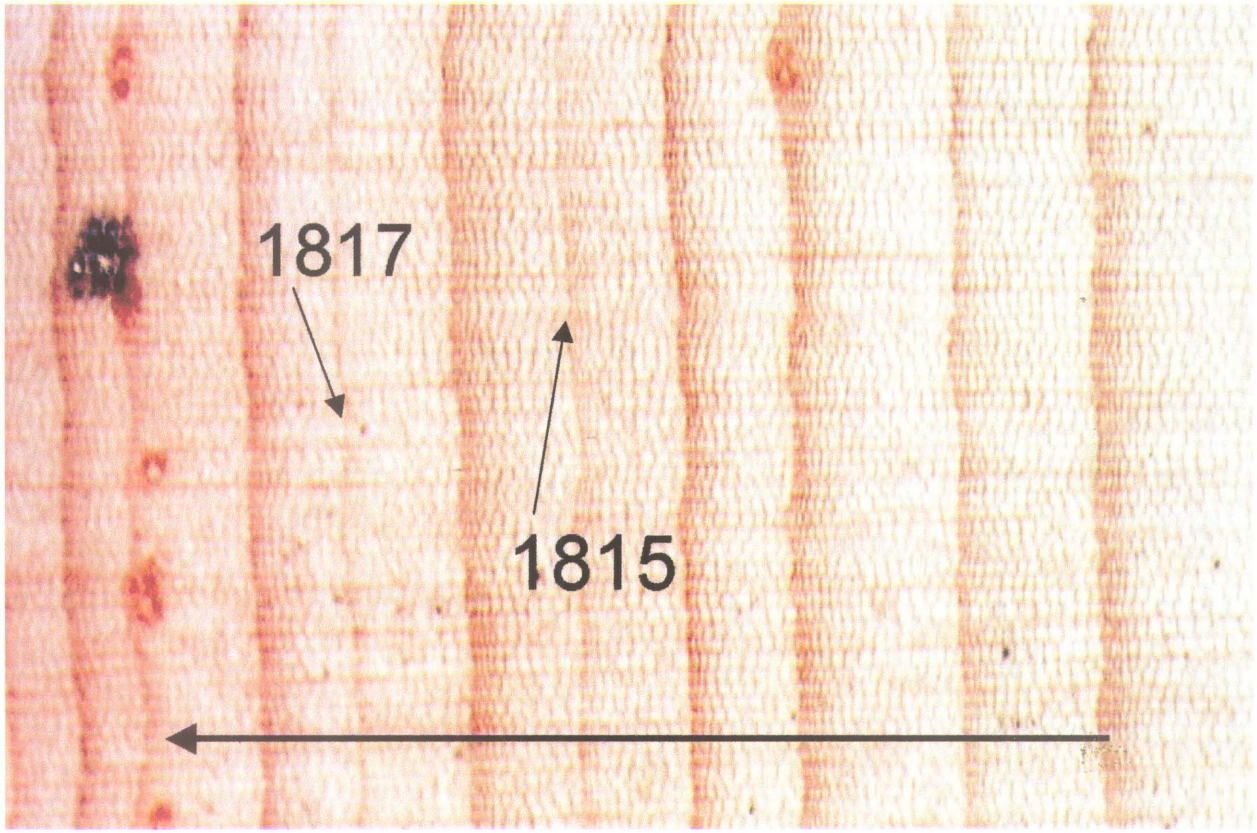

Figure 2. Example of pale latewood in white spruce from Churchill, Manitoba region, AD 1817 and AD 1815. The direction of growth is indicated by the arrow.

eastern larch relied upon ring-width patterns. Once the cores and disks were crossdated, the rings from the oldest tree from each site was measured to 0.01 mm, using a VELMEX® measuring system interfaced with a computer, to create a reference chronology. In the 2001 samples, two radii from the oldest tree of each species from each site were measured whereas in the 2001 samples, two radii were measured only from the oldest tree from each site.

Crossdating was further validated using the program COFECHA, which calculates cross correlations between individual ring series and a reference chronology (Holmes 1992). The three reference chronologies were constructed using ARSTAN (Cook 1985; Holmes 1992). The reference chronologies were then used to help date all the snag cross-sections collected. The three chronologies are presented as standardized indices with a mean of one (Figure 3). Standardization was performed by detrending the tree ring series to remove the affects of age and other undesired growth trends.

The VELMEX measuring system was also used to measure the ring widths for disks and cores that could not be dated through visual crossdating. Once the undated tree core or cross-section was measured, COFECHA was used to compare the ring-width patterns with the reference chronology for the species and provide possible dates. Cores or cross-sections would then be visually crossdated using the dates provided by COFECHA.

Of the ~2000 cores and disks examined for crossdating, only 64 (all snags) could not be crossdated, most of them due to the presence of extensive compression wood.

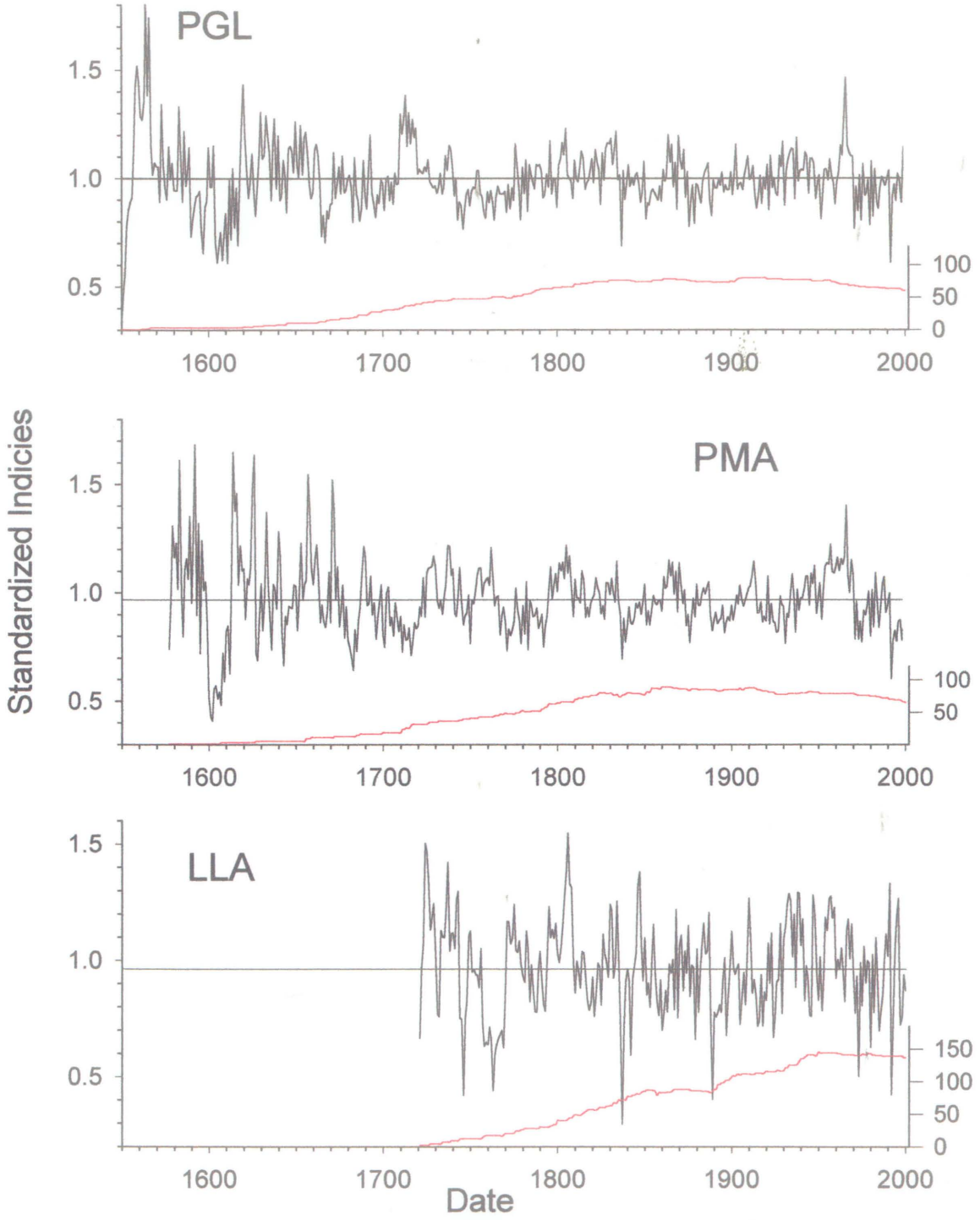

Figure 3. Standardized chronologies for Churchill, Manitoba. The red line indicates the number of series used to create the chronologies. PGL = white spruce, PMA = black spruce, and LLA = eastern larch.

2.5 Vegetation data collection

The vegetation data was collected between June 2 - July 10, 2001 and June 19 - July 24, 2002. In each of the 83 selected stands, one 10 x 10 metre quadrat was set up for vegetation sampling and for each quadrat a plant list was prepared. Unknown plant species were collected for later identification in the laboratory. The species nomenclature for this study follows Porsild and Cody (1980) for the vascular plants and the pteridophyta (fern allies). Vitt et al. (1999) was used as a guide to classify the bryophytes and lichens. No attempt was made to identify the genus or species of the mosses or lichens. The lichens were divided into four broad categories: Li1 - crustose lichen, Li2 - foliose lichen, Li3 - fruiticose lichen and Li4 - unknown lichens. The mosses were divided into three categories: sphagnum spp, feather moss spp, and moss spp. Each vascular and non-vascular species (or category) was assigned a cover value according to the Braun-Blanquet cover analysis (5 = 75-100%; 4 = 50-75%; 3 = 25-50%; 2 = 5-25%; 1 = 1-5%; + = <1%; and *r* = <<1%; Barbour et al. 1987).

In each of the quadrats, the height (in metres) of the all trees >1.0 m tall was measured with a survey rod and recorded. Trees with heights <1.0 m tall were recorded as 1.0 m. The diameter at breast height (DBH, in cm) was measured for all trees with a height >1.3 m tall. A value of 0.5 cm DBH was assigned to all living stems with a heights <1.3 m tall. Standing snags within each quadrat were measured for DBH only (often the tops of the snags were missing) and identified to species when possible.

2.6 Environmental data collection

In addition to the vegetation information, environmental variables were measured at each of the 83 sample sites (Table 1). The depth of the active layer was measured with a metal probe. Where the permafrost could not be detected, a value of one metre was used as a default. Soil type was recorded as a binary variable, organic (1) or not (0). Cover values were assigned to surface water, bare ground, downed woody debris, standing snags and rock on the surface using the Braun-Blanquet cover analysis. The slope of the site was determined using the clinometer in a Silva® compass and recorded to the nearest 5°. Aspect of the site was designed by direction (N, NE, E, SE, S, SW, W, NW) and by shape (concave or flat) and recorded as binary variables (0 or 1). A small pit (½ m x ½ m) was excavated to determine the substrate immediately below the surface vegetation. In areas with a deep active layer (>1 metre) the substrate was recorded as either sand, silt/clay, or rock. If permafrost was encountered within 1 metre of the surface the substrate was recorded as permafrost. Drainage was recorded for each site based upon a modification of the Ontario Institute of Pedology classification system (OIP 1985). One of three drainage classes were assigned to each site; 1 - well drained, 2 - imperfect, poor, and 3 - very poor. Soil or sub-surface water (in the case of organic soils) was used to determine pH. When possible the pH was measured in the field with a Palintest Universal pH kit from sub-surface water. If water could not be sampled, a soil sample was collected and returned to the laboratory for analysis using a soil paste method (soil and 0.1 M calcium chloride solution in a 1:3 soil to liquid

Table 1. Environmental factors measured for each of the 83 sites.

Environmental Factors	Data type
Depth of active layer (m)	Quantitative
Organic soil (0 or 1)	Qualitative
Surface water %	Quantitative
Bare ground %	Quantitative
Downed woody debris %	Quantitative
Snags %	Quantitative
Rock on surface %	Quantitative
Slope (degrees)	Quantitative
Aspect- N (0 or 1)	Qualitative
Aspect- NE (0 or 1)	Qualitative
Aspect- E (0 or 1)	Qualitative
Aspect- SE (0 or 1)	Qualitative
Aspect- S (0 or 1)	Qualitative
Aspect- SW (0 or 1)	Qualitative
Aspect- W (0 or 1)	Qualitative
Aspect- NW (0 or 1)	Qualitative
Aspect- concave (0 or 1)	Qualitative
Aspect- flat (0 or 1)	Qualitative
Substrate - sand (0 or 1)	Qualitative
Substrate - clay/silt (0 or 1)	Qualitative
Substrate - rock (0 or 1)	Qualitative
Substrate - permafrost (0 or 1)	Qualitative
Drainage (1 - 3)	Semi-Quantitative
pH	Quantitative
Charcoal in soil (0 or 1)	Qualitative
UTM1- northing	Quantitative
UTM2 - easting	Quantitative
Age1 - oldest living tree age	Quantitative
Age2 - youngest living tree age	Quantitative
Age3 - mean age of living trees	Quantitative
Age4 - interval between oldest and youngest living tree	Quantitative
Age5 - age of last cohort	Quantitative
Age6 - age of oldest tree (living or snag	Quantitative
Age7 - number of cohorts	Quantitative
Age8 - last disturbance	Quantitative

ratio; Scott 2003). The soil slurry was allowed to settle 30 minutes before the pH was recorded. Presence or absence (0 or 1) of charcoal in the soil was also recorded for each site. If significant amounts of below-ground charcoal was found, a sample was collected for possible radio-carbon testing at a future time. The geographical location for each site was determined using a hand-held GPS in UTM-83 units. The easting was recorded as UTM1 and the northing as UTM2. Ancillary ecological details were recorded in field books for each site.

To assess the stand age and time since disturbance for each site a series of age categories were created (Table 1). The age information for each site was extracted from the trees and snags sampled for the dendrochronological portion of this study (see Methods, section 2.4). Eight age categories were created. Age1 represent the age of the oldest living tree on the site. Age2 is the age of the youngest living tree on the site. Age3 is the mean age for each site while Age4 is the age range between the oldest and youngest living tree. Age5 is the age of the oldest tree from the youngest cohort (or oldest living tree if no obvious cohort is present). A cohort, for the purposes of this study, was defined as trees that cluster within 30 years of a given date. The cluster will contain at least 30% of the living trees from a given site. Age6 is the age of the oldest tree on the site (includes living and snags). Age7 is the number of cohorts on a given site and can provide information on disturbance regimes. Age8 is the estimated date of the last disturbance for each site. Age8 is derived from information that includes cohort dates, fire scar dates, radial growth suppression and release as well as stand initiation dates. If no cohorts, fire scars, radial growth suppression or

release were present in the trees samples for the site, the age of the oldest tree was used as the minimum date of the last disturbance. The oldest snag age was used only if the life of the snag overlapped with living trees on the site.

2.7 Fire history reconstruction

The time-since-last-fire (TSLF) date for each site (see Age8 in Methods 2.6) was used for the fire history reconstruction. TSLF was derived from information that includes cohort dates, fire scar dates, radial growth suppression and radial growth release, and stand initiation dates (Arno and Sneck 1977; Bergeron 1991). Fire scars provide absolute fire dates (non-censored), but were rarely found in our study area. When found, fire scars were only used if two or more trees in a given site had a fire scar of the same age (Dansereau and Bergeron 1993). The date of the fire was determined by crossdating the scar, following Arno and Sneck (1977). The year of the scar formation was determined in most cases by the dramatic change in growth occurring after the fire. When fire scars exist, the fire event is dated by counting the number of annual growth rings between the bark and the fire scar (Arno and Sneck 1977). As mentioned above, fire scars were rare and for most sites TSLF was estimated by the age of the oldest living tree (Van Wagner 1995). On some sites, tree ages were clustered into cohorts and the oldest tree in the youngest cluster (cohort) was used as the TSLF (Johnson and Gutsell 1994; Larsen 1997). When charred snags were available, TSLF was estimated by the date the trees died. If the TSLF date was derived from a fire scar, the date was considered a non-censored date providing an absolute fire date. All other fire dates were censored dates and

provided a minimum time-since-last-fire date. A total of 119 fire dates, pertaining to 119 locations (83 sites and 36 checkpoints) were extracted from the dendrochronological analysis of the tree cores and disks . Eleven of the fire dates were non-censored (from fire scars) and 108 dates were censored (minimum TSLF). Only the time-since-last-fire data will be analyzed here.

2.7.1 Fire mapping

A TSLF map records the occurrence of the most recent fire in each unit of the landscape of a study area (Johnson and Gutsell 1994) and is often used to calculate the natural fire rotation (or fire-cycle) for a given area (Heinselman 1973; Johnson and Gutsell 1994).

The standard method of constructing a TSLF map involves extracting fire boundary information and ultimately fire area from aerial photographs. The age of each fire is determined from historical fire records and/or ground surveys for fire scars (non-censored) or from maximum stand origin age (censored) (Heinselman 1973; Johnson and Gutsell 1994).

Poor aerial photo coverage of the Churchill forest-tundra made the construction of a traditional TSLF map impossible. To solve the problem, our TSLF map was created with ArcView® using the assigned proximity analysis function. The TSLF date for each of the 119 sites were assigned to 25-year classes starting from AD 1525. The fire dates were grouped into 25-year age classes to take into consideration the active period of seed regeneration in white and black spruce after a fire (Morneau and Payette 1989). Thiessen polygons were calculated by ArcView® using the assigned proximity analysis. The output

is represented as a grid theme in which each cell contains the value of the feature that it is nearest to, essentially using the mid-distance between two sites with different fire years (Gauthier et al. 2002). Once the map was created, area data was extracted for fire-cycle analysis.

2.7.2 Fire-cycle analysis

The fire-cycle is defined as 1) the length of time required to burn an area equal in size to a specified area or 2) a fire-return interval calculated using a negative exponential (or Weibull) distribution, applied using current age-class structure on the landscape (Heinselman 1973; Agee 1993; Johnson and Gutsell 1994).

To calculate the fire-cycle either frequency data or area data are needed (Heinselman 1973; Johnson and Gutsell 1994). For this study the area data was produced through the construction of a TSLF map (see methods section 2.7.1) and the frequency data was determined by bootstrapping the 119 TSLF dates extracted from the dendrochronological analysis (Age8). Bootstrapping is a re-sampling method that was used to reduce the possible bias of over-sampling in accessible areas and under sampling inaccessible areas. Using a spatially constrained grid of 18 units, one TSLF date was randomly selected from each unit and this was repeated 10,000 times. The resulting data provided us with a mean frequency distribution of stand age over the period AD 1525 - 2002 for the forest-tundra study area. The bootstrap program was written by Dr. Scott Forbes, University of Winnipeg, Biology Department. The TSLF dates (used for the bootstrapping process) were also coded by forest type (white spruce PGL, black

spruce PMA, or eastern larch LLA) based upon information from the vegetation analysis (see methods section 2.8). Coding of the data into vegetation type allowed us to compare the fire-cycles and fire frequency for the different forest types in the study area.

As mentioned, the fire-cycle for a given area of study, is a function of TSLF date and fire frequency or fire area (Van Wagner 1978; Agee 1993; Johnson and Gutsell 1994). The fire-cycle for our study area was calculated using both, area (from the TSLF map produced by ArcView®) and mean frequency data from the bootstrapping procedure. There are a several methods for calculating fire-cycles, but for the purpose of this study we used: 1) the natural fire rotation (NFR) (method proposed by Heinselman (1973)) and 2) the negative exponential model.

To prepare the data for fire-cycle analysis, the frequency and area data were first transformed into percent of the total frequency (or area). The reverse cumulative percent (starting with 100%) was calculated for each age class (see Appendix 1 for an example of a data table for the area data) and graphed using semi-log paper producing TSLF distribution curves (Heinselman 1973; Johnson and Gutsell 1994). Each graph was then examined for any break in slope that would indicate a change in the fire-cycle (Johnson and Van Wagner 1985). The data was then split into periods of constant fire frequency (straight lines on the semi-log paper) (Johnson and Larsen 1991) and the fire-cycle was calculated for each time period.

For both the area and frequency data, a negative exponential model was

fit to the homogenous time periods identified on the TSLF distribution curves to calculate the fire-cycle. The fire-cycle was calculated using the following formula:

$$A(t)= \exp(-(t/b))$$

were A(t) = the proportion of the landscape surviving longer than time (t) and b = fire-cycle (Johnson and Gutsell 1994). All regression models were calculated using Microsoft® Excel for Windows version 9.0.0.3822.

The negative exponential model fit to a TSLF reverse cumulative distribution curve can be significantly biased or misinterpreted by a "missing tail" caused by censored data (Finney 1995). Heavily censored data can alter the shape of the reverse cumulative age-class distribution from a straight line to a curve and is often interpreted as a change in fire frequencies over time (Finney 1995). As mentioned in section 2.7, most of the TSLF dates for this study are censored. Of the 119 TSLF location dates used to construct the TSLF map (from which the area data was generated), 91% were censored, providing only a minimum time since the last fire (Appendix 2). For the bootstrapped frequency data, 88% of the fire dates are censored for forest-tundra as a whole (18 units). The effect of the censored dates are two fold; 1) to underestimate the length of the fire-cycle, again providing a very conservative estimate of fire-cycles for the study area and 2) to indicate a change in fire frequency and thus a change in the fire-cycle (Finney 1995).

Only the area data, generated from the TSLF map, was used to calculate the natural fire rotation for periods of constant fire frequency. Natural fire rotation was calculated using the following formula:

$$NFR = \frac{\text{Number of years in period}}{\text{Total area burned over period / Study area size}}$$

where NFR = fire-cycle (Heinselman 1973). From the NFR, the percent of the study area burned per year was calculated for time of homogenous fire-cycles (Heinselman 1973; Agee 1993):

$$\% \text{ burned per year} = 1/\ NFR$$

It is important to mention the NFR can be significantly biased if the aerial extent of the fires are not accurately mapped. Under-estimating the spatial extent of fires will significantly over-estimate the length of the fire-cycle. For this study, the aerial extent of the fires in the forest-tundra area in the Churchill region (generated by the TSLF map) were over-estimated resulting in a very conservative estimate of the fire-cycle.

2.8 Succession data analysis

Two strategies were pursued to analyze the vegetation data. The first strategy was to analyze the species composition and the second one was to analyze the stand structure data.

To analyze the vegetation composition data, the abundance values from the Braun-Blanquet classification for each species for each site were transformed to percent values using the mid point for each class (5 = 87.5%; 4 = 62.5%; 3 = 37.5%; 2 = 15%; 1 = 2.5%; + = 0.1%; and *r* = 0.05%). Species that occurred with a frequency of less than five percent were considered rare and were removed. The vegetation matrix was made up of 38 species (or species groups) and 83 sites.

