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PEATLAND DRAINAGE AND IMPROVEMENT PROGRAM (PHASE 2): CONTROLLING WATER TABLE LEVELS TO ENHANCE TREE ESTABLISHMENT AND GROWTH

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EXECUTIVE SUMMARY

Three experimental forest drainage sites were established in Alberta's boreal forest to determine the effects of lowered water tables on soils, local hydrology, ground vegetation composition and tree growth. The sites were established in 1985 and ditched using from 30- to 60-m ditch spacings in 1986-87, as part of the Canada-Alberta Forest Resource Development Agreement (FRDA): Wetland Drainage and Improvement for Forestry Program (Phase 1). Data were collected before (from 1985 to ditching) and after ditching from instrumented transects and permanent sample plots established on drained and undisturbed control areas. Preliminary results from some of the component studies were published in 1990[1].

Funding for continuation of the project (Phase 2) was approved in 1992 as part of the Canada-Alberta Partnership Agreement in Forestry (PAIF). The primary objectives of this phase were to evaluate the growth of commercial tree species on drained forested peatlands and to determine the effects of water table management on ground vegetation composition. These objectives required that previously established permanent sample plots be remeasured periodically. This report provides results from a number of component studies including those on water table drawdown, substrate water content, peat subsidence, ground vegetation composition changes, the effects of ditching, thinning and fertilization on black spruce growth, and the survival and growth of tree seedlings on a ditch-mounded site.

Results from the three experimental areas showed that after ditching water table levels were lower on the treed fens than on the treed swamp, and that the 30-m ditch spacing was overeffective in lowering the water table in all three areas. In general, the 50-m spacing was the most suitable one for obtaining the desired mean groundwater table level of 40 cm. We speculate that for most peatland areas 50-m spacing would produce the desired water table level, and cut costs.

In the substrate water content study, water content was not significantly affected by ditch spacing several years after drainage. Variation was greater between different sampling locations relative to the position of the ditch edge within similar ditch spacings. Mean substrate water content within each ditch spacing decreased from the ditch edges towards the midpoint between ditches and was strongly correlated with changes to substrate bulk density, resulting from post-drainage peatland subsidence.

Peat subsidence was observed at all three sites and varied among sites, ditch spacings, and by location within ditch spacings. Drainage ditch spacing had a considerable effect on subsidence at all three peatlands, where the mean elevation loss (all sites) was 10.4 cm for 30-m spacings, 6.7 cm for 40-m spacings, and 5.5 cm for 50-m spacings. In general, the greatest subsidence occurred at ditch edges, and the least, at midpoints between ditches. There was no appreciable subsidence in adjacent undrained areas.

To measure changes in ground vegetation composition, transects consisting of a series of 1 x 1 m plots were established on the same ditched and control areas as the instrumentation networks set up to measure water table levels and soil temperatures. Plots were located every third metre, starting

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[1] Hillman, G.R.; Johnson, J.D.; Takyi, S.K. 1990. The Canada-Alberta Wetlands Drainage and Improvement for Forestry Program. Canada-Alberta Forest Resource Development Agreement report, Edmonton, Alberta.

at the point closest to the ditch where the vegetation was undisturbed by the clearing for ditch construction. Six replicates were established for each distance from a ditch centre, for a total of 150 plots for the three sites (48 each at Wolf Creek and Goose River, 54 at McLennan). Percent cover was recorded for all species in the plots from tall shrubs to mosses and lichens. Five measurements were done at Wolf Creek and Goose River, and four measurements at McLennan.

Some changes in the ground vegetation following drainage were immediate and dramatic, other changes took several years to appear. When compared to the control, changes occurring in the drained areas could be categorized into four main groups: those species that decreased in cover (and/or vigour), or disappeared from the site altogether; those species that increased in cover; those species that showed little change in cover; and those species that were not present initially, but invaded the site following drainage.

The bryophytes were the first group of plants to show a decrease in cover following drainage, particularly the peat mosses (*Sphagnum* spp.) and the brown mosses (*Drepanocladus* spp.). Among the vascular plants, the greatest decreases in cover following drainage were observed in the shallowly-rooted species and the sedges (*Carex* spp.). Several forbs disappeared from the sites entirely within a few years of drainage. The reduction in cover was more dependent on microhabitat than distance from a ditch. The plots that showed the greatest decreases in cover were those that were most exposed to the drying influence of the sun, particularly those at the south end of the transects closest to the ditch, where the clearings for ditching had removed any shading tree cover, and those plots that were initially well elevated above the water table.

Glow moss (*Aulacomnium palustre)* had the greatest increase in cover following drainage and was clearly expanding to fill the void left by the declining peat mosses. There was some increase in shrub cover, but a more marked increase in shrub height (particularly of dwarf birch, *Betula pumila*) following drainage. Pelt lichens (*Peltigera* spp.) and cup lichens (*Cladonia* spp.) also increased in cover following drainage. Dwarf shrubs and forbs were slower to respond.

A number of species that were not present prior to drainage invaded the drained areas at various times following construction of the ditches. Many of these are weedy species that first appeared on the freshly exposed soil of the ditch spoil piles and subsequently spread from these into the undisturbed vegetation. Invading species included: bluejoint (*Calamagrostis canadensis*), Canada thistle (*Cirsium arvense*), annual hawk's-beard (*Crepis tectorum*), fireweed (*Epilobium angustifolium*), northern willowherb (*E. ciliatum*), and common dandelion (*Taraxacum officinale*). Two common weedy mosses, fire moss (*Ceratodon purpureus*) and nodding pohlia (*Pohlia nutans*), became conspicuous following drainage, growing on the dried out remains of the previous bryophyte occupants of the sites. Replacement of one species by another lagged several years behind the disappearance.

The groundwater table was lowered sufficiently, even at the 60 m spacing, to virtually negate the possibility of detecting any changes in the ground vegetation related specifically to distance from ditches. Under the current ditching regime the sites would appear to be "overdrained."

A split-plot design experiment replicated in four blocks was established to determine the effects of thinning (main plots) and fertilization (subplots) on growth of a stagnant stand of black spruce on a shallow peatland (swamp) drained in the previous year. The thinning treatments were selective hand thinning to 1600 trees ha^{-1} (2.5 m by 2.5 m) and no thinning. The hand-broadcast fertilizer treatments were: no fertilizer, nitrogen (N), phosphorus (P), potassium (K), NP, PK, NK and NPK. Nitrogen as NH_4NO_3 was applied at 200 kg ha^{-1}, P as triple superphosphate at 100 kg ha^{-1}, and K as potassium chloride at 100 kg ha^{-1}. Diameter at breast height (dbh) and height growth increments were significantly greater on the thinned than on the unthinned treatments after six growing seasons. Because there were four times as many trees on the unthinned than on the thinned treatment, the basal area and total volume increments were greater on the unthinned treatment. Basal area and total volume growth increments per tree, however, were about 2.5 times greater on the thinned than on the unthinned treatment. Nitrogen and the N-containing fertilizer treatments significantly increased dbh, height, basal area and total volume. P, K and PK treatments showed little effects and P applied alone tended to produce a negative effect.

The ditch-mounding study consisted of three experiments. The first compared growth and survival of tree seedlings planted on mounds with the performance of seedlings planted on flat ground. The second compared growth and survival of three tree species planted on the mounds in spring, and in the third the growth and survival of five tree species planted on the mounds in late August were compared. Preliminary results indicated that, except where competition was unduly heavy, the five tree species planted on the mounds showed satisfactory survival rates six years after planting. In the one replicate for Experiment I where competition was severe, tamarack survival was only 13% on the flat but 100% on the mounds. Also in Experiment I after six years, survival of black spruce on the flat was the same as black spruce on the mounds. Overall, the height and root collar diameter growth of the larches was about two to three times that of the spruce species. Lodgepole pine seedlings planted on the mounds showed vigorous growth comparable to that of the two larch species. The mean maximum height increment recorded was 28 cm year^{-1} for tamarack and the mean maximum root collar diameter increment was 0.5 cm year^{-1}, recorded for both tamarack and Siberian larch.

Tree growth data from permanent sample plots, including stem analysis and ingrowth information, for all three sites are still being collected and analysed. Results so far indicate that tree growth responds positively to lowered water tables. Complete results will appear in later reports.

Some recommendations relating to operational forestry situations and future research directions are provided, and an economic evaluation of peatland drainage, by M. Pattison and W.A. White, is presented in the Appendix.

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INTRODUCTION

In this report, the terms peatland drainage, forest drainage and water table management are used interchangeably. The term "drainage" is used to imply "water table control", or removal of excess water rather than indiscriminate removal of water from a site.

Alberta's boreal forest contains extensive areas of wetlands that support stagnant stands of black spruce (*Picea mariana*) and tamarack (*Larix laricina*). Very little is known about these stands or their potential for conversion to productive forest through groundwater table management. It is known, however, that peatland drainage has been practiced extensively and successfully in parts of Europe, resulting in wood volumes as high as 300 m^3 ha^{-1} and annual increments of over 10 m^3 ha^{-1} (Heikurainen 1964). Finland has converted 5.7 million ha or 55% of its peatlands in this way to enhance growth of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) (Päivänen 1991). The former Soviet Union has treated a similar amount of peatland (Vompersky 1991) and Sweden has drained one million ha of peatland for forestry purposes (Hånell 1991).

Given the potential for this level of tree growth enhancement on suitable peatlands and also the withdrawal of forested public lands for uses other than forestry, the Alberta Land and Forest Service (LFS) became interested in exploring the possibility of increasing forest productivity through drainage. About 4 million hectares in Alberta are considered suitable for water table management and conversion to productive forest. Subsequently, in 1981, the first scientific forest drainage study in Alberta was initiated on a treed fen in the Saulteaux River drainage basin in central Alberta (Tóth and Gillard 1988). The objective of the study was to develop techniques for designing drainage systems and measuring their performances.

In 1985, three additional forest drainage study areas were established in Alberta as part of the Wetlands Drainage and Improvement Program (Phase 1) - a program initiated under the Canada-Alberta Forest Resource Development Agreement (FRDA). The objectives of the program were to determine: i) if peatland drainage was an economically feasible method of enhancing tree growth in Alberta, ii) what effects peatland drainage had on the environment, especially water quality, and iii) what changes in vegetation composition occurred as a result of peatland drainage.

During the course of the Agreement, from 1985 to 1990, the three experimental drainage areas were mapped, instrumented and ditched. Permanent sample plots were established to measure tree growth and changes in ground vegetation composition. A fertilization/thinning experiment and a ditch-mounding trial were also conducted on one of the experimental areas (Goose River). Some preliminary results on the effects of ditching on groundwater table levels and stream water quality were also obtained. The establishment of the study, the methodolgy employed and the preliminary results were described by Hillman *et al.* (1990). Preliminary results were also presented at symposia (Hillman 1987a, 1988, 1991), and a review of peatland drainage for forestry in Canada was published (Hillman 1987b).

Funding for continuation of the study (Phase 2) was approved in 1992 as part of the Canada-Alberta Partnership Agreement in Forestry (PAIF). The primary objectives of this phase were to evaluate the growth of commercial tree species on drained forested peatlands and to determine the effects of water table management on ground vegetation composition. These objectives required that previously established permanent sample plots be remeasured periodically. No new plots or instrumentation were required to implement Phase 2.

SITE DESCRIPTIONS

The three experimental sites, identified as Goose River, McLennan and Wolf Creek, were drained in 1986-87 and the water table levels monitored between 1986 and 1992. Goose River and McLennan are located in the Boreal Forest Natural Region and Wolf Creek is located in the Foothills Natural Region (Alberta Environmental Protection 1994); the vegetation on each originated after fire. The site locations are shown in Figure. 1 and their legal descriptions and other details are given in Table 1. Descriptions for each site are presented below:

Table 1. Legal descriptions and ditching information for the three experimental areas

Site (legal description)	Total area (ha)[a]	Ditching		Total ditch length (km)	Nominal ditch spacing (m)	Ditch spacings evaluated (m)	Drainage ditch density (m ha^{-1})
		Area (ha)	Date completed (dd/mm/yy)				
Goose River (14-68-19-W5[b])	320	135	30/09/86	40	40	30, 40, 50	294
McLennan (28-79-19-W5)	259	90	02/08/ 87	30	30, 40	30, 40, 50, 60	333
Wolf Creek (19-51-14-W5)	132	60	28/10/87	35	35	30, 40,50	333

[a] Undrained portions were designated as control areas.
[b] Section 14, Township 68, Range 19, West of 5th Meridian.

Goose River

The Goose River experimental area is situated near Valleyview, Alberta at 54° 55'N, 116° 45'W and 850 m above mean sea level. Located in the Central Mixedwood Subregion of the Boreal Forest Natural Region (Alberta Environmental Protection 1994), its climate is characterized by long, cold winters and short, cool summers and precipitation that falls mainly between May and August. The long-term (1951-1980) mean annual temperature at Valleyview is 2.3°C, and the average January and July temperatures are -15.9°C and 15.8°C, respectively (Atmospheric Environment Service 1982a). The average annual precipitation is 519 mm, 302 mm of which falls during May through September (Atmospheric Environment Service 1982b).

Before drainage, the swamp supported a black spruce stand 40-50 years old and a shrub understory dominated by Labrador tea (*Ledum groenlandicum*). The herb stratum consisted primarily of three-seeded sedge (*Carex trisperma*), common horsetail (*Equisetum arvense*), woodland horsetail (*E. sylvaticum*), and bog cranberry (*Vaccinium vitis-idaea*), with lesser amounts of cloudberry (*Rubus*

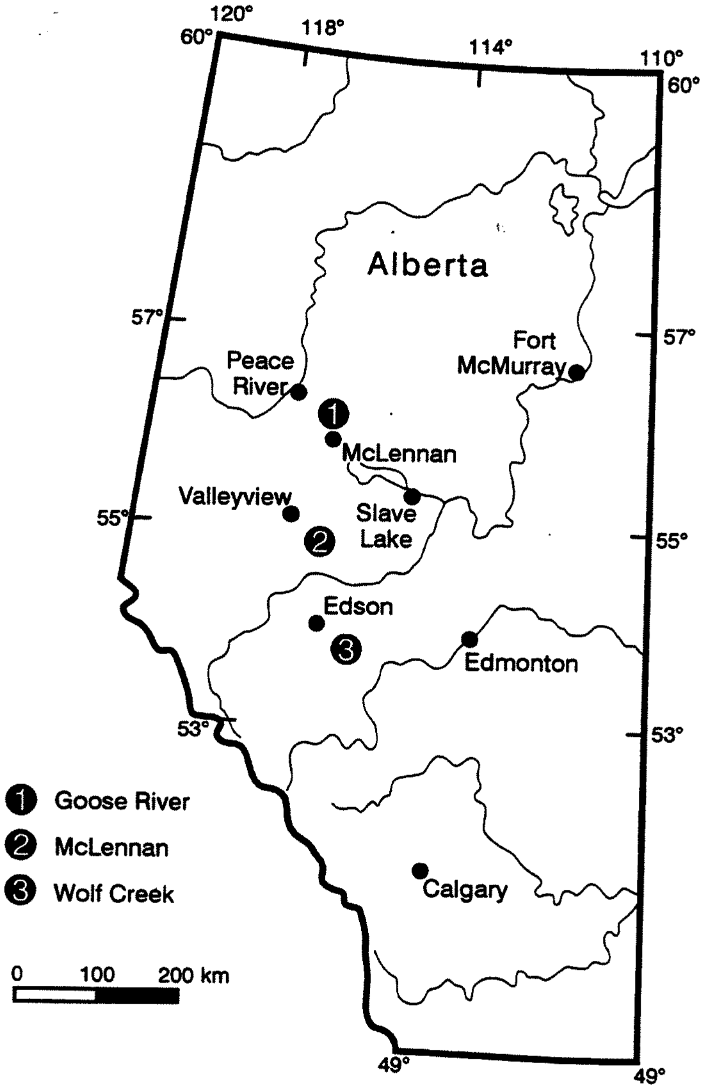

Figure 1. Locations of the three experimental drainage projects.

chamaemorus). Northern reed grass (*Calamagrostis inexpansa*) and small bog cranberry (*Oxycoccus microcarpus*) were constant species but had generally lower cover. *Sphagnum angustifolium* and *S. magellanicum* were the predominant mosses in the wetter areas; *S. fuscum* and *Pleuroziun schreberi* predominated in the drier areas. A few patches of reindeer lichen (*Cladina mitis*) occurred in more open, drier and elevated areas.

The 320-ha peatland is classified as a treed swamp (National Wetlands Working Group 1988) and is characterized by thin (30 to 60 cm) peat (von Post humification: 2 to 4) over mineral soil ranging from silt loam and silty clay to clay texture, probably of a lacustro-till origin with a slope of 0.8%. Soil pH ranged from 4.4 at the surface to 6.3 at the peat-mineral soil interface at 50-60 cm depth, and bulk density increased from 0.02 Mg m^{-3} at 5 cm depth to 1.61 Mg m^{-3} at 60 cm depth. Total N ranged from 1.1% near the surface to 0.1% at the 50-60 cm depth. Organic P ranged from 0.05 to 0.13%, and exchangeable K ranged from 0.5 to 3.0 cmol kg^{-1}. More detailed chemical and physical characteristics of the peat and the underlying soil are described by Mugasha *et al.* (1991).

McLennan

The McLennan experimental drainage area is an intermediate treed fen, characterized by a bog cap in places, supporting 60- to 70-year-old black spruce and tamarack. One legal section (259 ha) in size, it is located about 15 km north of McLennan, Alberta (55° 53' N, 116° 55' W) at an elevation of 660 m. Like Goose River, it is situated in the Boreal Forest Natural Region, but in the Dry Mixedwood Subregion (Alberta Environmental Protection 1994). The mean annual temperature (1951-1980) at McLennan, the closest meteorological station to the study area, is 0.9°C. The average January and July temperatures are -18.9°C and 15.9°C, respectively (Atmospheric Environment Service 1982a). Average annual precipitation at McLennan is 469 mm, 279 mm of which falls during May through September. The average annual snowfall depth is 160 cm (Atmospheric Environment Service 1982b).

On the experimental area, which encompasses the ditch network and the undisturbed control area to the north, the east portion slopes (0.6%) from southeast toward the beaver ponds to the northwest, and the west portion slopes (0.4%) from south to north. Groundwater flow into the experimental area is primarily from south and west. A water track -- defined as vegetation types marking the path of mineral-influenced waters through a peatland (Sjörs 1948; Heinselman 1963) -- located along the western edge of the experimental area feeds into the beaver ponds. The experimental area contains only one short, well-defined stream channel -- located just north of the drainage network and south of the beaver pond.

