GENECOLOGY OF JACK PINE
IN
NORTH CENTRAL ONTARIO

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for the degree of
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A CAUTION TO THE READER

This Master of Science in Forestry thesis has been through a formal process of review and comment by several members of the Faculty of Forestry at Lakehead University. As well, it has been reviewed by an external examiner. It is made available for loan by the Faculty to advance the practice of professional and scientific forestry.

The reader should be aware that any opinions expressed in this thesis are those of the student, and do not necessarily reflect the opinions of either the supervisor, the Faculty, or Lakehead University.

MAJOR ADVISOR'S COMMENTS

ABSTRACT

van Niejenhuis, A. 1995. Genecology of jack pine in north central Ontario. 193 pp. Advisor: Dr. W.H. Parker

Key Words: adaptation, genetic variation, phenology, *Pinus banksiana,* provenance test, seed source, seed origin, seed transfer.

To understand the pattern of adaptive variation of jack pine in north central Ontario better, short-term provenance tests were established. Seed was collected from 64 sites to the east and west of Lake Nipigon and grown in three common garden tests, including a greenhouse trial at Lakehead University, a farm field trial at Lakehead University, and a field trial near Raith. Eight growth variables were measured (two annual heights from the greenhouse trial and three annual heights from each of the field trials), fourteen phenological variables were determined (elongation initiation and cessation dates, elongation duration and needle flush date at each trial; and foliage purpling at the greenhouse and Lakehead University field trials), and survival at the Raith trial was examined. Variation expressed among seed sources was significant for all growth variables and many phenological variables. Multiple regressions were run for 18 of the 23 variables against climatic variables interpolated using geographic information systems techniques from weather data of 56 weather stations, as well as spatial, soil, and vegetative variables which described the environment at seed origin resulting in coefficients of determination as high as 0.57. Principal components analysis (PCA) was used to summarize the variables examined, with 33 and 21 per cent of the variation accounted for by the first and second component respectively. Multiple regressions were run on the factor scores produced from PCA against the variables describing environment at seed origin. These regression models had coefficients of determination of 0.323 and 0.429 for the first and second factor scores respectively. The pattern of variation in this portion of the range as displayed in the mapping of the predicted factor scores was clinal with numerous irregularities. July and average annual temperatures, heating degree days, frost dates, and soil and vegetation variables were included in the predictive models. The contrast displayed in height performance between seedlings from the southwestern portion of the range and those from the north shore of Lake Superior reflects trends seen in a previous study of cone and needle characteristics.

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INTRODUCTION

Trees are long-living, immobile organisms that must be adapted to their environments, and in temperate climates the environment tends to be variable in space and time. To avoid disaster and take advantage of the environmental adaptations of forest tree species, some understanding of the adaptive variation is necessary when artificial regeneration involving seed transfer and tree improvement strategies is being implemented.

Jack pine, *Pinus banksiana* Lamb., is a leading forest crop species in Ontario. Artificial regeneration of jack pine comprised at least 25% of the planting stock produced in Ontario (OMNR 1991), and cone collection of jack pine far exceeds that of any other conifer species in Ontario (OMNR 1991).

Jack pine studies have determined a significant level of genetic variability in the species (Rudolph and Yeatman 1982), thus it is a promising candidate for tree improvement (Magnussen and Yeatman 1987a). In Ontario, jack pine is listed as a top priority species, together with black spruce (*Picea mariana* (Mill.) B.S.P.). These two species combined receive 70% of the Ontario tree improvement effort (OMNR 1987a).

Adaptive variation in jack pine has been examined by range-wide provenance tests (Schantz-Hansen and Jenson 1952; Schoenike *et al.* 1959; Schoenike and Brown 1963; Yeatman 1966, Hyun 1979) and more intensively in some portions of the range (Williams and Beers 1959;

Jenson *et al.* 1960; Batzer 1961, 1962). Characteristics that showed variation related to seed origin included survival, height growth, bark thickness, tree form, winter injury, cold hardiness, and pest resistance.