To analyze changes in stand structure, stem diameter at breast height

(DBH) and height were used to construct a structural pseudo-species matrix. Using data from the three tree species and the 83 study plots, 70 pseudo-species were created. To create the structural data, stem DBH was first divided into seven classes based upon the minimum and maximum DBH of the trees sampled (0.0 - 29.99 cm DBH) (Table 2). Because of the slow growth of the trees in the Churchill area, an initial class of 0.99 cm DBH and then six classes at 4.99 cm DBH intervals were created in an attempt to capture changes in tree structure over time. In each DBH class, three height categories (L: low, M: mid, H: high) were constructed using maximum and minimum heights from individuals in each of the DBH classes. In total 21 pseudo-species were created for each species of tree, resulting in 63 pseudo-species. A final seven pseudo-species were added to the matrix to capture the snags with no species designation.

Once the structural matrix was created, all stem DBH values for each pseudo-species was transformed into basal area values to provide a measure of structure.

$$BA = 0.00007854(DBH^2),$$

where *BA* is basal area per tree and *DBH* is the diameter at breast height (in cm) (Avery and Burkhart 2002). The basal area for each pseudo-species was then summed for each site and converted into basal area per hectare (m^2/ha) providing an estimate of the importance of a pseudo-species within a stand. The summed basal area values were scaled to 100 by transforming the basal area (m^2/ha) into percent values (maximum basal area value in the matrix equaling 100%). This transformation helped reduce the difference between the minimum

Table 2. Class ranges derived from diameter at breast height (DBH). L = low, M = mid, H = high

DBH class (cm)	Code	height (m) low value (h2)	high value (h1)	(h1-h2)/3	class range (m)		Class
0.0 - .99	1	0.06	3.11	1.02	0.06	1.08	1L
					1.08	2.09	1M
					2.09	3.11	1H
1.0 - 4.99	2	0.3	5.58	1.76	0.30	2.06	2L
					2.06	3.82	2M
					3.82	5.58	2H
5.0 - 9.99	3	0.73	7.62	2.30	0.73	3.03	3L
					3.03	5.32	3M
					5.32	7.62	3H
10.0 - 14.99	4	1.95	9.14	2.40	1.95	4.35	4L
					4.35	6.74	4M
					6.74	9.14	4H
15.0 - 19.99	5	4.57	9.45	1.63	4.57	6.20	5L
					6.20	7.82	5M
					7.82	9.45	5H
20.0 - 24.99	6	6.1	13.72	2.54	6.10	8.64	6L
					8.64	11.18	6M
					11.18	13.72	6H
25.0- 29.99	7	9.14	11.28	0.71	9.14	9.85	7L
					9.85	10.57	7M
					10.57	11.28	7H

and maximum values while retaining the overall order and distance between the pseudo-species.

2.9 Species-environmental relationships

Two-Way Indicator Species Analysis (TWINSPAN) (Hill 1979) was used to classify both vegetation and structural data sets. TWINSPAN is a numerical classification technique developed specifically for hierarchical classification of community data (Stelfox 1995). The default parameters were used for the analysis. While vegetation and structural classification was undertaken as a strategy for delineating ecological groups, ordination analysis was used to examine the relationship between the vegetation and structural matrix and the environmental variables respectively.

Canonical correspondence analysis (CCA) was used to examine the extent to which trends in the vegetation and structural data reflect environmental variability. CCA is a direct, constrained ordination technique, where the species and environmental data are analyzed together and the ordination axes are constrained to represent a linear relationship with the environmental factors (ter Braak 1994). CCA assumes a unimodal distribution of the species across environmental gradients and it was chosen because of its ability to deal with species that come and go across a gradient. This is represented by the presence of many zeros in the data set. Significant environmental variables were selected using a forward selection and 999 Monte Carlo Permutation. Only environmental variables with a p value <0.05 were retained. The environmental variables were initially screened and only those showing a variance inflation factor (VIF) <20.00

were used in the analysis as recommended by ter Braak and Smilauer (1998). A large VIF implies that the variable is redundant with other variables in the data set (ter Braak and Smilauer 1998). Both the species and structural CCA analysis was evaluated for significance of the first ordination axis and significance of all canonical axis together, with a Monte-Carlo permutation test with 999 permutations. In both analysis the p value was <0.05. The CANOCO software (Version 4.0; ter Braak and Smilauer 1998) was used in all ordination analyses.

3. Results

3.1 Fire history

Fire occurrence for the forest-tundra south of Churchill, Manitoba is presented in Figure 4. Most of the fire occurrence information was derived from stand initiation dates and was considered censored. Of the 119 dates, 91% are censored, 92% for the white spruce, 88% for the black spruce and 83% for the eastern larch respectively. Censored data provides a minimum date of the last fire and not absolute dates. Most of the fire scars occurred within the last 125 years and provided the 11 non-censored fire dates. Using the bootstrapped data, the mean age of forest-tundra was 237 years. Mean age of the white spruce forest was 259 years, black spruce was 251 years and eastern larch was 239 years.

3.1.1 Time-since-last-fire map and natural fire rotation

The TSLF map covers an area of 173501 hectares (excluding major rivers and lakes) with 77% of landscape area being older than AD 1900 (Figure 5 and Figure 6a). The TSLF map shows a general decrease in fire activity since about

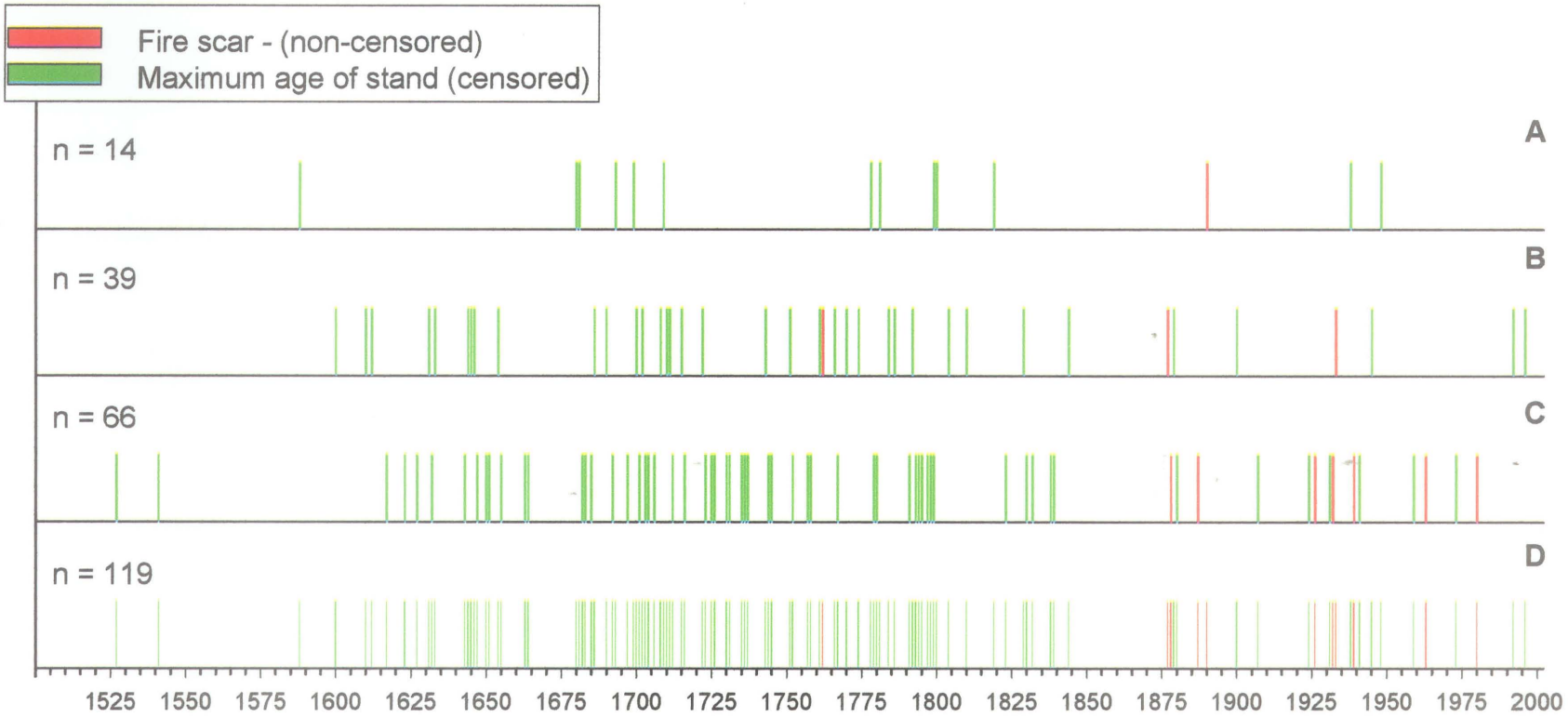

Figure 4. Last fire occurrence in each of the 119 sites and checkpoints. Subsets of the fire occurences were used for each of the fire-cycle analysis and for the preparation of the time-since-last-fire map. A = eastern larch, B = white spruce, C = black spruce, D = total fire occurrence.

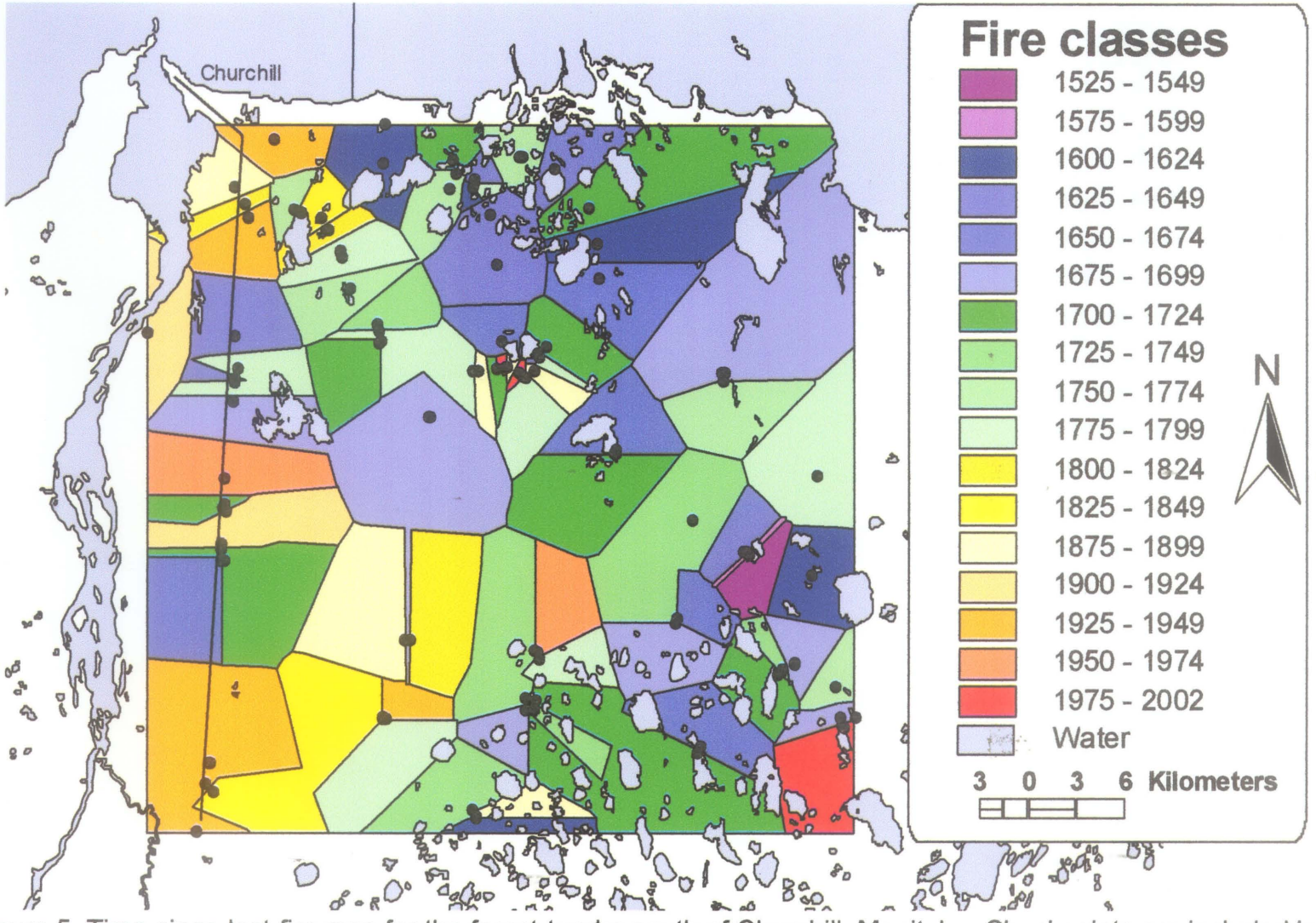

Figure 5. Time-since-last-fire map for the forest-tundra south of Churchill, Manitoba. Checkpoints are included in the sample sites. The black dots indicate the location of the 119 sample sites utilized in the fire history. The black line indicates the railway.

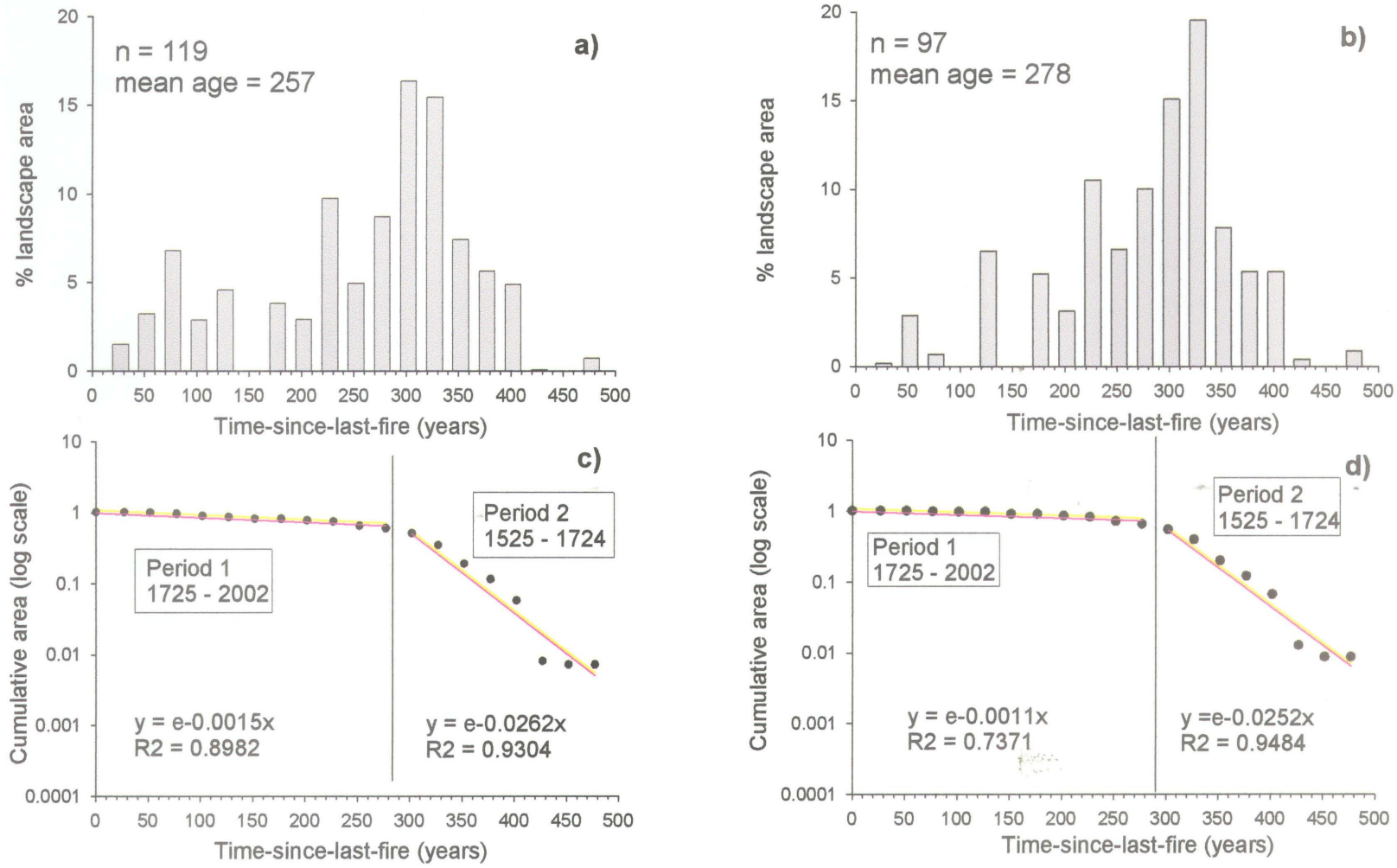

Figure 6. Time-since-last-fire distribution for the forest-tundra south of Churchill, Manitoba. a and b represent repectively the % landscape area in given age classes for the entire study area and after removal of the sites related to the railway. c and d represent the cumulative distribution for the entire study area and after removal of the sites related to the railway. Data for sub figure a and c were extracted from Figure 5 and data for b and d were extracted from Figure 7.

AD 1725 interrupted by an increased period of fire activity during the AD 1925 - 1950 (~10% of the landscape area originates from this age class). Figure 6a also showed an intense period of fire activity between AD 1700 - 1725 (18% of the landscape area originates from this class) just prior to the general decrease in fire activity at AD 1725. The cumulative distribution of burnt areas (Figure 6c) showed a break in the fire-cycle (change in distribution) about 275 years ago (AD 1725), this corresponded to the intense fire activity that ended in AD 1725. The natural fire rotation (NFR) (based upon fire area from the TSLF map, Figure 5) for the period AD 1725 - 2002 is 558 years and 345 years from AD 1525 - 1724 (Table 3). The percent burned per year (1/NFR) for the AD 1725 - 2002 period is 0.0018% (312 ha) and 0.0025% (434 ha) for the AD 1525 - 1724 period, a decrease of 0.0007% or 122 ha burned annually. A second TSLF map was generated with a reduced area to remove the possible effects of human activity related to the building of the railway (Figure 7) and covers an area of 139702 hectares. Figure 6b and 6d represented the % landscape and cumulative distribution of area burned for Figure 7. Figure 6b showed the same general decrease in fire activity after AD 1725 but does not show the spike in fire activity in AD 1925 - 1950. A break in the fire-cycle occurs in AD 1725 (Figure 6d) as it does for the TSLF map covering the full study area. The NFR, based upon Figure 7, shows a change from 322 years prior to AD 1725 to 608 years after AD 1725. The affect of removing the sites along the railway increased the NFR for the AD 1725 to AD 2002 period from 558 to 608, a change of 50 years.

Table 3. Fire-cycle estimated using area and bootstrap frequency data for the forest-tundra and associated forest types south of Churchill, Mb. based upon natural fire rotation (NFR) and fire frequency analysis (fitted to a negative exponential model).

Forest type	NFR from TSLF map		fire frequency analysis fitted to a negative exponential model (from fire map)		fire frequency analysis (using bootstrapped frequency data) fitted to a negative exponential model (n = 18)	
	AD 1525-1724	AD 1725-2002	AD 1525-1724	AD 1725-2002	AD 1525-1774	AD 1775-2002
Entire forest-tundra n = 119	345 years	558 years	38 years	667 years	58 years	588 years
Modified area of forest tundra n = 97	322 years	608 years	40 years	909 years	59 years	714 years
PGL n= 12					55 years	1000 years
PMA n= 16					65 years	667 years
LLA n= 6					96 years	625 years

PGL = white spruce forest, PMA = black spruce forest and LLA= eastern larch forests

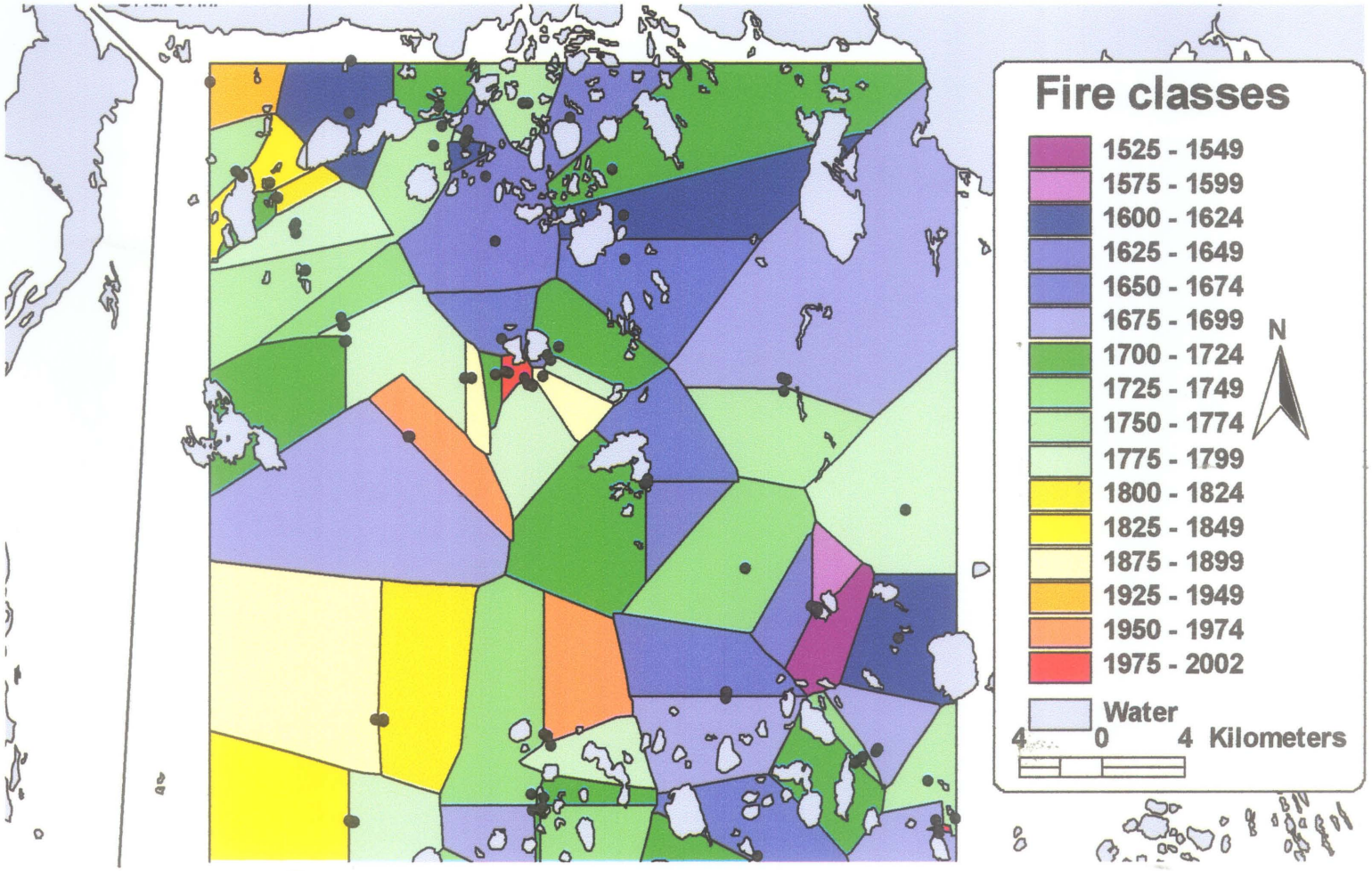

Figure 7. Modified time-since-last-fire-map for the forest-tundra south of Churchill, Manitoba to remove the effects of human caused fires associated with the railway. Checkpoints are included in the sample sites. The black dots indicate the location of 97 sampling sites. The black line indicates the railway.