At the time of drainage, the soil consisted of peat more than 1.5 m thick, overlying clay. The fibric layer of peat consisted of sphagnum moss, 15 to 165 cm thick or, less frequently, of feather mosses 15 to 30 cm thick. The degree of humification ranged from 1 to 6 for sphagnum peat and from 1 to 4 for the feather moss peat. The mesic layer was woody peat with a von Post number of 6 and varied in thickness from 15 to 230 cm.

The shrub stratum before drainage was dominated by various species of willow (primarily *Salix farriae* and *S. planifolia*) with lesser amounts of dwarf birch (*Betula pumila*) and some Labrador tea. Black crowberry (*Empetrum nigrum*), a dwarf shrub, occurred sporadically. The herb stratum was dominated by water sedge (*Carex aquatilis*), small bog cranberry, and bog cranberry with lesser amounts of northern reed grass, northern bog sedge (*Carex gynocrates*), and bog sedge (*C. paupercula*). Cloudberry and three-leaved Solomon's-seal (*Smilacina trifolia*) were constant species with low cover. The predominant mosses were *Sphagnum fuscum*, *S. warnstorfii* and *Tomenthypnum nitens*. *Sphagnum angustifolium* was present in some areas. *Aulacomnium palustre* was a constant moss with low cover.

Wolf Creek

The Wolf Creek experimental drainage area lies about 30 km southeast of Edson, Alberta (53° 25'N, 116° 03'W) at an elevation of 950 m. It is located in the Lower Foothills Subregion of the Foothills Natural Region (Alberta Environmental Protection 1994) and experiences a subhumid continental climate with long, cold winters and moderately mild summers. It is subject to warm chinook winds during the winter. (Dumanski *et al.* 1972). At Cold Creek Ranger Station, the station with long term records and closest to the Wolf Creek site, the mean annual air temperature (1951-1980) is 1.1°C. The average January and July temperatures are -16.3°C and 14.6°C, respectively (Atmospheric Environment Service 1982a). The average annual precipitation is 536 mm, 361 mm of which falls during May through September. The average annual snowfall depth is 150 cm (Atmospheric Environment Service 1982b).

The 132-ha experimental area is located within a confluence of Wolf Creek at the downstream end of a large (>2500 ha) treed fen. The fen is bounded on the northeast and southwest sides by tributaries of Wolf Creek. Groundwater within the fen flows in the direction of the topographic slope, from southeast to northwest, toward the north tributary of the confluence. Uplands with mineral soils located at the south end of the fen provide the fen with a steady water supply.

Black spruce (90 years) and tamarack (80 years) are the predominant species in the fen, but mineral islands within the fen support mature lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*). The area has been subjected to intense geophysical exploration activity and, as a result, the forest is criss-crossed with a network of seismic lines, each about 7 metres wide, that provide ready access to the area.

Before drainage, the dominant understory shrub was dwarf birch (*Betula pumila*) with lesser amounts of bog willow (*Salix pedicellaris*) and Labrador tea. Bog rosemary (*Andromeda polifolia*) was a conspicuous and constant dwarf shrub. The herb stratum was dominated by water sedge, prostrate sedge (*C. chordorrhiza*), and swamp horsetail (*Equisetum fluviatile*) with lesser amounts of two-stamened sedge (*Carex diandra*) and mud sedge (*C. limosa*). Labrador bedstraw (*Galium labradoricum*), buck-bean (*Menyanthes trifoliata*), swamp cranberry (*Oxycoccus quadripetalus*), marsh cinquefoil (*Potentilla palustris*), three-leaved Solomon's-seal, and seaside arrow-grass (*Triglochin maritima*) were constant and characteristic species, but with low cover. The predominant moss species were *Sphagnum warnstorfii* and *Tomenthypnum nitens*, although *Sphagnum angustifolium* was prominent in certain areas; *Drepanocladus vernicosus* occurred in wet hollows. *Aulacomnium palustre* and *Meesia triquetra* were constant species on hummocks and in hollows respectively, but with low cover.

METHODS

The experimental design required that i) a portion of each experimental area be designated for ditching and the remainder be preserved as control; ii) pretreatment as well as post-treatment data be obtained from each site. Only a brief description of the methods employed in the study are provided here. A more detailed account is given in Hillman *et al.* (1990). The drainage networks, and the locations of the instrumented transects and permanent sample plots for Goose River, McLennan and Wolf Creek are shown in Figures 2, 3 and 4, respectively.

Preliminary work

The three experimental areas were surveyed, instrumented, and sampled in a similar manner. Weather stations consisting of a recording precipitation gauge and a hygrothermograph were installed. Survey lines were cut, topographic surveys conducted, and topographic maps produced with contour intervals of 0.5 m and scales of 1:2000 or 1:5000.

Preliminary peat, water, vegetation and tree foliage surveys and sampling programs were completed to determine wetland, vegetation, and peat types, peat depths, nutrient status, and other site characteristics. Measurements were taken either on a rectangular grid with 200 m sampling intervals or on two transects running perpendicular to each other across each site. The pH, saturated hydraulic conductivity, moisture content (volumetric and gravimetric) and bulk density of the peat substrate were determined. The peat was analysed for total elements (Ca, Mg, Na, K, Al, Ti, Pb, As, Cu, Fe, Mn, Zn, Ni, S, P) and available nitrogen, phosphorus, and potassium. Groundwater samples were analysed for the same 15 elements analysed in the peat samples. Total nitrogen (N) for peat and groundwater samples was determined by the modified Kjeldahl method.

In 1986, and prior to ditching, four transects were established on each experimental area, one on the control site and three at different ditch spacings (30, 40, and 50 m) perpendicular to ditch lines, on the area to be drained. Two additional transects were added at McLennan for the 60-m spacing. Each transect was instrumented, sampled, and surveyed to measure the effects of drainage on groundwater table levels, ground temperatures, and peat subsidence.

Ditch networks: design and construction

Drainage ditch network designs were prepared for each site using field observations, topographic maps, and enlarged aerial photos. An adaptation of Tóth's synthetic hydraulic curve method (Tóth and Gillard 1984, 1988) was used to find the optimum ditch spacings. Each network design allowed for evaluation of different ditch spacings on a homogeneous portion of each site.

Evaluation of drainage network performance was an important part of this study. Results from drainage studies in European forests suggest trees grow best at drainage norms (water table depth at midpoint between ditches) of 0.18 - 0.50 m (Heikurainen 1964). Tóth and Gillard (1988) used a drainage norm of 40 cm and a flood duration limit of 14 days in their forest drainage experiment near the Saulteaux River in north-central Alberta. The flood duration limit is the specified maximum time interval during which the water table level at the midpoint between ditches is allowed to remain above a specified depth, the drainage norm.

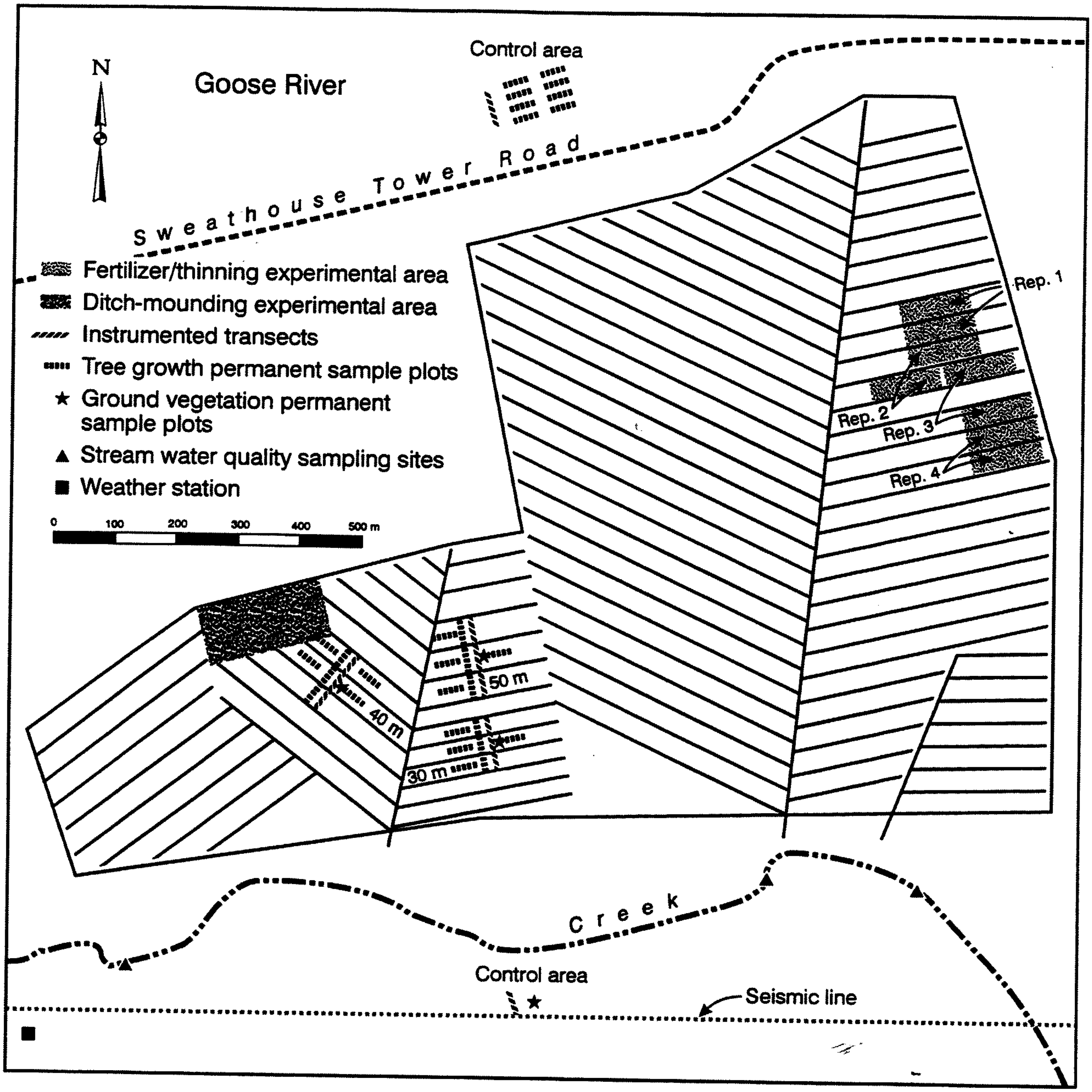

Figure 2. Locations of instrumented transects and permanent sample plots at Goose River.

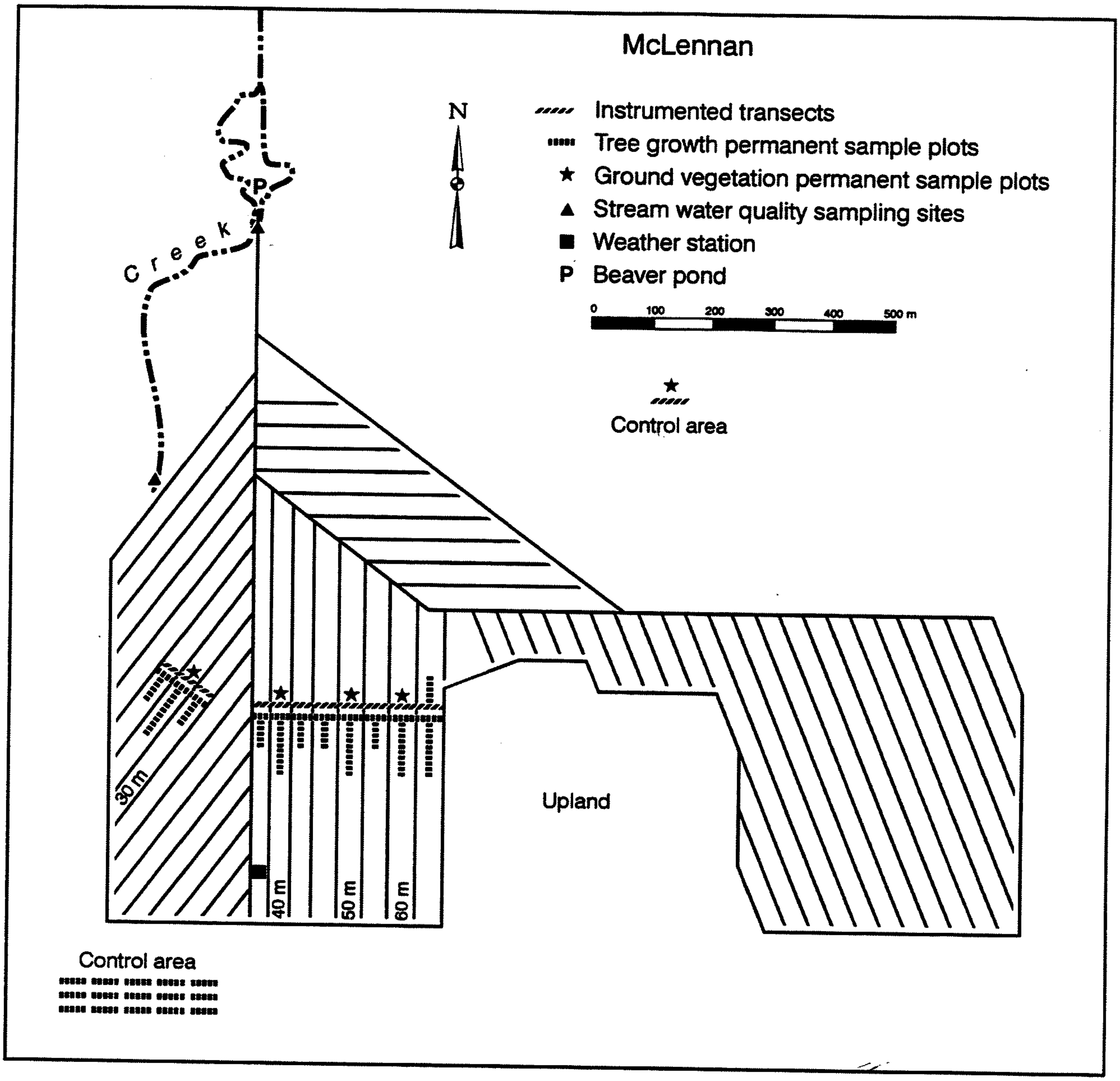

Figure 3. Locations of instrumented transects and permanent sample plots at McLennan.

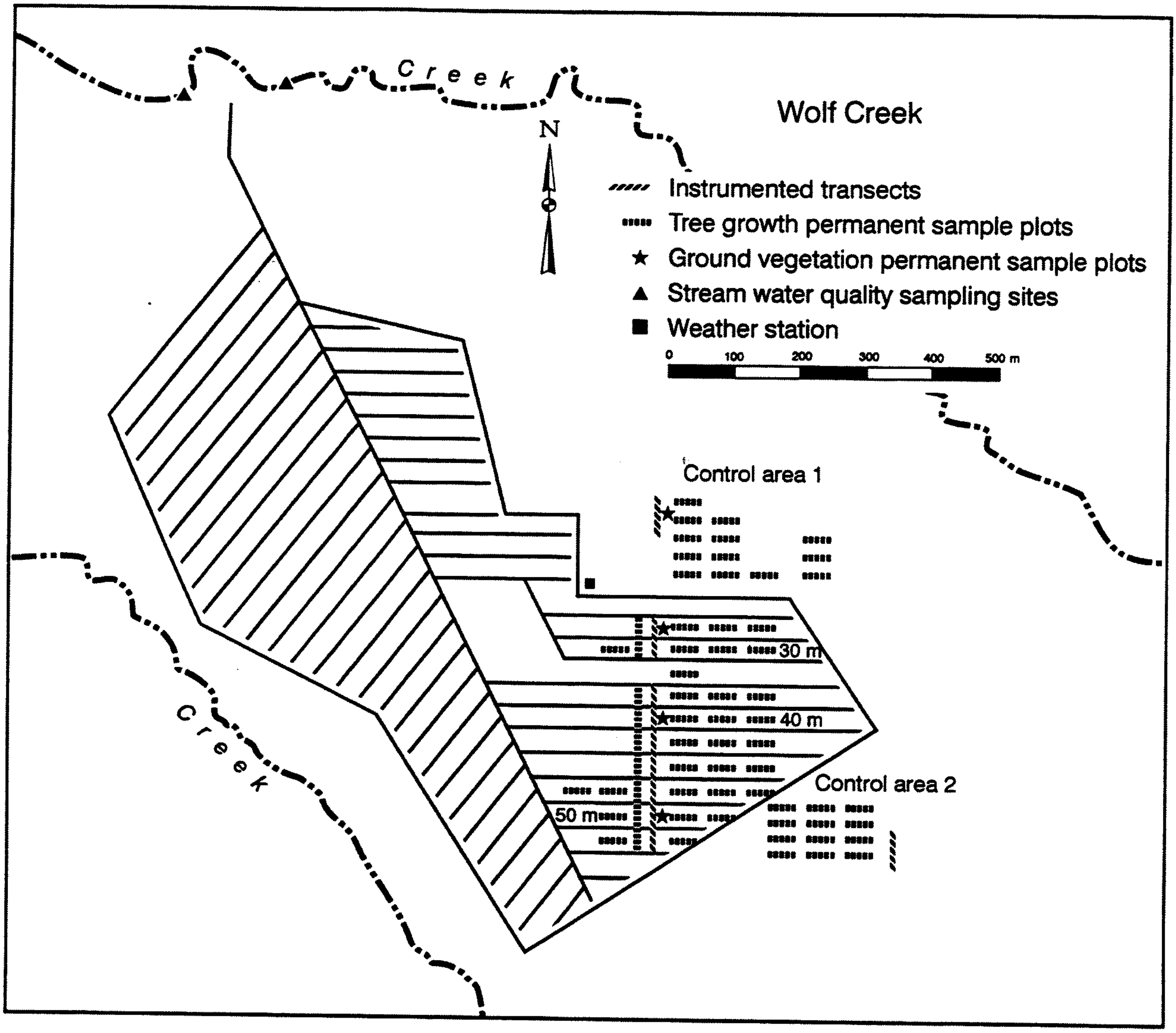

Figure 4. Locations of instrumented transects and permanent sample plots at Wolf Creek.

These same design criteria were used in this study to evaluate the effectiveness of the drainage ditches at McLennan and Wolf Creek. Drainage was rated successful if during the growing season the water table depth, on average, was 40 cm (v_m) and did not exceed a flood duration limit of 14 consecutive days. Drainage was rated unsuccessful if the average water table depth consistently fell below the 40 cm level (i.e., overdrained); or if the water table remained above the 40 cm level for more than 14 consecutive days any time during the growing season (i.e., underdrained).