Three silvicultural tools: artificial regeneration by planting and by seeding, and tree improvement, all involve movement of seed over some distance greater than that which occurs naturally in a population. Strong and Grigal (1987) found that site productivity may be increased by selecting a seed source best suited to the site. Differences in performance relate, in part, to the adaptations of seed sources to differing environmental conditions.

Throughout Ontario, seed collection zones and breeding zones have been established (OMNR 1987b). A seed collection zone is defined as a geographic area which confines the collection and movement of seed. Breeding zones are used by tree improvement programs to define the geographic area from which plus trees are selected for production seed orchards and future breeding.

The best performance of artificially regenerated jack pine sites will come from seed of superior genetic stock well adapted to the planting site. Rehfeldt and Wykoff (1981) have developed intensive short-term provenance testing procedures to examine the genecology of western species. This thesis presents similar examination of the genecology of jack pine north of Lake Superior to determine the adaptive variability and the risk of seed movement. Schoenike (1962) determined that the area to the north and west of Lake Superior may be interpreted as a major gene pool for jack pine. Within this area jack pine occurs on the greatest variety of sites and attains its best form.

This study examines jack pine seed sources in the former North

Central Region of the Ontario Ministry of Natural Resources (OMNR), which is located to the north and west of Lake Superior. Intensive provenance tests have been established to reveal genotypic variation among these sources. Phenotypic variation of these seed sources was examined by Maley (1990).

The first objective of this study is to determine patterns of genotypic variation in survival; growth initiation, cessation, and duration; annual growth increment; and fall colour of jack pine grown in common gardens tests. The second objective is then to relate the genotypic variation to the environmental variation in terms of location, elevation, vegetative association, and soil type of seed source, thereby determining the degree of adaptive variation. Comparison of the patterns of variation displayed in this study to previous work will lead to a better understanding of the species' adaptive variation in this portion of the range.

The intensive provenance tests of this study will eventually form an improved wealth of information upon which silviculturalists and forest tree breeders may draw in making seed transfer decisions and refining breeding zones for jack pine in this area. The environmental variables that correspond to the observed patterns of genetic variation can then be incorporated into seed transfer guidelines and breeding zone development. The data will be included in the data base used in experimental methods of seed zone development using Geographic Information Systems (GIS) techniques.

LITERATURE REVIEW

JACK PINE

Classification and Nomenclature

The subdivisions of the genus *Pinus* have been examined by Little and Critchfield (1969). In this system jack pine, *Pinus banksiana* Lamb., is classified into the subsection *Contortae* Little & Critchfield, of the section *Pinus*, of the subgenus *Pinus*, the hard pines.

The subsection *Contortae* is characterized by two short (2 - 8 cm) leaves in a fascicle. Two or more whorls of branches may occur on spring-shoots (multinodal). Cones are 3 - 8 cm long, and often serotinous (Little and Critchfield 1969).

Jack pine is the smallest of the three pines found in northwestern Ontario. It averages 19 m in height, but may be as tall as 30 m (Sims *et al* 1990). The paired needles are divergent, and are straight or slightly curved, stiff and twisted, and sharply pointed (Hosie 1979).

Species Range

The range of jack pine is almost entirely within the borders of Canada; the range extends outside Canada only around the Great Lakes and in the northeastern United States (Fig. 1). The western end of the