3.1.2 Forest age distribution and fire-cycles

The results for the fire-cycle analysis are presented in a comparative manner in Table 3, along with the natural fire rotation results. The length of the fire-cycle varied from one data set to another (area or frequency) but there was an overall increase in the length of the fire-cycle in all the results. The mean fire frequency (Figure 8) showed an overall increase in the fire frequency with age, similar to the trend in Figure 6a and c. The cumulative time since fire distributions for the bootstrap data shows a break in slope (Figure 9), suggesting a change in the fire-cycle at AD 1775. This break in the fire-cycle is seen in all the forest types (PGL, PMA and LLA) at AD 1775 (Figure 9). The fire-cycle (using a negative exponential model) was calculated for the periods of homogenous fire frequency, AD 1775-2002 and for AD 1525-1774 for the frequency analysis and AD 1725-2002 and AD 1525-1724 for the area analysis (Table 3). The fire-cycle for AD 1775-2002 range from 625 years to 1000 years in the different forest types, with the white spruce forests having the longest fire-cycle. For the time period AD 1525-1774 the fire-cycle ranges from 55 years to 96 years for the different forest types and again the longest fire-cycle was in the eastern larch forest. The change in the fire-cycle ranges from 529 years in the eastern larch, 602 years in the black spruce and 945 years in the white spruce forests. For the entire study area the fire-cycle has increased from 58 years (AD 1525-1774) to 588 years (AD 1775-2002) over time, with a shift in the fire-cycle of 530 years.

The fire-cycle analysis (again fitted to a negative exponential model) of

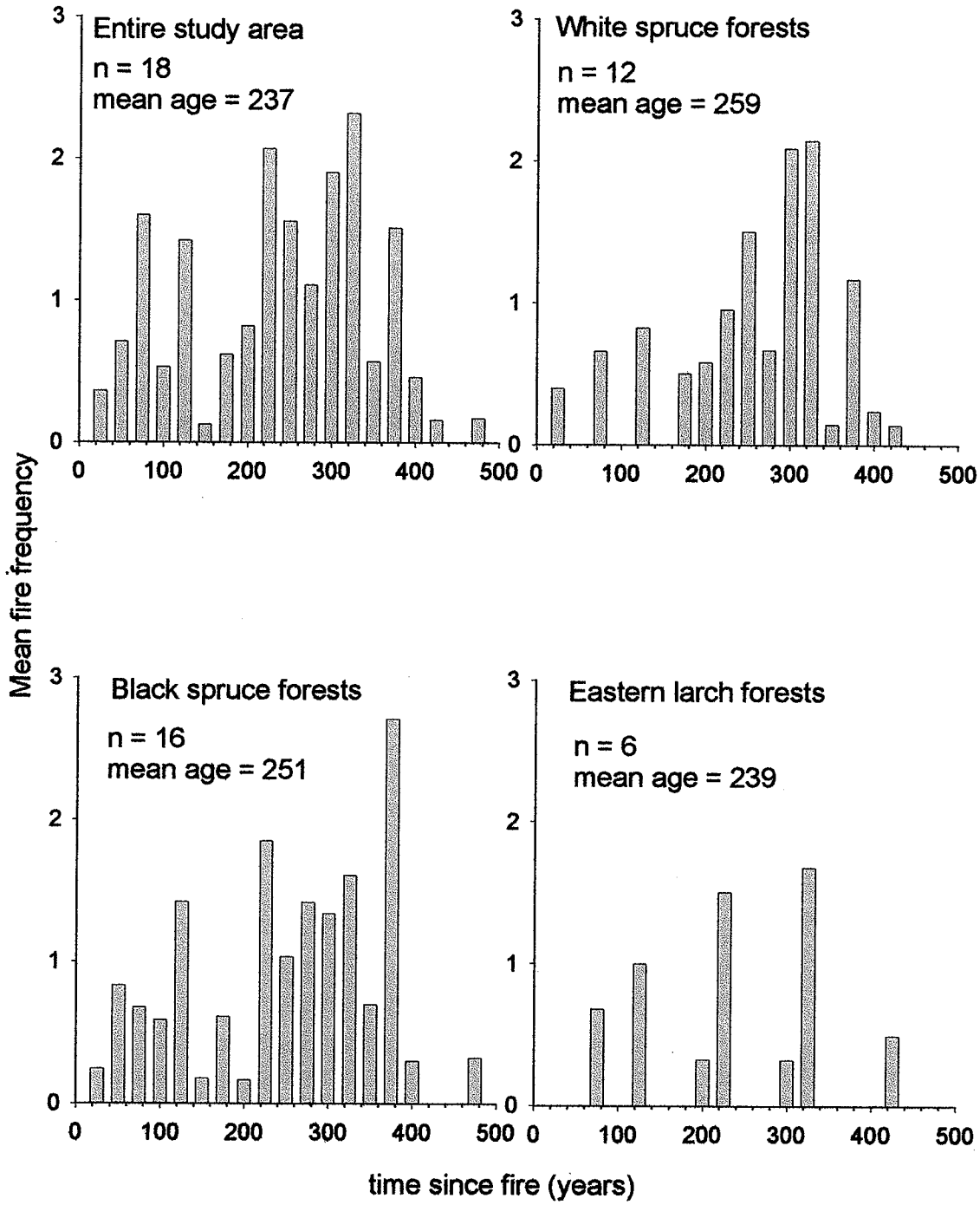

Figure 8. Mean fire frequency in 25-year age classes for the forest-tundra south of Churchill, Manitoba (AD 1525 - 2002), calculated after 10,000 bootstrap iterations.

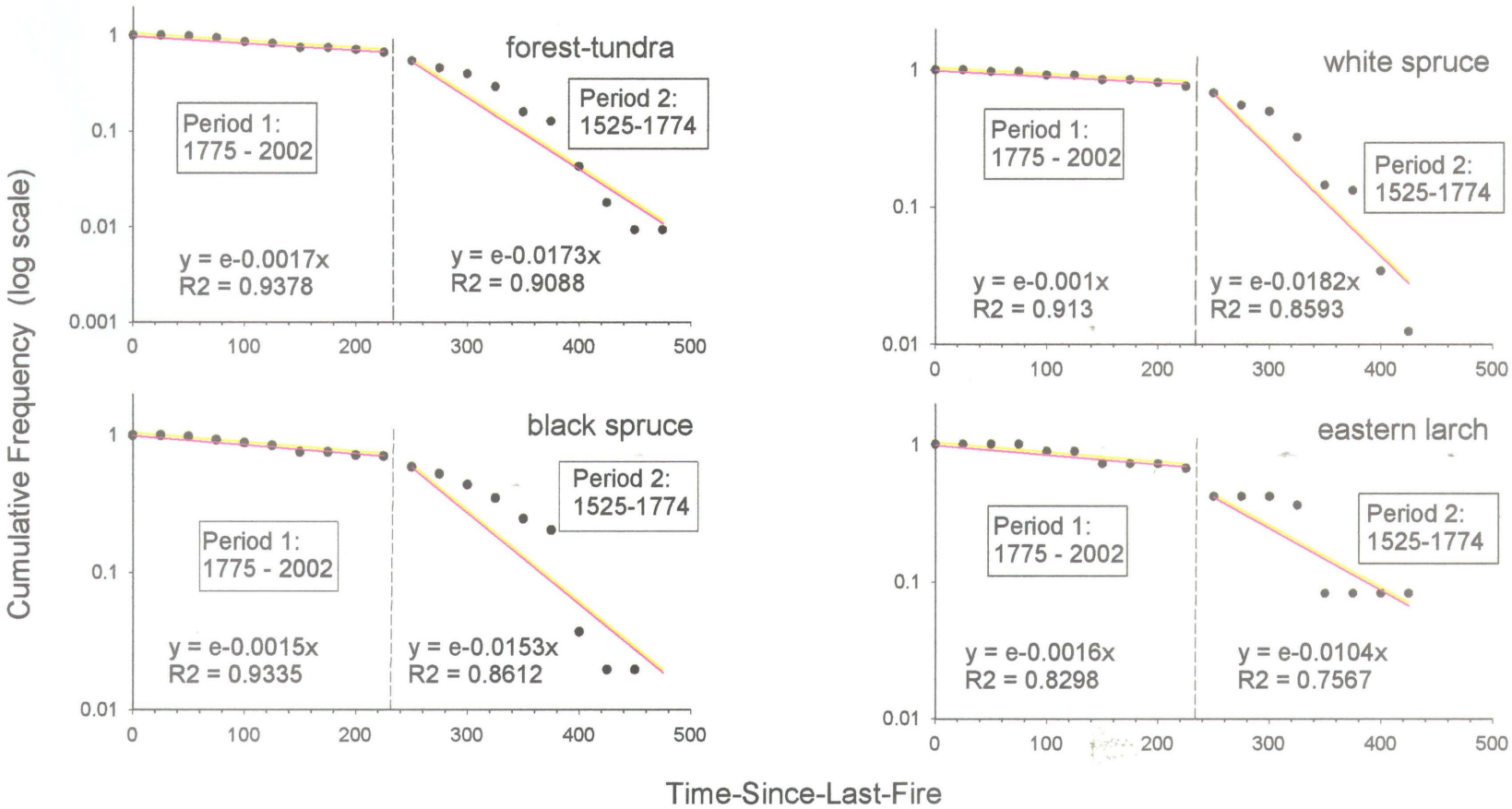

Figure 9. Semi-log cumulative time-since-last-fire distribution of bootstrap data for the forest-tundra and associated forest types south of Churchill, Mb. The solid line represents the fitted fire cycle calculated using the negative exponential model for the time periods AD 2002-1775 and AD 1774-1525.

the area data generated from the TSLF shows a change to a longer fire-cycle at AD 1725 from 38 years to 667 years. Fire-cycle analysis, using the negative exponential model, for the modified TSLF map show a change in the fire-cycle at AD 1725 from 40 to 909 years, again showing the significant impact of the railway on the fire-cycle for the AD 1725 to AD 2002. The NRF calculations of fire-cycle (from Figure 5) shows a fire-cycle of 345 years prior to AD 1725 changing to 558 years after AD 1725, a change of 213 years. The NFR for the modified TSLF map (Figure 7) is 608 years for the AD 1725 - 2002 period, and 322 years for AD 1525 - 1724, a change of 286 years.

3.2 Species classification

TWINSPAN analysis of the 81 sites identified 5 clusters (Figure 10 and Table 4). Two of the original 83 sites, D4.2 and D5.6 were removed from the vegetation cluster analysis. A review of these two sites vegetation and environmental parameters showed that D4.2 had a high percent of bare ground (62.5%) and *Epilobium angustifolium* (62.5%) and D5.6 was dominated by *Dryas integrifolia* (87.5%) and grasses (62.5%). D4.2 was a very recent burn and has been disturbed by human activity associated with salvage cutting of dead trees. D5.6 was located atop an inland beach ridge and the reason for the abundance of grasses and *Dryas integrifolia* in this quadrat is unknown. Because of CCA's sensitivity to outliers, both of these sites were removed from the multivariate analysis. Five vegetation clusters (labeled 1-5) were recognized, based upon species composition (Table 4). Each vegetation cluster has been named for its dominant plant life form (highest mean percent cover and frequency) and

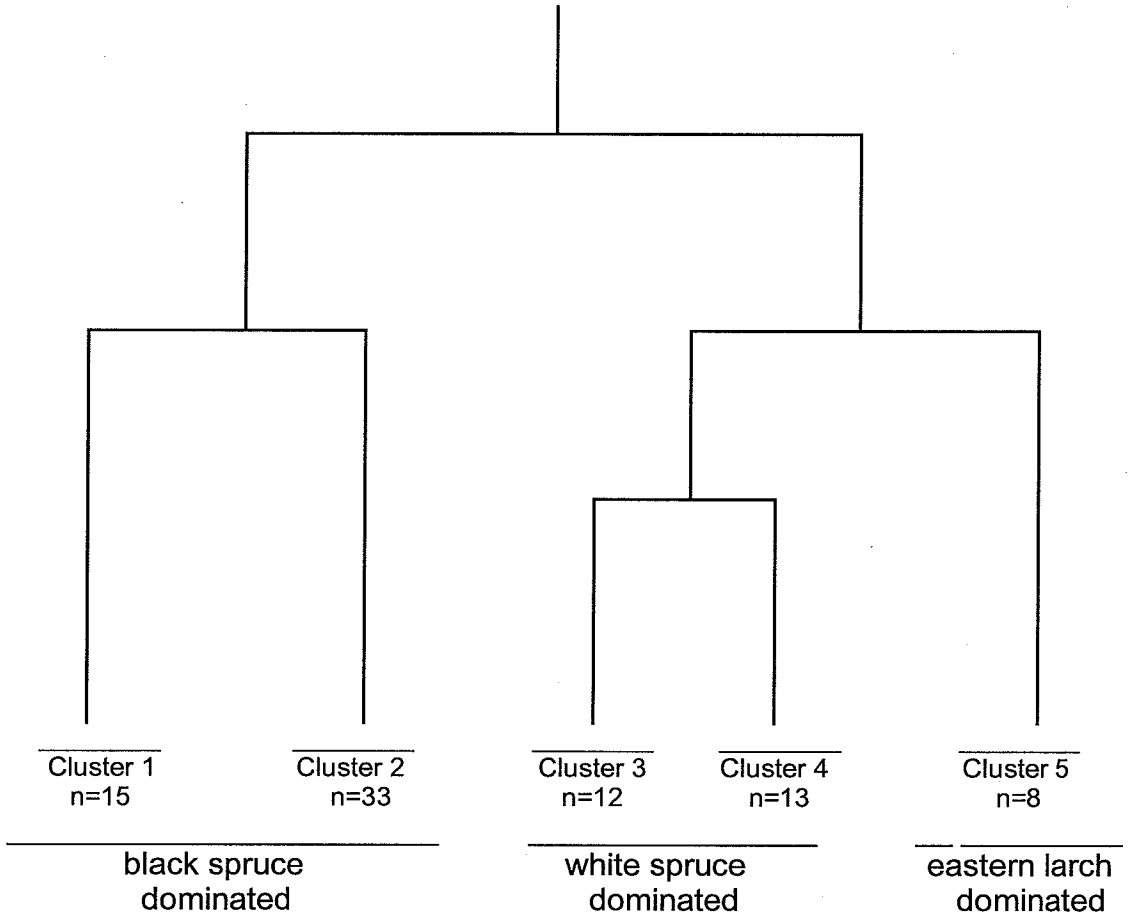

Figure 10. Results of the TWINSPAN cluster analysis for 81 sites based upon 38 species (or species groups). The five clusters described in the text are indicated. The n value indicated the number of sites in each cluster.

Table 4. Mean cover and frequency of species in each cluster. Species ordered to reflect the TWINSPAN output. Only species with a value of at least 50% frequency* (F) or cover* (C) are included in the table.

	Cluster 1 n=15		Cluster 2 n=33		Cluster 3 n=12		Cluster 4 n=13		Cluster 5 n=8	
	F	C	F	C	F	C	F	C	F	C
Trees										
Picea mariana (PMA)	86.67	37.18	90.91	39.62	50.00	2.93	30.77	3.28	75.00	5.04
Larix laricina (LLA)	66.67	2.01	78.79	4.20	91.67	15.43	69.23	3.09	87.50	20.95
Picea glauca (PGL)	13.33	0.33	9.09	3.48	75.00	21.47	92.31	21.54	12.50	0.31
Shrubs										
Ledum decumbens (LeDe)	100.00	32.01	87.88	22.74	50.00	14.17	38.46	3.85	25.00	0.03
Rhododendron groenlandicum (LeGr)	93.33	52.17	93.94	51.82	75.00	19.60	61.54	18.48	75.00	5.04
Vaccinium vitis-idaea (VaVi)	100.00	20.35	96.97	35.01	91.67	37.29	84.62	39.05	25.00	0.03
Salix spp. (Salix)	33.33	3.84	36.36	2.45	100.00	33.33	76.92	12.52	87.50	48.46
Vaccinium uliginosum (VaUl)	33.33	4.83	33.33	5.24	91.67	37.71	76.92	33.28	37.50	0.34
Betula glandulosa (BeGl)	20.00	0.18	12.12	0.09	75.00	11.47	53.85	1.37	100.00	45.95
Shepherdia canadensis (ShCa)	0.00	0.00	0.00	0.00	0.00	0.00	61.54	1.57	0.00	0.00
Herbs										
Oxycoccus macrocarpus (OxMi)	20.00	0.18	54.55	11.31	16.67	0.01	7.69	1.15	50.00	19.08
Rubus chamaemorus (RuCh)	66.67	36.01	96.97	62.58	50.00	28.13	15.38	2.89	25.00	1.89
Empetrum nigrum (EmNi)	86.67	25.85	93.94	38.34	91.67	56.46	92.31	59.23	62.50	2.23
Kalmia polifolia (KaPo)	40.00	0.19	36.36	4.34	33.33	1.27	15.38	0.01	62.50	0.06
Cyperaceae spp. (Sedges)	33.33	1.35	33.33	1.83	58.33	7.73	23.08	2.90	100.00	73.45
Smilacina trifolia (SmTr)	6.67	0.01	6.06	0.00	0.00	0.00	0.00	0.00	75.00	10.04
Andromeda polifolia (AnPo)	13.33	0.35	30.30	1.23	58.33	7.73	46.15	2.92	50.00	7.84
Poaceae spp. (Grass)	40.00	0.52	27.27	0.46	66.67	12.31	61.54	12.72	75.00	37.83
Arctostaphylos rubra (ArRu)	0.00	0.00	3.03	0.08	25.00	0.03	69.23	28.28	0.00	0.00
Geocaulon lividum (GeLi)	6.67	0.01	3.03	0.00	0.00	0.00	53.85	19.44	0.00	0.00
Rubus acaulis (RuAc)	0.00	0.00	3.03	0.00	33.33	0.23	15.38	4.81	50.00	12.52
others										
Fruiticose lichens (Li3)	66.67	45.17	15.15	5.53	16.67	1.26	33.33	7.12	0.00	0.00
Moss spp.	60.00	28.67	6.06	0.53	33.33	3.75	7.69	0.19	12.50	10.94
Sphagnidae spp. (Spha)	6.67	0.01	84.85	46.29	16.67	7.30	0.00	0.00	37.50	12.83
Feather mosses (Fmos)	33.33	21.00	54.55	23.94	66.67	26.48	84.62	42.31	75.00	38.13
Equisetum arvense (EqAv)	0.00	0.00	15.15	0.01	8.33	5.21	7.69	0.00	62.50	14.39

*Frequency is percent of sites the species occurs in (each cluster). Cover is the mean percent of ground covered by the species in the cluster

environmental characteristics (e.g. pH, drainage). A complete list of identified species and environmental factors are presented in Appendix 3 and 4.

3.2.1 Cluster descriptions

The first dichotomy of the TWINSPAN cluster analysis (Figure 10) separates fen vegetation types from bog types and separates the black spruce dominated forest from the white spruce and eastern larch forests (Table 5). Cluster 1 and 2, the black spruce dominated forests, are located in environments with imperfect drainage, found inland of the Hudson Bay coast on deep peat deposits with thin active layers (permafrost close to the surface) (Table 5). These clusters are typified by organic soils, imperfect drainage (but with little standing water, 0 - 0.71%) with a black spruce-dominated over-story. Cluster 3 and 4 are white spruce-dominated upland sites on inland relic beach ridges or coastal rock outcrops. High pH values for these clusters indicate a more nutrient-rich environment (Table 5). Cluster 5 is eastern larch-dominated fens and are typified by deep active layers, silt and clay substrates, very poor drainage and the presence of surface water. These sites are dominated by eastern larch, sedges and willows.

Cluster 1 (Black spruce-lichen-moss) includes bogs with a well-developed peat layer. Black spruce is the dominant tree on the sites with a frequency of 86.67% and a mean cover of 37.18% indicating an open, sparse tree cover (Table 4). Eastern larch occurs in 66.67% of the sites but with very low cover. Ericaceous shrubs (e.g. *Ledum groenlandicum* and *Ledum decumbens*), usually completely cover the ground surface. Fruticose lichens occur in 66.67%of the plots with a

Table 5: Environmental and floristic characterization of the five vegetation types recognized in Figure 10. The mean and standard deviation (in parenthesis) are presented for the quantitative variables.

Cluster	1	2	3	4	5
Number of sites sampled	15	33	12	13	8
Substrate	permafrost	permafrost	sand	sand/rock	silt/clay
Active Layer depth (m)	0.41 (0.31)	0.28 (0.20)	0.42 (0.35)	0.83 (0.32)	0.73 (0.37)
pH	5.40 (1.00)	6.08 (1.08)	6.50 (1.00)	7.15 (0.09)	6.25 (0.88)
Drainage	imperfect	imperfect	moderate	well/moderately well	very poor
% Surface water	0.00	0.71(2.66)	1.26 (4.33)	0.00	35.01 (35.4)
Dominant trees	*Picea mariana*	*Picea mariana*	*Picea glauca* *Larix laricina*	*Picea glauca*	*Larix laricina*
Dominant tall shrubs	-	-	*Salix spp* *Betula glandulosa*	-	*Salix spp* *Betula glandulosa*
Dominant low shrubs	*Ledum groenlandicum* *Ledum decumbens*	*Ledum groenlandicum* *Vaccinium vitis-idaea* *Ledum decumbens*	*Vaccinium uliginosum* *Vaccinium vitis-idaea*	*Vaccinium vitis-idaea* *Vaccinium uliginosum*	-
Dominant herbs	*Rubus chamaemorus* *Empetrum nigrum*	*Rubus chamaemorus* *Empetrum nigrum*	*Rubus chamaemorus* *Empetrum nigrum*	*Empetrum nigrum* *Arctostaphylos rubra*	*Oxycoccus macrocarpus* *Rubus acaulis*
Dominant graminoids	-	-	*Poaceae spp*	*Poaceae spp*	*Cyperaceae spp*
Dominant mosses	moss spp Feather mosses	Sphagnum mosses	Feather mosses	Feather mosses	Feather mosses
Dominant lichens	Fruticose	-	-	-	-

mean cover of 45.17%. These communities are underlain by permafrost as a substrate, are very acidic (low pH) and have active layers about 0.5 m thick.

Cluster 2 (Black spruce-sphagnum bog) is a treed wetland with black spruce. Eastern larch occurs in low numbers on 78.79% of the sites (Table 4) and the under-story is dominated by ericaceous shrubs, particularly *Ledum groenlandicum.* Ground cover consists primarily of *Sphagnum spp* and accounts for the low pH of the sites. The sites have a very thin active layer with permafrost close to the surface (Table 5). Organic soils dominated all the sites and the drainage is impeded (Table 5 and Appendix 4).