The ditch networks were marked and 5-m rights-of-way cleared with a D6 crawler tractor during winter when the ground was frozen. Ditch networks were constructed in unfrozen ground using a Lannen S10 excavator. The ditches, parabolically shaped to maintain ditch stability, were 0.9 m deep and about 1.4 m wide. Ditch design details for each experimental site are provided (Table 1). Large sediment ponds were constructed near the downslope end of each main ditch to trap sediments. Buffer strips were left between main ditches and the water course, i.e., each main ditch terminated before reaching the creek, and effluent water passed over the undisturbed stretch of ground (the buffer) between the ditch and creek before entering the water course. The purpose of the buffer was to filter out sediment particles that may escape the sediment ponds.

Groundwater table levels

Groundwater table configurations were monitored using between seven and thirteen 5-cm diameter wells installed along each transect in 1986. Pressure transducers connected to battery-operated data recorders were inserted in 8 of the wells to provide continuous records of changes in water levels with time; data were recorded at 90-minute intervals. The other wells were measured once or twice a month with a carpenter's tape. Two or three 15-cm diameter wells on each experimental area were equipped with Leupold-Stevens F-type water level recorders. The t-test was used to test the hypothesis that there was no difference between the before- and after-drainage means for groundwater table levels ($p < 0.05$).

Substrate water content

Substrate water content and bulk density were measured during the summer of 1989 at the three experimental areas by volumetric sampling with a modified peat box sampler (Rothwell *et al.* 1996). Three drainage ditch spacings (30-, 40- and 50-m) and an adjacent undrained (control) area were sampled at each peatland. Within each ditch spacing, samples were taken along three randomly located transects extending from the ditch edge to the midpoint between adjacent ditches. For each transect, one core was sampled from each of three different locations: (1) within 1 m of the ditch edge (spoilbank was avoided), (2) at one quarter of the ditch spacing (i.e, half way between the ditch edge and the midpoint), and (3) at the midpoint between adjacent ditches. The peat cores were subsampled into depth increments of 0-10, 10-20, and 20-30 cm. Each peatland was sampled three or four times during the summer. The data were analyzed using a split-block analysis of variance.

Peat subsidence

Post-drainage subsidence was monitored using 13-mm diameter steel reinforcing rods driven through the peat into the mineral soil below. Each rod projected 15 cm above the ground surface. Three transects were established within each ditch spacing at each peatland. On each transect, a rod was installed 1) 5 m inward from ditch edges, 2) at one quarter of the distance between ditches, and 3) at the midpoint between ditches. A single transect was established in each control area for comparison. The rods were level surveyed, bench marked, and resurveyed 9 to 26 months after ditch construction.

Ground vegetation composition

In 1986, before drainage was implemented, a total of 150 ground vegetation permanent sample plots were established on the three experimental areas (Table 2).

Table 2. Number of ground vegetation composition permanent sample plots for different ditch spacings

Ditch spacings (m)	Goose River	McLennan	Wolf Creek	Total
30	8	6	8	22
40	12	10	12	34
50	22	14	22	58
60	0	18	0	18
Control	6	6	6	18
Total	48	54	48	150

Transects consisting of a series of 1 x 1 m plots were established on the same ditched (30, 40, 50, and 60 m spacings) and control areas as the instrumentation networks set up to measure water table levels and soil temperatures (Hillman *et al.* 1990). The ground vegetation transects were located 15 m east of the instrumented lines at Wolf Creek and Goose River, and 5 m north of the line at McLennan. Plots were located every third metre from the centre of a ditch along these transects, starting at 4 m from the ditch centre (7 m at McLennan). The starting point was determined as the point closest to the ditch where the vegetation was undisturbed by the clearing of the ditch rights-of-way. Every third metre spacing was also used on the control areas. Plot centres were thus established at mean distances from ditch centre of 4.5, 7.5, 10.5, 13.5, 16.5, 19.5, and 22.5 m at Wolf Creek and Goose River. The distances at McLennan were 7.5, 10.5, 13.5, 16.5, 19.5, 22.5, 25.5, and 28.5 m. Six replicates were established for each distance from a ditch centre, for a total of 150 plots for the three sites. The sampling design was determined by the availability of time and resources split amongst the three experimental drainage sites, and compatibility with the Canadian Wetland Registry (Tarnocai 1980).

For each plot, the four corners were marked with metal pins, and an aluminum tree tag identifying the plot number was attached to the pin at the northwest corner of the plots at Wolf Creek and the drained area at Goose River, and to the southwest corner of the plots at McLennan and the Goose River control. Plot numbers were prefaced with the ditch strip number and numbered consecutively from north to south on transect lines at Wolf Creek and the drained area at Goose River, and from west to east at McLennan and the Goose River control. Contiguous plots at the centre of the 50-m ditch spacing at Wolf Creek and Goose River were numbered from west to east, while those at the 50- and 60-m ditch spacings at McLennan were numbered from south to north.

Five sets of measurements were taken at Wolf Creek (1986, 1987, 1989, 1992 and 1996); five at Goose River (1986, 1987, 1989, 1994 and 1996); and four at McLennan (1986, 1987, 1989 and 1993). Plots were measured between mid-June and late August in all years.

Percent cover (to the nearest 5% for species with > 20% cover) was recorded for all species in the plots from tall shrubs (> 1.5 m tall) to mosses and lichens. Coniferous species occurring in the plots were not included in the tally. Scientific nomenclature follows Moss (1983) for vascular plants; Ireland *et al.* (1987) for mosses; and Esslinger and Egan (1995) for lichens. Common names have been taken from Ealey (1993).

Species cover values were averaged across the series of six replicates for each distance from ditch centre and the control. The t-test was used to test the hypothesis that there was no difference between the before- and after-drainage means for ground vegetation cover ($p < 0.05$).

Thinning and fertilization of black spruce at Goose River

The thinning-fertilization experiment at Goose River which occupies an area of about 4 ha was ditched with 40-m spacing between ditches in July, 1986 (Fig. 2). The experiment was a split-plot design replicated in four blocks (Fig. 5). Selective hand-thinning and no thinning (control) treatments were the main plots, and fertilizer treatments the subplots. Each main plot measured 35 m by 120 m, and the fertilizer subplots each measured 12 m by 35 m. Fertilizer was applied to the entire subplot. Tree measurements were carried out on trees in the middle 4-metre strips (measuring 4 m by 35 m) of the subplots to provide a 4-metre wide buffer on each side of a strip and 8 m between trees in adjacent subplots.

Thinning occurred in March and April, 1987 with the target spacing set at 2.5 m by 2.5 m (1600 trees ha^{-1})), with the criteria that crop (leave) trees be dominant and co-dominant with good form, and free of disease. On June 8 and 9, 1987, between bud swell and needle flush, fertilizers were hand-broadcast on the entire subplots as: no fertilizer, nitrogen (N), phosphorous (P), potassium (K), NP, PK, NK and NPK. Nitrogen was applied as ammonium nitrate at 200 kg ha^{-1}, P as triple superphosphate at 100 kg ha^{-1}, and K as potassium chloride at 100 kg ha^{-1}.

Tree diameters at breast height, representing diameter growth up to the end of the 1986 growing season, were measured using a standard tree diameter tape between June 9 and 30, 1987. Tree heights were measured using an 8.22-m telescoping height measuring pole. Because the current year (1987) leader growth was excluded, these measurements represented tree heights at the end of the 1986 growing season. Average basal area per hectare was calculated by summing the individual tree basal areas. Total tree volume (volume from stump height to tree tip), was computed using an equation developed by Alberta Energy and Natural Resources (1985a, b) for black spruce in the region.

Tree measurements were carried out again in late August and early September 1992 using the same procedures used in 1987. Analyses of variance for a split-plot design (Freese 1967, Steel and Torrie

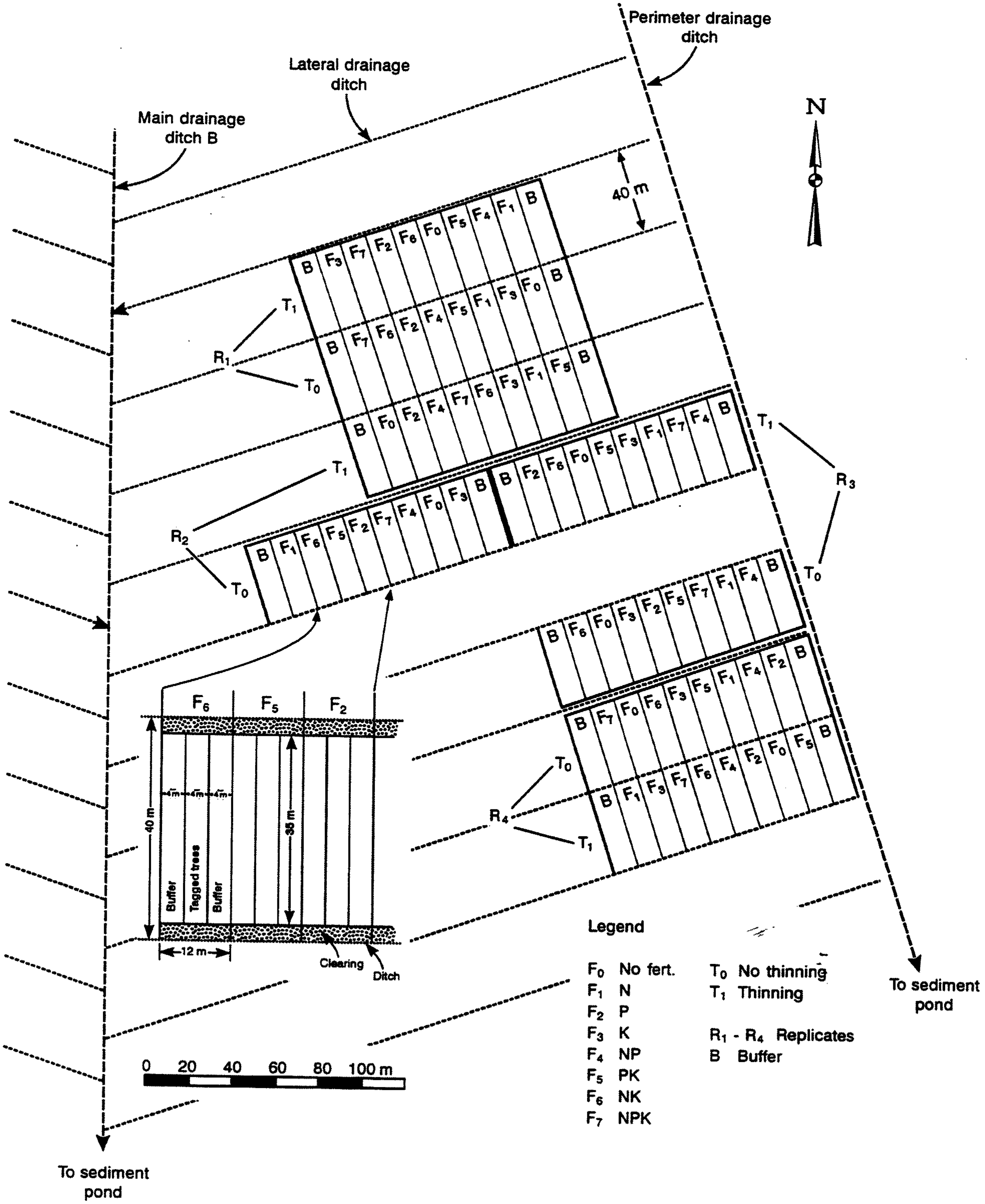

Figure 5. Layout of the thinning and fertilization study plots.

1980) and appropriate software (SAS Institute Inc. 1989) were used to test, at $p = 0.05$, the null hypothesis that fertilization and thinning of black spruce on the drained swamp would not affect growth. Dunnett's test was used to compare growth due to fertilizer treatments with growth on the unfertilized subplots.

Ditch-mounding experiments at Goose River

In March 1986, after the ditch network was marked out but before ditching took place, a 2-hectare area where peat depth was generally less than 60 cm (Fig. 2) was cleared and piled, and then burned a month later. Ditches 10 m apart were constructed in August 1986 with a Lännen S10 ditcher. The ditches were parabolically shaped, 90 cm deep and 1.4 m wide at the top. Spoil from the ditches was placed on the strips between the ditches as mounds, evenly distributed and about 2.5 m apart. Each mound contained approximately 420 L of soil (the volume of the ditcher's bucket), was about 0.5 m high, and covered a surface area of approximately 1 m by 1m. The mounds were left to settle before planting. The approximate height at planting was less than 0.5 m.

The study consisted of three experiments (Table 3) each in a randomized block design, each containing four replicates. The first (Experiment I) compared growth and survival of seedlings planted on the mounds with the performance of seedlings planted on flat ground. The second (Experiment II) compared growth and survival of three tree species planted on the mounds in spring, and in the third (Experiment III) the growth and survival of five tree species planted on the mounds in late August were compared. Each plot was planted to16 seedlings in Experiment I, and 28 seedlings in Experiments II and III.

The planting stock (Table 3) consisted of seedlings grown in 65-cm^3 containers. The exceptions were the white spruce seedlings in Experiment III, where the container volume was 90 cm^3. All seedlings, with the exception of white spruce and lodgepole pine in Experiment III were grown in the greenhouse for 10 weeks. The white spruce and lodgepole pine seedlings were grown in the greenhouse for 14.5 and 12 weeks, respectively. Except for white spruce in Experiment II, all seedlings were taken out of the greenhouse and kept outside until planting time. The white spruce seedlings in Experiment II were taken outside the greenhouse after 10 weeks and, later (November 22, 1987), placed in cold storage where they remained until two days before planting on June 1, 1988. In Experiments I and II, black spruce and tamarack were flushing at planting time.

After the seedlings were planted, tagged and numbered, the total height and root collar diameter of each seedling were measured. Pre-flush height and total height were recorded on seedlings that had flushed before planting. Seedlings planted in spring 1988 were remeasured in the fall 1988 for survival, total height and diameter at root collar. Measurements were repeated on all live seedlings in each experiment in September 1989, September 1990, October 1992, and September 1994. The severity of competition (proximity to seedling, intensity and overtopping) and the condition of the seedlings (multiple leaders, dead, dead top, browsed) were noted at these times. Seedling height was measured with a 1-metre measuring stick or carpenter's tape, and the root collar diameter was measured with calipers.

Table 3. Containerized seedlings used in ditch-mounding experiments

Experiment	Species	Seeding date	Planting date (1988)	Seedling size at planting		Planting location	Seed source (legal location)
				Mean height (cm)	Mean root collar dia. (cm)		
I	tamarack	Mar. 23, 1987	June 1-2	11.9	0.23	mound[a]	59-11-5-79[c]
	tamarack	Mar. 23, 1987	June 1-2	12.2	0.23	flat[b]	59-11-5-79
	black spruce	Mar. 23, 1987	June 1-2	8.6	0.15	mound	80-8-5-77
	black spruce	Mar. 23, 1987	June 1-2	9.3	0.16	flat	80-8-5-77
II	tamarack	Mar. 23, 1987	June 1-2	11.1	0.21	mound	59-11-5-79
	black spruce	Mar. 23, 1987	June 1-2	8.8	0.15	mound	80-8-5-77
	white spruce	Mar. 23, 1987	June 1-2	7.3	0.19	mound	62-20-5-79
III	tamarack	Mar. 23, 1987	Aug. 24-26	33.4	0.25	mound	59-11-5-79
	black spruce	Mar. 23, 1987	Aug. 24-26	17.6	0.21	mound	80-8-5-77
	white spruce	Feb. 24, 1988	Aug. 24-26	10.7	0.16	mound	62-21-5-83
	lodgepole pine	Mar. 8, 1988	Aug. 24-26	12.8	0.22	mound	63-12-5-80
	Siberian larch	June 1, 1988	Aug. 24-26	23.4	0.34	mound	72-10-6-87

[a] Anywhere on the mound excluding crest; generally planted in mineral soil. [b] cleared without mounding; planted in peat.
[c] Township - Range - West of 5th or 6th Meridian - year seed collected.

Tree growth (permanent sample plots)

A total of 137 permanent sample plots were installed and measured on the three experimental areas (Table 4). Plots oriented parallel (midway between ditches) with the ditches are 5 m by 40 m. Plots running perpendicular to the ditches are 5 m wide and have length equal to the distance between ditches. The purpose of the latter is to determine tree growth as a function of distance from the nearest ditch.

Table 4. Number of tree growth permanent sample plots and numbers of trees at plot establishment

	Goose River		McLennan		Wolf Creek		Total
	Control	Drained	Control	Drained	Control	Drained	
Parallel plots	8	12	15	17	25	30	107
Trees	1336	1732	1127	1295	1275	1692	8457
Trees/plot (mean)	167	144	75	76	51	56	-
Trees/ha	8350	7217	3757	3809	2550	2820	-
Perpendicular plots	-	9	-	11	-	9	29
Trees	-	1136	-	578	-	396	2100
Total plots	29		43		64		136
Total trees	4204		3000		3363		10567

Establishment and initial measurement of the control and parallel permanent sample plots at Wolf Creek was done in October, 1986. Establishment and measurement of the control and parallel plots at Goose River and McLennan, and the perpendicular plots at all three sites was completed in August, 1988. Additional plots in the control areas at Goose River and McLennan were established and measured in summer, 1989. All plots were remeasured at Goose River in 1991 and 1996, at McLennan in 1994, and at Wolf Creek in 1993 and 1996.

RESULTS

Groundwater table levels

At Goose River, the mean water table depths across the profiles after drainage were 26, 22 and 17 cm greater than before drainage, for the 30-, 40- and 50-m spacings, respectively (Fig. 6a). In contrast, on the undrained control, the average depth to water table for the postdrainage period was 15 cm less than for the predrainage period. At the midpoint between ditches the mean depths to water table after drainage were 44, 33 and 31 cm, respectively. Thus the 30-m spacing resulted in a mean depth to water table greater than the drainage norm of 40 cm while the mean depth to water table at the other two spacings were less than the norm. A more complete description of the Goose River groundwater results is provided in published reports (Hillman 1987a, 1988, 1991 and Hillman *et al.* 1990).