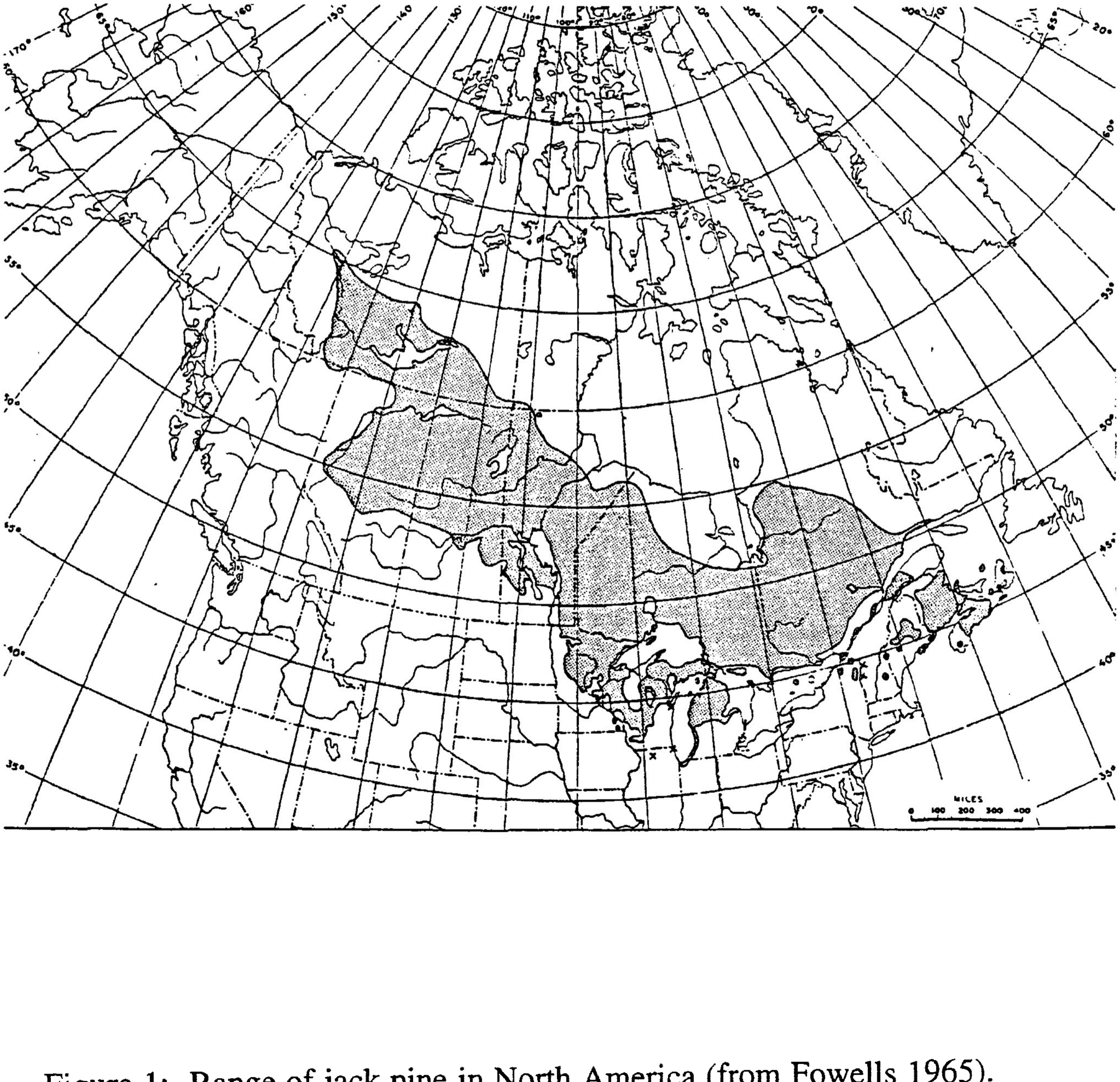


Figure 1: Range of jack pine in North America (from Fowells 1965).

range begins in the Northwest Territories, in the Mackenzie River basin, at about the 65th parallel (Critchfield and Little 1966). Its range covers much of the Boreal Forest Region (Rowe 1972) in the prairie provinces and Ontario. The range extends south into Minnesota, Wisconsin, Michigan and Indiana, where it reaches its southern limit (Schoenike 1976), and into the Great Lakes - St. Lawrence Forest Region (Rowe 1972) in Ontario. In Quebec its range covers most of the area southwest of Labrador and north of the St. Lawrence River. South of the St. Lawrence River, jack pine is found on the Gaspe Peninsula, and in New Brunswick, Nova Scotia, and Prince Edward Island as a member of the Acadian Forest Region (Rowe 1972), as well as in Maine, Vermont, New Hampshire, and New York (Schoenike 1976). A few disjunct populations occur at the eastern end of the range (Critchfield and Little 1966). In the Lake States a number of isolated natural stands have been delineated by Rudolf and Schoenike (1963) together with plantations outside the natural range of jack pine.