Cluster 3 (White spruce-eastern larch forests) are often found on the slopes along inland beach ridges and on the southern edge of the coastal bedrock as it grades slowly into fens or bogs. The over-story is dominated by white spruce and eastern larch, both with high frequency values and moderate cover values (Table 4). Black spruce occurs on 50% of the sites but with a low mean cover value of 2.93%. The diversity of the shrub community increases in this cluster and includes *Ledum sp.* and *Salix spp* in moderately drained sites and *Vaccinium vitis-idaea, Betula glandulosa* and *Vaccinium uliginosum* on the well-drained sites. The active layer is thin with permafrost close to the surface on many of the sites (Table 5), but sites with steeper slopes tend to have deeper active layers and more xeric species such as *Empetrum nigrum, Arctostaphylos rubra* and grasses (Appendix 3 and 4). Calcareous sand is the dominant substrate for the sites in this cluster.

Cluster 4 (White spruce-feather moss) occurs on inland beach/kame ridges,

gravel mineral substrates or coastal rock outcrops, all with thin organic soils. The over-story is open and sparse, dominated by large DBH white spruce (Table 4). The under-story is dominated by *Vaccinium uliginosum* and *Ledum groenlandicum*. *Shepherdia canadensis* occurs in 61.54% of the sites but with a very low mean cover and occurs on the coastal rock-substrate dominated sites. The herb layer is dominated by *Empetrum nigrum, Arctostaphylos rubra* and *Geocaulon lividum*. The ground cover is mainly feather mosses with fruticose lichens present in 33.33% of the sites, but with a low mean cover of 7.12%. These are the most xeric of the sites found in the Churchill region, with no standing surface water (Table 5). The active layer is deep and on most sites the permafrost was not detected within 1 metre of the surface.

Cluster 5 (Eastern larch-scrub birch-sedge fens) include fens with scattered eastern larch with a mean cover of 20.95% (Table 4). The shrub layer of *Salix spp* and *Betula glandulosa* (scrub birch) is often thick, forming the transition between open fens and black spruce peat plateaus. Small hummocks form raised areas for eastern larch and some of the other shrubs to grow on. Although present in many of the sites, *Ledum groenlandicum* and *Vaccinium uliginosum* occur in very low mean cover (>5%) and are confined to these small raised hummocks. Sedges dominate the herb cover with *Oxycoccus macrocarpus* and *Rubus acaulis* common on many sites. The water table is at or just below the vegetation surface resulting in very poor drainage (Table 5). The substrate for most of the sites is clay or silt, with a thick active layer. Permafrost is found at a depth of more than one metre from the surface on most sites in Cluster 5. The

mean pH is 6.25.

3.2.2 Species ordination (CCA)

Statistics of the CCA showed that eigenvalues and species-environment correlation coefficients for the first and second axis were respectively $E_1 = 0.341$, $E_2 = 0.191$, $r_1 = 0.812$, and $r_2 = 0.747$ (Table 6). In total, the five significant environmental variables retained explained 17.8% of the variation in site and species distribution for the first four axes of the ordination (Figure 11).

The first axis was primarily related to presence or absence of permafrost (Sbpf), clay (Sbc) and rock (Sbr) as a substrate. Permafrost was positively related to the black spruce-dominated clusters (Cluster 1 and 2), and negatively related to the eastern larch-dominated fens (Cluster 5) sites which were clustered to the right (Figure 11a). Clay as a substrate was positively related to the eastern larch-scrub birch-sedge fens while permafrost as a substrate and the % bare ground were negatively related. Species such as *Smilacina trifolia*, sedges species, *Betula glandulosa* and *Equisetum arvensis* were located on the far right side of the biplot positively related to clay as a substrate (SBc). Moving left along axis one the species composition started to shift to more mesic plants and to species more adapted to shallow organic (O) soils with permafrost as a substrate (Sbpf) (Figure 11b). These plants include *Picea mariana*, *Ledum decumbens*, *Ledum groenlandicum*, *Rubus chamaemorus* and sphagnum moss. The white spruce- eastern larch forests and the white spruce-feather moss forest (Clusters 3 and 4) are more influenced by the second axis in relation to a substrate of sand (SBs) and rock (Sbr). Bare ground (BG), appears on the biplot

Table 6. Statistics of the CCA for the vegetation analysis

Axes	1	2	3	4	Total inertia
Eigenvalues	0.341	0.191	0.161	0.083	4.36
Species-environment correlations	0.812	0.747	0.841	0.629	
Cumulative percentage variance					
of species data	7.8	12.2	15.9	17.8	
of species-environment relation:	44.0	68.6	89.3	100.0	
Sum of all unconstrained eigenvalues					4.36
Sum of all canonical eigenvalues					0.775

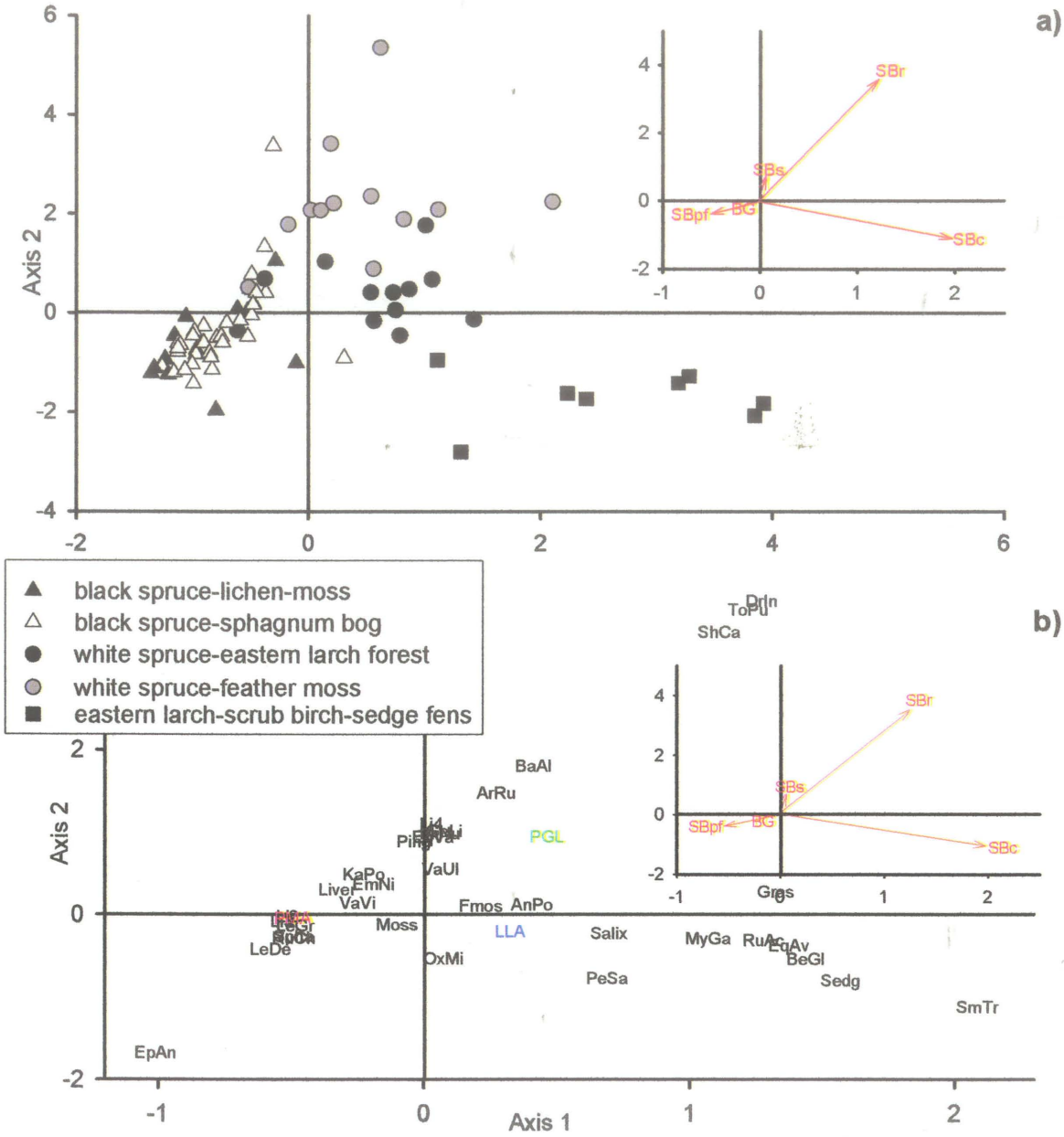

Figure 11. Results of the CCA conducted on the 81 sites showing the position along the first two axes of a) samples and b) species. Vectors with arrows at sharp angles Are positively correlated. By contrast, obtuse angles between the vectors indicate negative correlations. The significant variables retained at p = 0.05 are illustrated in red (substrate clay = Sbc, substrate sand = Sbs, substrate rock = Sbr, substrate permafrost = Sbpf and % bare ground = BG. Sites D4.2 and D5.6 were removed from the analysis as CCA is sensitive to outliers and will often highlight unique variable-individual combinations at the expense of summarizing overall data trends (ter Braak 1994). Species on the lower graph are designated by the first two letters pf their genus and species names. For full species names see Appendix 3.

as a significant influencing variable, but must be interpreted with care. Only one site in the ordination has significant bare ground (F2.2) and is the site of a recent burn (within the last 35 years).

3.3 Classification of structure

The TWINSPAN cluster analysis dendrogram for the structural data from the 83 stands is given in Figure 12. Six stand clusters were recognized, based upon pseudo-species composition. Three of the clusters are composed of two or fewer sites.

3.3.1 Stand cluster descriptions

The first dichotomy of the cluster analysis of the plots represents the division between black spruce forests and the white spruce forests (Figure 12). The second dichotomy breaks apart the black spruce cluster into black spruce and eastern larch-dominated stands. Cluster 1, 4 and 6 are special cases of the black spruce, white spruce and eastern larch clusters. These clusters represent recent burns, odd stand structure (e.g. krumholtz) or relic topographic features and will not be discussed further.

Cluster 2 (Black spruce-eastern larch) is a black spruce-dominated forest with a small amount of eastern larch growing throughout the stands (Table 7). Of the 70 pseudo-species defined in this study, 40 occur in Cluster 2, with the dominant pseudo-species being PMA - 3M, 3H, 2M and 4M respectively (Appendix 5). There is a small amount of dead woody debris and few standing snags (Table 7 and 8). This cluster forms a distinctive group restricted to the acidic inland peat-plateaus and bog environments, very acidic (pH = 5.53), with moderate to

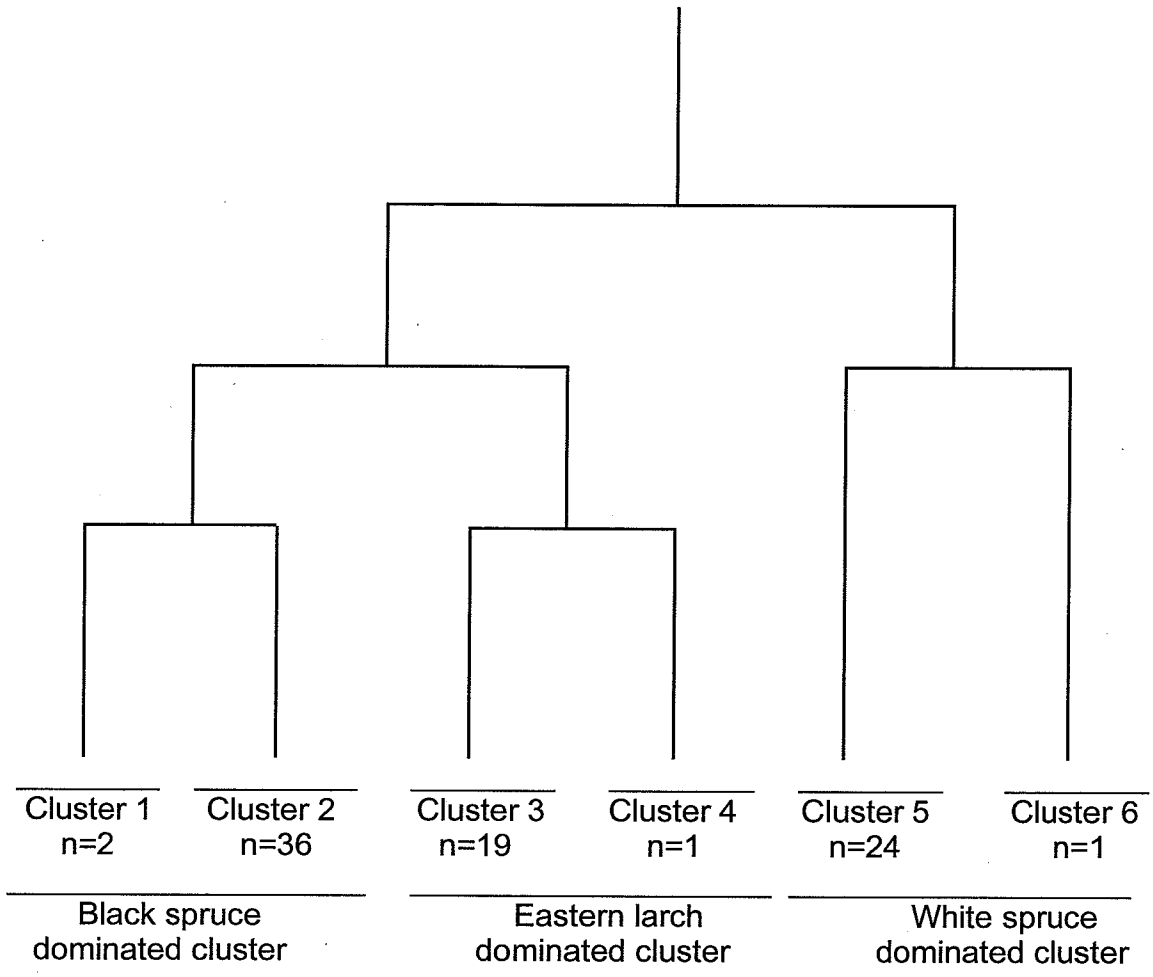

Figure 12. Results of the TWINSPAN cluster analysis for 83 sites based upon 70 pseudo-species. Clusters 2, 3 and 5 are described in the text. The n value indicates the number of sites in each cluster.

Table 7. Mean cover (C)and frequency (F) of pseudo-species in each major cluster. Pseudo-species ordered to reflect the TWINSPAN output.

Pseudo-species	Black spruce-eastern larch Cluster 2 n=36		Eastern larch-black spruce Cluster 3 n=19		White spruce-eastern larch Cluster 5 n=24	
	F	C	F	C	F	C
PMA-1S	0.00	0.00	0.00	0.00	0.00	0.00
PMA-2H	33.33	0.94	5.26	0.08	0.00	0.00
PMA-2M	94.44	6.70	42.11	0.66	12.50	0.14
PMA-2S	36.11	0.52	0.00	0.00	0.00	0.00
PMA-3H	47.22	6.84	5.26	0.64	4.17	0.26
PMA-3M	80.56	14.88	10.53	0.81	8.33	0.30
PMA-4M	33.33	5.94	0.00	0.00	4.17	0.31
PMA-1M	86.11	0.08	42.11	0.01	4.17	0.01
PMA-2L	97.22	0.89	52.63	0.13	4.17	0.01
PMA-1L	100.00	0.31	63.16	0.13	20.83	0.03
u-2S	36.11	0.49	26.32	0.88	16.67	0.58
LLA-1L	25.00	0.16	100.00	5.31	70.83	0.10
LLA-1M	25.00	0.02	68.42	0.08	45.83	0.03
LLA-2L	22.22	0.04	63.16	0.50	25.00	0.13
LLA-2M	22.22	0.34	84.21	3.43	41.67	1.04
LLA-3H	5.56	0.90	26.32	1.44	20.00	1.70
LLA-3M	22.22	1.71	36.84	3.40	29.17	1.29
u-3S	27.78	2.70	26.32	2.23	25.00	2.39
LLA-4S	2.78	0.27	5.26	0.39	0.00	0.00
LLA-5H	0.00	0.00	0.00	0.00	8.33	2.08
PGL-3H	0.00	0.00	5.26	0.30	29.17	2.47
PGL-8S	0.00	0.00	0.00	0.00	0.00	0.00
PGL-1L	0.00	0.00	15.79	0.01	83.33	0.65
PGL-1M	0.00	0.00	5.26	0.00	50.00	0.02
PGL-2L	0.00	0.00	0.00	0.00	75.00	0.43
PGL-2M	0.00	0.00	5.26	0.02	75.00	1.87
PGL-3M	2.78	0.63	0.00	0.00	75.00	9.11
PGL-4H	0.00	0.00	0.00	0.00	25.00	4.06
PGL-4M	2.78	0.20	0.00	0.00	41.67	8.32
PGL-2S	0.00	0.00	0.00	0.00	8.33	0.08
PGL-3S	0.00	0.00	0.00	0.00	5.56	0.39
PGL-6S	0.00	0.00	0.00	0.00	8.33	2.56

Only pseudo-species with a value of at least 25% (F or C) were included in this Table. PMA are black spruce pseudo-species, LLA are eastern larch pseudo-species, PGL are white spruce pseudo-species and u are snags of unknown species. The extension associated with each pseudo-species are the DBH derived class ranges for each pseudo-species (see Table 2).

Table 8. Environmental, structural and floristic characterization of the three major structural pseudo-species clusters recognized in Figure 12. The mean and standard deviation (in parenthesis) are presented for the quantitative variables.

	black spruce-eastern larch	eastern larch-black spruce	white spruce-eastern larch
Cluster	2	3	5
Number of sites sampled	36	19	24
Substrate	permafrost	permafrost	sand/permafrost
pH	5.53 (1.00)	6.13 (1.20)	6.88 (0.90)
Drainage	moderate/imperfect	imperfect	well drained
Active layer depth (m)	0.32 (0.3)	0.45 (0.3)	0.71 (0.4)
% open water	3.01 (14.70)	8.31 (21.35)	2.19 (8.12)
% bare ground	0.00	2.76 (10.0)	0.10 (0.5)
% standing snags	1.15 (2.6)	4.10 (9.3)	2.31 (5.0)
% down woody debris	6.71 (12.6)	16.74 (32.7)	5.45 (11.0)
Mean age of the oldest living tree per site	233.61 (58.3)	190.90 (58.6)	264.64 (68.2)
Mean number of cohorts	0.78 (0.7)	1.16 (0.8)	0.75 (0.7)
Dominant tree species	*Picea mariana*	*Larix laricina*	*Picea glauca*
Dominant pseudo-species	PMA -3m PMA -3h PMA -2m PMA -4m	LLA -1l LLA -2m LLA -3m	PGL-4m PGL-4h PGL-3h

imperfect drainage, permafrost as a substrate and a thin active layer. The over-all basal area for the cluster (all tree species) is 5.635 m^2/ha with a basal area for the dominant tree species, black spruce, 4.338 m^2/ha. The over-all tree density for cluster 2 (all tree species) is 5519 stems per hectare with a black spruce density of 4117 stems per hectare (Table 9).

Cluster 3 (Eastern larch-black spruce) is a eastern larch forest with a dominance of small to mid-structure LLA pseudo-species mixed with smaller PMA pseudo-species (Table 7). There are 36 of the 70 pseudo-species represented in this cluster and the dominant pseudo-species are LLA - 1L, 2M and 3M. This cluster is typified by marshy (imperfect drainage), fen-like environment with standing surface water on many of the sites (Table 8). Although often underlain with permafrost, the stands with low numbers of PMA pseudo-species have deep active layers and a substrate of clay. There is an abundance of dead wood and a small numbers of standing snags in these eastern larch forests. The overall basal area (all tree species) for the cluster is 2.417 m^2/ha with a mean basal area for the eastern larch of 2.004 m^2/ha (Table 9). The total density of all species of trees for the cluster is 4437 stems per hectare with a density of eastern larch of 3147 stems per hectare.

Cluster 5 (White spruce-eastern larch) represents the white spruce upland and coastal forests. The dominant pseudo-species are the mid-size PGL pseudo-species (PGL - 4M, 4H and 3H) mixed with a wide structural size range of LLA-pseudo-species (Table 7). Of the 70 pseudo-species defined, 51 occur in this cluster. These forests are well drained, with a deep active layer and substrates

Table 9. Mean and standard deviation (in parenthesis) of the DBH, height, and basal area (m^2/ha) and density (per ha) of the tree species for each of the major forest clusters.

Cluster	species	n	Living or snags	mean DBH (cm)	Mean height (m)	Basal area (m^2/ha)	Density per hectare
2 Black spruce- eastern larch	LLA	20	S	3.86 (2.58)	-	0.09	55.5
	LLA	433	L	1.44 (2.68)	1.11 (1.63)	0.87	1202.7
	PGL	0	S	-	-	-	-
	PGL	6	L	8.22 (1.42)	4.34 (0.36)	0.09	16.6
	PMA	46	S	4.18 (2.66)	-	0.24	127.8
	PMA	1482	L	2.41 (2.76)	1.96 (1.68)	4.33	4116.7
	Total					5.64	5519.3
3 Eastern larch- black spruce	LLA	12	S	2.93 (3.26)	-	0.02	63.2
	LLA	598	L	1.56 (3.38)	1.35 (1.36)	2	3147.4
	PGL	0	S	-	-	-	-
	PGL	17	L	1.11 (2.06)	0.91 (1.30)	0.04	89.5
	PMA	0	S	-	-	-	-
	PMA	216	L	1.03 (1.46)	0.94 (1.04)	0.29	1136.8
	Total					2.42	4436.9
5 White spruce- eastern larch	LLA	0	S	-	-	-	-
	LLA	258	L	2.21 (3.44)	1.87 (2.04)	1.41	1075.2
	PGL	7	S	11.76 (6.58)	-	0.52	29.2
	PGL	507	L	3.72 (5.18)	2.35 (2.34)	6.74	2112.5
	PMA	0	S	-	-	-	-
	PMA	91	L	1.86 (2.28)	1.71 (1.56)	0.26	379.2
						8.93	3596.1

n = the number of stems. LLA = eastern larch, PGL = white spruce and PMA = black spruce. ha = hectares

dominated by calcareous sand (Table 8). There are small quantities of standing snags and down woody debris in these forests. The overall basal area for all trees in this cluster is 8.93 m^2/ha with a basal area for white spruce of 7.742 m^2/ha. (Table 9). The densities of these white spruce forests are 3596 stems per hectare for all the tree species and 2113 stems per hectare for white spruce.

3.3.2 Stand ordination

The statistics of the CCA are presented in Table 10 and the ordination biplot of the forest stands is shown in Figure 13 a and b. Plot D4.2 (a recent fire, <5 years old) was an outlier and removed from the analysis. The eigenvalues and species - environment correlation coefficients for the first and second axes are $E_1 = 0.514$, $E_2 = 0.435$, $r_1 = 0.88$, and $r_2 = 0.861$ respectively (significance of all canonical axes at $p < 0.005$) (Table 10). In total, the significant environmental variables explain 15.3% of the variation in structure/pseudo-species distribution for the first four ordination axes.