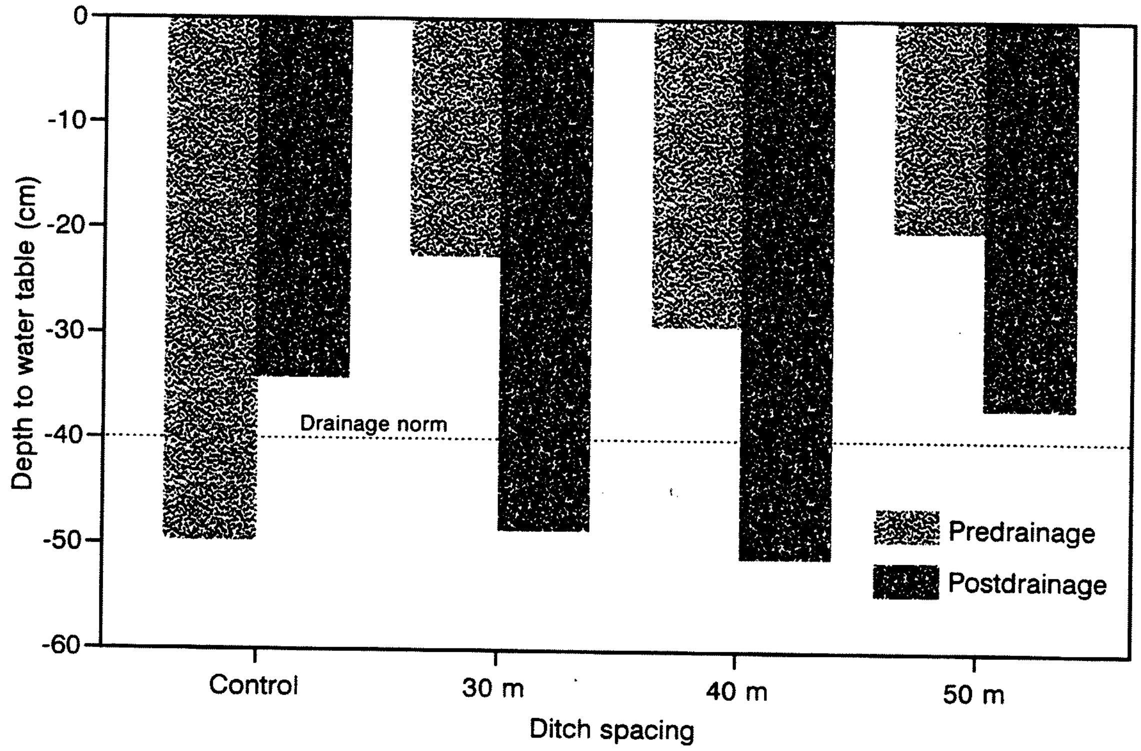

Figure 6a. Goose River: Average water table depths across the profiles before (1986) and after (1987-89) drainage for the undisturbed control and for the 30-, 40- and 50-m ditch spacings.

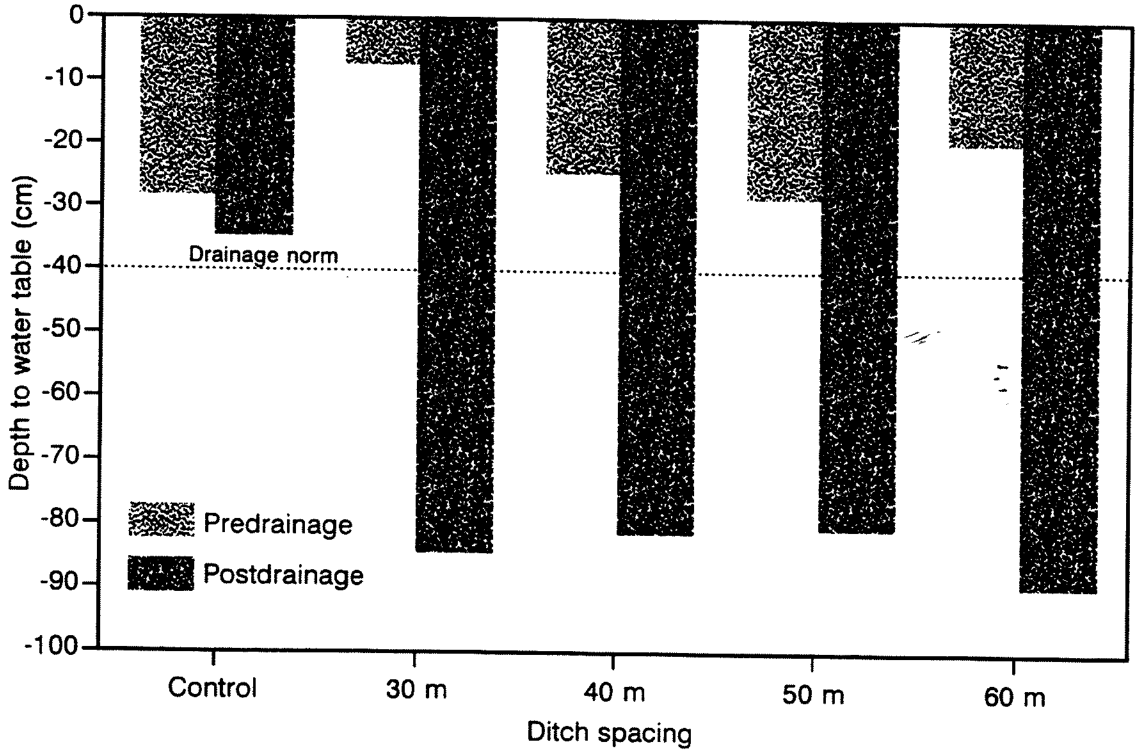

Figure 6b. McLennan: Average water table depths across the profiles before (1986-87) and after (1987-89) drainage for the undisturbed control and for the 30-, 40-, 50- and 60-m ditch spacings.

At McLennan, the average water table depths across the profiles after drainage were 85, 83, 82 and 90 cm for the 30-, 40-, 50-, and 60-m spacings, respectively (Fig. 6b). Thus the different ditch spacings lowered the water table to approximately the same depth. Analysis of the results showed that although drainage had a significant effect ($p < 0.05$) on groundwater table levels on the drained area compared with the control, differences among the four ditch spacings were not detected. However, because the average depth to water table before drainage was not uniform across the instrumented portion of the experimental area, it is more meaningful to compare the average change in water table levels after drainage. For the 30-, 40-, 50- and 60-m ditch spacings, the drops in water table levels were, respectively, 78, 60, 55, and 72 cm (Fig. 6b). Analysis of the groundwater table levels indicated the drop for the 30-m spacing was significantly greater ($p < 0.05$) than for the other ditch spacings, and the drop for the 50-m spacing was significantly less.

After drainage, the mean depths to water table at the midpoints between ditches were respectively 80, 52, 58 and 72 cm for the 30-, 40-, 50- and 60-m spacings. These mean depths are well below the targeted drainage norm of 40 cm. The corresponding declines in water table levels at the midpoints were 74, 46, 37, and 54 cm. Complete details of the McLennan groundwater study results are given in Hillman (1992).

The average water table depths across the profiles at Wolf Creek (Fig. 6c) indicate that, on all sites before ditching, the water table was less than 20 cm below the ground surface. After ditching, the average depths to water table across the profiles were 77, 52 and 58 cm for the 30-, 40- and 50-m ditch spacings, respectively (Fig. 6c). The corresponding average declines in water table levels across the profiles after ditching were 61, 45 and 48 cm. On the two undrained controls, the average drops in the water table during the postdrainage period were 16 and 7 cm (Fig. 6c). The greater drop in average water table level for Control 1 may be attributed to its location downstream from the ditch network (Fig. 4). The ditches to the south likely prevented some portion of the total groundwater flow from reaching the Control 1 area. Control 2, located upstream from the ditch network was not affected by the ditches.

After drainage the average depths to water table at the midpoints between ditches over four years were 64, 47, and 53 cm or declines in water levels of 53, 42, and 41 cm for the 30-, 40- and 50-m spacings, respectively. In all three ditch spacings, the average depth to water table at or near the centre between ditches fell below the drainage norm of 40 cm. The greatest difference (24 cm) occurred on the 30-m spacing and the least (7 cm) on the 40-m spacing. A complete description of the Wolf Creek groundwater study results is provided by Hillman (1996).

Substrate water content

Large differences in substrate water content were observed between drained and undrained areas ($p = 0.029$), between sample dates ($p = 0.004$), and between soil depths ($p < 0.001$). No significant interactions between these factors were evident (Rothwell *et al.* 1996). Seasonal variation in soil water content was similar for both drained and undrained areas at all three study sites, though mean water content in drained areas was 5-25% less than in undrained areas (Table 5). Water content of drained peat averaged 20% at 0-10 cm depth, 40% at 10-20 cm depth and 62% at 20-30 cm depth compared to 35%, 55% and 75% for the same depths in the undrained areas.

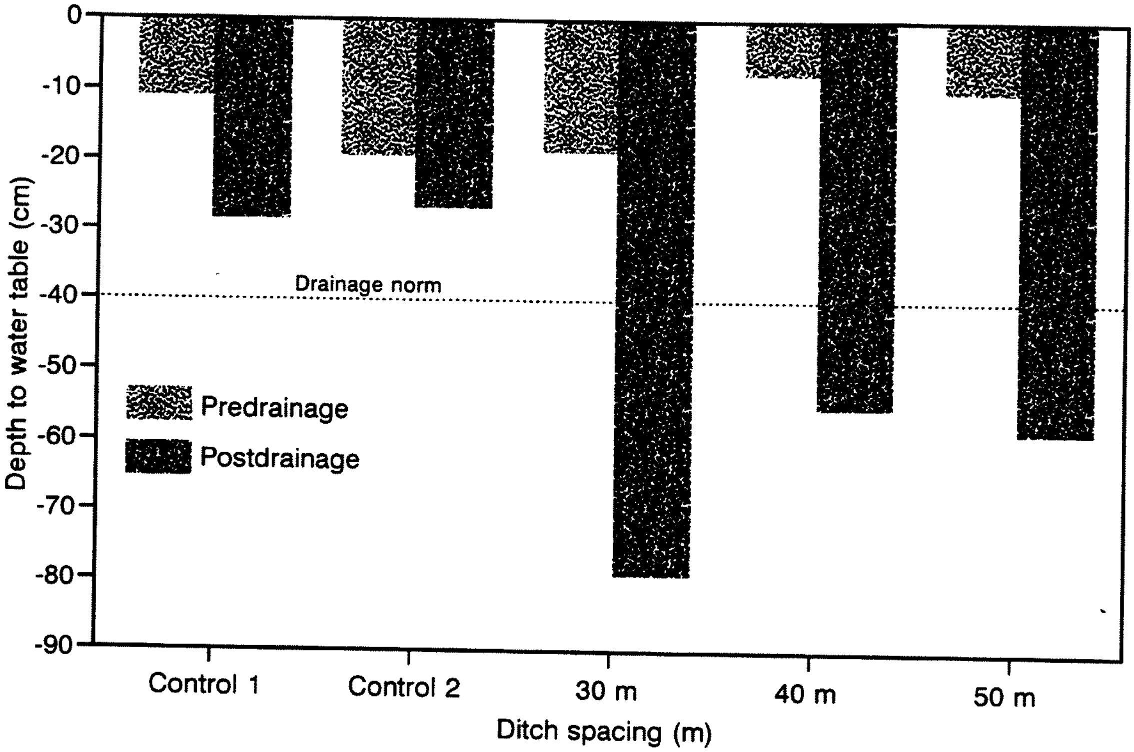

Figure 6c. Wolf Creek: Average water table depths across the profiles before (1986-87) and after (1988-91) drainage for the controls and for the 30-, 40- and 50-m ditch spacings.

Differences in peat bulk density were also observed between drained and undrained areas (p = 0.013), between sample dates ($p < 0.001$), and among soil depths ($p < 0.001$). Interactions were evident between soil depth and drainage condition ($p < 0.001$), and between soil depth and sample dates ($p < 0.001$). These interactions were probably a reflection of variation in substrate volume with peat hydration due to precipitation and associated water table fluctuations. Mean bulk density of drained peat was 45-50% greater than that of peat from the undrained areas (Table 5). Bulk density of drained peat averaged 0.040 g cm^{-3} at 0-10 cm depth, 0.085 g cm^{-3} at 10-20 cm depth, and 0.13 g cm^{-3} at 20-30 cm depth compared with 0.03, 0.055 and 0.085 g cm^{-3} for the same depths in the undrained areas. A more comprehensive description of the results from the substrate water content study is provided in Rothwell *et al.* (1996) and Silins (1997).

Table 5. Mean peat water content and bulk density for three depths at Goose River, McLennan and Wolf Creek

	Water content (% vol.)		Bulk Density (g cm^{-3})	
Depth (cm)	Drained	Undrained	Drained	Undrained
		Goose River		
0-10	17.25	25.64	0.041	0.027
10-20	32.23	46.44	0.073	0.042
20-30	57.02	69.19	0.124	0.061
		McLennan		
0-10	15.27	27.52	0.048	0.031
10-20	31.06	46.34	0.088	0.059
20-30	53.44	71.76	0.137	0.102
		Wolf Creek		
0-10	24.05	58.35	0.042	0.034
10-20	55.79	76.80	0.091	0.064
20-30	77.10	83.22	0.133	0.097

From Rothwell *et al.* 1996, Can. J. For. Res. 26:53-62. With permission.

Peat subsidence

Peat subsidence, as evidenced by ground surface elevation loss was observed at all three sites and varied among sites, ditch spacings, and by location within ditch spacings (Rothwell *et al.* 1996). Though the greatest variation in subsidence occurred among sites ($p = 0.003$), drainage ditch spacing had a considerable effect on subsidence at all three locations ($p = 0.010$). Mean subsidence (all sites) was 10.4 cm for 30-m spacings, 6.7 cm for 40-m spacings, and 5.5 cm for 50-m spacings (Table 6), and the overall mean was 7.5 cm. In general, the greatest subsidence occurred at ditch edges, and the least, at midpoints between ditches ($p = 0.037$). Mean elevation loss at ditch edges was 8.5 cm, with 7.4 cm and 6.7 cm observed at quarter points and midpoints, respectively. This general pattern is consistent with the observed gradients in water content and bulk density. There was no appreciable subsidence in adjacent undrained areas.

Table 6. Mean elevation loss (cm) at Goose River, McLennan and Wolf Creek (n =3 for each ditch spacing by location mean)

	Ditch spacing (m)			
	30	40	50	Mean
		Goose River[a]		
Ditch	6.8	1.8	4.3	4.3
Quarter point	10.3	2.0	3.2	5.2
Midpoint	4.7	1.2	0.7	2.2
Mean	7.3	1.7	2.7	3.9
		McLennan[b]		
Ditch	19.5	10.2	8.7	11.9
Quarter point	11.2	9.2	9.2	9.8
Midpoint	17.0	11.2	6.0	11.4
Mean	15.4	10.2	7.9	11.0
		Wolf Creek[c]		
Ditch	8.8	14.3	7.3	9.6
Quarter point	8.5	6.0	6.7	7.1
Midpoint	9.5	7.0	3.5	6.7
Mean	8.9	8.4	5.8	7.7

[a]24 months after drainage, [b]26 months after drainage, [c]11 months after drainage.
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Ground vegetation composition

Goose River

Drained area

Initial species diversity at Goose River was lower than at the other two sites. This may in part account for fewer gross changes seen in the ground vegetation. Common Labrador tea, the dominant shrub at the site, showed little overall change in cover after 10 years. As with the other two sites the most dramatic decreases in cover occurred in the peat mosses and sedges. There was a three-fold decrease in total cover of the peat mosses over the 10 years following drainage. Midway peat moss (*Sphagnum magellanicum*) had virtually disappeared from the site, and the cover of poor fen peat moss and rusty peat moss was greatly reduced. Presence of three-seeded sedge, the dominant graminoid on the site, was reduced from 28 to 20 plots, and its cover was reduced six-fold, over 10 years. However, even though their cover was greatly reduced, all the sedge species present initially could still be found in the drained area after 10 years. Close-sheathed cotton grass (*Eriophorum brachyantherum*) was the only graminoid to disappear from the site entirely following drainage. After 10 years, cover of three-leaved Solomon's-seal was about one half of what it was before drainage. This contrasts with the slight increase in cover for this species at Wolf Creek and no change at McLennan. Cover measurements for the horsetails varied widely, but in general there appeared to be about a two-fold decrease in the cover of common horsetail over 10 years, but little change in the cover of woodland horsetail.

Cover increases were seen in all groups. Balsam willow (*Salix pyrifolia*) showed about a three-fold increase over 10 years. Common blueberry (*Vaccinium myrtilloides*) nearly doubled its cover. Creeping snowberry (*Gaultheria hispidula*), although not abundant, increased in cover by a factor of about two. Palmate-leaved coltsfoot (*Petasites palmatus*) increased its cover about 4.5 times. Bunchberry (*Cornus canadensis*) increased in cover about 2.5 times.

Among the mosses, glow moss (*Aulacomnium palustre*), stair-step moss, big red stem, nodding pohlia (*Pohlia nutans*) and slender hair-cap increased in cover between 1.5 and 2.5 times. All of these species expanded to fill the niche vacated by the peat mosses. Among the lichens, all species of pelt lichen increased in cover, but the most dramatic increase occurred in frog pelt (*Peltigera neopolydactyla*) which increased over 10 years from presence in 20 to presence in 29 plots, and from a presence to 2% cover averaged over all plots in the drained area. The cup lichens (*Cladonia* spp.) showed a marked increase in abundance, going from presence in six plots before drainage to 31 plots 10 years after drainage.

Cloudberry, one of the characteristic and dominant plants on the site, showed an interesting pattern of change. Eight summers after drainage, its cover had fallen to about one half of predrainage levels, but two years later it had rebounded to near predrainage levels.

Two species invaded plots in the drained area in the 10 years following ditching, both of them lichens. Spraypaint lichen (*Icmadophila ericetorum*) was found in six plots, in one with over 10% cover. In all cases the lichen was growing on the remains of peat moss. Temporary pelt (*Peltigera didactyla*) occurred in three plots, on the edges of the formerly water-filled hollows around some of the tree bases.

Control area

Common blueberry had only a modest increase in cover in the control area compared to the drained area. Creeping snowberry had about three times the increase in the control area as seen in the drained area. Palmate-leaved coltsfoot showed little change in cover in the control. Bunchberry had about the same increase in cover in the control as in the drained area, and was one of the few species where a significant change in cover in either the control or drained area was matched by an equal change in the other area.

McLennan

Drained area

The experimental area at McLennan has many characteristics in common with the site at Wolf Creek. Both are intermediate treed fens, but the site at McLennan is not as mineral-rich, peat depths are shallower, and the trees are generally much younger than those at Wolf Creek.

The majority of the changes occurring in the ground vegetation at McLennan are negative in terms of reduced species cover and abundance. This is again particularly evident in the mosses. As a group, the peat mosses had more than a five-fold decrease in cover. Rusty peat moss and Warnstorf's peat moss showed the greatest declines. Poor fen peat moss showed a less marked decline as it was less common on the site to start with. By the seventh summer following drainage, peat mosses had disappeared entirely from one-fifth of the plots they had occupied prior to drainage. Cover of golden moss was reduced to about one-half of its predrainage levels. Presence of hook mosses (*Drepanocladus* spp.) decreased from 10 to 6 plots seven years after drainage and their cover was reduced by a factor of seven compared to predrainage levels. Richardson's water moss (*Calliergon richardsonii*) decreased in presence from 13 to 5 plots and straw-colored water moss (*C. stramineum*) went from six plots to one over seven years.

