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Moss growth, production, and paludification in the hypermaritime north coast of British Columbia

Introduction

Mosses are a major component of the vegetation in the hypermaritime north coast of British Columbia. We are interested in their responses to forest management practices because of possible interactions with forest productivity and long-term vegetation succession. The vegetation of the outer north coast is a complex of wetlands and upland forests (Banner *et al.* 1987). The wetlands are mainly open blanket bogs, bog woodlands, and bog forests that have accumulations of peat comprised mostly of the remains of mosses mixed with sedges and other vascular plants. There is evidence that these wetlands have expanded in the past at the expense of upland productive forests (Banner *et al.* 1983, 2002), a process known as paludification. Paludification can be influenced by several factors, including the physical and chemical properties of soils, plant succession, and climatic change. In several parts of the world, human activities such as forest clearing and agriculture, have also played a role in promoting paludification (Moore 1987). These activities likely caused a rise in the water table because of a reduction in canopy interception and evapotranspiration, facilitating the invasion by peat-forming sphagnum mosses. It is thus important to understand the ecological relationship between moss growth and forest dynamics, and how this relationship may be affected by forest management practices.

There is a concern that forest harvesting followed by site preparation may promote the invasion of sphagnum mosses. Research conducted near Prince Rupert has shown that 20-25% more precipitation reaches the soil in open (non-forested) sites compared with cedar-hemlock forests. Removal of forest canopies and reduction of canopy interception by harvesting will thus increase the amount of water reaching the forest floor by similar amounts (Maloney *et al.* 2002). In an attempt to produce drier microsites to improve seedling survival and growth, we have used mounding as a site preparation method (Shaw and Banner 2001a; Londo 2001). Our trials have shown that while there is positive seedling response from such treatments, mounding can result in adjacent wet depressions that may facilitate the invasion of sphagnum mosses and initiate paludification on forested sites.

This extension note summarizes information from Asada (2002), a component of the HyP^3 Project (Pattern, Process, and Productivity in Hypermaritime Forests). HyP^3 is a multi-disciplinary study concerned with the ecology and management of lower productivity forests on the outer north coast of British Columbia (Banner and Shaw 1999). This extension note:

- Provides quantitative estimates on growth and production of mosses on the outer coast of B.C.
- Examines the possible impacts of forest management practices on moss growth and productivity.
- Provides a summary of the effect of logging and mounding on paludification at the Port Simpson operational trial.

Study Description

The study sites are located in the Very Wet, Hypermaritime Coastal Western Hemlock subzone, Central variant (CWHvh2, Banner *et al.* 1993). In general, the hypermaritime environment is characterized by relatively mild temperatures and heavy rainfall. The growing season is long, the summers tend to be cool and cloudy, and the winters are extremely wet and mild. Climate data for the Prince Rupert area are presented in Maloney *et al.* 2002.

Within this environment, we chose two study sites, one at Diana Lake Provincial Park, 15 km southeast of Prince Rupert, where we could observe the old-growth condition, and the other at a logged site near Port Simpson, 30 km north of Prince Rupert (Figure 1). The Port Simpson site is an operational trial that was initiated in 1990, and has since been incorporated into the HyP^3 Project. Both areas are dominated by the zonal Western redcedar - Western hemlock - Salal (01) site series of the CWHvh2 (Banner *et al.* 1993) but also contain a complex of open bog (Non-forested slope/blanket bog (32) site series), bog woodland (Shore pine - Yellow cedar - Sphagnum (12) site series), bog forest (Western redcedar – Yellow-cedar - Goldthread (11) site series), and productive forest (Western hemlock - Sitka spruce - Lanky moss (04) and related site series) (Banner *et al.* 1993).