The first axis of the ordination was related to aspect (south and north (As, An)), and distance from the Hudson bay coast (UTM2 northing) (Figure 13 a). The second axis was positively related to depth of the active layer (Al) and an increasing easting (UTM1). The black spruce cluster was positively related to a southern aspect (As), and negatively related to distance from the coast (UTM2), a northern aspect and to an increase in the depth of the active layer. The black spruce stands were found inland, away from the Hudson Bay coast where the permafrost is seldom less than 30 cm from the surface (Table 8). Pseudo-species characterizing black spruce (PMA), are tightly clumped to the left along

Table 10. Statistics of the CCA for the stand analysis

Axes	1	2	3	4	Total inertia
Eigenvalues	0.514	0.435	0.353	0.219	9.964
Species-environment correlations	0.88	0.861	0.82	0.816	
Cumulative percentage variance					
of species data	5.2	9.5	13.1	15.3	
of species-environment relation	26.8	49.5	67.9	79.3	
Sum of all unconstrained eigenvalues					9.964
Sum of all canonical eigenvalues					1.919

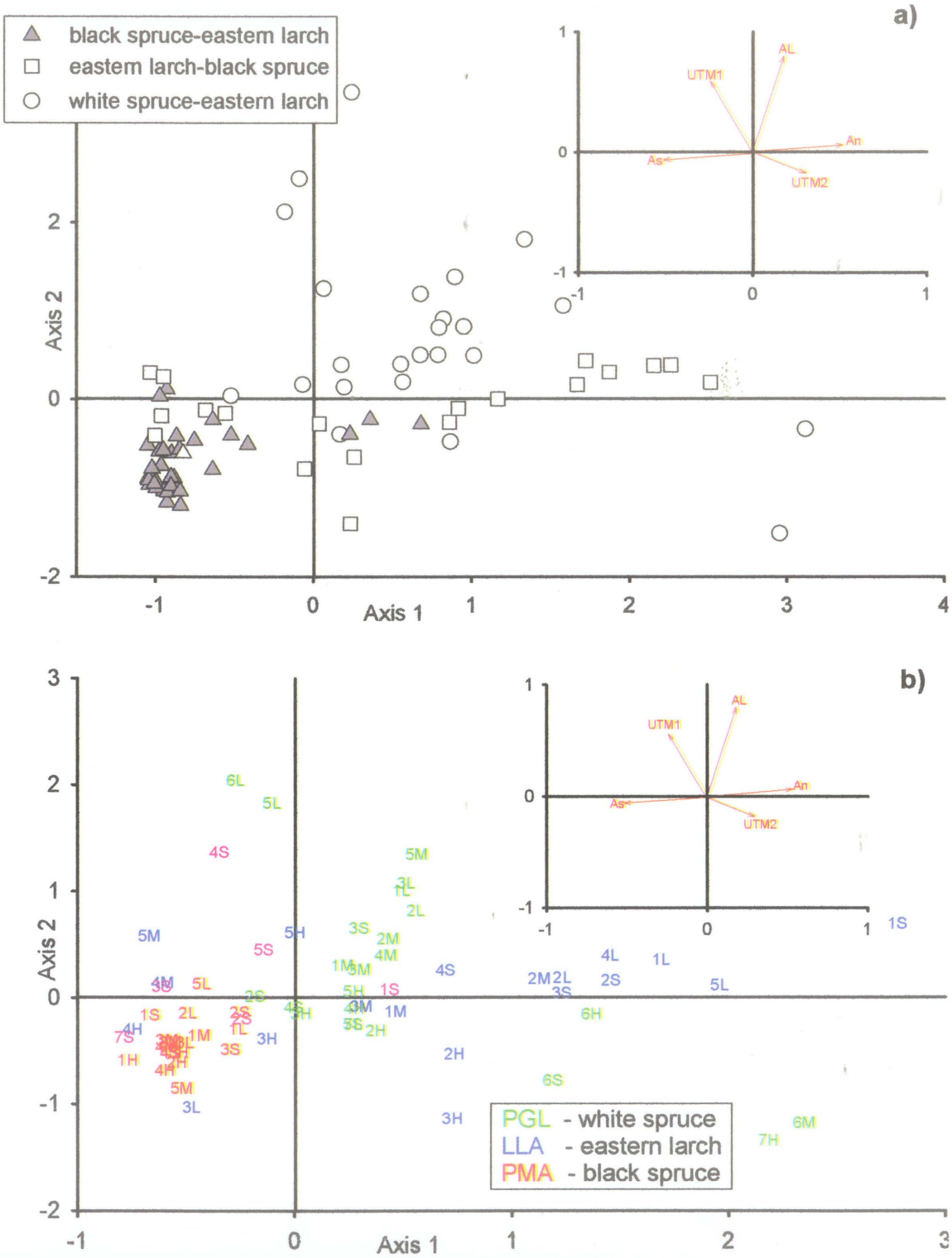

Figure 13. Results of the CCA conducted on the 82 sites showing the position along the first two axes of the a) major ecological communities and b) structural pseudo-species. The significant variables retained at $p = 0.05$ are illustrated in red (northinng = UTM1, easting = UTM2, aspect north = An, aspect south = As, depth of the active layer = AL

axis one, indicating a multi-structural forest complex with little variability despite a wide variation in age (Figure 13b).

The eastern larch cluster was tightly correlated to axis one and extended along the entire axis with a slight clumping of the larger LLA pseudo-species to the left in the biplot, thus indicated a large variability in structural attributes. The larger LLA pseudo-species are positively correlated to a southern aspect (As). The smaller LLA pseudo-species are positively related to a northen aspect and distance from the coast (UTM2) (increasing right to left) (Figure 13a).

There are a number of white spruce sites that fall to the far right of the biplot, along axis one and are riparian forests along some of the major creeks flowing into the Churchill River. These wet, riparian sites have deep active layers and are nutrient-rich, providing optimal growing conditions for white spruce (Table 8). The white spruce, in general, are distributed on a slight diagonal (upper left to lower right). The large white spruce (PGL) pseudo-species are positively related to the both the first and second axes and the small- to mid-sized pseudo-species form a cluster near the centre (right) of the ordination biplot (Figure 13b). The large PGL pseudo-species positively related to a northern aspect and a UTM2 northing along axis one, are found in the moist riparian zones along the creeks that flow into the Churchill River. The larger PGL pseudo-species related to axis two and positively correlated to increasing active layer depth (AL) and UTM1 easting, are isolated on the inland beach ridges that run parallel to the Hudson Bay (UTM1). The small to mid-size PGL pseudo-species are positively related to the UTM2 northing are the krumholtz white

spruce forests that grow along the Hudson Bay coastline.

A number of CCAs were conducted for individual clusters and groupings of clusters to better understand the relationship between the age or disturbance-related variables and the forest structure (not presented). This was done to assess if the structural variability observed mainly in LLA and PGL stands could be related to time-since-last-fire. Only the LLA-dominated pseudo-species group (eastern larch, cluster 3) showed any disturbance-related variable as significant (Figure 14a and b). The ordination produced a projection of the eastern larch cluster along the first axis related to clay as a substrate (SBc) and the number of cohorts found in the stand (A7) (Figure 14a). The second axis shows increasing amounts of down woody debris cover and is related to a cluster of burn sites (F2.2, C4.3 and D3.1). The stands of almost pure LLA pseudo-species are grouped to the right along the first axis and positively related to clay as a substrate (Figure 14b). These stands have deep active layers, higher pH, and are very poorly drained with standing water at the surface. The stands with a greater mixture of pseudo-species (PMA, LLA and PGL) are positively related to an increase in the number of cohorts (A7). These stands are typified by thinner active layers, permafrost as a substrate and less standing water at the surface. There is also a weak structural gradient along the first axis with an increase in the overall size of the pseudo-species, right to left (pure to mixed stands). No other CCAs showed significant insights to explain structural changes across the study area.

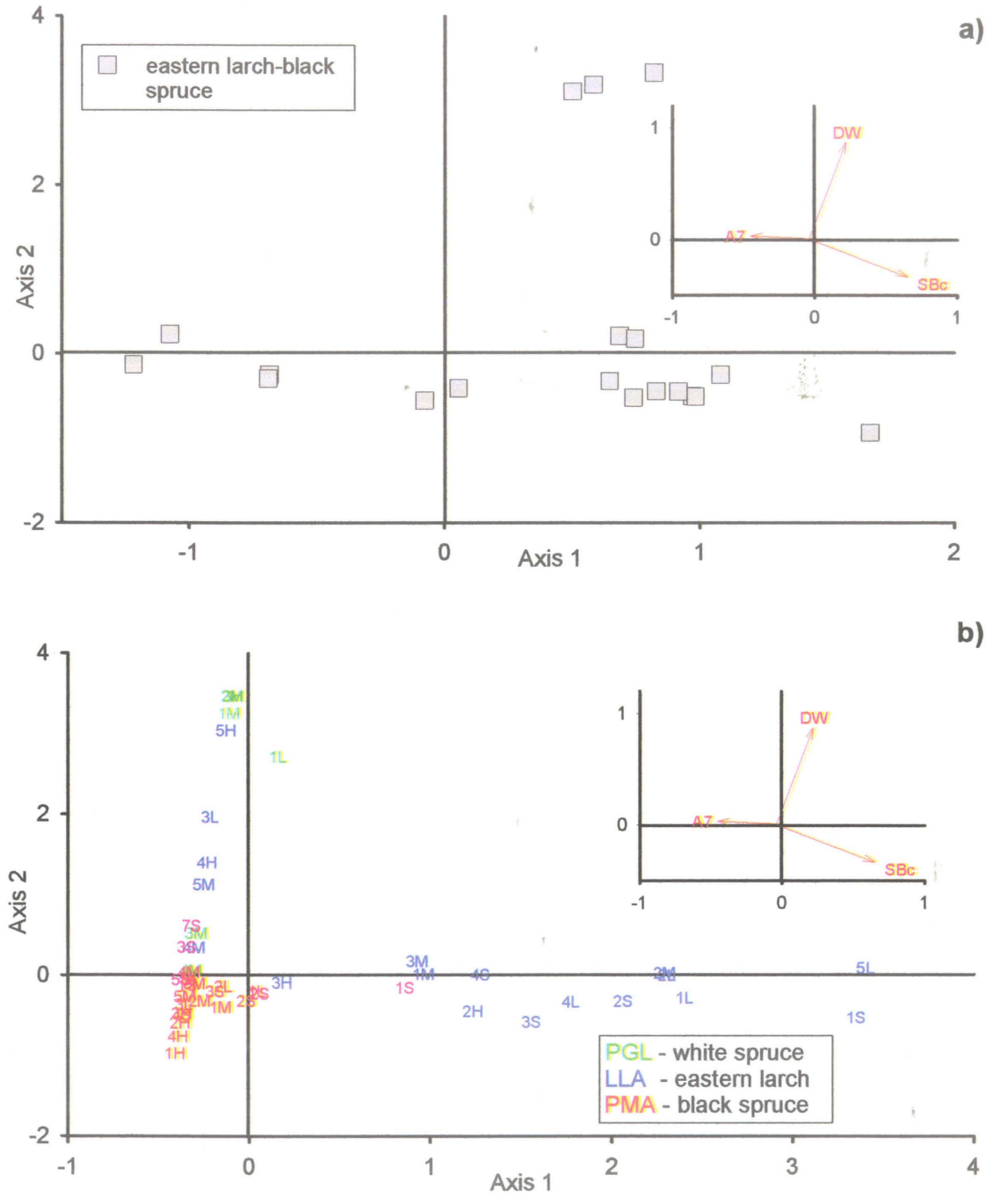

Figure 14. Graph a) illustrates the CCA ordination biplot showing the position of the eastern larch-black spruce cluster along the first and second axes of the analysis. Graph b) shows the positon of the structural pseudo-species. The significant variables retained at $p < 0.05$ are illustrated in red (% dead wood = DW, substrate clay = SBc and the number of cohorts = A7).

4. Discussion

It is important to mention that each of the methods used to calculate the fire-cycle (NFR and negative exponential model) are based upon a series of assumptions. For the NFR calculations, significant bias may result if the aerial extent of the fires are not accurately determined. In this study the aerial extent of the fires are over-estimated (from the assigned proximity analysis) and ultimately will under-estimate the fire-cycle (Heinselman 1973; Agee 1993). For the negative exponential model, significant bias can be introduced by using censored data and, as above, this will cause an underestimation in the length of the fire-cycle (Agee 1993; Johnson and Gutsell 1994; Finney 1995).

4.1 Fire-cycle and fire history

The fire-cycle results from the Churchill area do not directly compare to results form other forest-tundra studies. The fire-cycles from the Churchill area tend to be longer than those found in the western part of Canada (Johnson and Rowe 1977; Viereck 1983; Larsen 1997) and shorter than those reported in the eastern forest-tundra of Canada (Payette et al. 1889; Parisien and Sirois 2003). The study by Parisien and Sirois (2003) provide a good comparison of fire-cycles calculated for an area adjacent to Hudson Bay. Parisien and Sirois (2003) found that the modern fire-cycle length decreased from the Hudson Bay moving inland. They calculated a fire-cycle of 3,142 yrs in the coastal white spruce stands and a fire-cycle of 495 years in the black spruce forests further inland. Results from the Churchill area followed the same trend. The coastal white spruce forests have a modern (~AD 1775-2002) fire-cycle length of 1000 years and the inland black

spruce stands have a fire-cycle of 667 years.

Payette et al. (1989) and Johnson and Rowe (1977) in northern Alberta found a similar gradient moving from tree-line into the boreal forest. Payette et al. (1989) found that the fire-cycle length decrease dramatically from the forest-tundra (1460 yrs) to the boreal forest (180 yrs). In the Churchill study, there was a dramatic decrease in the length of the fire-cycle moving inland away from the coast.

The difference in modern fire-cycle lengths across northern Canada may be a reflection of the methods used in fire-cycle calculation and/or problems with the data in general. The NFR values for the Churchill area suggests the modern fire-cycle was 558 to 608 years where as the fire frequency analysis fitted to a negative exponential model gave a modern fire-cycle of 667 to 909 years for the same data. The Churchill data is heavily censored (providing only the minimum time-since-last-fire date) and this can have the affect of seriously under-estimating the fire-cycle length. However, despite the difference in fire-cycle values (calculated from the two methods), there is a decrease in fire frequency and/or area burned across all forest types in the Churchill area from AD 1525 and this is consistent with results found in other northern boreal forests in Canada (Payette et al. 1989; Masters 1990; Bergeron 1991; Parisien and Sirois 2003).

There was an increase in area burned during the period from AD 1925 - 1950 which contributed to reduce the fire-cycle length (714 to 588 years), probably related to the construction of the railway to Churchill. The railway

reached the Hudson Bay in AD 1929 and the first shipment of wheat arrived at the port in AD 1930 (Bickle 1995). The fire areas associated with the extensive burns during the AD 1925-1950 time period all border the railway and are related to increased human activity in the area. Despite this increase in human-caused fires during the AD 1925 -1950 age class, overall we still observe a lengthening of the fire-cycle since ~AD 1750.

Many authors have observed an overall decrease in fire frequency and a corresponding increase in fire-cycle lengths in the eastern (Bergeron 1991; Bergeron and Archambault 1993; Bergeron et al. 2001) and western (Larsen 1997; Weir et al. 2000) boreal forest of Canada since AD 1850. The results from this study also show an increase in the fire-cycle length occurred in the AD 1700's, in the forest-tundra near Churchill, Manitoba. There are some fire history studies that show a break in the fire-cycle in the AD 1700's. These include studies from Ruttledge Lake in the North West Territories (Johnson 1979), the Boundary Waters Canoe Area in Minnesota (Heinselman 1973), the Canadian Rockies (Johnson and Fryer 1987; Masters 1990; Johnson and Larsen 1991), the Columbian Mountains of British Columbia (Johnson et al. 1990) and in northern Minnesota (Clark 1990). Further north, at the treeline in Quebec, Arseneault and Payette (1992) found signs of a large fire that occurred in AD 1750 that caused a shift in the vegetation cover of the area from lichen-spruce forests to lichen-tundra. All the authors hypothesized that the increase in the fire-cycle length was related to a climate less conducive to fires, although the exact mechanism was not articulated (Johnson 1992).

Climate change, associated with the end of the Little Ice Age (AD 1850) is most often given as the probable cause for a change in the fire-cycle in the northern boreal forest (Bergeron 1991; Bergeron and Archambault 1993; Engelmark et al. 1994; Larsen 1996, 1997; Bergeron et al. 1998; Niklasson and Granstrom 2000). Climate-related studies for northern Canada indicate that there was a warming in the late AD 1700's, a cooling in the early 1800's and a continuous warming trend starting in the late 1800's (Jacoby and D'Arrigo 1989; D'Arrigo et al. 1992; Briffa et al. 1994; Gajewski and Atkinson 2003). How this warming in the late 1700's affected the fire-cycle of the Churchill region is unknown and further climatic studies using proxy data are needed. Archives from the Hudson Bay company for both Churchill and Eskimo Point (now Arviat) could also be consulted for records of fires in the 1700 and 1800's.

4.2 Species succession

Secondary succession is described by Johnson and Rowe (1977) as an orderly unidirectional change in plant communities, in which one set of dominants replace another as they make the environment unsuited for themselves. The terminal or climax stage is reached when a set of dominants is able to replace itself in perpetuity. But, Johnson and Rowe (1977) prefer to use the term "vegetation compositional changes" in preference to "succession" when describing vegetation changes in the northern boreal forest. Like many other boreal researchers (Ritchie 1962; Dix and Swan 1971; Johnson 1981; Jasieniuk and Johnson 1992; Auclair 1983; Viereck 1983; Foster 1985; Kenkel 1987; Morneau and Payette 1989; DeGrandpré et. al. 2000; Payette et. al. 2000; Brook

2001), they have found that the traditional idea of succession is a difficult concept to apply to these northern forests.

The results of the canonical correspondence analysis confirmed that age was not a significant variable related to species composition in the subarctic forest-tundra south of Churchill, Manitoba. This indicates that secondary succession, as described by Clements (1918), is relatively unimportant in this landscape (Dix and Swan 1971). The difference in species composition, between the five vegetation clusters, is primarily determined by the nature of the substrate, soil moisture and nutrient availability. CCA's were conducted on each of five clusters and then on different groupings of the clusters to understand the importance of age (and age-related variables) upon the species distribution within vegetation clusters. None of the age variables were significant for any of the vegetation clusters or groupings of clusters, indicating that there is no distinct pattern of vegetation change over time.

The zonation of the vegetation in the forest-tundra region in the Churchill region has been attributed to species life histories and not to time since last disturbance (Ritchie 1957). Vegetation which occupies a site after a fire (or other disturbance) can come from three sources: 1) vegetative reproduction (layering), 2) viable seeds buried in the soil, and 3) invasion of propagules (Johnson 1981).

The forest-tundra of the Churchill area can broadly be divided into three types of vegetation communities, white spruce forest, black spruce bogs and forest, and eastern larch treed fens.

The white spruce forest communities are limited in their distribution

predominately by substrate as speculated by Ritchie (1957). They form the "maritime tree-line" and are completely absent from the peat-dominated substrates found inland. Inland white spruce-dominated populations are isolated to the tops of old calcareous beach ridges and large glacio-fluvio deposits and to calcareous rich alluvial soils that accumulated in the riparian zones of prominent creeks. The differences in vegetation and stand structure, in the white spruce forest, from inland to coastal and from site to site, are related to habitat characteristics, not the age of these forests.

The black spruce forests of the boreal and forest-tundra zone have been intensely studied. Referred to as black spruce - feather moss and black spruce - lichen woodland (Viereck 1983), open spruce forest with lichen shrub and open spruce forest with moss-shrub (Ritchie 1962), open black spruce-lichen forest (Johnson and Rowe 1977), lichen spruce woodlands (Morneau and Payette 1989) and spruce heath treed bog and lichen heath plateau bog (Brook 2001) they describe wide expanses of black spruce forests with under-story vegetation ranging from lichen in drier areas to sphagnum moss in wet areas. The classification of the black spruce forests, in this study, identified two clusters, the black spruce-lichen moss community and the black spruce-sphagnum bog community.

These two communities were found inland on the peat deposits, underlain by permafrost. The two vegetation clusters that represented these forests were differentiated by minor changes in drainage, substrate and in pH. There was a large overlap in species composition in these two clusters with minor differences

in tree cover, moving from, very open lichen-dominated forests to a more closed canopy, moss-dominated forest on the flanks of relic beach and fluvio-glacio deposits. The black spruce vegetation communities may be lime and salt intolerant and may restrict their distribution in the Churchill region to the acid-rich deep inland peat deposits (Ritchie 1957; E. Punter, botanist, personal communication). Age was not a factor influencing the vegetation composition of these forests. Even in young, post-fire sites the vegetation community consisted largely of species found in the unburned forests nearby. The minor changes in vegetation composition and structure with time-since-last-fire were probably due largely to differences in growth rates (Dix and Swan 1971; Auclair 1983; Foster 1985; Morneau and Payette 1989).

The inland black spruce dominated forest in the study area are old forests and show little indication of fire (no even age stands and few fire scars). Payette and Morneau (1993) suggested that these black spruce-dominated communities of the forest-tundra are self-perpetuating open forests with relatively low tree density even in a fire-free environment. The variable ages of these forests are related to the ability of black spruce to reproduce vegetatively through layering and probably not due to high levels of disturbance (Légère and Payette 1981). DeGrandpré et al. (2000) found that black spruce forests evolved towards a multi-aged forest in the absence of fire.

The final vegetation group was the eastern larch-scrub birch-sedge fen community. The CCA results showed that substrate was the dominant variable controlling the distribution of these eastern larch fen communities throughout the

forest-tundra in the Churchill region. A calcareous clay substrate, and a deep active layer, provide a higher pH for these fen communities. As with the vegetation clusters above, age was not a significant variable in explaining vegetation distribution. Fire rarely burns fen vegetation types due to the wetness and open water patches, only occasionally burning the graminoid vegetation. Although fen communities wide-spread throughout the forest-tundra in the Churchill region, little is understood about their dynamics. Légère and Payette (1981) stated that eastern larch reproduces mainly by seed after a disturbance and that poor reproduction would create regular, even-age stands. Many of the eastern larch-dominated sites sampled in this study were even-aged, but there were exceptions, indicating the ability of the eastern larch to reproduce successfully by seed in the Churchill region.

In view of the above observations, any attempt to fit these vegetation clusters into the mold of classical secondary succession would be unrealistic and in the words of Dix and Swan (1971) unjustifiable. In saying this, the response and regeneration of the vascular plants in the study area seems to fit well with the concept of cyclical succession described by Barbour et al. 1987. The post-fire community reflects the species found in the pre-burned forest (Foster 1985).

It is interesting to note that Ritchie (1962) concluded his paper on the vegetation of northern Manitoba by stating that "the chief factor governing the nature of the vegetation appears to be topography, or more particular drainage pattern while climate and disturbance are important as secondary local factors".

4.3 Structural succession

Structural succession in the forest-tundra was controlled not by the age of the forest but by habitat characteristics such as aspect, geographic location, substrate, and depth of the active layer.