The only shrub to show an evident decline in cover was flat-leaved willow which decreased from 5% average cover across the drained area to 3%. Black crowberry, a dwarf shrub, decreased by roughly a similar amount. The most notable declines among the vascular plants occurred in the sedges, with nearly a five-fold overall decrease in cover in seven years. Most of this decrease was accounted for by water sedge, the dominant species on the site. Short sedge (*C. curta*), two-stamened sedge, and bristle-stalked sedge (*C. leptalea*) could not be located in any of the plots seven years after drainage. Small bog cranberry had a four-fold decrease in cover after seven years. Cloudberry cover decreased by about 2.5 times.

Several species disappeared entirely from the plots in the seven years following drainage, including marsh marigold, round-leaved sundew, and tufted loosestrife (*Lysimachia thyrsiflora*). Labrador lousewort (*Pedicularis labradorica*) was not far behind, being found in 30 plots before drainage, but in only two plots seven years after drainage.

Fewer species increased in cover following drainage than decreased or disappeared, and the magnitude of change was smaller. Dwarf birch showed a modest 1.5 times increase in cover, but a much more evident increase in height over seven years. Some shrubs increased in height by 30-50 cm over this time period. Height growth in the shrubs was more evident at McLennan than at Wolf Creek. The increase in cover of dwarf birch matched the decrease in cover of flat-leaved willow, but it is unknown if there is any direct connection between the two. In the herbaceous species, only northern reed grass showed a significant change, increasing in presence from 9 to 34 plots, with a concomitant four-fold increase in cover.

Several nonvascular plants showed an increase in cover as well. Glow moss, slender hair-cap, and stair-step moss (*Hylocomium splendens*) all approximately doubled in cover over seven years. The latter also increased in presence from 12 to 16 plots. Big red stem showed no significant change in cover. This is in contrast to the decrease in feather moss cover seen in the drained area at Wolf Creek, which may be due to the fact that feather mosses were less common there to start with. A lichen, temporary pelt, increased in presence from 5 to 12 plots. This is a transitory species well-known for colonizing freshly disturbed habitats. Cup lichens (*Cladonia* spp.) were found in 12 plots prior to drainage, increasing to 41 plots seven years after drainage.

Two species invaded plots on the site in the years following drainage, common dandelion (*Taraxacum officinale*) (one plot) and fire moss (five plots). A further increase in the abundance of these species could be expected if Wolf Creek can be used as an indicator. Fireweed (*Epilobium* *angustifolium*), annual hawk's-beard (*Crepis tectorum*), and long-leaved chickweed (*Stellaria longifolia*) were abundant on the ditch spoil piles three years after drainage, however, unlike Wolf Creek, none of these species had invaded any of the plots in the drained area by the seventh year following drainage.

Control area

Only two species showed a significant change in cover in the control area over the seven years of measurement. Myrtle-leaved willow (*Salix myrtillifolia*) nearly doubled in cover. Water sedge had about a two-fold decrease in cover, but this was only about half of the decrease seen in the drained area. No other species showed a significant change in cover, although there were slight decreases in the cover of glow moss and the peat mosses.

Wolf Creek

Drained area

Some changes in the ground vegetation following drainage were immediate and dramatic, other changes took several years to appear. When compared to the control, changes occurring in the drained area could be categorized into four main groups: those species that decreased in cover (and/or vigour), or disappeared from the site altogether; those species that increased in cover; those species that showed little change in cover; and those species that were not present initially, but invaded the site following drainage. (A number of species could not be categorized because they occurred too infrequently on the site to make statistically valid comparisons.)

During the first nine years following drainage nearly as many species decreased in cover, or disappeared from the site altogether, as the rest of the groups combined. Among the vascular plants, the greatest negative changes following drainage were observed in the shallowly-rooted species and graminoids. Deeply-rooted perennials, or those with wide-spreading root systems, exhibited greater inertia to change.

Bog rosemary and small bog cranberry declined in cover over the first five years following drainage and the surviving plants were less vigorous, with evident drying and browning of the leaves, by the second summer following drainage. This decline had stabilized by the ninth summer following drainage with little change in cover from the fifth summer.

Several forbs quickly disappeared from the site following drainage. Round-leaved sundew (*Drosera rotundifolia*), swamp lousewort (*Pedicularis parviflora*), and sticky false asphodel (*Tofieldia glutinosa*) had disappeared by the second summer following drainage. Northern green bog orchid (*Habenaria hyperborea*) joined this list by the fifth summer, and by the ninth summer, marsh horsetail (*Equisetum palustre*) could not be located in any of the plots in the drained area either. The vigour of the more common swamp horsetail was clearly reduced following drainage, but a decline in cover was not significant until between five and nine years after drainage. Seaside arrow-grass (*Triglochin maritima*) was found in only a single plot by the ninth summer following drainage compared to 25 plots in the drained area before drainage. Marsh marigold (*Caltha palustris*) and buck-bean, while persisting in the drained area, had substantially reduced cover and produced leaves that were much smaller when compared to predrainage conditions and plants growing in the control area.

The sedges showed a clear decline in both vigour and cover almost immediately following drainage. Fewer flower spikes were produced and this made identification of species difficult. Most of the predrainage species were still present to varying degrees nine years following drainage. Hairy-fruited sedge (*Carex lasiocarpa*) and thin-leaved cotton grass (*Eriophorum viridi-carinatum*), which could not be located in the drained area at all, and mud sedge, which was found in only one plot nine years after drainage, compared to 31 before drainage, were the three species that showed the greatest negative effects of drainage.

The bryophytes were the first group of plants to show a negative change following drainage, particularly those species favoring the wetter microhabitats. Three-angle thread moss (*Meesia triquetra*), found in 25 plots before drainage, had disappeared from the drained area by the fifth summer following drainage. Two other characteristic moderate-rich fen species, tall clustered thread moss (*Bryum pseudotriquetrum*) and stick hook moss (*Drepanocladus vernicosus*), could be found in only one and two plots, respectively, in the drained area nine years after drainage, compared to 27 and 39 plots before drainage. The average cover of stick hook moss dropped from 12.5% before drainage to a presence by the ninth summer. Big red stem (*Pleurozium schreberi*) showed about a three-fold decrease in cover over the nine years following drainage. Although they were still present throughout the drained area after nine years, the cover of poor fen peat moss (*Sphagnum angustifolium*), Warnstorf's peat moss (*S. warnstorfii*), and golden moss (*Tomenthypnum nitens*) was reduced by a factor of 12, 4 and 2, respectively, compared to predrainage levels. The surviving plants were also clearly less vigorous. The reduction in cover was more dependent on microhabitat than distance from a ditch. The plots that showed the greatest negative impacts were those that were most exposed to the drying influence of the sun, particularly those at the south end of the transects closest to the ditch, where clearing of the rights-of-way had removed any shading tree cover, and those plots that were initially well elevated above the water table.

Several species showed an increase in cover following drainage, in some cases almost as great as some of the species that decreased in cover. Dwarf birch (*Betula pumila*), a low shrub, increased in both height and cover over the nine years following drainage. Dwarf shrubs and forbs were slower to respond. Bog cranberry (*Vaccinium vitis-idaea*) showed some expansion in cover by the ninth summer following drainage. Marsh cinquefoil and three-leaved Solomon's-seal showed a slow but steady increase in cover over the nine years following drainage, the increase being about four-fold for marsh cinquefoil. Dwarf raspberry (*Rubus arcticus*), although it was present with low cover in seven plots in the drained area before drainage, markedly expanded its abundance and cover between the fifth and ninth summers, occurring in 19 plots, with a cover of 2.4% averaged over all plots in the drained area.

Among the bryophytes, glow moss had a six-fold increase in cover over the nine summers following drainage and was clearly expanding to fill the void left by the declining peat mosses. Wavy dicranum (*Dicranum undulatum*) and slender hair-cap (*Polytrichum strictum*) also increased in cover, but this trend was less marked than that for glow moss as these species were not abundant on the site to start with. Frog pelt, a leafy lichen, also increased in cover in the drained area.

A number of species that were not present prior to drainage invaded the drained area at various times following construction of the ditches. Many of these are weedy species that first appeared on the freshly exposed soil of the ditch spoil piles and subsequently spread from these into the undisturbed vegetation. Species invading within five years of construction of the ditches included: rough hair grass (*Agrostis scabra*) (12 plots), Canada thistle (*Cirsium arvense*) (one plot), annual hawk's-beard (one plot), fireweed (10 plots), northern willowherb (*E. ciliatum*) (24 plots), and cut-leaved ragwort (*Senecio eremophilus*) (one plot). Later invaders included bluejoint (*Calamagrostis canadensis*) (six plots), one-sided wintergreen (*Orthilia secunda*) (one plot), common pink wintergreen (*Pyrola asarifolia*) (two plots), and common dandelion (three plots). The grasses and fireweed appear to be expanding in the drained area. By the ninth summer following drainage, two common weedy mosses, fire moss (*Ceratodon purpureus*) and nodding pohlia, had invaded the drained area and were widespread and conspicuous, growing on the dried out remains of the previous bryophyte occupants of the site. Fire moss occurred in 19 plots (average cover 2%), while nodding pohlia was found in 35 of the 42 plots in the drained area (average cover 3%). At the same time, squamules of cup lichens (*Cladonia* spp.) began to appear in some of the drier plots in the drained area, being found in 10 plots nine years after drainage compared to just one before drainage.

Two vascular plants exhibited a pattern of change quite different from any other species. Both long-leaved chickweed and Labrador bedstraw showed a significant increase in cover by the fifth summer following drainage. Long-leaved chickweed increased from presence in 13 plots in the drained area before drainage, to 24 plots by the second summer after drainage, to 35 plots by the fifth summer after drainage, with cover changing from a presence before drainage to 6.7% in the fifth summer after drainage. This change showed no relationship to distance from the ditch, even though some of the spoil piles were completely covered by this species within three years of ditching. However, nine years after drainage, presence for this species had dropped to 28 plots, with an average cover of 0.6%, just slightly above predrainage levels. Labrador bedstraw did not have such a marked increase in presence, going from 29 plots before drainage to 36 plots nine years after drainage. However, its cover followed a similar pattern, increasing from a presence before drainage to 1.5% in the fifth summer following drainage, falling to just over 0.5% nine years after drainage.

Control area

For the vascular plants in the control area, little change was evident in low shrub cover, with the exception of common Labrador tea, which showed roughly a doubling in cover over nine summers. Bog rosemary increased slightly in cover, but the increase was not significant; no change was evident in small bog cranberry. Marsh cinquefoil had a similar increase in cover in the control as in the drained area, but three-leaved Solomon's-seal showed little change over nine summers. Bog cranberry increased in cover from 10% to 25% in one plot over nine years. Buck-bean had a two- to three-fold increase in cover over the first five years following drainage, but had declined to about one third its predrainage cover nine years after drainage. Swamp horsetail showed similar declines in cover and vigour in the control area as in the drained area. The sedges showed marked declines in both cover and abundance in the control as well as the drained area. Cover in both areas was reduced by a factor of about six. Two-stamened sedge, northern bog sedge (*C. gynocrates*), and mud sedge could not be found in any of the control plots nine years after drainage.

Among the bryophytes, glow moss increased in cover, but the increase was less than half of that in the drained area. Wavy dicranum saw a tripling in cover over the first five years after drainage, but cover declined to predrainage levels by the ninth summer following drainage. Clumps of this moss were still evident, but the majority of plants in them appeared to be dead. Big red stem showed a similar decline to that in the drained area. Poor fen peat moss had a slight, but not significant, increase in cover; rusty peat moss (*Sphagnum fuscum*) increased in cover from 25% to 60% in one plot; Warnstorf's peat moss and golden moss showed little change in cover. Stick hook moss and three-angle thread moss had disappeared completely from the control plots nine years after drainage.

Thinning and fertilization of black spruce at Goose River

Natural stand parameters and stand mortality

Tree measurement results for the unthinned plots (Table 7) represent the natural stand parameters of the 60-year-old black spruce growing on the experimental site and perhaps on the entire swamp.

Table 7. Stand parameters and changes due to thinning at time of experiment establishment in 1987

	Thinned	Unthinned
Density, trees ha^{-1}	1607	6580
Mortality[a], trees ha^{-1}	40	198
Mortality, %	2.5	3.0
Dbh, cm	7.67	4.93
Height, m	6.28	4.62
Basal area, m^2 ha^{-1}	8.29	15.78
Basal area, m^2 $tree^{-1}$, x 10^{-3}	5.16	2.4
Total volume, m^3 ha^{-1}	25.86	43.77
Total volume, m^3 $tree^{-1}$, x 10^{-3}	16.09	6.65

[a] Mortality over 6 growing seasons (1987 through 1992)

The results for the thinned plots, primarily those of the dominant and co-dominant trees, indicate the changes in the stand resulting from thinning. The average dbh and height of the unthinned stand appear to be representative of similar-aged stagnant black spruce growing on swamps in Volume Sampling Region 6 (VSR6) (Alberta Energy and Natural Resources 1985b).

Considering the stand age of about 60 years, its total volume of 43.77 m^3 ha^{-1}, and the current minimum utilization standard (0.30 m stump height to 5.0 cm top diameter inside bark (Huang 1994)), for pulpwood in Alberta, the stand most probably has no future commercial potential without silvicultural interventions. The density of 6580 live trees ha^{-1} is perhaps low for a typical black spruce stand in VSR6. Tree mortality over the six growing seasons was essentially the same in the thinned (2.5%) as in the unthinned (3.0%) stand. Mortality results suggest that the unthinned stand may no longer thin out naturally fast enough to benefit even more from the drainage so that artificial thinning should be considered, especially for other high density black spruce stands, even after drainage.

Dbh growth

The thinning at 2.5 m by 2.5 m in 1987 increased the dbh 2.74 cm above that of the natural stand (7.67 vs. 4.93 cm, Table 7). In six growing seasons average dbh increase was 0.43 cm in the unthinned and unfertilized plots and 0.97 cm in the unfertilized plots that were thinned (Table 8), an increase of 0.54 cm (126%) due to thinning. Thinning effect was significant ($p = 0.0035$); the dbh growth increment being nearly twice (1.28 vs. 0.70 cm, Table 8) that for trees in the unthinned plots; and the effect due to fertilization was also significant at $p < 0.0001$, being two times as much with some N-containing fertilization treatments. The overall thinning-fertilizer interaction was close to significance ($p = 0.0562$), and the interactions between the various fertilizer treatments and thinning, with the exception of N-thinning (p = 0.0028), were not significant. Generally, P, K, and PK treatments had depressive or little effects in both the thinned and unthinned treatments (Table 8). Nitrogen and N-containing fertilizer treatments on the other hand resulted in dbh growth increments that exceeded dbh growth in the unfertilized treatments; the increments being slightly better in the thinned plots (0.61 to 0.70 cm) than in the unthinned plots (0.45 to 0.66 cm).

Table 8. Six-year black spruce diameter and height increases due to thinning and fertilization on a drained swamp

Fertilizer treatment	Dbh (cm)			Height (m)		
	thinned	unthinned	mean	thinned	unthinned	mean
N	1.63	0.89	1.26	0.88	0.72	0.80
P	0.95	0.42	0.69	0.62	0.50	0.56
K	0.91	0.45	0.68	0.62	0.51	0.57
NP	1.64	1.09	1.37	0.90	0.89	0.90
PK	0.92	0.49	0.71	0.70	0.49	0.60
NK	1.58	0.88	1.23	0.93	0.75	0.84
NPK	1.67	0.93	1.30	0.90	0.86	0.88
No fert.	0.97	0.43	0.70	0.66	0.48	0.57
Mean	1.28	0.7	-	0.78	0.65	-
Incr., %	83	-	-	20	-	-

Height growth

The thinning of the natural stand in 1987 to 1600 trees per ha resulted in the trees averaging 1.66 m taller than trees in the unthinned treatment (Table 7) because the leave trees in the thinning were the dominants and co-dominants. The effects of thinning and fertilizer treatments on height growth increments and the overall interaction between the two treatments were significant ($p = 0.0098$, $p < 0.0001$, and $p = 0.0111$, respectively). Significant interactions between individual fertilizer treatments and thinning occurred only for thinning-P ($p = 0.0268$) and thinning-NP ($p = 0.0082$). Among individual fertilizer treatments, N or P applied alone significantly affected height increments ($p < 0.0001$ and $p = 0.0115$, respectively). Overall, thinning averaged 0.13 m (20%) more height growth increment (Table 8) than the unthinned treatment. Nitrogen and N-containing treatments averaged greater height growth increments (40 to 58%) than the increments in the unfertilized treatment. The height growth increments due to P, K, and PK treatments were essentially the same as in the unfertilized treatment. In comparison with the unfertilized plots in the unthinned treatment height growth increments were higher in each fertilized plot in the thinned treatment than in the unthinned treatment (Table 8) particularly the fertilized plots that contained N.

Basal area and total volume growth

The thinning in 1987 leaving dominant and co-dominant trees reduced the basal area per ha to about half of the level in the unthinned treatment, however, basal area per tree was more than double that of the unthinned treatment (Table 7). Basal area growth increments in six growing seasons resulting from thinning and fertilizer treatments were significant ($p = 0.0152$ and $p < 0.0001$ respectively). Among the individual fertilizer treatments only the N effect was significant ($p < 0.0001$). The basal area growth increment per tree was much larger (158%) in the thinned than in the unthinned treatment (Table 9), and overall, fertilizers increased growth, particularly those fertilizer treatments containing N, the increments being higher in the thinned treatment.

The spacing to a density of 1600 dominant and co-dominant trees in the thinned treatment at the beginning of the experiment (1987) decreased total volume per ha to 59% of that in the unthinned treatment (Table 7). Total volume per tree was about 2.5 times the value for the unthinned treatment. The volume growth increments (Table 9) achieved in six growing seasons and the levels of statistical significance were similar to those mentioned earlier for basal areas. Nitrogen and NPK treatments among all the fertilizer treatments were the only two treatments that had significant effects ($p < 0.0001$, and $p = 0.0355$, respectively). The volume growth increment per tree in the thinned treatment was 168% more than the increment in the unthinned treatment (Table 9). The N and N-containing fertilizer treatments resulted in the highest total volume increments per tree, and those increments were best for the thinned treatment (Table 9).