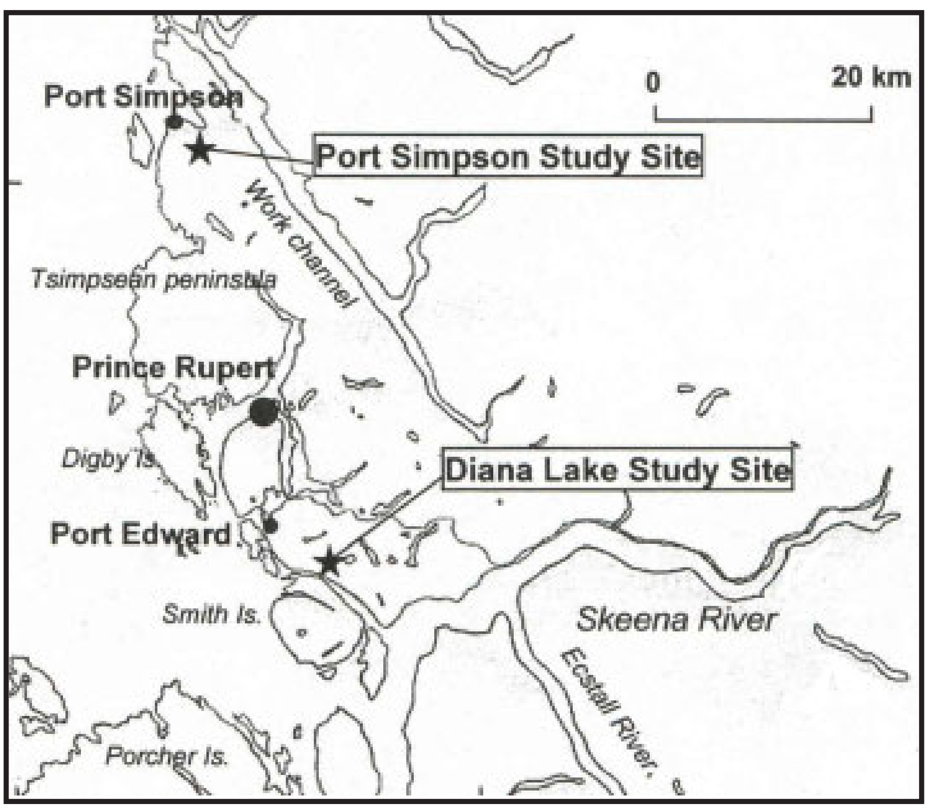

Figure 1. Location map of Diana Lake and Port Simpson study sites.

Diana Lake

Measurement of Growth and Production

Nine abundant moss species at the Diana Lake site were selected for study: *Sphagnum austinii, S. fuscum, S. rubellum, S. papillosum, S. lindbergii, S. tenellum, S. pacificum, Racomitrium lanuginosum* (hoary rock moss), and *Pleurozium schreberi* (red-stemmed feather moss). The selected mosses are the most representative peatland species in the region and have fairly specific habitat preferences. Their growth was measured periodically and compared with the local climatic parameters (Table 1).

Winter growth measurements for sphagnum species could not be made due to interference from snow. Therefore, winter growth was estimated by using the relationship between moss growth and temperature and precipitation, derived from the climatic index (described below). Estimated winter growth was added to summer growth in order to estimate total annual growth. Total annual production of each moss was estimated by multiplying the average annual linear growth by the average mass per unit length and the average number of stems per unit area. Due to uncertainties regarding winter growth, especially for hummock-forming species that show poorer relationships between climatic parameters and growth, the data presented here should be viewed as trends rather than absolute values.

Climatic Index

The climatic index produces a regression equation that relates moss growth to temperature and precipitation. Daily precipitation and daily mean, maximum, and

Table 1: Growth and production of Sphagnum and other mosses and their relation to climatic parameters at the Diana Lake study site. Estimated annual growth and production for Sphagnum mosses is from May 21, 1999 to May 20, 2000, and for other mosses the first year growth is from July 16, 1999 to July 11, 2000, and the second year growth is from July 11, 2000 to June 5, 2001.