The white spruce pseudo-species showed the greatest variation in DBH and height of the three species studied. This variability was not related to the age of the trees but to the depth of the active layer and distance from the coast. The largest of the trees where found in rich riverine habitat near the coast or protected inland relict beach ridges, both areas with deep active layers. The variation in forest structure of the coastal white spruce was probably dependant upon gap dynamics and time since the land has risen above sea level and not on fire-cycle. Parisien and Sirois (2003) found that the coastal white spruce forests along the east coast of Hudson Bay exhibit this same gap dynamics and found that fallen trees accounted for much of the mortality and subsequent seedling recruitment.

Moving south and west (away from the coast) in the study area, there is a very narrow transition to the inland black spruce forest zone. The white spruce is ill-adapted to the presences of permafrost as a substrate and gives way quickly to black spruce. Unlike studies in northern Quebec, where the transition from white spruce to black spruce is marked by an increase in fires (Parisien and Sirois 2003), there is little evidence that fire is common in the black spruce zone in the forest-tundra south of Churchill. Ritchie (1957), attributed the transition from white spruce to black spruce to increased paludification as you move away

from the Hudson Bay coast. Brook (2001) concurred with Ritchie(1957), noting this coastal-inland gradient and attributed the change to isostatic rebound, nutrient and in particular, moisture changes.

The black spruce forest zone has a multi-dimensional structure and can be attributed to recruitment through layering (Ritchie 1962; Johnson and Rowe 1977; Morneau and Payette 1989; Brook 2001). Morneau and Payette (1989) found that during long fire-free periods in black spruce forests, layering became the dominant regenerative process and also noted that a similar age-size structure of layers could be found in old black spruce forest and is sometimes misinterpreted as an even-aged cohort, indicating disturbance. There was little evidence of wide spread disturbance in the Churchill black spruce forests and the forests are multi-structural. This same pattern was found by DeGrandpré et al. (2000) in the boreal forest. DeGrandpré (2000) concluded that, in the absence of fire, black spruce forests evolve towards an uneven size distribution. In this study, substrate, aspect and distance from the coast are the dominant variables controlling distribution of the black spruce zone. The tight clumping of the black spruce zone sites shows little variation in pseudo-species and indicates that there is little evidence of succession in the structure of these forests over time. The lack of structural variation in the black spruce pseudo-species may be due to the extremely slow growth of the black spruce and perhaps the low severity or absence of fire.

The eastern larch forest zone occurs within the black spruce zone, forming long fingers of wet fens that surround black spruce forest communities

and the inland white spruce forest communities. These eastern larch forests are unique to the Hudson Bay lowlands and are absent from most discussions on the forest-tundra (Ritchie 1962; Brook 2001). Ritchie (1962) refers to these forests as young forests, associated with calcareous alluvial deposits. Results of this study show that the eastern larch fen community was the youngest forest communities (mean of oldest living trees = 208 years) and were positively related to clay as a substrate, as identified in the CCA. This forest community was the only community that showed a disturbance-related variable as significant when analyzed as a separate group. Age-7 (the number of cohorts) is positively related to the eastern larch zone with an increasing number of PMA pseudo-species. This relationship may be the result of layering in the black spruce. Black spruce produce even-aged layers in the absence of disturbance and can mimic even-age cohorts caused by fire (Morneau and Payette 1989). The percent dead wood is the third environmental variable to be significant for the eastern larch zone and was related to recent burns in sites C4.3, D3.1 and F2.2. Dead wood is quicky grown over with vegetation in older sites.

The strong gradient within the eastern larch zone along the first axis of the CCA was probably related to increasing paludification and a change from clay substrate to a permafrost substrate.

The results of this study show no classical secondary succession in any of the vegetation or structural groups. Unlike the recent study by DeGrandpré et al. (2000), who found a major post-disturbance succession trend in black spruce stands in northern Quebec, no such trend was found in the Churchill region. The

distribution of vegetation, forests and forest structure appear to be controlled by substrate, distance from the Hudson Bay coast, and paludification.

5. Conclusion

The objectives of this study were to examine the role that fire plays in controlling vegetation and structural succession in the forest-tundra south of Churchill, Manitoba and to estimate the fire-cycle for the region. Results indicated that fire-cycles for the study area are long and follow the trends reported by other researchers (Flannigan et al. 1998). The lengthening of the fire-cycle observed, moving either inland from the Hudson Bay or away from tree-line, and reported by many authors (Sirois and Payette 1989; Parisien and Sirois. 2003; Johnson 1979) was found in the Churchill area. The forests with the longest fire-cycle (1000 years) were the coastal white spruce forest communities growing in dry, upland sites.

The modern fire-cycle for the forest-tundra south of Churchill was estimated between 558 - 667 (area) or 588 (frequency) years. There was a break in the fire-cycle length in the AD 1700's, coinciding with a lengthening of the fire-cycle. This trend to a longer fire-cycle, but not the timing, is consistent with reports from studies world wide in the boreal forest (Bergeron and Archambault 1993; Engelmark et al. 1994; Larsen 1997; Flannigan et al. 1998). The lengthening of the fire-cycle was observed despite an apparent increase of anthropogenic disturbance in the 20th century. The synchroneity of the increase in the length of the fire-cycle in the northern forests of Canada, suggest a response to a synchronous climate change. The timing of the change in the fire-

cycle in the Churchill region however, is out of line with the rest of northern Canada (~ AD 1850) and the cause of this discontinuity is outside the realm of this study. However, many researchers (Heinselman 1973; Johnson 1979; Johnson and Fryer 1987; Clark 1990; Johnson et al. 1990; Masters 1990; Johnson and Larsen 1991) also found a lengthening in the fire-cycle in the 18th century in the subarctic forests. They suggested that changes in climate associated with the Little Ice Age was the cause. This will need to be further addressed in future studies.

Based upon the results of the fire-cycle analysis, there were many forest stands in the study area that have their origins prior to the change in the fire-cycle in the 1700's and have sustained themselves (floristically and structurally) though a change in the fire-cycle length. Although fire is a pivotal ecosystem process in the boreal forest (Weber and Flannigan 1997), time-since-last-fire was not a significant variable in determining the vegetation or structural compositions of forest-tundra south of Churchill, Manitoba. Differences in composition between forest stands were primarily due to site differences such as distance from the Hudson Bay, substrate, depth of the permafrost and paludification. The results of this study suggest that a lengthening of the fire-cycle, associated with climate change, for the Churchill region would unlikely affect forest composition or structure in the forest-tundra. These forests can seemingly maintain themselves with or without fire. Long term climatic warming ($2xCO^2$), often associated with drought, may cause a degradation in permafrost, limit peat accumulation, ultimately increasing the affects of paludification protecting the inland black

spruce and eastern larch forests by limiting the spread and intensity of fire. The affects on the white spruce forests, both coastal and upland could, however, be devastating. Parisien and Sirois (2003) suggested that the coastal white spruce are a relict feature and persist only because of low fire occurrence. The white spruce forest, both coastal and upland, in the Churchill area, are probably relict forests and depend upon sexual reproduction for survival. Increased fire activity predicted with climate warming (Flannigan and Van Wagner 1991), could see increased fragmentation of these white spruce forests and severe fire may cause a shift in the vegetation from forest to tundra as suggested by Sirois and Payette (1991).

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7. Appendices

Appendix 1. Fire area data for the forest-tundra south of Churchill, Manitoba from the time-since-last-fire map generated in ArcView® (Figure 5).

age class	T-S-L-F	area (ha)	cumulative area	Cumulative %
2000	0	0.000	173267.331	1
1975	25	2635.766	173267.331	1
1950	50	5637.056	170631.565	0.985
1925	75	11810.424	164994.509	0.952
1900	100	5045.930	153184.085	0.884
1875	125	7952.948	148138.155	0.855
1850	150	0.000	140185.207	0.809
1825	175	6631.997	140185.207	0.809
1800	200	5085.031	133553.21	0.771
1775	225	16901.354	128468.179	0.741
1750	250	8622.256	111566.825	0.644
1725	275	15104.663	102944.569	0.594
1700	300	28386.419	87839.906	0.507
1675	325	26817.047	59453.487	0.343
1650	350	12916.207	32636.44	0.188
1625	375	9817.014	19720.233	0.114
1600	400	8511.662	9903.219	0.057
1575	425	153.063	1391.557	0.008
1550	450	0.000	1238.494	0.007
1525	475	1238.494	1238.494	0.007
totals		173267.331		

Appendix 2. Censored (C) and non-censored (NC) TSLF dates for the area and bootstrap frequency data-sets

Area		Frequency									
forest-tundra n = 119		forest-tundra n=18		PGL n = 12		PMA n = 16		LLA n= 6			
C	NC	C	NC	C	NC	C	NC	C	NC		
108	11	15.9	2.13	11	1	14	2	5	1		
91% censored		88% censored		92% censored		88% censored		83% censored			

Appendix 3. Species list and % cover for each species per site

	A4.1	B1.1	B2.1	B2.2	B2.3	B2.4	B3.1	B3.2	B3.3	B3.4	B3.5	B3.6	B4.1	B4.2	B4.3	B4.4	B4.5	B5.1	B5.2
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alpine bistort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0.1	0
Arctostaphylos rubra/UU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
Bartsia alpina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0	0.1	0	0.05	2.5	0	0	0	0	0	0	0	0.05	0	0	0	2.5	0.1	0.05
Caltha palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drosera rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryas integrifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	62.5	2.5	87.5	37.5	2.5	62.5	0.1	0.1	2.5	37.5	0	37.5	87.5	87.5	87.5	87.5	87.5	2.5	15
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	62.5	0	0	0	0
Equisetum scirpoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum variegatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriophorum spp	0	0	0	0	0.1	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0
Feather moss	87.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87.5	87.5	15	87.5
Fungi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geocaulon lividum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Grasses	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	62.5	0	0	37.5	37.5
Habenaria hyperborea	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hippuris vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juniperus communis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kalmia polifolia	0	0.1	2.5	2.5	0	0.05	0.1	0	0.05	0.05	0.1	0.1	0	0	0	0	0	0.05	0
Larix laricina	2.5	15	2.5	2.5	15	0	0	0.05	15	0	0	0.05	15	15	15	15	0.1	15	2.5
Ledum decumbens	0	87.5	62.5	0	37.5	15	87.5	62.5	0	2.5	37.5	0.1	15	15	0	15	0	0	15
Ledum groenlandicum	15	87.5	87.5	37.5	0.05	87.5	37.5	62.5	87.5	87.5	87.5	87.5	87.5	62.5	87.5	87.5	2.5	37.5	62.5
Lichen1 - Crustose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen2 - Foliose	37.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	2.5
Lichen3 - Fruiticose	0.1	15	87.5	2.5	37.5	62.5	87.5	87.5	15	87.5	0	0	87.5	0	0	0	0	15	0
Lichen4 - unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liverwort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loiseleuria procumbens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menyanthes trifoliata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mitella nuda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	A4.1	B1.1	B2.1	B2.2	B2.3	B2.4	B3.1	B3.2	B3.3	B3.4	B3.5	B3.6	B4.1	B4.2	B4.3	B4.4	B4.5	B5.1	B5.2
Moneses uniflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moss spp	0	0	0	0	62.5	0	0	37.5	0	87.5	87.5	0	0	0	0	0	0	0	0
Myrica gale	0	37.5	0	0	0	0	0	0	0	0	0	0	0	0	87.5	0	87.5	0	0
Orchis rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxycoccus microcarpus	0	0	0	0	0	15	0.05	0	0	0	0	0	37.5	0	0	0	0	0	0
Pedicularis flammea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedicularis lapponica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedicularis sudetica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petasites sagittatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0
Phyllodoce caerulea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguicula spp	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0
Picea glauca	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	87.5	37.5	87.5	0.1	15
Picea mariana	0	37.5	62.5	62.5	2.5	37.5	0.05	87.5	87.5	62.5	87.5	37.5	62.5	62.5	0	0	0	15	0
Polygonum viviparum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Purple Sax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola secunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reindeer moss (Cladina)	0	0	0	0	0	0	0	0	0	0	87.5	87.5	0	87.5	0	15	0	0	0
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ribes hudsonianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0
Ribes oxyacanthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus acaulis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.05
Rubus chamaemorus	0	87.5	87.5	62.5	37.5	62.5	87.5	87.5	87.5	87.5	0	87.5	62.5	87.5	87.5	87.5	87.5	0	0
Rush spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix spp	37.5	0	0	2.5	15	0	0	0	0	0	0	0	0	0	37.5	0	15	62.5	37.5
Sedges	0.05	0	0	2.5	15	0	0	0	0	0	0	0	15	0	0	0	37.5	37.5	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smilacina trifolia	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphagnum spp	0	62.5	0	87.5	0	87.5	0	0	87.5	0	0	87.5	87.5	87.5	87.5	0	0	0	0
Spiranthes romanzoffiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
Vaccinium uliginosum	87.5	0	0	37.5	15	0	0	0	0	0	0	0	0	0	87.5	0	15	62.5	87.5
Vaccinium vitis-idaea	62.5	37.5	0.1	2.5	2.5	0	15	2.5	37.5	37.5	0.1	37.5	87.5	37.5	87.5	62.5	87.5	0	37.5

	B5.3	B6.1	C2.1	C2.2	C2.3	C2.4	C3.3	C3.4	C4.1	C4.2	C4.3	C4.4	C4.6	C5.1	C5.2	C5.3	C5.4	C5.5	C5.6
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alpine bistort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0
Andromeda polifolia	2.5	0.1	0	0	0	0	0	0.05	0	62.5	0	0	0.1	0.1	0	0.05	15	62.5	0
Arctostaphylos rubra/UU	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0
Bartsia alpina	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0.1	15	0	0	0	37.5	0	2.5	0	87.5	0	0	2.5	0	37.5	2.5	0	2.5	0.05
Caltha palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Drosera rotundifolia	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryas integrifolia	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	15	0	2.5	0.1	37.5	0	15	0	87.5	2.5	15	37.5	15	37.5	62.5	37.5	37.5	37.5	87.5
Epilobium angustifolium	0	0.05	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0.05	0	0	37.5	0.05	0	0	0	0	0
Equisetum scirpoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum variegatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriophorum spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feather moss	0	15	0.1	15	87.5	15	0	0	0.05	87.5	0	15	37.5	0	0	0	87.5	37.5	87.5
Fungi	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0
Geocaulon lividum	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Grasses	0.1	87.5	0	0	0	62.5	0	0	0	2.5	2.5	0.1	87.5	2.5	0	15	2.5	15	0.1
Habenaria hyperborea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hippuris vulgaris	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juniperus communis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kalmia polifolia	0	0	0	0	0	0	15	0.1	0	0	0.05	0	0.1	0	0.05	0	0	0	87.5
Larix laricina	2.5	2.5	0	0	2.5	15	0	0.1	0.05	37.5	0.05	0.1	2.5	2.5	87.5	15	15	2.5	2.5
Ledum decumbens	15	0	37.5	15	15	0	0.1	0	62.5	0	87.5	87.5	0.1	0.05	0.05	2.5	2.5	15	15
Ledum groenlandicum	15	0	15	62.5	87.5	0	37.5	0.05	87.5	2.5	87.5	87.5	0.1	62.5	62.5	0	0.05	0	0
Lichen1 - Crustose	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	0	0	0	0
Lichen2 - Foliose	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	2.5	15	2.5	0
Lichen3 - Fruiticose	87.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen4 - unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liverwort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	2.5
Loiseleuria procumbens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37.5	0	0	0
Menyanthes trifoliata	0	0	0	0	0	87.5	0	37.5	0	0	0	0	2.5	0	0	0	0	0	0
Mitella nuda	0	0	0	0	0.1	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
Moneses uniflora	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0

	B5.3	B6.1	C2.1	C2.2	C2.3	C2.4	C3.3	C3.4	C4.1	C4.2	C4.3	C4.4	C4.6	C5.1	C5.2	C5.3	C5.4	C5.5	C5.6
Moss spp	0	0	0	0	15	0	0	0	0	0	15	0	0	0	0	0	2.5	0	0
Myrica gale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0.05	0
Orchis rotundifolia	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxycoccus microcarpus	0	0	0.1	0	2.5	2.5	2.5	87.5	62.5	62.5	0	37.5	0.1	15	0.1	0	0	0	0.1
Pedicularis flammea	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0.1	0
Pedicularis laconic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedicularis sudetica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petasites sagittatus	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0.05	0	0
Phyllodoce caerulea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguicula spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0
Picea glauca	0	37.5	0	0	0	0	0	0	0	0	0	0	0	0	0.05	37.5	2.5	0	0
Picea mariana	62.5	0	37.5	87.5	62.5	0.1	15	0.05	87.5	0.05	0.1	37.5	2.5	15	15	0	0	0.05	87.5
Polygonum viviparum	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla palustris	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0
Purple Sax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0
Pyrola secunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reindeer moss (Cladina)	0	0	87.5	87.5	37.5	0	15	0	62.5	0	0.1	37.5	0.1	62.5	2.5	87.5	87.5	37.5	2.5
Rhododendron lapponicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ribes hudsonianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ribes oxyacanthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus acaulis	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0.1	0	0	0	0
Rubus chamaemorus	0.05	0	37.5	87.5	62.5	0	62.5	0	62.5	0	87.5	62.5	0.1	0.1	0	0	0.1	62.5	37.5
Rush spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix spp	0	0	0	0	0	0	0	0.05	0	0.1	0	0	37.5	37.5	62.5	15	37.5	15	0.05
Sedges	0.1	0	0	0	2.5	87.5	0.1	87.5	0	87.5	0	0	87.5	37.5	2.5	0	0	15	0
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smilacina trifolia	0	0	0	0	0	0	0	0	0	2.5	0	0	15	0	0	0	0	0	0
Sphagnum spp	0	0	37.5	0	0	0.1	87.5	87.5	87.5	0	0.1	37.5	15	62.5	0	0	0	0.1	2.5
Spiranthes romanzoffiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0.1	0.1	0.1	0
Vaccinium uliginosum	15	87.5	0	0	37.5	0	0	0	0	0	0	0	0	15	15	15	0	2.5	0.1
Vaccinium vitis-idaea	15	0	15	37.5	37.5	0	15	0	2.5	0	2.5	15	0	2.5	15	15	37.5	15	87.5

	C5.7	C5.8	C6.1	D2.1	D2.2	D2.3	D2.4	D3.1	D3.2	D4.1	D4.2	D4.3	D4.4	D4.5	D4.6	D4.7	D4.8	D5.1	D5.2
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0
Alpine bistort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	15	0	37.5	0.05	0.05	0	0	0.05	0	2.5	0	0	0.1	0	0.1	0.1	0	0.1	0
Arctostaphylos rubra/UU	0	0	0	2.5	0.1	0	0	0	0	0	0	0	0	37.5	0	0	0	0	0
Bartsia alpina	0	0	0.05	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Betula glandulosa	37.5	0	0.1	0	15	0	0	2.5	0	0	0	0	0	0	0	0	0	2.5	0
Caltha palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drosera rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryas integrifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
Elymus arenarius	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	87.5	0.1	62.5	15	87.5	87.5	0	15	37.5	87.5	0.1	87.5	87.5	2.5	2.5	0	62.5	15	15
Epilobium angustifolium	0	0	0.05	0	0	0	0	0	0	0	62.5	0	0	0.1	0	0	0	0	0
Equisetum arvense	0	0	0	0.05	0	0	0	0	0.05	0	0	0	0.1	0	0	0	0	0	0
Equisetum scirpoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum variegatum	0	0	0	0.1	0	0	0	0	0	0	15	0	0.1	0	0	0	0	0	2.5
Eriophorum spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feather moss	2.5	0	15	37.5	0.1	87.5	0	87.5	37.5	87.5	0.1	87.5	87.5	15	87.5	37.5	15	37.5	15
Fungi	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geocaulon lividum	0	0	0	0	0	0	0	0	0	0	0	0	0	62.5	0	0	0	0	0.1
Grasses	0	0	0	2.5	0.1	0.1	0	0	0	0.05	0	0	0	0.05	0	0	0	2.5	2.5
Habenaria hyperborea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hippuris vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juniperus communis	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Kalmia polifolia	0	0	0.1	0	0	37.5	0	0.05	0	0	0	0	0.1	0.05	0	0	0	0	0.1
Larix laricina	2.5	0	0.05	2.5	0	2.5	0.1	0.05	15	0.05	2.5	0.05	0.1	2.5	2.5	0.1	0.1	0.1	2.5
Ledum decumbens	0	37.5	0	37.5	62.5	2.5	0	87.5	15	2.5	0	0	0	0	0.1	15	0.1	0	15
Ledum groenlandicum	0	62.5	0.05	37.5	0.1	37.5	37.5	87.5	37.5	87.5	62.5	87.5	87.5	0	62.5	2.5	87.5	0	2.5
Lichen1 - Crustose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen2 - Foliose	0	0	0	0	62.5	0	0	0	0.05	2.5	0.1	15	0	0.05	0.05	0	0	2.5	0
Lichen3 - Fruiticose	0	0	0.1	0	0	0	0	0	0	37.5	0	87.5	0	2.5	87.5	0	0	0	15
Lichen4 - unknown	0	0	0	62.5	0	0	87.5	0	0	0	0	0	0	0	0	0	0.1	37.5	0
Liverwort	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
Loiseleuria procumbens	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menyanthes trifoliata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mitella nuda	0	0	0	0	0	0	0	0	0	2.5	0	0	0	87.5	0	0	0	0	0
Moneses uniflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	C5.7	C5.8	C6.1	D2.1	D2.2	D2.3	D2.4	D3.1	D3.2	D4.1	D4.2	D4.3	D4.4	D4.5	D4.6	D4.7	D4.8	D5.1	D5.2
Moss spp	0	0.1	0	0	2.5	0	0	0	0	87.5	0	0	0	0	0	0	0	0	0
Myrica gale	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Orchis rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxycoccus microcarpus	0	0.1	0	0	0	0.05	0	0	0	0	0	0	0.1	0	0	0.1	62.5	0	0
Pedicularis flammea	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0
Pedicularis laconic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedicularis sudetica	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0
Petasites sagittatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodoce caerulea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguicula spp	0.1	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0.05	0	0.05	0
Picea glauca	2.5	0	37.5	0	0	0	0	0	0	0	2.5	15	0	0	2.5	0	0	37.5	0
Picea mariana	0	15	0	62.5	2.5	37.5	15	2.5	87.5	62.5	0	0	62.5	2.5	15	37.5	15	0	37.5
Polygonum viviparum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Purple Sax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola secunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reindeer moss (Cladina)	62.5	87.5	0	87.5	0	15	87.5	87.5	37.5	0	0	0	87.5	0	0	87.5	2.5	37.5	0
Rhododendron lapponicum	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62.5	0
Ribes hudsonianum	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Ribes oxyacanthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Rubus acaulis	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus	0	0	0	2.5	0	87.5	0	87.5	87.5	0	0	0	0.1	37.5	0.1	87.5	87.5	0	2.5
Rush spp	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Salix spp	62.5	0	2.5	0	2.5	0	0.1	0.1	37.5	2.5	2.5	0.1	2.5	15	0.05	0	0	0.1	2.5
Sedges	0.1	0	0	0	0	0	0	0.1	0.05	0	0	0	0.1	0.1	2.5	0	0	0	0.1
Shepherdia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	15	0
Smilacina trifolia	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0
Sphagnum spp	0	0	0	2.5	0	2.5	0.1	87.5	2.5	0	0	0	0	0	0	87.5	37.5	0	0
Spiranthes romanzoffiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0
Tofieldia pusilla	0	0	0.05	0.1	0	0	0	0	0	0	0	0	0.1	0	0	0	0	2.5	0
Vaccinium uliginosum	62.5	0	15	62.5	87.5	15	0	37.5	0	0	0	0	0	0.1	2.5	0	0	0	2.5
Vaccinium vitis-idaea	15	2.5	2.5	62.5	37.5	87.5	0.1	87.5	15	37.5	0.05	62.5	0.1	37.5	62.5	87.5	62.5	0	15