Ditch-mounding experiments at Goose River

Experiment I

Seven years after planting, tamarack and black spruce seedling survival rates were high (Fig. 7a). Tamarack survived better on the mounds than on the flat, but there was no difference in survival rates between black spruce planted on the mounds and black spruce planted on the flat. Greatest mortality occurred between 1990 and 1992. Generally, tamarack did very well on the flat, but severe

Table 9. Six-year black spruce basal area and volume increases due to thinning and fertilization on a drained swamp

Fertilizer	Basal area						Total volume					
treatment	(m^2 ha^{-1})			(m^2 $tree^{-1}$, x 10^{-3})			(m^3 ha^{-1})			(m^3 $tree^{-1}$, x 10^{-3})		
	thinned	unthinned	mean	thinned	unthinned	mean	thinned	unthinned	mean	thinned	unthinned	mean
N	3.39	6.28	4.84	2.11	0.95	1.53	14.62	23.30	18.96	9.10	3.54	6.32
P	1.80	2.51	2.16	1.12	0.38	0.75	7.23	11.07	9.15	4.50	1.68	3.09
K	1.99	2.98	2.49	1.24	0.45	0.85	8.74	13.30	11.02	5.44	2.02	3.73
NP	3.26	5.64	4.45	2.03	0.86	1.45	13.32	21.57	17.45	8.29	3.28	5.79
PK	1.91	2.89	2.4	1.19	0.44	0.82	8.29	11.35	9.82	5.16	1.72	3.44
NK	3.22	5.06	4.14	2.01	0.77	1.39	12.55	19.38	15.97	7.81	2.94	5.38
NPK	3.51	5.85	4.68	2.18	0.89	1.54	13.99	23.48	18.74	8.71	3.57	6.14
No fert.	2.06	2.46	2.26	1.28	0.37	0.83	9.05	10.69	9.87	5.63	1.62	3.63
Mean	2.64	4.21	-	1.65	0.64	-	10.97	16.77	-	6.83	2.55	-
Incre., %	(-37)	-	-	158	-	-	(-35)	-	-	168	-	-

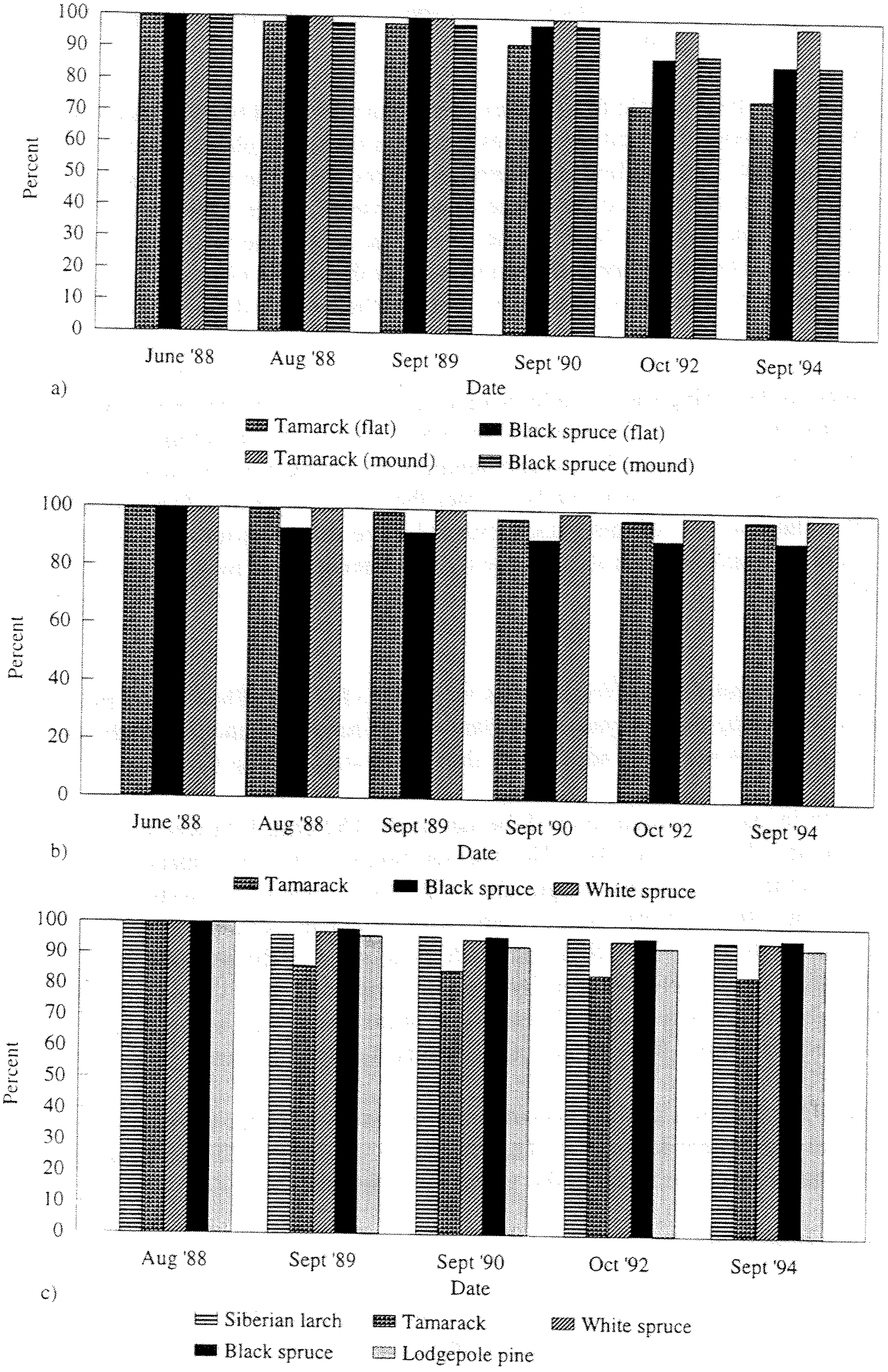

Figure 7. Survival rates of different tree seedling species planted in the ditch-mounding experiments at Goose River: a) Experiment I, b) Experiment II, and c) Experiment III.

competition in replicate four resulted in only 13% tamarack seedling survival on the flat in this replicate versus no mortality on the mounds. Black spruce survival was also reduced in this replicate, to 63% on the flat and 56% on the mounds.

Seven years after planting, the mean height of tamarack was 2.3 times that of black spruce (Fig. 8a). There were no significant differences, for either species, between seedlings planted on the mounds and seedlings planted on the flat. These differences were small throughout the seven-year period. A similar trend was observed for the root collar diameter response (Fig. 8b) where the tamarack diameter was twice that of black spruce. In this case, there was a tendency for both species to respond better on the mounds. The differences between root collar diameters of mounded seedlings and of those on the flat tended to increase with time, in favor of the mounded seedlings.

Experiment II

All three species planted in the spring showed a high survival rate - greater than 90% (Fig. 7b) in seven growing seasons. Black spruce initial mortality started high shortly after planting but remained virtually unchanged the following seasons. The mean height of tamarack in seven years was more than twice that of black spruce (Fig. 9a) and nearly 3 times that of white spruce. During the same period, the mean root collar diameter of tamarack increased more than 14 times the diameter at planting (from 0.22 cm to 3.18 cm) which is about twice the diameter attained by the spruces during the same time (Fig. 9b).

Experiment III

In six growing seasons survival rates for all five species were high (Fig. 7c). The highest mortality occurred in tamarack (16%) during the first year after planting and remained unchanged thereafter. Survival of the other four species remained above 90% during the six growing seasons.

The largest height growth in six years occurred in Siberian larch (152 cm), followed by tamarack (119 cm) and lodgepole pine (115 cm) (Fig. 10a). The average height of the larch species (136 cm) was nearly three times, and the lodgepole pine height almost 2.5 times, that of the spruces (47 cm), In six years, patterns of root collar diameter growth were, with the notable exception of lodgepole pine, similar to those for height (Fig. 10b). Siberian larch again showed the greatest increase in growth (to 3.2 cm) but this was closely matched by the pine seedlings (to 3.0 cm). Root collar diameter of Siberian larch after six years was 1.7 times that of tamarack. The average root collar diameter of the larches (2.5 cm) was 2.3 times that of the spruce species (1.1 cm).

In all three experiments much of the growth occurred in the last two or three years, after the seedlings made the initial adjustment to the site. This was especially true of Siberian larch and lodgepole pine in Experiment III where much of the growth was delayed until 1993-94.

Tree growth (permanent sample plots)

Tree growth data for Goose River, McLennan and Wolf Creek are still being collected and analyzed. Recent field measurements included tallies of ingrowth (regeneration) into the permanent sample plots. Additional data were obtained from 162 sectioned trees for stem analyses from Goose River (87 trees), Mclennan (45 trees) and Wolf Creek (30 trees). Results of the complete analyses will appear in a later report.

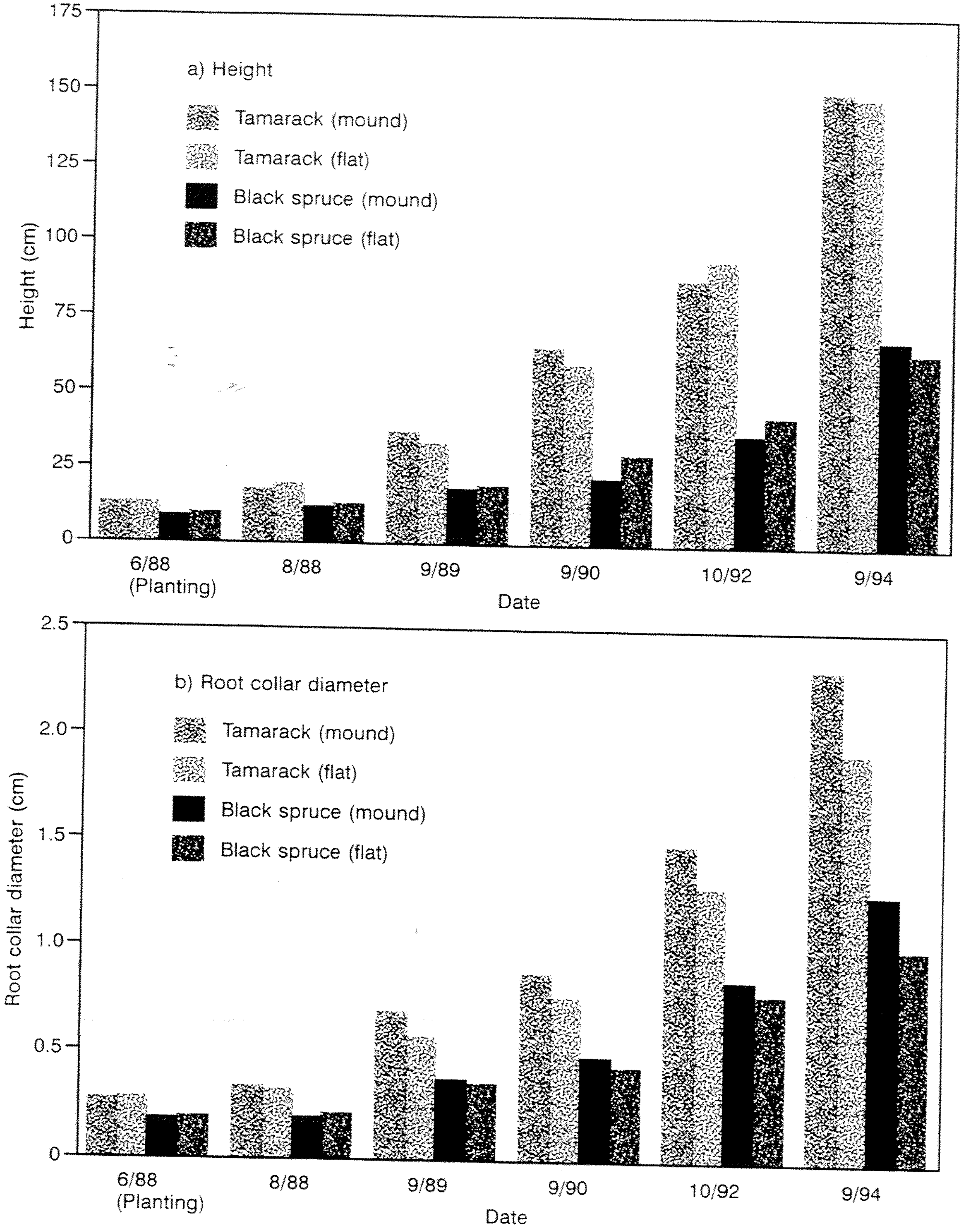

Figure 8. Experiment I. Heights and root collar diameters of tamarack and black spruce seedlings during the first six years following planting on mounds and on flat ground in spring, 1988.

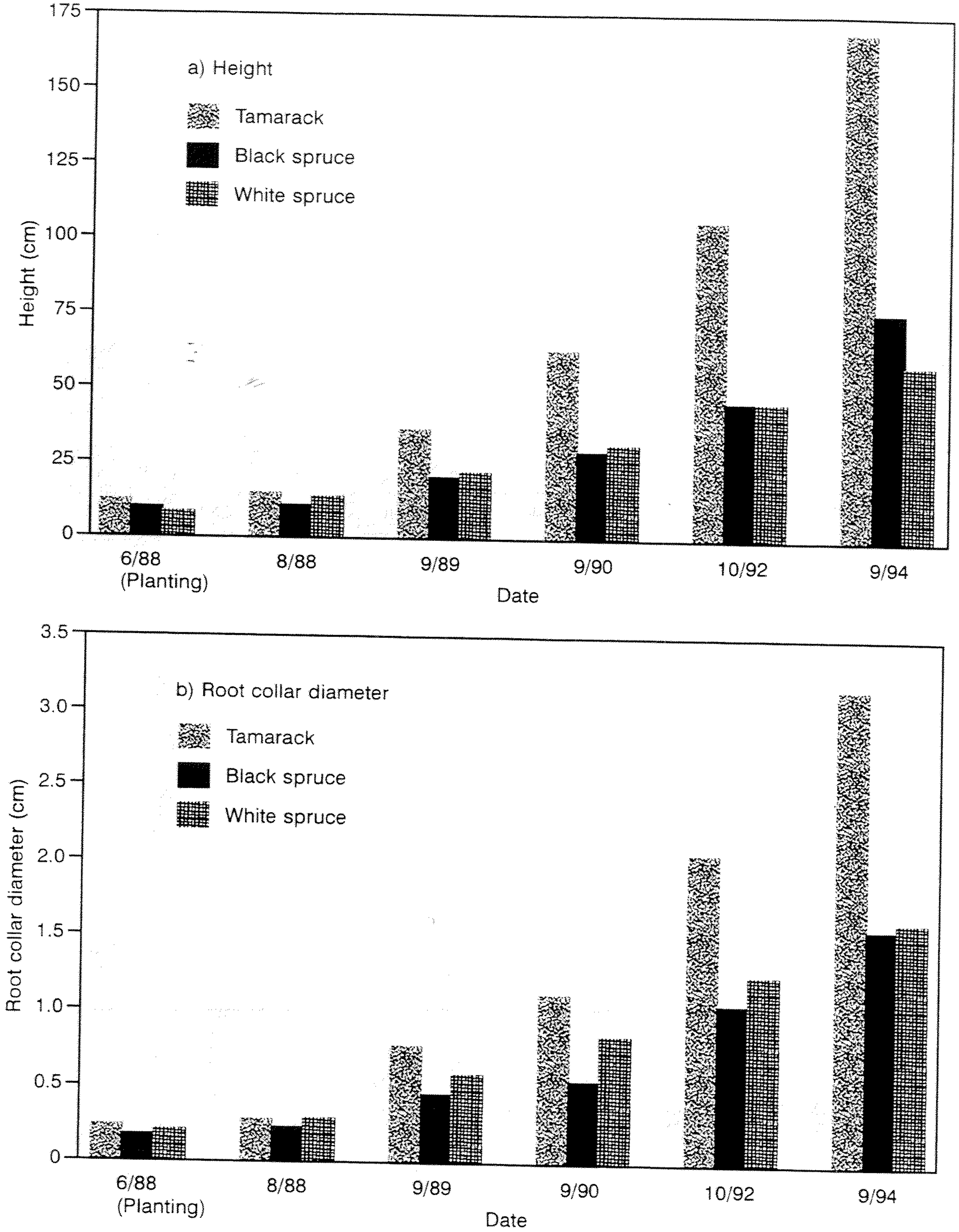

Figure 9. Experiment II. Heights and root collar diameters of tamarack, black spruce, and white spruce seedlings during the first six years following planting on the mounds in spring, 1988.

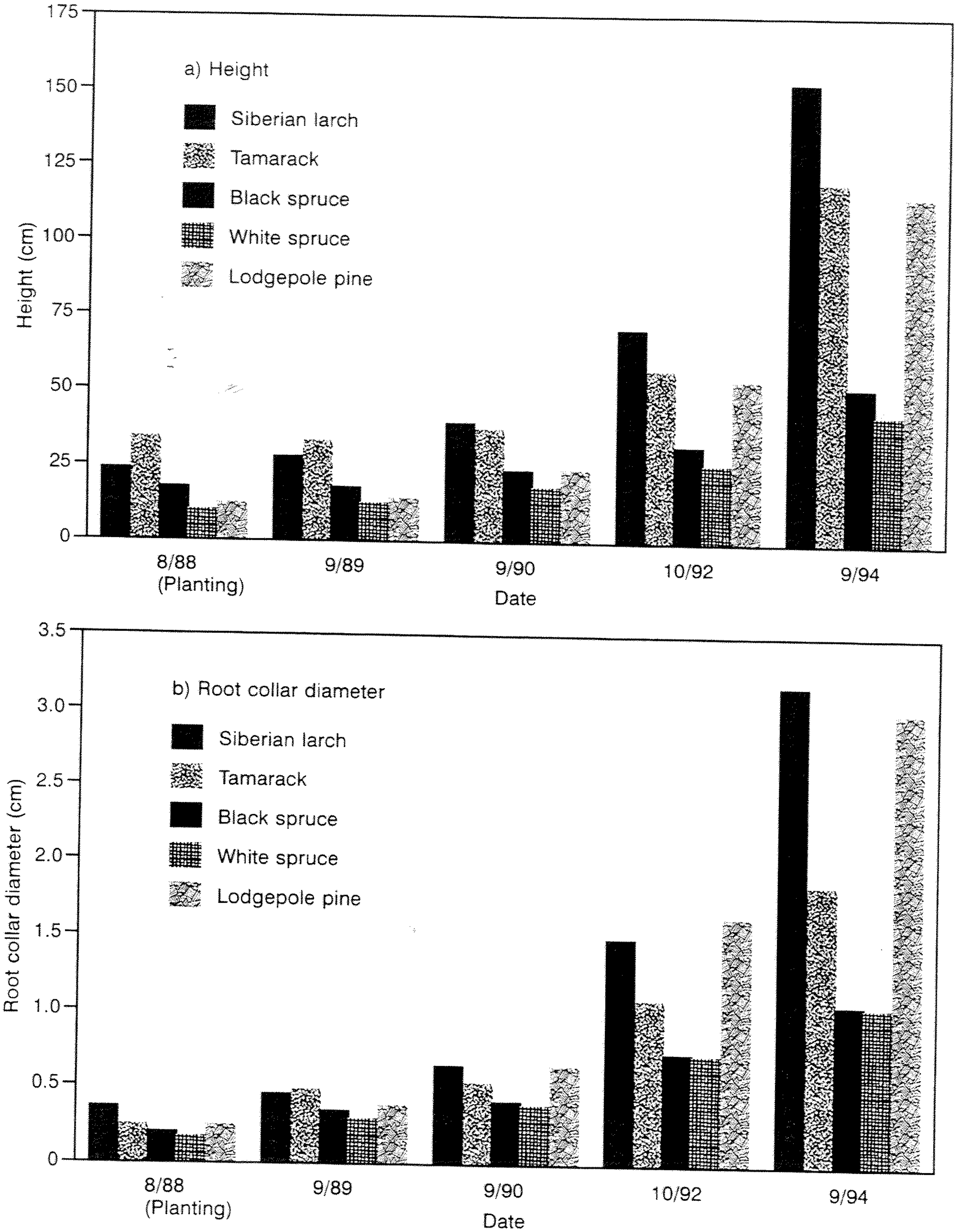

Figure 10. Experiment III. Heights and root collar diameters of Siberian larch, tamarack, black spruce, white spruce and lodgepole pine seedlings during the first six years following planting on the mounds in fall, 1988.