Species	Habitat preference	Estimated annual growth (mm)	Estimated annual production (g/m^2)	Correlation with mean daily precipitation	Correlation with mean daily temperature	Correlation with Climatic Index
S. austinii	Large hummock	12.5	365.3	0.17	0.09	0.28
S. fuscum	Large hummock	21.3	413.8	0.60	-0.16	0.70
S. rubellum	Small hummock	19.4	280.5	0.80*	-0.42	0.70
S. papillosum	Wet hummock	27.8	202.7	0.73*	-0.20	0.77*
S. tenellum	Around pools and wet lawns	20.1	155.9	0.78*	-0.09	0.90**
S. pacificum	Wet lawns	68.5	299.0	0.74*	-0.20	0.87**
S. lindbergii	Depressions and small streams	59.6	359.9	0.72*	-0.14	0.83**
Racomitrium lanuginosum	Dry mounds in bog	8.7 – 9.9	356.5 – 405.0	0.59	0.18	0.94**
Pleurozium schreberi	Bog woodland	20.4 – 23.0	285.6 – 321.7	0.47	0.25	0.87**

* - p<0.05, ** - p<0.01

minimum temperatures were obtained from the meteorological station in the open bog of the Diana study site. Temperature and precipitation were treated as separate parameters, and in combination for the climatic index. The climatic index was developed to reflect the following assumptions that were expected from previous studies: (1) growth of mosses is controlled primarily by precipitation; (2) precipitation cannot contribute to the growth if the temperature is lower than certain temperature threshold required for growth; and (3) the higher the temperature, up to moderate temperatures, the more precipitation relates to growth.

The climatic index adjusts the precipitation for each day by the temperature for that day, so that when the temperature is lower than a set threshold temperature, the amount of precipitation is adjusted to zero; precipitation on warmer days gets increasing weight based on the number of degrees above the threshold.

The growth of the mosses and all climate parameters were expressed as a mean per day in a given period. Correlation coefficients between the growth and each climate parameter (precipitation, temperature, and the climatic index) were calculated for each species.

Port Simpson

The Port Simpson operational trial area was skidder logged in late summer/fall of 1990. The objective of the trial was to study the effects of mounding and mixing soils on tree survival and productivity. (see Shaw and Banner 2001a and b for descriptions of studies relating to seedling growth and nutrition at Port Simpson).

This moss study was conducted in 1998 and 1999, eight years post-treatment. The plant communities at Port Simpson were compared to those of Diana Lake, (as there was no comparable pre-harvest data on the plant communities at Port Simpson), to examine what changes likely occurred at the harvested site. To quantify concerns about paludification, the growth rates of three sphagnum species, *S. pacificum, S. rubiginosum* and *S. rubellum* were measured at Port Simpson, and compared to that in unharvested areas at Diana Lake. Again, snow interfered with winter measurements of sphagnum growth. For this reason, the maximum growth values were considered more accurate than mean values, and were used for comparison. In addition to measuring sphagnum height growth, we also monitored the changes in area and volume covered by mosses, especially sphagnum, over a one-year period at the Port Simpson site. Sphagnum decomposition rates were also examined at both Port Simpson and Diana Lake.

Results

Diana Lake

Annual growth and production

Growth and production patterns for selected moss species in relation to temperature, precipitation, and climatic index are illustrated in Table 1 and Figures 2 and 3. The fastest growing species (in terms of vertical stem growth) was *Sphagnum pacificum*, which had an estimated annual growth of 68.5 mm/year; *S. lindbergii* also had significant stem growth of 59.6

mm/year. *S. austinii* had the slowest growth rate estimated at 12.5 mm/year. *S. fuscum*, *S. rubellum* and *S. tenellum* had similar growth rates with an estimated annual growth of about 20 mm/year.

The most productive sphagnum species (total annual biomass) were the hummock-forming *S. fuscum* and *S. austinii* (Table 1). Although the vertical growth of the hummock species was small, their dense growth form contributed to this high productivity. In particular, the bulk density of *S. austinii* was the highest among the species studied. Lindholm and Vasander (1990) show the same trend for *S. fuscum*. The next highest productivity values were observed in the wet hollow and lawn species, *S. lindbergii* and *S. pacificum*. The high vertical growth of both of these species contributed considerably to this productivity, as they had the lowest bulk density among the species studied. The productivity of *S. rubellum* was close to that of *S. pacificum*, but was more dependent on bulk density rather than vertical growth. The vertical growth and bulk density of *S. papillosum* was relatively low, resulting in low overall productivity. *S. tenellum* had the lowest productivity, (in spite of it having the highest number of capitula per area among the species studied) due to its low bulk density (Table 1). The annual stem growth of *P. schreberi* was about 22 mm/year compared to about 9 mm/year for *R. lanuginosum* (Table 1). The annual production of *R. lanuginosum* was higher than that of *P. schreberi*, however, due to a more dense growth form. Annual production of these two drier habitat mosses approached that of some of the more productive sphagnum species.