	D5.3	D5.4	D5.5	D5.6	D6.1	E2.1	E2.2	E2.3	E2.4	E2.5	E3.1	E3.2	E3.3	E3.4	E3.5	E3.6	E4.1	E4.2	E4.3
Achillea nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alpine bistort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Andromeda polifolia	0.1	0	0.05	0	0.1	0	0	2.5	0	0.1	0.1	0	0.1	37.5	0	0	0	0	0
Arctostaphylos rubra/UU	0	0	2.5	2.5	62.5	0.1	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Bartsia alpina	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula glandulosa	0.1	0	0	0	0	0	37.5	0	0	2.5	62.5	0	0	0.1	0	87.5	0	0	87.5
Caltha palustris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drosera rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryas integrifolia	0.05	0	0.05	87.5	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	87.5	87.5	62.5	15	87.5	87.5	0	15	15	87.5	0.1	37.5	37.5	62.5	2.5	0.1	37.5	62.5	0
Epilobium angustifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0
Equisetum arvense	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62.5	0	0	15
Equisetum scirpoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum variegatum	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriophorum spp	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Feather moss	0	37.5	15	0.1	15	87.5	0	0	0	0.1	87.5	87.5	87.5	0	0	62.5	15	2.5	15
Fungi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geocaulon lividum	0	0	0	0	0	62.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Grasses	0	0.1	0.1	62.5	0.1	0	15	0	2.5	0.1	0	0	2.5	2.5	0	62.5	0	2.5	87.5
Habenaria hyperborea	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hippuris vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juniperus communis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kalmia polifolia	0	0	0	0	0	0	15	0.05	0	0.1	0.05	0	0.1	0	0	0.1	0	0	0
Larix laricina	0	0	0	2.5	0	0	15	15	0.1	15	37.5	0	2.5	0.1	0	37.5	0	2.5	37.5
Ledum decumbens	15	2.5	2.5	0	0	2.5	0	37.5	62.5	87.5	0	62.5	2.5	2.5	15	0.1	0.1	15	0
Ledum groenlandicum	0	0	0.1	0	0	0.1	15	0.1	0.1	15	0.05	62.5	37.5	0	15	0.1	62.5	87.5	0
Lichen1 - Crustose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen2 - Foliose	0	2.5	0	2.5	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Lichen3 - Fruiticose	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lichen4 - unknown	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liverwort	0	37.5	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0.1	37.5	0
Loiseleuria procumbens	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menyanthes trifoliata	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0
Mitella nuda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moneses uniflora	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	D5.3	D5.4	D5.5	D5.6	D6.1	E2.1	E2.2	E2.3	E2.4	E2.5	E3.1	E3.2	E3.3	E3.4	E3.5	E3.6	E4.1	E4.2	E4.3
Moss spp	2.5	37.5	0	0	0	0	37.5	0	0	2.5	0	0	0	15	0	0	0	0	0
Myrica gale	0	0	0	0	0	0	0.1	0	0	0	2.5	0	0	0	0	62.5	0	0	15
Orchis rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxycoccus microcarpus	0	0	0	0	0	0	0	0	0	0.05	0	0.05	0.1	0	37.5	0	62.5	37.5	0
Pedicularis flammea	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Pedicularis laconic	0.05	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0
Pedicularis sudetica	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
Petasites sagittatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	2.5	0.1
Phyllodoce caerulea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinguicula spp	0	0	0	0	0	0	0.1	0	0	0	0	0.05	0	0	0	0	0	0	0
Picea glauca	15	0	15	37.5	15	15	37.5	0	0	0	0	62.5	0	0	0	0	0	15	0
Picea mariana	0	0	0	0	0	0	2.5	15	2.5	0.1	37.5	0	62.5	0.1	37.5	0.1	62.5	0	0
Polygonum viviparum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla palustris	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0	15
Purple Sax	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Pyrola secunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reindeer moss (Cladina)	37.5	62.5	87.5	37.5	0.1	87.5	0.1	87.5	87.5	37.5	0	87.5	2.5	87.5	15	0	2.5	2.5	0
Rhododendron lapponicum	0	0	0	0	37.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ribes hudsonianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ribes oxyacanthoides	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus acaulis	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0.1	0	0.1	62.5
Rubus chamaemorus	0	0	0	0	0	0	62.5	37.5	62.5	37.5	15	87.5	87.5	62.5	62.5	0	62.5	62.5	0
Rush spp	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
Salix spp	2.5	0	0	0	0	0.05	37.5	0	0.05	15	87.5	0	0.1	0.1	0	87.5	0	0.1	87.5
Sedges	0.05	0	0	0	0	0	0	0	0	0.1	87.5	2.5	0	0.1	0	62.5	0	0.1	87.5
Shepherdia canadensis	2.5	0	0.1	37.5	2.5	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
Smilacina trifolia	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	0	62.5
Sphagnum spp	0	0	0	0	0	0	0	0	0	0	0	87.5	15	37.5	37.5	0	87.5	37.5	0
Spiranthes romanzoffiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tofieldia pusilla	0.05	0	0	0	15	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	62.5	0	15	0.1	0	37.5	15	2.5	0.1	2.5	0.1	0	0	2.5	0	2.5	0	0.1	0
Vaccinium vitis-idaea	87.5	37.5	15	0	2.5	87.5	37.5	15	15	37.5	0	2.5	37.5	87.5	2.5	0.1	15	37.5	0

	F2.1	F2.2	F2.3	F2.4	F2.5	F3.1	F3.2
Achillea nigrescens	0	0	0	0	0	0	0
Alpine bistort	0	0	0	0	0	0	0
Andromeda polifolia	0	0	0	0.05	0	0	0
Arctostaphylos rubra/UU	87.5	0	87.5	0	87.5	0	0
Bartsia alpina	0	0	0	0	0.05	0	0
Betula glandulosa	0.05	0.05	0	0	0.05	0	0.1
Caltha palustris	0	0	0	0	0	0	0
Drosera rotundifolia	0	0	0	0	0	0	0
Dryas integrifolia	0	0	0	0	0	0	0
Elymus arenarius	0	0	0	0	0	0	0
Empetrum nigrum	87.5	0	87.5	15	87.5	2.5	0.1
Epilobium angustifolium	0	37.5	0	0	0	0	0.1
Equisetum arvense	0	0	0	0	0	0	0.1
Equisetum scirpoides	0	0	0	0	0	0.1	0
Equisetum variegatum	0	0	0.1	0	0	0	0
Eriophorum spp	0	0	0	0	0	0	0
Feather moss	0	0	87.5	0	87.5	2.5	0
Fungi	0	0	0	0	0	0	0
Geocaulon lividum	37.5	0	87.5	0	0.1	0	0
Grasses	37.5	0	0	0	0.1	0	0.1
Habenaria hyperborea	0	0	0	0	0	0	0
Hedysarum mackenzii	0	0	0	0	0	0	0
Hippuris vulgaris	0	0	0	0	0	0	0
Juniperus communis	0	0	0	0	0	0	0
Kalmia polifolia	0	0	0	0	0	0	0.1
Larix laricina	2.5	2.5	15	15	15	0.1	0
Ledum decumbens	0	15	0	15	15	15	0
Ledum groenlandicum	37.5	15	15	37.5	37.5	15	37.5
Lichen1 - Crustose	0	0	0	0	0	0	0
Lichen2 - Foliose	0	0	0	0	0	0.1	0
Lichen3 - Fruiticose	0	62.5	0	0	0	0	0
Lichen4 - unknown	0	0	0	0	0	0	0
Liverwort	0	0	0	0	0	0.05	0
Loiseleuria procumbens	0	0	0	0	0	0	0
Menyanthes trifoliata	0	0	0	0	0	0	0
Mitella nuda	0	0	0.05	0	0	0	0
Moneses uniflora	0	0	0	0	0	0	0

	F2.1	F2.2	F2.3	F2.4	F2.5	F3.1	F3.2
Moss spp	0	0	0	0	0	2.5	87.5
Myrica gale	0	0	0	0	0	0	0
Orchis rotundifolia	0	0	0	0	0	0	0
Oxycoccus microcarpus	0	0	15	0	0	2.5	0
Pedicularis flammea	0	0	0	0	0	0	0
Pedicularis laconic	0	0	0	0	0	0	0
Pedicularis sudetica	0	0	0	0	0	0	0
Petasites sagittatus	0	0	0	0	0	0	0.1
Phyllodoce caerulea	0	0	0	0	0.05	0	0
Pinguicula spp	0	0	0	0	0	0.05	0
Picea glauca	37.5	2.5	2.5	0	37.5	0	2.5
Picea mariana	0.1	0	37.5	15	2.5	37.5	0
Polygonum viviparum	0	0	0	0	0	0	0
Potentilla palustris	0	0	0	0	0	0	0.1
Purple Sax	0	0	0	0	0	0	0
Pyrola grandiflora	0	0	0	0	0	0	0.1
Pyrola secunda	0	0	0	0	0	0	0.1
Reindeer moss (Cladina)	87.5	0	0	87.5	2.5	87.5	0
Rhododendron lapponicum	0	0	0	0	0	0	0
Ribes hudsonianum	0	0	0	0	0.05	0	0
Ribes oxyacanthoides	0	0	0	0	0	0	0
Rubus acaulis	62.5	0	0	0	0	0	37.5
Rubus chamaemorus	0	0	0.05	87.5	0	37.5	0
Rush spp	0	0	0	0	0	0	0
Salix spp	2.5	37.5	87.5	0.1	15	0	87.5
Sedges	37.5	0	0	2.5	0	0	0.1
Shepherdia canadensis	0.05	0	0	0	0.05	0	0
Smilacina trifolia	0	0	0	0	0	0	0.1
Sphagnum spp	0	0	0	87.5	0	15	0
Spiranthes romanzoffiana	0	0	0	0	0	0	0
Tofieldia pusilla	0	0	0.05	0	0	0	0
Vaccinium uliginosum	37.5	0	87.5	0	2.5	0.1	0.1
Vaccinium vitis-idaea	87.5	37.5	0.1	0.05	87.5	62.5	0.1

Appendix 4. Environmental data used in species and pseudo-species analysis

Site	A4.1	B1.1	B2.1	B2.2	B2.3	B2.4	B3.1	B3.2	B3.3	B3.4	B3.5	B3.6	B4.1	B4.2	B4.3	B4.4
Age1-olt	1758	1839	1825	1809	1819	1838	1723	1779	1890	1711	1750	1815	1910	1748	1644	1676
Age2-ylt	1915	1940	1939	1939	1951	1963	1966	1930	1950	1901	1926	1961	1955	1877	1939	1895
Age3-mean age	1878	1905	1883	1853	1922	1883	1850	1861	1911	1825	1836	1917	1940	1829	1831	1801
Age4-rangeL	157	101	114	130	132	125	243	151	60	190	176	146	45	129	295	219
Age5-alc	1900	1933	1933	1823	1930	1838	1717	1767	1805	1867	1868	1924	1931	1802	1828	1675
Age6-aot	1758	1839	1577	1656	1600	1735	1657	1700	1687	1711	1551	1669	1764	1685	1644	1643
Age7-Cohort#	2	1	2	1	1	1	2	1	1	2	1	1	1	0	1	0
Age8-lastdisturb	1900	1932	1926	1823	1930	1930	1932	1767	1927	1867	1868	1832	1931	1832	1836	1643
Aspect-Concave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-Flat	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00
Aspect-N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Aspect-NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Aspect-NW	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare ground %	0.00	0.00	0.05	0.00	0.00	0.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Charcoal in soil	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Depth of active layer (m)	0.20	0.22	0.22	0.18	0.22	0.25	0.22	0.28	0.27	0.22	0.22	0.18	0.22	0.25	0.22	0.25
Downed woody debris %	0.10	37.50	15.00	15.00	0.10	15.00	62.50	0.10	0.10	0.10	62.50	0.10	0.10	0.10	0.05	15.00
Drainage	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00
Organic Soil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ph	6.00	4.00	4.00	6.00	6.50	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	6.00	6.00
Rock at surface %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-clay/silt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Permafrost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	1.00
SB-Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00
Slope = degrees	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	10.00
Standing snags %	0.00	0.10	0.10	0.10	2.50	2.50	37.50	0.10	0.10	2.50	2.50	2.50	0.10	2.50	0.10	15.00
UTM1	429588	432617	433129	433448	433346	433677	434092	434306	434246	434212	434125	434374	434369	434802	434969	434957
UTM2	6499890	6469480	6472509	6473709	6473741	6471925	6486192	6486110	6489566	6489423	6486931	6488989	6490986	6495698	6496851	6499702
Water on surface %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.10	0.10	0.00	0.00	0.00

Site	B4.4	B4.5	B5.1	B5.2	B5.3	B6.1	C2.1	C2.2	C2.3	C2.4	C3.3	C3.4	C4.1	C4.2	C4.3	C4.4
Age1-olt	1676	1813	1810	1562	1800	1726	1676	1796	1832	1778	1770	1820	1781	1772	1791	1795
Age2-ylt	1895	1897	1957	1933	1965	1869	1920	1904	1924	1947	1896	1967	1860	1894	1926	1870
Age3-mean age	1801	1851	1920	1752	1891	1801	1832	1847	1896	1893	1839	1877	1813	1835	1860	1827
Age4-rangeL	219	84	147	371	165	143	244	108	92	169	126	147	79	122	135	75
Age5-alc	1675	1830	1942	1562	1845	1712	1676	1796	1888	1938	1835	1948	1794	1806	1853	1825
Age6-aot	1643	1784	1770	1562	1757	1712	1617	1688	1830	1778	1556	1699	1781	1772	1629	1697
Age7-Cohort#	0	1	2	0	0	1	0	0	2	2	1	2	1	0	1	1
Age8-lastdisturb	1643	1830	1942	1562	1757	1933	1676	1688	1899	1938	1835	1948	1794	1772	1974	1825
Aspect-Concave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-E	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Aspect-Flat	0.00	1.00	0.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00
Aspect-N	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-W	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare ground %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.00	0.00
Charcoal in soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of active layer (m)	0.25	0.22	0.23	0.46	0.22	1.00	0.20	0.20	0.30	1.00	0.30	1.00	0.18	0.92	0.50	0.35
Downed woody debris %	15.00	0.10	2.50	37.50	0.00	0.00	0.10	0.00	0.10	0.10	0.10	0.05	37.50	0.05	87.50	2.50
Drainage	2.00	3.00	1.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	2.00	2.00
Organic Soil	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ph	6.00	7.00	6.00	8.00	8.00	8.00	5.00	5.00	6.00	6.00	5.00	5.00	5.00	8.00	6.00	5.00
Rock at surface %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-clay/silt	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00
SB-Permafrost	1.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	1.00
SB-Rock	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Sand	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope = degrees	10.00	0.00	15.00	0.00	0.00	25.00	0.00	7.00	0.00	0.00	0.00	0.00	9.00	0.00	0.00	0.00
Standing snags %	15.00	0.10	2.50	0.10	0.00	0.00	0.00	0.00	2.50	2.50	2.50	0.10	2.50	15.00	2.50	0.10
UTM1	434957	435141	435813	434995	438650	437407	449827	449685	444126	444148	445396	445725	449693	449936	446977	446920
UTM2	6499702	6497695	6506966	6508816	6507452	6511778	6470387	6470945	6476503	6476470	6481334	6481315	6497788	6497777	6494945	6494931
Water on surface %	0.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	87.50	0.10	0.00	0.00	15.00	0.00	0.00

Site	C4.6	C5.1	C5.2	C5.3	C5.4	C5.5	C5.6	C5.7	C5.8	C6.1	D2.1	D2.2	D2.3	D2.4	D3.1	D3.2
Age1-olt	1795	1721	1829	1720	1792	1743	1790	1695	1799	1775	1743	1791	1736	1751	1912	1751
Age2-ylt	1988	1829	1957	1937	1954	1921	1927	1940	1957	1954	1934	1978	1918	1863	1943	1931
Age3-mean age	1867	1790	1917	1834	1876	1847	1842	1832	1873	1841	1873	1895	1816	1813	1931	1840
Age4-rangeL	193	108	128	217	162	178	137	245	158	179	191	187	182	112	31	180
Age5-alc	1867	1775	1829	1720	1893	1853	1819	1695	1799	1775	1743	1791	1736	1751	1912	1851
Age6-aot	1710	1700	1804	1679	1612	1743	1780	1467	1725	1702	1743	1700	1735	1682	1726	1751
Age7-Cohort#	2	1	0	0	2	2	0	0	0	0	0	0	0	0	0	1
Age8-lastdisturb	1867	1775	1804	1680	1893	1853	1780	1631	1725	1702	1674	1700	1735	1682	1668	1963
Aspect-Concave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-Flat	1.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00
Aspect-N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Aspect-NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SE	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-W	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bare ground %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Charcoal in soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of active layer (m)	1.00	0.22	0.18	1.00	1.00	0.15	0.17	1.00	0.30	1.00	0.23	0.30	0.15	1.00	0.22	0.28
Downed woody debris %	0.10	2.50	0.10	2.50	0.10	0.00	15.00	0.10	0.10	0.10	2.50	2.50	0.00	0.00	87.50	2.50
Drainage	3.00	3.00	3.00	1.00	2.00	3.00	2.00	1.00	1.00	2.00	3.00	1.00	3.00	1.00	3.00	3.00
Organic Soil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ph	6.00	6.00	7.00	8.00	7.00	5.00	5.00	7.00	5.00	6.00	7.00	6.00	5.00	6.00	5.00	6.00
Rock at surface %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-clay/silt	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Permafrost	0.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00	1.00
SB-Rock	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Sand	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
Slope = degrees	0.00	0.00	15.00	0.00	5.00	7.00	0.00	3.00	10.00	5.00	0.00	0.00	0.00	0.00	0.00	10.00
Standing snags %	0.10	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	37.50	2.50
UTM1	443907	440652	440652	448208	449655	442030	441493	444083	443741	448423	452872	453500	453427	452915	453502	453626
UTM2	6499469	6506434	6506434	6508973	6509073	6502906	6505160	6510500	6500643	6510548	6477765	6477600	6477114	6476973	6480412	6480380
Water on surface %	87.50	2.50	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.10	0.10

Site	D4.1	D4.2	D4.3	D4.4	D4.5	D4.6	D4.7	D4.8	D5.1	D5.2	D5.3	D5.4	D5.5	D5.6	D6.1	E2.1
Age1-olt	1813	1893	1690	1722	1706	1795	1782	1644	1761	1639	1681	1715	1764	1700	1766	1668
Age2-ylt	1887	1918	1938	1858	1980	1918	1949	1943	1969	1971	1896	1927	1915	1966	1862	1870
Age3-mean age	1860	1906	1784	1788	1809	1847	1853	1858	1891	1784	1776	1840	1828	1844	1824	1799
Age4-rangeL	74	25	248	136	274	123	167	299	208	332	215	212	151	266	96	202
Age5-alc	1837	1893	1734	1829	1725	1822	1834	1864	1761	1639	1779	1844	1764	1700	1766	1833
Age6-aot	1541	1736	1655	1722	1706	1646	1651	1644	1761	1639	1627	1654	1600	1700	1766	1663
Age7-Cohort#	1	2	1	2	1	1	1	1	0	0	1	1	0	0	0	2
Age8-lastdisturb	1837	1893	1734	1829	1964	1996	1834	1864	1761	1910	1775	1844	1600	1700	1766	1968
Aspect-Concave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Aspect-Flat	0.00	1.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00
Aspect-N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-NW	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Aspect-S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SW	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
Bare ground %	0.00	62.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00
Charcoal in soil	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of active layer (m)	1.00	1.00	0.15	0.46	1.00	0.18	0.20	0.15	1.00	0.25	1.00	0.95	1.00	1.00	1.00	1.00
Downed woody debris %	15.00	2.50	15.00	15.00	37.50	0.10	2.50	0.10	0.00	15.00	0.00	0.00	15.00	0.10	0.00	0.10
Drainage	2.00	1.00	2.00	2.00	1.00	3.00	3.00	3.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Organic Soil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Ph	4.00	5.50	8.00	8.00	8.00	8.00	4.00	6.00	8.00	6.00	7.00	6.00	6.00	7.00	7.00	7.00
Rock at surface %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-clay/silt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Permafrost	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
SB-Sand	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
Slope = degrees	10.00	0.00	5.00	0.00	5.00	0.00	0.00	12.00	5.00	5.00	20.00	0.00	6.00	0.00	5.00	5.00
Standing snags %	0.10	0.00	15.00	0.10	2.50	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	2.50
UTM1	451759	451771	451497	451162	454182	453775	458476	458473	452784	451176	454737	457396	457340	456799	452449	463773
UTM2	6497981	6498021	6499456	6497726	6499040	6498406	6492959	6492791	6510977	6504134	6510010	6503500	6505601	6507785	6510958	6474556
Water on surface %	0.00	0.00	0.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Site	E2.2	E2.3	E2.4	E2.5	E3.1	E3.2	E3.3	E3.4	E3.5	E3.6	E4.1	E4.2	E4.3	F2.1	F2.2	F2.3
Age1-olt	1796	1714	1689	1847	1775	1776	1839	1911	1723	1758	1741	1751	1826	1821	1954	1780
Age2-ylt	1920	1954	1813	1966	1910	1870	1954	1965	1903	1960	1981	1877	1977	1948	1987	1930
Age3-mean age	1862	1852	1766	1914	1856	1807	1884	1932	1829	1871	1853	1809	1928	1857	1974	1835
Age4-rangeL	124	240	124	119	135	94	115	54	180	202	240	126	151	127	33	150
Age5-alc	1853	1851	1689	1940	1905	1776	1864	1911	1844	1932	1741	1771	1940	1821	1975	1802
Age6-aot	1716	1711	1680	1692	1767	1776	1527	1588	1681	1650	1668	1690	1752	1686	1653	1751
Age7-Cohort#	1	1	0	2	2	1	1	1	3	2	0	1	1	1	1	2
Age8-lastdisturb	1853	1851	1680	1940	1905	1776	1864	1911	1844	1932	1668	1771	1940	1821	1980	1802
Aspect-Concave	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-E	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-Flat	0.00	0.00	0.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00
Aspect-N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Aspect-NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-SW	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspect-W	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Bare ground %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.50	0.00
Charcoal in soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
Depth of active layer (m)	0.22	0.30	0.30	0.36	1.00	0.22	0.15	0.20	0.40	0.50	0.20	0.25	0.20	1.00	1.00	0.22
Downed woody debris %	0.00	0.00	2.50	2.50	0.10	2.50	0.10	0.00	0.10	0.10	0.10	2.50	0.00	2.50	87.50	0.00
Drainage	3.00	2.00	2.00	2.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	2.00	3.00	1.00	1.00	3.00
Organic Soil	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ph	5.00	5.00	8.00	8.00	6.00	5.00	5.00	6.00	5.00	6.00	6.00	5.00	6.00	8.00	8.00	6.00
Rock at surface %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-clay/silt	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
SB-Permafrost	0.00	1.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
SB-Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SB-Sand	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Slope = degrees	10.00	5.00	5.00	0.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	0.00	10.00
Standing snags %	0.00	0.00	0.10	0.00	2.50	15.00	0.00	0.00	0.10	0.10	2.50	0.10	0.00	2.50	15.00	0.00
UTM1	463581	468504	469490	469560	463209	463222	466670	466595	462193	462255	464964	465224	465079	472571	472504	472018
UTM2	6474098	6479257	6479811	6479989	6488430	6488401	6486611	6486691	6482389	6482706	6497755	6497672	6497146	6475895	6476035	6478423
Water on surface %	0.00	0.00	0.00	0.00	15.00	0.10	0.00	2.50	0.00	0.10	0.10	0.10	37.50	0.00	0.00	0.00