The immediate area surrounding Lake Superior in Minnesota does not all fall into the natural range of jack pine. Schoenike (1961) reports its absence along the northwest shore of Lake Superior from Duluth to Hovland in a band measuring 8 to 32 km wide. This region was covered by former Lake Duluth and is characterized by heavy clay soils inhabited by spruce-fir forest types. As well, between Lake Superior and Lake Michigan there are some extensive areas into which jack pine has not ranged naturally, except for a few isolated stands (Rudolf and Schoenike 1963).

Jack pine grows in diverse habitats throughout its range in North America. Mean annual temperatures vary from -5° C to 9.5° C, and mean minimum temperatures from -20° C to -45° C or lower. Precipitation varies between 13 to 58 cm during the 60 to 170 day growing season. Droughts may last for periods of thirty days or more (Rudolf 1958).

Soils commonly associated with pure jack pine stands have a large component of sand in them, though other soils including loam, shallow soils over granite or limestone, and organic soils may also be colonized by this species (Rudolph and Yeatman 1982). In the North Central Region of Ontario, jack pine stands occur on dry to fresh coarse or fine sands, or coarse loam soils (Sims *et al* 1990).

Jack pine is the dominant species or a codominant in 8 recognized Forest Ecosystem Classification (FEC) Vegetation Types in Northwestern Ontario (Sims *et al* 1989). Common overstory associates include black spruce (*Picea mariana* (Mill.) B.S.P.), trembling aspen (*Populus tremuloides* Michx.), and white birch (*Betula papyrifera* Marsh.). Less frequent overstory associates are Balsam fir (*Abies balsamea* (L.) Mill.) and white spruce (*P. glauca* (Moench) A. Voss). Often jack pine stands have a predominantly ericaceous shrub layer together with feathermoss ground cover (Sims *et al* 1990).

Migrational History

Because of its extensive range across North America, jack pine has undergone differentiation and natural selection in response to various environments. The genetic variation within the species can be better understood in light of its origin, evolution, and migrational history (Rudolph and Yeatman 1982).

During the most recent glaciation, the Wisconsin stage, the entire present-day range of jack pine, except for the 'Driftless Area' to the southwest of the Great Lakes, was covered by an ice sheet (Flint 1957). The location of the glacial refugia may help explain observed geographic variation in the species. Yeatman (1967) made an extensive literature review of the migratory history of jack pine. He concluded that the geological and paleobotanical evidence supports a single extensive refugium centered on the Appalachian Highlands of eastern North America. However, Delcourt and Delcourt (1987) use fossil pollen data to support primary population centres in the Atlantic Coastal Plain and the central and eastern Gulf Coastal Plain at the time of maximum glaciation, 20,000 BP. By 12,000 BP, the advancement of pines following the retreating glaciers had brought the population centre into southern New England. At this time, pines comprised more than 40 per cent of the forests of the Appalachian Highlands and the eastern Great Lakes region, however, in these studies jack pine pollen was not distinguished from other pines having similar pollen (Delcourt and Delcourt 1987).

Jack pine may have reached the area to the north and west of Lake Superior by diverging below the Great Lakes and converging once again in northwestern Ontario, or by coming around the east side of the Great Lakes in a single path, and spreading south from northwestern Ontario. Ice retreat from the Wisconsin glaciation began about 18,000 BP, but readvancement occurred twice after that time. During the second readvancement, the Valders period (10,500 BP), jack pine was established around the lower shores of the Great Lakes, and after the Valders period, ice retreat was rapid, allowing jack pine to migrate into much of its present range (Schoenike 1976). According to Rudolph and Yeatman (1982) a steep cline or partial discontinuity in cone characteristics in

Minnesota may have resulted from divergent migrational routes converging in this area. Schoenike (1976) reports a critical region of intersecting clines to the northwest of Lake Superior, based on his examination of a number of morphological traits.