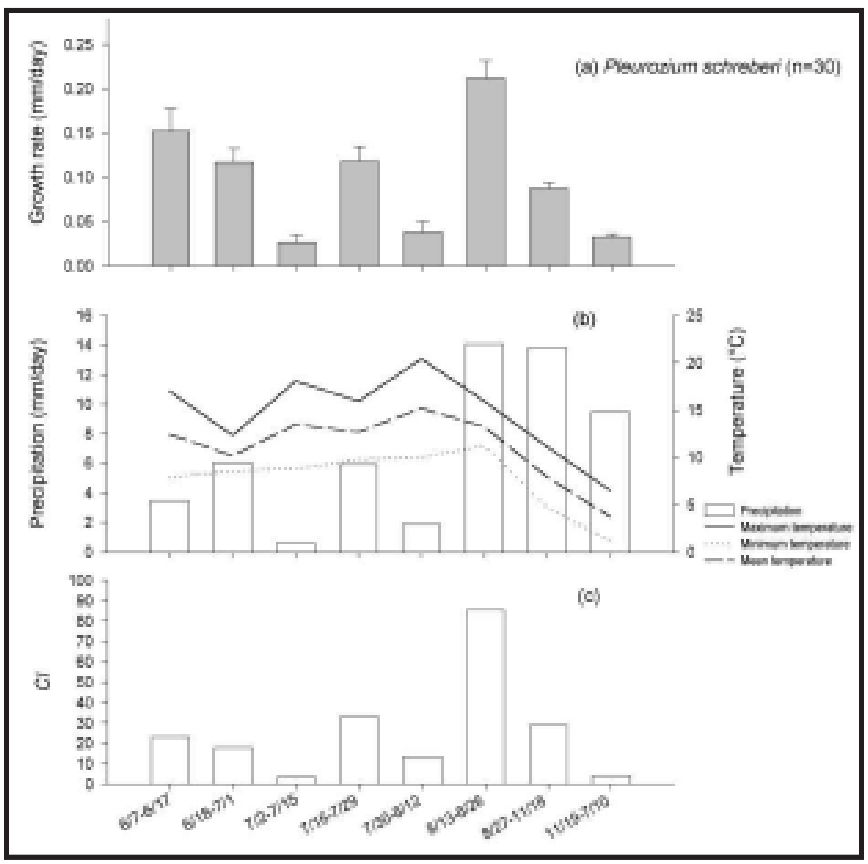

Figure 2. (a) Mean daily growth (±1 SE) of *Pleurozium schreberi* at the Diana Lake study site. (b): Mean daily precipitation and daily maximum, minimum and mean temperature. (c): Mean daily Climatic Index when temperature = daily mean, and temperature threshold (x) = 7; all for eight consecutive sampling intervals from June 1999 through July 2000 (interval given as m/d - m/d).

Growth in relation to climatic parameters

Generally, the variation in seasonal growth of *P. schreberi* (and *R. lanuginosum*), and the seven sphagnum species reflected precipitation patterns better than temperature patterns. Correlation coefficients between precipitation and growth were higher than those between temperature and growth for all species (Table 1), with five species having statistically significant correlations.

The climatic index had a much higher correlation with growth than either precipitation or temperature alone for all species except for *S. rubellum* (Figures 2 and 3). Six of nine species were significantly correlated with the climatic index, with the species having non-significant relationship all being hummock-forming sphagnum species.

The climatic index is expected to have the highest correlation coefficient with moss growth when the lowest temperature during which vegetative growth occurs is used in the index. The growth of *R. lanuginosum* and *P. schreberi* had the highest correlation coefficients with the climatic index when daily mean temperature was set at $5^{o}C$, implying that this is the temperature threshold for the growth of these two species. For the sphagnum species, the threshold for growth was found to be $0^{o}C$ for most species; $5^{o}C$ lower than that for *R. lanuginosum* and *P. schreberi*. The temperatures given for growth thresholds are preliminary due to difficulties in obtaining winter growth measurements. More detail on the estimation methods for temperature thresholds can be found in Asada (2002).