DISCUSSION

Groundwater table levels, substrate water content and subsidence

Results from the three experimental areas show (Hillman 1987a, 1992 and 1996) that after ditching water table levels were lower on the treed fens (McLennan and Wolf Creek) than on the treed swamp (Goose River). During ditch excavation at Goose River, it was evident that even though the ditches were dug to a depth of 0.9 m, most of the water running into the ditch came from the interface between the organic and mineral (clay) soils. The average depth to this boundary was 0.6 m. After ditching, water above the interface was readily released to the ditch but below the boundary water was retained in the soil. The 30-m ditch spacing was overeffective in lowering the water tables in all three experimental areas, i.e., the water tables were lowered well below the targeted norm of 40 cm.

At the Goose River swamp, acceptable depths to groundwater, comparable to those recommended in the forest drainage literature for different tree species (Heikurainen 1964) were achieved with 50-m ditch spacings (Hillman 1991). Of the three ditch spacings evaluated at the McLennan fen, the 50-m spacing was also hydrologically the most appropriate one for that site (Hillman 1992). At McLennan, the 60-m spacing, like the 30-m spacing, was overeffective but in this case, overeffectiveness was attributed more to edge effects, i.e., to site factors such as the proximity to upland areas and the small size of upstream source areas, than to distance between ditches. The McLennan results illustrate the importance, for ditch network design purposes, of taking into account hydrological conditions both within and well beyond the boundaries of areas selected for draining. The results from the Wolf Creek fen showed that, of the three ditch spacings evaluated, the 50-m ditch spacing was also the most suitable spacing for this peatland and similar areas (Hillman 1996). We speculate that for most peatland areas 50-m spacing would produce the desired water table level i.e., at about 40 cm below the ground surface.

It is possible, of course, that for any of the three experimental areas, a ditch spacing greater than 50 meters would be satisfactory and, for economic reasons, would be preferred. Although the groundwater hydrology studies on the three experimental areas were useful for designing the ditch networks and evaluating their performances, ultimately, the depth to water table is not a good measure of a site's potential for tree growth enhancement. For this purpose, it is better to relate tree growth directly to characteristics and conditions of the soil, particularly to soil water content, bulk density, subsidence, temperature and nutrient conditions. Steps in this direction were taken when the substudy to this project, *to determine the effects of forest drainage on soil water and bulk density, and to examine what role, if any, subsidence plays in modifying soil water conditions*, was initiated (Rothwell *et al.* 1996). Another substudy investigated the effects of drainage combined with thinning and fertilization on black spruce growth. Both substudies are described in this report.

In the first-mentioned substudy (Rothwell *et al.* 1996) it was determined that, despite differences in water table depression between ditch spacings, ditch spacing had little effect on overall mean substrate water content of all three sites. This unexpected result was related to differences in bulk density between ditch spacings among the three study sites. Though no difference in soil water content between ditch spacings was detected at Goose River and McLennan, some differences were observed between ditch spacings at Wolf Creek. Soil water content and bulk density increased with ditch spacing at Wolf Creek. Mean soil bulk densities (0-30 cm) were 0.076, 0.087, and 0.100 g cm^{-3} for the 30-, 40-, and 50-m spacings, respectively. Greater soil bulk densities in some ditch spacings at Goose River and McLennan were also associated with higher mean soil water contents. No clear pattern of soil water content or bulk density was evident between ditch spacings over all three sites. However, as ditch spacing did have a significant effect on elevation loss at all three peatlands, a hypothesis of greater subsidence and soil water retention in narrower ditch spacings may be a valid expectation.

Larger differences were observed between locations within ditch spacings at all three study sites. In general, soil water contents and bulk densities at ditch edges were greater than those at locations away from the ditches regardless of ditch spacing. These observations indicated spatially non-uniform subsidence at all three peatlands.After drainage, water table levels were lowest near the ditches and increased toward the midpoint between the ditches. In contrast, and contrary to what was expected, soil water content and bulk density were greatest near the ditch and diminished toward the midpoint. The greatest change in these properties occurred within 0-10 m from the ditch edge, with little change evident beyond this distance. This distance corresponded to the approximate position at which the parabolic shape of the water table between adjacent drainage ditches becomes asymptotic (Hillman *et al.* 1990; Lieffers and Rothwell 1987).

Subsidence appeared to buffer the effect of low water table levels on soil water conditions. Observations indicated relatively high soil water content within the surface 30 cm throughout the growing season, suggesting sufficient soil water retention or capillary transport from the water table for tree growth.

Ground vegetation composition

Only some of the most obvious changes occurring in the ground vegetation following drainage have been commented on in the results. More detailed conclusions will require further analysis of the data and additional plot measurements (particularly an update at McLennan) at some future date.

Sampling design for the ground vegetation permanent sample plots was based on the initial assumption that there would be changes in the vegetation due to drainage and that these changes would be related to the distance from the ditches. However, the groundwater table was lowered sufficiently, even at the 60 m spacing, to virtually negate the possibility of detecting any changes in the ground vegetation related specifically to distance from ditches. Comments on changes related to drained versus undrained conditions, and changes in the plots in the drained area before and after drainage, have been made, but there are limitations to this. With only six control plots and one or two years of predrainage measurements, it was sometimes difficult to determine whether or not a change in the ground vegetation was due to drainage or was simply a reflection of annual variability or normal plant growth. More control plots and additional years of predrainage measurement would have helped to resolve this question.

Some of the changes in cover seen in the control plots at Wolf Creek were unexpected. The control plots were located at the downstream end of the direction of water flow through the fen. Despite the fact that the nearest control plot was located 135 m from the perimeter ditch around the drained area, there was a 15 cm drop in the water table in the control area due to interception of incoming waters following construction of the drainage ditches (Figs. 4 and 6c). This was in comparison to a drop of about 50 cm in the water table in the drained area. This was significant in that it resulted in some changes in the control area that mimicked those in the drained area, but on a smaller scale. These changes would not likely have been noticeable without the drop in the water table. However, none of the species that invaded the drained area did so in the control.

Beaver moved into the site at Goose River subsequent to construction of the drainage ditches and built dams (most likely during the summer of 1993) on some of the collector ditches downstream from the location of the permanent sample plots. This has resulted in rehydration of the site with reversion to predrainage conditions or actual flooding in some of the plots. The most noticeable immediate effect of the dams on the ground vegetation has been a refilling of the hollows around some of the trees with water, with subsequent revitalization of many of the previously dried out leafy liverworts located there. Flooding by the beaver may also be responsible for the recovery noted in cloudberry after an initial decline. There is also some indication of revival/return of some of the peat moss species in the wet hollows.

Observational errors recording plant cover are another difficulty in determining the cause of change. Species morphology, the distribution of individual plants, and misidentification of species all contributed to errors. Species with the smallest covers exhibited large measurement errors between successive measurements, indicating that cover estimates for these species are unreliable. Leaning branches of the shrub species contributed in some cases to wide fluctuations in cover estimates between successive measurements in the same plot. In one instance at Wolf Creek, a dead snag fell across two plots, virtually annihilating half the vegetation in them. Observational errors in recording sedge cover may be as responsible as drainage effects for the changes seen over the period of measurement.

Misidentification of species was a greater problem than expected. Following drainage, many of the sedges in the drained area failed to produce flowering spikes, making identification difficult. It was also more difficult to separate living from dead tissue in the graminoids. Separating the various peat moss species was more difficult when they were completely dehydrated versus when they were fresh and completely hydrated. Cover estimates for both the sedges and peat mosses were often attributed to different species between successive measurements. This problem was lessened by grouping the species by genus in the data analysis. Unexpected problems compounding measurement error and annual variability were simple recording errors that were not caught at the time of sampling and misalignment of plots between successive measurements because of missing or bent corner pins (usually due to a wayward moose). These problems contributed in some cases to large discrepancies in cover estimates between measurements.

Observational bias cannot be completely overcome. It can be lessened by having the same observer, familiar with the vegetation, measuring the plots at the same time each year, but because it cannot be eliminated entirely, changes in the vegetation need to be greater than 20% before they can be attributed to factors other than annual fluctuation and measurement error (Kennedy and Addison 1987).

Other difficulties with the sampling procedure became evident with time. Considerable trampling around the plots occurs as measurements are being taken. This trampling, by creating a pedestalled plot in the soft peat, could cause changes in the vegetation independent of drainage. For this reason, plots should be measured no more frequently than every third, or possibly even every fifth year, if long term measurements are contemplated. Also, because of the inherent difficulties in identifying desiccated peat mosses and sterile sedges *in situ*, it is better to treat these as species groups for analysis, rather than trying to separate all species present.

A number of species readily invaded the spoil piles along the ditches. However, the time lag between their arrival on the spoil piles and their appearance in the plots indicates that it is difficult for new species to invade undisturbed vegetation (Revel *et al.* 1984; Strong 1994). *Epilobium* and composite seeds, with their tufts of hair, are readily dispersed long distances by the wind and these species are ideally suited to colonization of new areas. Plants already on site can take quicker advantage of changes in site conditions than those species which have to invade from outside. Annuals initially are the most responsive, but they are ultimately replaced by the more persistent perennials. Replacement of one species by another can lag several years behind the disappearance.

In general, within the first five years following drainage, the majority of changes occurring in the ground vegetation are negative, in terms of reduced plant cover and vigour. Increase in cover of opportunistic species already on site, or invasion of the site by "weedy" species is the first positive cover change to be noted.

Ground vegetation reflects microenvironmental conditions. Microhabitat differences can be as important as drainage effects in altering the composition of the vegetation. Under the current ditching regime the site would appear to be "overdrained." Exposure of the plots to the drying influence of the sun is as important a factor as distance from a ditch in determining the degree of change in the vegetation.

Concerns were expressed initially that drainage of the site would increase the amount of shrub competition to tree growth. The small change in shrub cover in the ground vegetation composition permanent sample plots over the period of measurement indicates that this is not yet occurring. Shrubs like willows will most probably first appear in the disturbed areas (cleared lines and ditched/ spoil areas).

Thinning and fertilization of black spruce at Goose River

An earlier report by Mugasha *et al.* (1991) on this experiment found the black spruce had responded in current year needle mass, N, P and K concentrations and contents of current year needles. This suggests that the dbh and height growth increments observed in six growing seasons started to occur perhaps as early as in the first growing season. The results showed significant height and dbh, and calculated basal area and total volume growth increments due to thinning and fertilization treatments, particularly N and N-containing fertilizers. This indicated N is limiting black spruce growth on the drained swamp, confirming the earlier finding by Mugasha *et al.* (1991) that P and K were not limiting growth. Our measurements of tree heights and dbh, and the subsequent calculations of basal areas and total volume five years later further confirmed the initial responses reported by Mugasha *et al.* (1991). We speculate that perhaps we could have applied N at a higher rate than 200 kg ha^{-1} to obtain even better growth responses. Phosphororus tended to have an insignificant, slightly depressive effect on black spruce growth variables, particularly on thinned plots.

The significantly greater height increment due to thinning in our study suggests that the spacing of 2.5 m by 2.5 m to 1600 trees ha^{-1} removed much of the competition from the smaller trees. Height growth increments in the thinned plots we observed so far will likely continue for several years. Burns *et al.* (1996) found the response to spacing in black spruce was still detectable after 20 years and attributed this to the slower growth rate associated with this species.

Black spruce basal area growth responded significantly to both thinning and fertilization treatments in our study on a drained swamp. Weetman (1971) reported similar results and Weetman (1975) indicated that the response occurred after one year with N treatment, and to thinning after seven years. After 15 years the response to N had mostly disappeared although the responses to thinning were largely on-going (Weetman *et al.* 1980). As mentioned earlier for this study, black spruce responses to treatment occurred very quickly on the swamp. Although the diameter growth increments are greater in the thinned treatment for both fertilized and unfertilized plots, six growing seasons is not enough time for the basal area ha^{-1} in the thinned treatment to outstrip that in the unthinned treatment. We presume the growth responses we found in our study will be sustained for more than 10 years after treatment.

Van Nostrand (1979) indicated that the volume growth responses to N-containing fertilizers was greater for dominant and co-dominant trees. We speculate that in our study, the volume growth increments in the fertilized plots in the unthinned treatment occurred mostly in the dominants and co-dominant trees. Morrison (1991), on the other hand, indicated the poor or inconsistent response to fertilizer treatments similar to ours he found on black spruce growing on lowland, and also observed by others in other studies, suggested fertilizer-site interaction. Our study found blocking to be significant for total volume (p = 0.0171) which we attributed to the variable depths to the underlying mineral soil of this shallow peatland.

The black spruce growth responses to fertilizer and thinning treatments we observed in six growing seasons of treatment indicate that drainage should be supplemented with these two silviculture interventions if growth is to be enhanced during the first few years after drainage. Sundström (1992) found that after 5 years, black spruce on drained and fertilized plots had significantly greater diameter growth than trees on drained, unfertilized plots, the same general trend we found in our study. Studies in which there were no silvicultural interventions, by Dang and Lieffers (1989) on 33- to 107-year-old black spruce, and by Sundström and Jeglum (1992) indicated that black spruce does not respond with increased growth during the first six years following drainage. Sundström and Jeglum (1992) detected a trend toward growth decline in the first three years after drainage, and greater growth than on the undrained sites during the following two years.

Natural stands of black spruce growing on Alberta peatlands are not inventoried because even the best old stands are low uncommercial (merchantable volume < 50 m^3 ha^{-1}). The data from this study show that total volume growth increment per tree was increased about 3.5 times in 6 growing seasons simply by thinning. Even larger increments are obtained by fertilizing with N or N-containing fertilizers. This suggests that trees in thinned stands, especially when a N-containing fertilizer is applied as well, will attain commercial size earlier than trees in unthinned stands. From the initial growth response data of our study, we anticipate the rotation age of black spruce could be comparable to that of white spruce, lodgepole pine or black spruce growing on upland sites in

Alberta, thus some natural black spruce stands that otherwise would never become merchantable, could be 40 to 60 years after treatment.

Combining fertilization and thinning as added silvicultural options to drainage of peatlands to enhance black spruce growth could be an expensive operation compared with the current forestry operations in Alberta where, for unmanaged natural stands, costs have been harvesting expenditures only. Once the amount of growth improvement has been ascertained, the financial feasibility of managing peatlands for merchantable wood production, taking into account any environmental concerns, needs to be determined. The successful and profitable application of drainage, thinning and fertilization to enhance wood production on peatlands is best exemplified in Finland where these treatments are the foundation of a profitable and highly successful forest industry.

Ditch-mounding experiments at Goose River

The purpose of ditch-mounding in forest regeneration operations is to provide an environment that enhances the survival and growth of tree seedlings on naturally occurring wet sites, and on sites made wet as a result of forest harvesting. Benefits from mounding include more favorable soil moisture and soil temperatures that promote seedling growth while reducing competition from grass, willow and other water-loving plants.

The preliminary results from the Goose River ditch-mounding experiments indicate that, except where competition was unduly heavy, the five tree seedling species planted on the mounds showed satisfactory survival rates in six seasons after planting. In one replicate of one experiment, tamarack survival was only 13% on the flat but 100% on the mounds. Also in one experiment, black spruce survival on the flat was the same as black spruce planted on the mounds indicating that this species tolerated competition in early growth.

Overall, the height and root collar diameter growth of the larches was about two to three times that of the spruce species. Lodgepole pine seedlings planted on the mounds showed vigorous growth comparable to that of the two larch species. Further analyses of the ditch-mounding data are planned in which the effects of animal browsing, dieback, competition and infection by pathogens on tree seedling survival and growth will be examined.

RECOMMENDATIONS

1. Forest drainage studies carried out on treed peatlands in Alberta's boreal forest and elsewhere indicate that growth responses are likely to occur on shallow peat (< 0.75 m), with ditch spacing of about 40-50 m, and in young trees (about 60 years). In future operational forest drainage, site factors, stand age, and appropriate ditch spacings must be carefully considered during the site selection process.

2. Construction procedures simpler than the ones adopted in this research study could be used in future operational forest drainage projects. The operational (topographic surveys, ditch line layout and clearing for the ditch networks, and ditch construction) phases of this research were more elaborate than we would consider necessary for a normal commercial forest drainage operation, where we expect costs per hectare would be much lower. A ditch spacing wider than 50 m (e.g., 60

m) will reduce operational costs without unduly impacting the beneficial effect of drainage on tree growth. Future forest drainage operations should be limited to 20-40 hectares and patterned after those commonly found on privately owned small forests in Finland, and as we observed on privately owned small woodlots on some Quebec farms. In Alberta, candidate drainage areas would include the low areas in large stands where tree growth has been limited by too much water, and where a few ditches up to 100 m apart, or a small network of ditches, could direct water to even lower areas (not necessarily water bodies). Drainage networks covering large areas (> 50 ha) are not being recommended at this stage.

3. The ditch networks at Goose River, McLennan and Wolf Creek remain intact up to 10 years after ditching, however, they should be checked every two years to ensure that the drained condition is preserved. Alberta Land and Forest Service has several operational drainage projects in the north. The projects should be checked every 2 or 3 years for beavers dams and other obstructions causing water backup in the ditches.

4. The tree growth permanent sample plots at the three experimental areas should continue to be measured once every five years to determine wood production rates until the year 2012, 25 years after drainage was implemented on these sites. The next measurements of the Goose River, McLennan and Wolf Creek plots are due in 2001, 2002 and 2001, respectively. The wind firmness of trees, particularly older trees, in the plots should be checked over time, especially in areas where the peat is deep.

5. If possible, the ground vegetation composition permanent sample plots should continue to be measured periodically by a qualified botanist to determine the effects of forest drainage on vegetation over the long term.