Genetic Variation

Provenance Tests

Provenance studies have been established to determine the genetic variation in jack pine. Growth measured in these tests has shown a clinal pattern that follows the environmental gradients of day-length, and temperature and length of the growing season, except where growing seasons and low temperatures are limiting (i.e., frost pockets). Generally, though many exceptions have been reported, 'local' provenances are among the best performers in common garden field trials (Rudolph and Yeatman 1982).

In a study of jack pine progeny produced by inter- and intra-provenance breeding, Magnussen and Yeatman (1989) noted that duration of growth correlated positively with growing degree days at seed origin. Growing degree days at seed origin also correlated with dry weights and heights measured in a range wide study including 9 provenances (Giertych and Farrar 1962). Though seed origin was significant, enough variation is seen in jack pine to allow for breeding of greater height growth without adverse effect on periodicity (Magnussen and Yeatman 1989).

Variability in stem form and branch angle of jack pine have been measured through provenance tests. A great deal of variability is noted, though much of the poor form may be attributed to spacing (Magnussen and Yeatman 1987a). Spacing trials are recommended as part of the breeding program for jack pine (Magnussen and Yeatman 1987b).

Cold hardiness and winter injury are a major concern in the consideration of moving seed throughout the range of jack pine. Schantz-Hansen and Jensen (1952) reported variation among jack pine seed sources in their ability to withstand winter injury. Seed from sources with long, warm growing seasons should not be moved to areas with severe winters and short growing seasons. Yeatman (1976) also concluded that winter hardiness is the critical factor in the survival and growth of planted jack pine in the boreal forest. The risk of winter injury and the increased susceptibility to disease as a result of increased stress may be expected from moving provenances north. Potential for early frost injury increases for trees displaying lammas growth. Lammas shoots occur more frequently when seed from southern sources is planted on northern sites (Rudolph and Yeatman 1982).

Seed origin does not appear to influence the tolerance of jack pine to spring frost damage; rather, growth initiation in the spring depends primarily on temperature of planting site. Cold hardiness and associated physiological and morphological characteristics such as cessation of growth and date of bud set are provenance-related (Rudolph and Yeatman 1982).

Foliage colour change in jack pine in the fall of the year is provenance-related. The most intense purple and the greatest percentage of colour change were seen in northern provenances in a Wisconsin study (Rudolph 1980).

Jack pine provenance tests have revealed evidence of genetic variation in the susceptibility or resistance to certain diseases (Hunt and Van Sickle 1984) and insects (Batzer 1961, 1962). Jack pine showed differential rates of infection in a range wide provenance test to sweet-fern rust, *Cronartium comptoniae* Arth. Seedlings from sources outside the range of one of the alternate hosts, sweet-fern, *Comptonia peregrina* (L) Coult. showed high incidence of infection (Hunt and Van Sickle 1984). Similarly, nonlocal seed sources showed greater damage from white pine weevil, *Pissodes strobi* (Peck), than did local sources in seed source studies in northern Minnesota (Batzer 1962).

Isozyme Analyses

A limited amount of research has been published concerning genetic variation in jack pine as revealed by isozyme studies. Cheliak *et al* (1985) reported on the mating system of the species, describing it as a mixed mating model, with 88 per cent outcrossing. They noted that jack pine appeared to be genetically depauperate relative to other conifers, particularly lodgepole pine, *P. contorta* Dougl. Dancik and Yeh (1983) reported that jack pine displayed 46 per cent polymorphic loci, compared to 51.4 per cent in lodgepole pine. Likewise, jack pine displayed 11.5 per cent heterozygous loci, compared to 18.4 per cent in lodgepole pine.