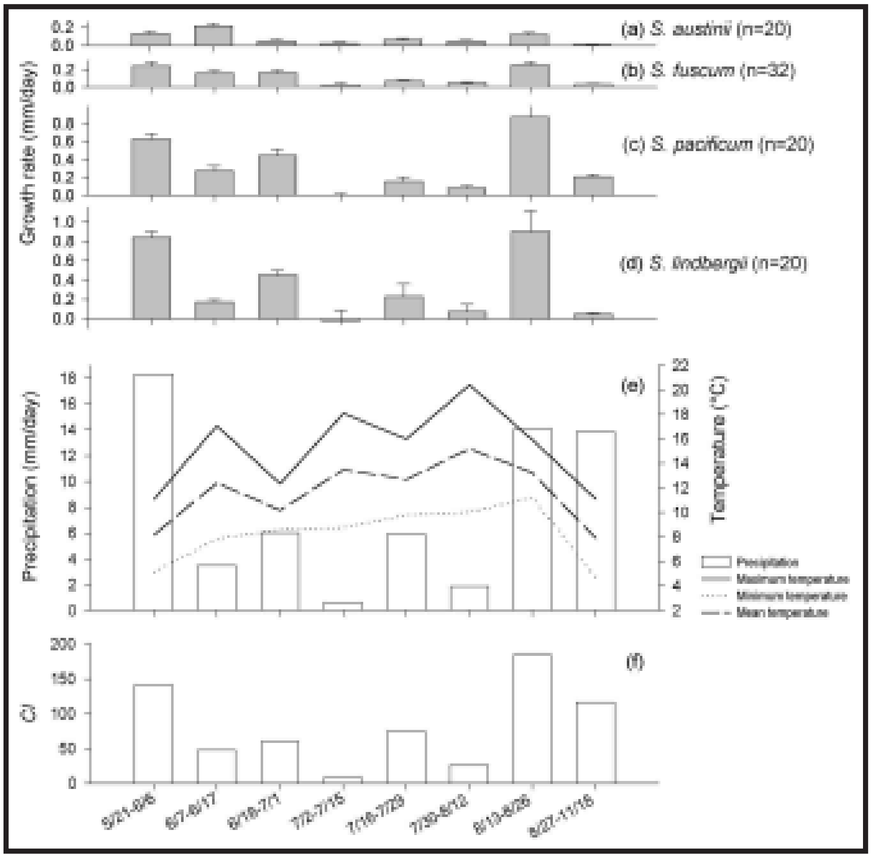

Figure 3. (a)-(d): Mean daily growth (±1 SE) of sphagnum at the Diana Lake study site. (e): Mean daily precipitation and daily maximum, minimum and mean temperature. (f): Mean daily Climatic Index when temperature = daily mean, and temperature threshold (x) = 0: all for eight consecutive sampling intervals from May through November in 1999 (interval given as m/d - m/d).

Post Harvest Sphagnum Succession at Port Simpson

The majority of the plant communities at the harvested site at Port Simpson were similar to those at the natural forest site at Diana Lake, with the exception being the presence of sphagnum-dominated communities in the mounded portion of the cutblock. *Sphagnum pacificum* and *S. angustifolium* dominated these communities, suggesting that these species are the most responsive to the changes in habitat due to management actions. In fact, these two sphagnum species are not commonly found in forested areas and therefore likely colonized the harvested site after logging. Communities dominated by these sphagnum species were found mainly in fens in the Diana Lake area.

A statistical analysis of the relationship between environmental variables and plant communities showed that the distribution of plant communities was mainly controlled by moisture, with water chemistry gradients being a secondary factor. Pools formed by the mounding, possibly in combination with a post-logging rise in water table, appears to have provided habitat conditions that allow colonization by these sphagnum species (Figure 4). The gradients of water chemistry, pH, and water conductivity, are likely set-up by the acidifying ability of sphagnum, and may facilitate additional sphagnum growth that could limit the potential for vascular plant establishment and growth (van Breeman 1995).