Site	F2.4	F2.5	F3.1	F3.2
Age1-olt	1758	1719	1711	1828
Age2-ylt	1914	1853	1914	1969
Age3-mean age	1817	1798	1821	1907
Age4-rangeL	156	134	203	141
Age5-alc	1758	1794	1711	1828
Age6-aot	1758	1692	1623	1799
Age7-Cohort#	1	1	0	0
Age8-lastdisturb	1758	1794	1711	1828
Aspect-Concave	0.00	0.00	0.00	0.00
Aspect-E	0.00	0.00	0.00	0.00
Aspect-Flat	0.00	0.00	0.00	1.00
Aspect-N	0.00	0.00	0.00	0.00
Aspect-NE	0.00	0.00	1.00	0.00
Aspect-NW	0.00	0.00	0.00	0.00
Aspect-S	0.00	0.00	0.00	0.00
Aspect-SE	0.00	0.00	0.00	0.00
Aspect-SW	0.00	0.00	0.00	0.00
Aspect-W	1.00	1.00	0.00	0.00
Bare ground %	0.00	0.00	0.00	0.00
Charcoal in soil	0.00	0.00	0.00	0.00
Depth of active layer (m)	0.22	1.00	1.00	0.20
Downed woody debris %	15.00	0.10	15.00	0.00
Drainage	3.00	2.00	2.00	3.00
Organic Soil	1.00	1.00	1.00	1.00
Ph	5.00	6.00	6.00	7.00
Rock at surface %	0.00	0.00	0.00	0.00
SB-clay/silt	0.00	0.00	0.00	1.00
SB-Permafrost	1.00	0.00	0.00	0.00
SB-Rock	0.00	0.00	0.00	0.00
SB-Sand	0.00	1.00	1.00	0.00
Slope = degrees	5.00	5.00	5.00	0.00
Standing snags %	0.10	15.00	0.00	0.00
UTM1	473321	472399	470617	470363
UTM2	6476592	6476541	6485284	6485333
Water on surface %	0.10	0.00	0.00	37.50

Appendix 5. Pseudo-species data

	A4.1	B1.1	B2.1	B2.2	B2.3	B2.4	B3.1	B3.2	B3.3	B3.4	B3.5	B3.6	B4.1	B4.2	B4.3	B4.4	B4.5	B5.1	B5.2	B5.3	B6.1	C2.1	C2.2	C2.3
IIa-1L	1.74	1.88	0.00	0.77	1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	1.39	1.88	0.14	0.49	3.14	0.35	0.28	0.00	0.00	0.00
IIa-1M	0.73	1.82	0.73	0.00	1.45	0.00	0.00	0.00	0.73	0.00	0.00	0.73	2.55	0.00	2.18	0.00	0.00	1.45	0.00	1.45	0.00	0.00	0.00	0.00
IIa-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2H	8.95	0.00	0.00	20.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.45	0.00	3.49	0.00	0.00	0.00	0.00	8.95	0.00	0.00	0.00	0.00
IIa-2L	11.29	0.00	0.00	0.00	0.71	0.00	0.00	0.00	4.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2M	2.49	0.00	0.00	0.07	1.04	0.00	0.00	0.00	1.06	0.00	0.00	0.00	0.34	1.97	0.56	0.00	0.00	1.96	0.00	1.81	1.13	0.00	0.00	0.00
IIa-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3H	4.66	0.00	0.00	7.11	6.10	0.00	0.00	0.00	13.76	0.00	0.00	0.00	0.00	9.55	6.26	12.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3M	2.59	6.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.29	2.19	0.00	0.00	1.39	0.00	0.00	0.00
IIa-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.86
IIa-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.96	0.00	0.00	0.00	0.00	0.00	12.81	13.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4M	0.00	0.00	3.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.39	0.00	4.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-1L	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.44	0.25	0.25	0.00	0.70	0.00	0.00	0.00
pgl-1M	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.31	7.69	0.00	0.00	3.85	0.00	17.31	0.00	0.00	0.00
pgl-2H	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46.69	0.00	4.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2L	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	3.43	9.60	0.88	0.98	0.00	0.69	0.00	0.00	0.00
pgl-2M	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.29	0.00	6.54	0.00	0.64	0.00	15.58	0.00	0.00	0.00
pgl-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3H	9.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.06	0.00	10.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.89	0.00	0.00	0.00
pgl-3M	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.49	13.44	4.36	0.00	1.21	0.00	7.25	0.00	0.00	0.00
pgl-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.42	13.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4M	19.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00	11.83	9.41	0.00	0.00	0.00	4.00	0.00	0.00	0.00
pgl-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.18	0.00	0.00	0.00	0.00	0.00
pgl-5S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	A4.1	B1.1	B2.1	B2.2	B2.3	B2.4	B3.1	B3.2	B3.3	B3.4	B3.5	B3.6	B4.1	B4.2	B4.3	B4.4	B4.5	B5.1	B5.2	B5.3	B6.1	C2.1	C2.2	C2.3
pgl-6H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.88	0.00	38.12	0.00	0.00	0.00	0.00	0.00
pgl-6S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-8S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1H	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1L	0.00	0.75	1.72	3.50	0.00	1.51	0.00	1.65	5.97	1.10	0.34	1.37	4.74	1.24	0.00	0.00	0.00	2.95	0.00	1.51	0.00	1.51	2.13	0.48
pma-1M	0.00	0.00	5.34	5.34	0.00	0.59	0.00	3.86	16.91	1.19	0.59	3.26	5.34	0.59	0.00	0.00	0.00	0.00	0.00	0.59	0.00	2.08	0.59	3.86
pma-1S	0.00	0.00	0.00	0.00	0.00	0.00	42.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-2H	0.00	0.00	0.00	13.85	0.00	0.00	0.00	0.00	7.87	0.00	8.60	0.00	15.81	8.29	0.00	0.00	0.00	0.00	0.00	4.49	0.00	0.00	0.00	8.23
pma-2L	0.00	0.90	4.27	0.85	0.00	0.96	0.00	1.64	2.05	0.27	3.04	0.57	1.59	1.07	0.00	0.00	0.00	0.00	0.00	0.33	0.00	2.93	9.44	0.38
pma-2M	0.00	1.34	2.43	2.63	0.00	1.64	0.00	3.91	3.19	2.17	8.37	2.32	3.45	4.06	0.00	0.00	0.00	0.91	0.00	1.25	0.00	0.31	1.45	3.93
pma-2S	0.00	0.00	0.00	0.00	0.00	0.00	19.87	0.00	0.00	5.71	0.00	0.00	0.00	6.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.99	8.14
pma-3H	0.00	0.00	0.00	17.70	0.00	1.79	0.00	2.21	9.14	4.35	5.81	0.00	7.45	10.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.62
pma-3L	0.00	0.00	7.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-3M	0.00	0.00	1.38	0.89	0.00	2.36	0.00	2.21	0.82	0.00	1.81	0.85	0.74	4.73	0.00	0.00	0.00	0.45	0.00	0.32	0.00	0.00	1.50	4.88
pma-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-4H	0.00	0.00	0.00	25.55	0.00	0.00	0.00	0.00	25.56	0.00	0.00	0.00	10.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.64
pma-4M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.37
pma-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.40
pma-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.61	0.00	0.00	4.36	4.78	0.00	1.54	3.59	15.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
u-3S	0.00	1.28	0.00	0.00	0.00	0.00	0.00	0.00	2.71	0.00	0.00	2.18	0.00	0.00	0.99	10.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-5S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-7S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	C2.4	C3.3	C3.4	C4.1	C4.2	C4.3	C4.4	C4.6	C5.1	C5.2	C5.3	C5.4	C5.5	C5.6	C5.7	C5.8	C6.1	D2.1	D2.2	D2.3	D2.4	D3.1	D3.2	D4.1
IIa-1L	1.88	0.00	0.49	0.14	0.00	0.28	0.00	35.98	0.00	5.79	0.49	0.98	2.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.91	0.00
IIa-1M	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	13.82	4.00	1.45	1.09	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	8.00	0.00
IIa-1S	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2L	2.05	0.00	2.33	0.00	9.74	0.00	0.00	0.49	0.00	6.07	3.53	6.07	2.33	0.00	0.00	0.00	0.00	0.85	0.00	2.05	0.00	0.00	0.00	0.00
IIa-2M	7.24	0.00	0.64	0.00	6.22	0.00	0.00	0.00	0.00	0.87	1.57	3.89	1.24	0.00	0.00	0.00	0.00	2.68	0.00	1.13	0.00	0.00	3.00	0.00
IIa-2S	0.00	0.00	0.00	0.00	32.02	0.00	0.00	16.96	0.00	0.00	0.00	2.34	0.00	15.20	0.00	0.00	0.00	0.00	0.00	9.50	0.00	0.00	0.00	0.00
IIa-3H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3M	0.00	0.00	0.00	0.00	14.98	0.00	2.66	0.00	8.04	0.00	0.00	6.57	0.00	2.66	0.00	0.00	0.00	8.35	0.00	5.32	0.00	0.00	5.89	0.00
IIa-3S	0.00	0.00	0.00	0.00	31.98	0.00	0.00	20.00	13.59	0.00	0.00	0.00	0.00	15.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.33	0.00	0.00	0.00	0.00
IIa-4L	0.00	0.00	0.00	0.00	57.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.72	4.87	0.00	0.00	11.57	0.00	3.78	4.06	0.00	9.48	0.00
IIa-4S	14.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.62
pgl-1L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.81	1.96	0.00	0.00	72.93	0.00	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-1M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.69	3.85	0.00	0.00	0.00	0.00	9.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.53	0.69	0.00	0.00	0.00	0.00	5.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.06	4.87	0.00	0.00	3.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.29	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	C2.4	C3.3	C3.4	C4.1	C4.2	C4.3	C4.4	C4.6	C5.1	C5.2	C5.3	C5.4	C5.5	C5.6	C5.7	C5.8	C6.1	D2.1	D2.2	D2.3	D2.4	D3.1	D3.2	D4.1
pgl-6M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-8S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1L	0.62	0.48	0.34	10.78	0.00	2.33	0.75	4.94	0.75	2.33	0.00	0.00	0.00	2.61	0.00	0.14	0.00	0.62	2.47	5.83	0.62	2.13	1.72	4.19
pma-1M	0.59	0.00	0.00	1.19	0.59	0.00	5.93	2.08	0.00	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.86	0.59	2.67	1.19	0.00	6.53	1.48
pma-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-2H	0.00	0.00	0.00	4.49	0.00	0.00	7.36	0.00	0.00	0.00	0.00	0.00	0.00	4.10	0.00	0.00	0.00	0.00	0.00	4.10	0.00	0.00	0.00	4.30
pma-2L	0.00	1.72	0.00	6.82	0.00	0.19	2.82	3.31	0.00	0.74	0.00	0.00	0.19	3.67	0.00	2.46	0.00	7.23	0.60	4.49	8.10	0.00	1.92	1.31
pma-2M	0.00	1.27	0.00	2.10	0.00	0.00	3.59	1.18	1.37	0.11	0.00	0.00	0.00	1.59	0.00	3.07	0.00	8.58	0.17	2.99	2.50	0.00	3.96	2.63
pma-2S	0.00	4.63	0.00	0.00	0.00	0.00	0.00	5.83	2.27	0.00	0.00	0.00	0.00	5.35	0.00	9.94	0.00	2.87	0.00	0.00	0.00	0.00	0.00	0.00
pma-3H	0.00	0.00	0.00	2.31	0.00	0.00	4.68	0.00	0.00	0.00	0.00	0.00	0.00	5.94	0.00	4.15	0.00	0.00	0.00	1.84	0.00	0.00	0.00	4.73
pma-3L	0.00	7.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.76	0.00	18.23	0.00	16.44	0.00	0.00	0.00	0.00	0.00	0.00
pma-3M	0.00	1.97	0.00	2.92	0.00	0.00	4.03	1.05	3.08	0.00	0.00	0.00	0.00	5.56	0.00	4.05	0.00	3.74	1.69	5.22	0.67	0.00	11.09	5.82
pma-3S	0.00	7.14	0.00	0.00	0.00	0.00	15.41	4.36	0.00	0.00	0.00	0.00	0.00	36.46	0.00	0.00	0.00	0.00	0.00	0.00	6.08	0.00	0.00	0.00
pma-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-4M	0.00	0.00	0.00	0.00	0.00	0.00	6.89	0.00	10.03	0.00	0.00	0.00	0.00	9.90	0.00	8.99	0.00	4.22	0.00	0.00	0.00	0.00	0.00	15.27
pma-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
pma-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-1S	0.00	0.00	0.00	0.00	0.00	66.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-2S	1.99	2.41	0.00	6.42	0.00	24.53	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	2.60	0.00	0.00
u-3S	0.00	0.00	0.00	6.83	0.00	5.77	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	2.35	0.00	0.00	0.00	3.52	0.00	3.72	11.56	2.41
u-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-5S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.83
u-7S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	D4.2	D4.3	D4.4	D4.5	D4.6	D4.7	D4.8	D5.1	D5.2	D5.3	D5.4	D5.5	D5.6	D6.1	E2.1	E2.2	E2.3	E2.4	E2.5	E3.1	E3.2	E3.3	E3.4	E3.5
IIa-1L	0.00	1.12	0.35	1.39	0.00	0.00	0.28	0.14	1.53	0.00	0.00	0.00	0.14	0.00	0.00	0.28	0.91	0.00	1.26	17.64	0.14	0.00	1.39	0.00
IIa-1M	0.00	0.00	0.73	4.00	0.73	0.00	0.00	0.00	8.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.00	2.55	0.00	0.00	0.73	0.00
IIa-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2L	0.00	0.00	0.99	0.00	0.00	0.49	0.00	0.49	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	9.10	0.00	0.00	0.85	0.00
IIa-2M	0.00	0.00	0.00	3.38	1.62	0.00	0.00	0.00	0.12	0.00	0.00	0.00	4.18	0.00	0.00	0.00	1.50	0.00	0.92	4.82	0.00	0.00	0.64	0.00
IIa-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.73	6.37	0.00	4.44	0.00	0.00	0.00	0.00	0.00
IIa-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3M	0.00	0.00	0.00	0.00	4.15	0.00	0.00	3.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.06	1.94	1.34	0.00	0.00	0.00	0.00
IIa-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.75	0.00	0.00	0.00	0.00	0.00
IIa-4L	0.00	0.00	42.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4M	0.00	0.00	0.00	0.00	3.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.80	0.00	10.79	0.00	0.00	0.00	0.00	0.00
IIa-4S	65.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.13	0.00	0.00	0.00	0.00	0.00
pgl-1L	0.00	0.13	0.00	0.82	0.00	0.00	0.00	3.29	0.00	0.44	0.00	0.57	5.69	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-1M	0.00	0.00	0.00	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.62	0.00	0.00	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2L	0.00	0.00	0.00	1.67	0.00	0.00	0.00	44.96	0.00	1.37	8.03	3.53	9.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2M	0.00	1.63	0.00	2.34	0.00	0.00	0.00	11.57	0.00	0.31	0.00	2.20	9.12	3.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-2S	13.81	30.95	0.00	55.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3M	0.00	7.04	0.00	0.00	9.28	0.00	0.00	4.39	0.00	2.13	6.03	1.28	6.22	9.19	0.00	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3S	21.89	34.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4H	0.00	15.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.34	12.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4M	0.00	0.00	0.00	0.00	3.49	0.00	0.00	0.00	0.00	14.81	0.00	0.00	5.54	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4S	0.00	61.15	0.00	38.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5H	0.00	13.07	0.00	30.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.54	0.00	0.00	0.00	0.00	38.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5S	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	D4.2	D4.3	D4.4	D4.5	D4.6	D4.7	D4.8	D5.1	D5.2	D5.3	D5.4	D5.5	D5.6	D6.1	E2.1	E2.2	E2.3	E2.4	E2.5	E3.1	E3.2	E3.3	E3.4	E3.5
pgl-6M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6S	32.46	35.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7L	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-8S	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1L	0.00	0.00	1.85	0.14	1.10	3.36	1.72	0.00	1.51	0.75	0.14	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.84	1.10	0.27	0.27	2.61
pma-1M	0.00	0.00	4.75	3.86	1.19	1.19	0.59	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	2.08	2.08	1.19	0.00	0.00
pma-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57.14
pma-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.89	0.00	0.00	0.00
pma-2L	0.00	0.00	2.49	0.00	0.00	1.97	1.12	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.97	0.27	0.00	1.59	1.48	3.23	0.19	4.87
pma-2M	0.00	0.00	3.89	0.20	0.45	0.00	3.47	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.00	0.11	0.99	1.16	4.48	0.00	0.98
pma-2S	0.00	0.00	0.00	0.00	0.00	1.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.35	0.00	0.00	0.00	0.00	0.00	5.51
pma-3H	0.00	0.00	3.74	0.00	0.00	0.00	0.00	0.00	3.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	0.00	0.00	0.00
pma-3L	0.00	0.00	27.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-3M	0.00	0.00	0.76	0.00	4.32	0.00	1.88	0.00	4.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.99	2.81	0.00	0.00
pma-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.24	0.00	0.00
pma-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-4M	0.00	0.00	0.00	3.09	8.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.24	0.00	0.00	0.00	0.00	4.01	3.28	0.00	0.00
pma-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-5M	0.00	0.00	0.00	0.00	46.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-2S	0.00	0.00	0.60	6.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	4.86	3.93	0.00	0.00	0.00
u-3S	0.00	0.00	0.00	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50	0.00	0.00	0.00
u-4S	0.00	0.00	0.00	13.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-5S	0.00	0.00	0.00	22.30	0.00	0.00	0.00	0.00	31.92	0.00	0.00	0.00	0.00	0.00	2095	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-7S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	E3.6	E4.1	E4.2	E4.3	F2.1	F2.2	F2.3	F2.4	F2.5	F3.1	F3.2
IIa-1L	4.81	0.00	0.49	0.91	0.28	0.14	0.49	0.91	0.14	0.00	2.37
IIa-1M	15.27	0.00	0.73	4.36	0.73	1.82	1.45	2.55	0.00	0.00	8.00
IIa-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-2H	19.18	0.00	0.00	7.41	0.00	0.00	0.00	0.00	0.00	0.00	25.74
IIa-2L	28.72	0.00	0.49	2.33	0.00	0.00	0.00	1.76	0.00	1.13	0.71
IIa-2M	29.78	0.00	0.00	4.49	0.10	0.28	0.12	2.01	0.00	0.00	5.13
IIa-2S	14.47	9.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3H	3.80	0.00	0.00	4.89	0.00	0.00	0.00	0.00	5.73	0.00	8.74
IIa-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-3M	0.00	0.00	2.01	8.52	0.00	0.00	4.24	4.02	0.00	0.00	0.00
IIa-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4H	0.00	0.00	16.45	0.00	0.00	0.00	21.64	0.00	0.00	0.00	0.00
IIa-4L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-4M	0.00	0.00	15.91	0.00	0.00	0.00	3.58	0.00	4.87	6.54	0.00
IIa-4S	0.00	19.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.58	0.00	29.79
IIa-5L	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIa-5M	0.00	0.00	0.00	0.00	19.62	0.00	19.62	0.00	0.00	0.00	0.00
pgl-1L	0.00	0.00	0.00	0.13	1.01	0.32	1.14	0.00	0.44	0.00	0.25
pgl-1M	0.00	0.00	0.00	0.00	3.85	0.00	3.85	0.00	0.00	0.00	3.85
pgl-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.46
pgl-2L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.53	0.00	0.98
pgl-2M	0.00	0.00	0.00	0.00	9.61	0.00	0.99	0.00	1.85	0.00	7.49
pgl-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3H	0.00	0.00	8.21	0.00	9.19	0.00	8.79	0.00	0.00	0.00	0.00
pgl-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-3M	0.00	0.00	2.13	0.00	0.00	0.00	0.00	0.00	6.34	0.00	5.72
pgl-3S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.36
pgl-4M	0.00	0.00	0.00	0.00	9.12	0.00	0.00	0.00	10.70	0.00	0.00
pgl-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5H	0.00	0.00	14.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5L	0.00	0.00	0.00	0.00	17.38	0.00	0.00	0.00	20.53	0.00	0.00
pgl-5M	0.00	0.00	0.00	0.00	14.86	0.00	0.00	0.00	0.00	0.00	0.00
pgl-5S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6L	0.00	0.00	0.00	0.00	36.97	0.00	0.00	0.00	30.76	0.00	0.00

	E3.6	E4.1	E4.2	E4.3	F2.1	F2.2	F2.3	F2.4	F2.5	F3.1	F3.2
pgl-6M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-6S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-7L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pgl-8S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-1L	0.27	1.10	0.00	0.00	0.00	0.00	2.33	0.62	0.00	0.27	0.00
pma-1M	0.00	1.78	0.00	0.00	0.00	0.00	0.59	0.59	0.00	0.59	0.00
pma-1S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-2H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-2L	0.19	1.29	0.00	0.00	0.00	0.00	0.00	0.33	0.33	2.30	0.00
pma-2M	0.06	2.67	0.00	0.00	0.00	0.00	0.00	0.29	0.15	1.22	0.00
pma-2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.29	0.00
pma-3H	0.00	0.00	0.00	0.00	2.31	0.00	4.58	0.00	0.00	0.00	0.00
pma-3L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-3M	0.00	5.38	0.00	0.00	0.00	0.00	2.43	0.00	0.83	0.00	0.00
pma-3S	0.00	7.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-4H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-4M	0.00	5.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-5L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pma-5M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-1S	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-2S	0.79	7.04	0.00	0.00	0.00	0.00	0.00	0.00	3.20	0.00	0.00
u-3S	0.00	13.27	1.19	0.00	7.82	5.51	5.30	0.00	6.44	0.00	0.00
u-4S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.34	0.00	0.00
u-5S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
u-7S	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00