Genetic homogeneity displayed in jack pine results from large populations, a predominantly outcrossing mating system, and potential long-distance gene flow both by pollen and seed dispersal (Ross and Hawkins 1986). Ross and Hawkins (1986) used their own studies together with the results of Hamrick *et al* (1981), Dancik and Yeh (1983) and Cheliak *et al* (1985) to calculate weighted means of 43.5 per cent polymorphic loci and 13.0 per cent heterozygous loci. These values are considerably lower than the 67.7 per cent polymorphic loci and 20.7 per cent heterozygous loci on average reported for conifer species (Hamrick *et al* 1981). Ross and Hawkins (1986) found that 2 per cent of the genetic variation was due to origin among three populations separated by distances of 10 km in southern Manitoba.

Variation in Natural Stands

Natural populations of jack pine have been studied extensively by Schoenike (1962, 1976). He examined patterns of geographic variation for thirty-three traits of crown, bark, wood, foliage, and cones of mature jack pine trees in 90 populations across the range of the species. Maps showing the pattern of phenotypic variation were drawn for each of the traits.

From this work Schoenike (1976) concluded that all traits examined showed significant differences between populations. The amount of variation associated with geographic location averaged 37 per cent. Individual traits showed both continuous and irregular variation patterns across the range of the species. The most distinct clinal pattern was noted in an area from the Lake States to the Northwest.

Schoenike (1962, 1976) examined correlations of individual traits with four environmental factors: latitude, elevation, mean annual temperature, and mean annual precipitation. Most cases revealed low to moderate correlations. Higher correlations were seen for precipitation and bark thickness, precipitation and needle length, latitude and needle volume, latitude and stomatal counts, temperature and cone serotiny, and temperature and cone knobbiness.

Portions of the range of jack pine have been examined to determine variation in phenotypes. Studies of jack pine cone serotiny showed a clear differentiation between populations in northeastern Minnesota and those in southern and southwestern Minnesota (Rudolph *et al* 1957)

Maley (1990) examined eighteen cone and forty-two needle characters of 64 jack pine populations in northwestern Ontario. In this study, the portion of variance associated with seed source ranged from 1.62 per cent for cone apophysis depth to 18.85 per cent for seed length. As noted previously by Schoenike (1976) a steep east-west cline was reported at a longitude of 88° 15' in the Nipigon area (Maley 1990). Patterns of variation seen in the phenotypes of cones and needles appear to be a result of adaptation to local environments as described by 12 climatic variables, three spatial variables, and 13 ecological variables (Maley and Parker 1993).

Breeding Zones and Seed Collection Zones

Throughout the commercial range of jack pine in Ontario, breeding zones and seed collection zones have been established. In this context, breeding zones refer to discrete portions of the range in which plus tree selections are made for breeding programs in seed orchards; seed collection zones are more limited geographic areas that confine the collection and transfer of seed (OMNR 1987b).

To date little information about the genetic variation of jack pine in the former North Central Region of Ontario, the area surrounding Lake Nipigon and extending along the north shore of Lake Superior, has been available; thus climatic variation was used as the basis of the breeding zones. Climate variables examined included growing degree days over 6° C, mean start and end of growing season, mean dates of last spring and first fall frosts, and latitude (= photoperiod effect) (OMNR 1987b). The five resulting climatic zones were fitted to the existing administrative boundaries, with regard to both Hill's Forest Site Regions (1961) and Rowe's Forest Sections (1972). These five breeding zones are subject to change, based upon the findings of genetic variation studies for each of the species.

Within each of the breeding zones, three seed collection zones have been delineated. These seed collection zones reflect administrative units including Forest Management Agreement (FMA) and Crown Management Unit boundaries (OMNR 1987b). These geographic areas are the same for all species, as they are not based upon variation between populations of any given species.