Sphagnum rubiginosum is commonly found in forested areas and was found to be common at both Port Simpson and Diana Lake. At Port Simpson, however, it was much more abundant in the mounded portion of the harvested area than in the untreated area. The presence of pools, created by the mounding, is also likely responsible for the persistence of this species, and the closely related *S. girgensohnii*, in the mounded area, as these two species are often associated with the pits formed by blowdowns in forests (Noble *et al.* 1984).

When the maximum growth rates of three common sphagnum species at Port Simpson and Diana Lake were compared, *S. rubiginosum* had considerably higher growth rates in the cutover area than in the natural area (Table 2). The other two sphagnum species had similar growth rates at both areas. This indicates that the growth rate of *S. rubiginosum* may be enhanced by the conditions in the mounded cutblock.

The area and volume covered by mosses, especially sphagnum, expanded considerably in one year particularly at the two wetter locations (Figure 5); while at the driest location the changes were not as great. This shows that moisture is important in moss colonization and that mosses are actively expanding. Decomposition rates were not significantly different among the four plant communities at Port Simpson, and, in general, not different from the plant communities at Diana Lake.

Discussion

The sphagnum moss species examined had different growth responses to climatic variation, mostly related to their habitat and growth form. Species that form hummocks had lower linear growth rates and less

Figure 4. Mounding-created depressions at Port Simpson filled in with sphagnum moss after 6 years.

Table 2: Comparison of maximum sphagnum growth rates (mm/yr) at Diana Lake and Port Simpson.

Species	Diana Lake	Port Simpson
S. rubiginosum	55	85
S. rubellum	34	38
S. pacificum	120	105

although the growth rate would be slow. The difference in growing pattern between hummock-forming and hollow/lawn-forming species shown in this study agrees with some previous findings (Moore 1989; Gerdol 1995).

It appears that even if there is adequate moisture there will not be substantial growth if the temperature is too low. This hypothesis was supported by higher correlations between growth and the climatic index than precipitation alone for most of the species studied (Table 1). This relationship has been shown only for a few species in previous studies. Lindholm (1990) found that *S. fuscum* was only able to grow if the temperature was above zero, but above this temperature growth was controlled by water availability. Gerdol (1996) also found the same trend for *S. magellanicum*. Yearly growth

seasonal variation in growth, than species that grew in wetter lawns and hollows. These differences may be explained by the difference in moisture regime between hummocks and hollows. Since hollows are wet most of the year, species in this habitat type would be able to access water more readily and to be less stressed than hummock-forming species. During dry periods when the water level drops, however, species in hollows would not be able to retain water for growth because of their loose growth form. Conversely, hummock-forming species can retain water even in dry periods because of their superior water holding capacity explained by their dense growth form. Accordingly, the moisture content in hummocks is lower but more constant than that in hollows. This would allow hummock-forming species to grow during dry periods as well as during wetter periods,

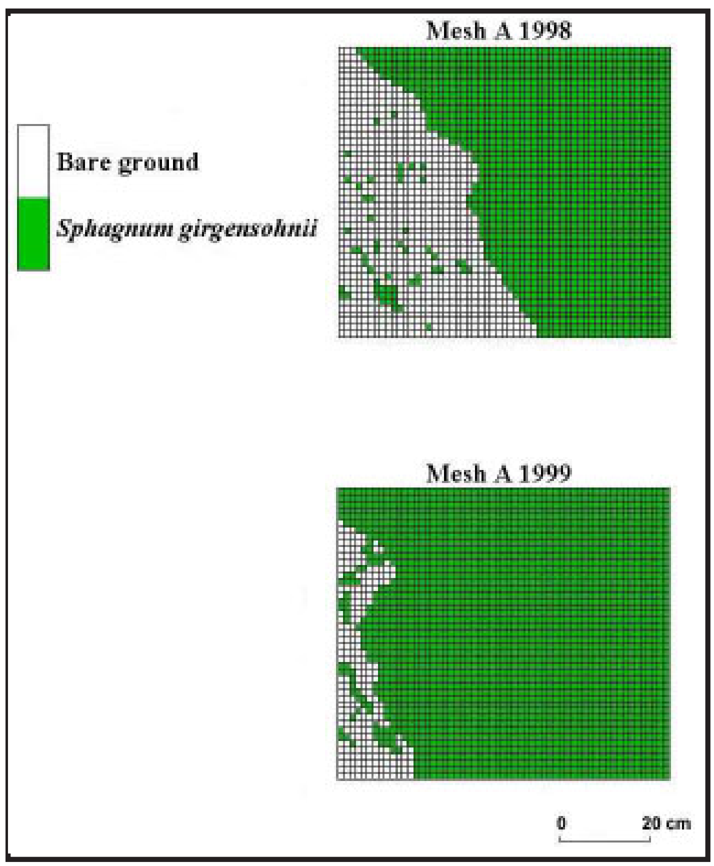

Figure 5. Change in cover of *Sphagnum girgensohnii* in one year at one of the three sites at Port Simpson.