6. In future establishment of ground vegetation composition permanent sample plots where variations in microhabitat and their influence on ground vegetation change are to be recorded, consideration should be given to the use of plots larger than those used in this study, to sample vegetation. A greater proportion of the control area should be surveyed as well.

7. Research has repeatedly shown that tree growth on peatlands can be considerably enhanced when drainage is supplemented with the application of nitrogen-containing fertilizers. Such fertilizers should be used in conjunction with ditching in future operational peatland drainage projects.

8. Larix species respond favorably to drainage much better than do *Picea* species. The good larch response suggests that more research should be done to find ways of utilizing *Larix* species.

9. When the experimental areas or similarly drained areas are harvested in the future, the effects of timber harvesting on such areas on groundwater table levels and ground vegetation composition should be investigated, and appropriate site preparation and tree planting methods (e.g., ditch mounding and planting on mounds) adopted for the harvested sites to ensure the areas are properly reforested.

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APPENDIX

APPENDIX I. Economic Evaluation of Peatland Drainage

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NORTHERN FORESTRY CENTRE

FORESTRY CANADA

1996

ABSTRACT

Successful drainage of peatlands in Finland has led to the consideration of similar drainage projects in Alberta. To determine the profitability of drainage, a benefit-cost analysis of drainage operations is performed, taking into account changes in discount rates, Net Merchantable Volumes, rotation ages, and stumpage values. The results of this study show drainage activities in Alberta peatlands to be profitable only for high wood values and high wood volumes.

INTRODUCTION

Concern had been expressed by Alberta forest managers that the productive forest land base in Alberta is decreasing as more forest land is withdrawn for non-forestry uses (Hillman *et al.* 1990). In response to this concern, unproductive stands of black spruce (*Picea mariana*) on peatlands are among the areas that have been under investigation as possible sources of new wood. Draining the excess water from these sites could improve Mean Annual Increment (MAI) and increase Net Merchantable Volume (NMV) on unproductive black spruce stands. Black spruce is important to the pulp industry in Alberta because of its long fibers which add strength to paper products. An increase in NMV on sites close to pulp mills could increase the supply of easy accessible and therefore low-cost pulpwood. Reports from Finland indicated that peatlands could be successfully and economically drained with profit resulting from increased wood yields on these sites (Heikurainen 1982; Paavilainen and Tiihonen 1983). This information prompted Alberta foresters to consider the possibility of peatland drainage as a means of providing an economic source of new wood.

Toward this end, in 1985, the Canadian Forest Service (CFS) and the Alberta Forest Service, now Alberta Land and Forest Service (ALFS), initiated the Wetland Drainage and Improvement for Forestry Program under the Canada-Alberta Forest Resource Development Agreement (FRDA). The goals of the program included: "... to develop cost-effective and environmentally sound forest drainage technology appropriate for the boreal forest and to meet the following objectives:

1. to develop optimal silvicultural regimes for increasing the growth of commercial tree species on forested wetlands with lowered water tables, and
2. to assess the effects of drainage on soils, local hydrology, ground vegetation, and tree growth." (Hillman *et al.* 1990)

In Alberta, there are nearly 13 million hectares of peatlands, which comprise about 11 percent of the peatlands in Canada (Tarnocai 1984). Of this area, about four million hectares are considered suitable for drainage and conversion to productive forest (Hillman 1987). Peat is an organic soil which has developed as a consequence of incomplete decomposition of wetland vegetation under high moisture and deficient oxygen conditions. On these wetland areas, tree growth is diminished due to the surplus of water in the rooting zone. Saturated soils bind nutrients that would be available only in the presence of oxygen, thereby inhibiting tree root development and consequently tree growth. Compared with upland sites, the tree growth rates in natural peatlands are generally low (Payandeh 1973a; Makitalo 1985). Assuming sufficient and balanced nutrients, these trees should reach merchantable size if the excess water is removed from the site, allowing the water table to be controlled at a more beneficial level and leaving a better aerated rooting zone (Personal communication, Antti Makitalo, Utilization and Valuation Forester, ALFS 1992).

Research projects have already been undertaken to explore the technical feasibility of draining peatlands and optimal methods for doing so. In 1972, Payandeh found that "...reports concerning these experiments deal almost exclusively with their physical aspects, (such as) drainage area, drainage system development, methods used for ditching, and limited observations of the effect of drainage on growth improvement" (Payandeh 1973a, p. 399) A literature review revealed that physical observations still comprise the bulk of the research in the area of peatland drainage. However, there is a recognized need for analysis to examine whether drainage is economically feasible. This paper will examine data from three study areas and compare drainage costs with discounted revenues from future harvests of timber from these areas. Since growth data are not yet available for these sites, a scenario approach will be taken to determine the conditions under which peatland drainage would be economically profitable, and make suggestions for the direction of future research on draining wetlands for the production of merchantable timber.

PROJECT DESCRIPTION

The intent of the Wetland Drainage and Improvement for Forestry Program was to determine the effects of drainage on tree growth, ground vegetation, soils, peat, and local hydrology. In the summer of 1985, three forested wetland sites were investigated and selected as experimental drainage sites, at Goose River, McLennan, and Wolf Creek. (Fig.1, page 3 in main text). Drainage systems were established at these locations in 1986 and 1987, and data were collected from both drained and undrained areas on the sites.

Initial data on drainage operations, tree growth, vegetation impacts, and stream water quality were gathered and the findings compiled in the report by G. Hillman, J. Johnson and S. Takyi (1990). At that time, the drainage systems had been in place for five years and the water table had been lowered. The ground vegetation cover had changed and drainage had had little effect on stream water quality. There had been no appreciable growth at the time the measurements were taken, however it was noted that a six to ten year period is usually required for growth to resume after the shock of drainage.

According to recent studies (Stanek 1977; Wang *et al.* 1985; Lieffers and Rothwell 1987b; Woons 1988; and Dang 1988), peatland drainage can result in dramatic increases in MAI for black spruce. With unproductive stands, it is apparent that some form of drainage is necessary to increase the productivity of peatlands so that the trees reach commercial size. But are the benefits of increased productivity worth the cost of drainage? While forest drainage has been shown to be a financially and economically feasible investment in Finland, it is uncertain whether the same is true for Alberta.

If drainage is to take place as a silvicultural treatment, there should be an economic rationale for the undertaking. The benefits associated with drainage must be at least equal to the cost of lowering the water table. For this type of operation, direct costs include: topographical surveys, ditch network layout, line clearing, ditch excavation and maintenance. Other costs to consider are the costs of controlling undesirable species, as well as indirect costs such as loss of ground vegetation and possible effects on water quality. The net impact on wildlife and wildlife habitat may be positive or negative. Some wildlife take advantage of the increased food supply (deciduous species) and improved shelter (black spruce). Other benefits expected to accrue from drainage include increased site index, additional areas producing commercial-sized trees, increased wood production, and a shorter rotation.

Ideally, projects cost should be compared with the discounted Net Present Value (NPV) of the future benefits. However, growth data for black spruce on drained peatland areas are limited. Until the trees on the permanent sample plots have grown, it is not possible to produce actual growth curves. As a result, a different approach is needed. This part of the economic analysis will identify the costs incurred, and the volume that would therefore be necessary for the project to break even. This paper will then try to identify the outcomes of several possible rates of growth, rotation age, and timber value scenarios, find the "break-even point" for benefits and costs, and attempt to predict the likelihood of making a profit through drainage projects.

BENEFIT/COST ANALYSIS

The analysis in this paper is based on actual cost from peatland drainage projects and will not take into account secondary costs such as impact on wildlife and wildlands, loss of carbon sinks, and other social and environmental costs. Figures for the costs of drainage were obtained from Alberta Land and Forest Service project reports and from ALFS Timber Management Branch cost figures. Projected revenues from drained stands were most difficult to determine. Discussion with silviculturalists and forest mensurationists revealed that little information is available concerning growth of black spruce on organic soils in drained peatland areas. Given this lack of knowledge about peatland soils in Alberta, this analysis will be conducted under a number of assumptions. We assume that the only problem with the wetland site is a surplus of water. Should the water level be lowered, the soil nutrient content and proportion of nutrients would be comparable to a mineral soil site. Scenarios will be evaluated assuming that drainage of these sites would take the stands from an "unproductive" state to "fair", "medium", and "good" classifications. The growth figures used in this analysis are from representative black spruce stands from the Alberta Phase 3 Forest Inventory. Due to the lack of growth data for black spruce on drained peatlands in Alberta, a scenario approach will be used to calculate net present (timber) benefits for various net merchantable volumes at rotation age, timber value per hectare (revenues less costs), rotation age, and discount rate possibilities. From these calculations, a range of values for the site ($ ha^{-1}) will be generated for various interest rates (Tables 1-3). The values in these tables represent the NPV of the existing crop at maturity and an infinite series of future crops. The forest manager will be able to estimate the probability of each scenario's occurrence, according to his/her knowledge of existing sites. Net Present Costs (NPC) of drainage can be compared with these tables to predict the profitability of drainage projects.

The values in the following tables are derived from formulas for site (or soil expectation) value:

$$S(A) = V * NMV \qquad (1)$$

$$V_s = \frac{S(A)}{(1+i)^n} + \frac{\dfrac{S(A)}{(1+i)^A - 1}}{(1+i)^n} \qquad (2)$$

S(A) - Stumpage ($ ha^{-1})
V - Final product revenue m^{-3} harvested, less harvest and manufacturing cost
NMV - Net Merchantable Volume (at rotation age) (m^3 ha^{-1})
Vs - Site Value (or soil expectation value) ($ ha^{-1})
i - discount rate (%)
n - number of years until the current stand is ready to harvest
A - rotation age for future stands (years)

Table 1: SITE VALUE FOR STANDS OF VARYING VOLUMES, VALUES, AND AGES ($ ha $^{-1}$)
(discount rate = 4%)

ROTATION AGE = 170 years, first harvest in 70 years (fair site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE ($ m^{-3})	75	100	125	150
1	4.82	6.43	8.04	9.65
5	24.11	32.15	40.19	48.23
10	48.23	64.3	80.38	96.45
15	72.34	96.45	120.56	144.68
20	96.45	128.6	160.75	192.9

ROTATION AGE = 150 years, first harvest in 50 years (medium site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE ($ m^{-3})	75	100	125	150
1	10.58	14.11	17.64	21.17
5	52.91	70.55	88.19	105.83
10	105.83	141.11	176.38	211.66
15	158.74	211.66	264.57	317.49
20	211.66	282.21	352.76	423.32

ROTATION AGE = 100 years, first harvest in 30 years (good site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE ($ m^{-3})	75	100	125	150
1	23.59	31.45	39.32	47.18
5	117.96	157.27	196.59	235.91
10	235.91	314.55	393.18	471.82
15	353.87	471.82	589.78	707.73
20	471.82	629.09	786.37	943.64

Table 2: SITE VALUE FOR STANDS OF VARYING VOLUMES, VALUES, AND AGES (\$ ha^{-1})
(discount rate = 6%)

ROTATION AGE = 170 years, first harvest in 70 years (fair site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE (\$ m^{-3})	75	100	125	150
1	1.27	1.69	2.12	2.54
5	6.35	8.46	10.58	12.7
10	12.7	16.93	21.16	25.39
15	19.04	25.39	31.74	38.09
20	25.39	33.86	42.32	50.78

ROTATION AGE- 150 years, first harvest in 50 years (medium site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE (\$ m^{-3})	75	100	125	150
1	4.07	5.43	6.79	8.14
5	20.36	27.15	33.94	40.72
10	40.72	54.3	67.87	81.45
15	61.08	81.45	101.81	122.17
20	81.45	108.59	135.74	162.89

ROTATION AGE = 100 years, first harvest in 30 years (good site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE (\$ m^{-3})	75	100	125	150
1	13.1	17.46	21.83	26.19
5	65.48	87.31	109.14	130.97
10	130.97	174.62	218.28	261.94
15	196.45	261.94	327.42	392.91
20	261.94	349.25	436.56	523.87

Table 3: SITE VALUE FOR STANDS OF VARYING VOLUMES, VALUES, AND AGES ($ ha $^{-1}$)
(discount rate = 8%)

ROTATION AGE = 170 years, first harvest in 70 years (fair site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE ($ m^{-3})	75	100	125	150
1	0.34	0.46	0.57	0.69
5	1.72	2.29	2.86	3.43
10	3.43	4.57	5.72	6.86
15	5.15	6.86	8.58	10.29
20	6.86	9.15	11.44	13.72

ROTATION AGE = 150 years, first harvest in 50 years (medium site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE ($ m^{-3})	75	100	125	150
1	1.6	2.13	2.67	3.2
5	8	10.66	13.33	15.99
10	15.99	21.32	26.65	31.98
15	23.99	31.98	39.98	47.97
20	31.98	42.64	53.3	63.96

ROTATION AGE = 100 years, first harvest in 50 years (good site):

	NET MERCHANTABLE VOLUME (m^3 ha^{-1})			
VALUE ($ m^{-3})	75	100	125	150
1	7.46	9.94	12.43	14.91
5	37.28	49.71	62.14	74.57
10	74.57	99.42	124.28	149.13
15	111.85	149.13	186.42	223.7
20	149.13	198.85	248.56	298.27

The cost figures associated with the experimental drainage sites at Goose River, McLennan and Wolf Creek do not accurately reflect the cost of "real" drainage operations. In discussions with ALFS, Timber Management Branch personnel it was indicated that there were other recent drainage projects which may have more realistic costs associated with them (Personal communication, Todd Nash and Antti Makitalo, ALFS, Timber Management Branch). One such project was established at Shaw Creek, near Slave Lake, Alberta. Following are the data recorded for the Shaw Creek drainage project (Personal communication, Darby Paver, Forester II - Silviculture, Slave Lake Forest).

COSTS	TOTAL	\$ HA^{-1}
Surveying area, topographic maps	\$ 19 400	\$ 35
Cutting lines for ditching	39 062	70
Ditching	111 378	199
Helicopter - viewing for contract bids, etc.	3 000	5
Professional time -design, overall supervision, etc.	3 000	5
To date:	\$ 175 840	\$ 314

AREA = 560 ha

These numbers are probably more useful for projecting the profitability of peatland drainage. Companies would bid for contracts to survey and drain, thereby reflecting a more realistic level of costs. Normal growth of black spruce on drained areas could then be estimated and the value of the increased wood volume approximated. Discounted to present value and compared with costs, a fairly accurate picture of profitability would emerge.

DISCUSSION

Using the cost per hectare for the Shaw Creek site, approximately \$314 ha^{-1}, the following conditions would be necessary for the project to make a profit or break even:

4% discount rate -- (medium site) NMV = 150 m^3 ha^{-1} and Value = \$15 m^{-3} or
NMV = 125 or 150 m^3 ha^{-1} and Value = \$20 m^{-3}
--(good site) NMV = 100, 125, 150 m^3 ha^{-1}, Value = \$10 m^{-3} or
NMV = 75, 100, 125, 150 m^3 ha^{-1}, Value = \$15 or \$20 m^{-3}
6% discount rate --(good site) NMV = 125, 150, m^3 ha^{-1} and Value = \$15 m^{-3} or
NMV = 100, 125, or 150 m^3 ha^{-1} and Value = \$20 m^{-3}

If these conditions are not present, the Net Present Value of drainage will be negative.

If we know the nutritive composition of the site in question, the site classification (fair, medium, or good), and the probabilities of various Net Merchantable Volumes (NMV) and Stumpage Values, the Net Present Value can then be estimated. Based on the values estimated, decisions can be made about the approximate profitability of producing new wood on these sites by drainage activities. NPV in other silvicultural treatments is rarely positive. Therefore, the low Benefit/Cost ratios derived in this analysis may not necessarily mean that peatland drainage is economically unfeasible. Compared with other operations, drainage may still be the least costly or most effective way of increasing the supply of pulpwood. Drainage decisions would be, in part, based on comparisons with alternate productivity increasing treatments on other sites. Drainage may show a higher NPV than other ways of obtaining new wood by different silvicultural methods and then may be selected as the least-cost, or most appropriate method for the needs of the forest company.

CONCLUSIONS AND RECOMMENDATION

After comparing the costs with discounted future benefit scenarios, it has been shown that drainage of wetland areas has little potential to be profitable. In addition to the low Net Present Values, the assumption that the site would have the same nutrient composition as saturated mineral soils seriously affects predictions of drainage profitability. This assumption may not be unrealistic, as evinced by drainage of agricultural wetlands resulting in increased productive land. However, tree growth on organic soils in Alberta is difficult or impossible to predict due to the lack of documented tree growth data for such areas in the province.

None of the areas reveal very high site values after drainage. On a good site with a discount rate of four percent, the NPV is just positive at a NMV of 100 m^3 ha^{-1} and a Value of \$10 m^{-3}. This is the lowest combination of values that shows a positive NPV. While a Value of \$10 m^{-3} is obtainable when markets are healthy, a NMV of 100 m^3 ha^{-1} is a fairly high estimate for a drained peatland site to achieve. If the lowest combination is on the high end of probable estimates of outcomes, the certainty of predicting a profitable outcome at this level diminishes. If the cost numbers are higher the probability of yield and net revenue values high enough to break even becomes even smaller. It is unlikely that most peatland areas would meet these minimum requirements for profitability.

If the decision was made to drain peatland stands of black spruce in response to a demand for new wood, certain sites should be selected before others in order to increase the NPV of the operation. Rotation age and Net Merchantable Volume can be influenced by selecting better sites --preferably "good" sites which would yield the best possible results. Net revenues could be affected by selecting stands or areas to be drained that are close to pulp mills. This strategy would increase the value portion of the Site Value formula. In addition, if the demand for pulpwood in Alberta increases to the point that peatland black spruce stands may be needed, the price per cubic metre will increase. This increase will also affect the value of the Site Value formula, increasing the Net Present Value of draining these sites.

To conclude, at this time it does not appear that drainage of peatland stands of black spruce is profitable. Circumstances may alter, however, making the investment more profitable under higher values for wood or a better understanding of the productive capabilities of drained peatland soils. When compared to the Net Present Values of other silvicultural treatments, it may be that drainage is a comparatively more profitable method of obtaining new wood. Forest managers may prefer to drain wetlands rather than conduct other treatments. These circumstances would affect the reaction of foresters to the outcome of this economic analysis.

Subsequent studies could examine the effects of combinations of treatments, such as fertilizing, thinning, and draining. Environmental and secondary effects of drainage, including effect on nontimber values, wildlife and wildlands, intrinsic value placed on the existence of peatland habitats, and the value of peatland as carbon sinks have not been addressed within this analysis. It is possible that the addition of this type of benefits and/or costs would affect the conclusions. Subsequent studies should address these issues and their association with peatland drainage.

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