variation of *Racomitrium microcarpon* was related to precipitation during the growing season (Vitt 1989), confirming the importance of precipitation above temperature thresholds.

The temperature threshold for growth seems to be different between sphagnum species and the other two moss species we studied. The preliminary results on the relationship between the growth and the climatic index indicate that the temperature threshold for sphagnum growth is about 0^{o}C, and for *R. lanuginosum* and *P. schreberi* it is about 5^{o}C. These low thresholds suggest potential winter growth, especially for sphagnum, in this mild hypermaritime region. Growth during winter appears to be considerable, as has been shown for sphagnum in other hyperoceanic regions (Hulme and Blyth 1982).

The productivity of sphagnum mosses tended to be at the top of the range of these measurements made in other sphagnum-dominated peatlands in Canada (Asada 2002). This high productivity could mean that the potential for paludification may be higher on the north coast than in other regions. When the productivity of the different peatland plant communities is considered, along with decomposition rates of sphagnum in these communities, the potential peat accumulation rate on the mounded portion of the Port Simpson site is comparable to that of the open peatland at Diana Lake (Asada 2002).

Sphagnum moss growth over eight years following forest harvesting at Port Simpson has progressed as follows:

1) Clear-cutting alone has not yet promoted significant colonization or advancement of sphagnum.

2) Mounding treatments following clear-cutting created hollows where water collected, resulting in conditions that were favourable to sphagnum establishment and growth.

3) The exposed organic, or mixed mineral-organic, soil provided a competition free substrate for pioneer moss species to invade.

4) The water chemistry gradient created by sphagnum along the mound-hollow transition may further facilitate moss growth and discourage the growth of other plant species, especially vascular plants.

The evidence of paludification is:

1) Presence of *Sphagnum pacificum* and *S. angustifolium* , which were presumably almost absent before harvesting, are increasing in area and volume, especially in the hollows. They are thought to be pioneer species that later provide conditions appropriate for other sphagnum species to get established.

2) Rapid expansion of *S. rubiginosum* patches, which are presumably contributing to wet lawn creation where other sphagnum species that occur in bogs (e.g., *S. rubellum*) can establish.

3) Vertical growth rates of sphagnum at the Port Simpson site are similar to, or greater than, growth rates at the undisturbed Diana site.

4) Decomposition rates at the Port Simpson site are similar to, or slower than, the Diana site.

Three potential development pathways for these sites are:

1) Tree regeneration doesn’t proceed well, sphagnum continues to expand, and species composition changes through succession with expansion of fen or bog communities in the cutover area.

2) Tree regeneration proceeds moderately well on the mounds, and owing to shading, the expansion of bog-type sphagnum species stops and shade tolerant, forest-type sphagnum species become dominant; the area becomes a wet lower-productivity forest.

3) Regeneration proceeds well on the mounds, and due to increasing interception and evapotranspiration the water table drops, sphagnum species are unable to persist; and a productive upland forest results.

Operational Considerations

The creation of conditions favourable to the establishment and growth of sphagnum mosses must be avoided when harvesting on the north coast. If site preparation is done for silvicultural purposes, the mixing of organic and mineral soils without creating mounds would be preferable over mounding treatments that result in pit/mound topography throughout the block. During harvesting, the partial retention of canopy trees and advance regeneration would maintain some of the rainfall interception capability of the forest, thus lessening the potential rise in water table. This, in addition to some increased shading, may reduce the potential for sphagnum establishment and growth.

Monitoring of the successional progression of the Port Simpson experimental site must continue for the long-term to further compare the effects of harvesting with and without mounding treatments.

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