In other parts of the range of jack pine similar geographic boundaries have been described to limit the movement of jack pine seed. In Manitoba, criteria used to establish seed zone boundaries included latitude, elevation, provenance variation, temperatures, frost dates, frost-free days, precipitation, and soils (Segaran 1979). Eight provenance seed zones (seed collection zones in Ontario) specific to jack pine have been recommended for the productive forests of Manitoba.

Development of seed collection and breeding zones based upon geographic variation displayed in a species will lead to utilizing the best possible seed collections to regenerate forest stands. An understanding of this variation will enable tree breeders to maintain the adaptations of trees to the environment (OMNR 1987a).

Phenology

Geographical variation in the timing of shoot growth is expected within a species if the environment varies in different parts of the range of the species (Kozlowski 1971). Provenance test results of numerous species generally show that southern or lower elevation seed sources extend their shoots more rapidly, for a longer time, but break bud later than those of more northerly or higher elevation seed sources. Southern and lower elevation seed sources are generally less susceptible, therefore, to spring frost, but more susceptible to winter injury (Kozlowski 1971).

Shoot elongation is the result of two phenomena: cell division and cell expansion. The centres of cell division responsible for leader elongation include the shoot apices where new stem units and potential needles are produced, and the subapical meristems which determine the elongation of the internode at each stem unit (Cannell *et al* 1976). Buds in pine contain fully preformed shoots. Internode elongation is rapid during the initial flushing, when little leaf expansion occurs, giving rise to the "candles". Internode elongation occurs over a shorter time than does leaf elongation (Kozlowski 1971).

Different types of late season shoot growth have been defined, all of which may be seen on jack pine: Lammas growth is described as the early elongation and development of all or a portion of a bud that would otherwise be resting (Lanner 1976). Rudolph (1964) describes it as 'borrowing' from the spring shoot, and while usually only a small portion of the base of the winter bud elongates, he reports lammas growth of up to 15 cm in jack pine. Second-year and older conifers generally show a decreasing portion of the stem units formed during a given growing season also elongating in that season, and an increasing portion remains in an overwintering bud (Cannell *et al* 1976). Proleptic shoots are those that develop from the current year laterals at the base of the terminal bud (Kozlowski 1971). Sylleptic shoots occur when axillary buds of an elongating shoot extend coincidentally with the normal, early shoot. Long buds are those terminal buds that elongate but do not flush until the following year; on pines these shoots have no externally visible needles (Kozlowski 1971).

Magnussen and Yeatmans' (1989) work which examined populations and population hybrids from 9 provenances in Ontario, Quebec, Michigan, and Wisconsin in common garden tests found tree heights from southern sources were taller than those of northern sources. They described the shoot extension activities in jack pine as a brief and abrupt flush, followed by five or six weeks of active elongation, and two to five weeks of gradual cessation. The abrupt shoot elongation initiation is attributed to the thermal time required, and the rapid rise in growing degree days throughout much of the range of jack pine. Elongation cessation appeared to be related to photoperiod thresholds (Magnussen and Yeatman 1989).

GENECOLOGICAL STUDIES

Methodology Development

Coniferous species occurring along the western coast of the North American continent show pronounced genecological variation in many cases (Rehfeldt 1984). Not only do western species have to adapt to climatic changes resulting from changes in latitude and longitude, but steep gradients in climatic conditions are encountered with changes in elevation.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.)Franco) shows broad ecological amplitude in the northern Rocky Mountains and has been studied extensively in terms of adaptive variation. The history of genecological studies in this species will be presented here to illustrate the development of the methodology.

Rehfeldt (1974 a, b) examined populations of Douglas-fir from various elevational environments in a portion of its range in northern Idaho, Washington, and Montana. Cones from seven trees in each of 24 populations were collected, and their seed was extracted (Rehfeldt 1974b). These 24 populations were selected such that 4 populations represented each of six habitats in which Douglas-fir occurs in the northern Rocky Mountains, south of the Canadian border. Geographic and elevational distances were maximized between populations representing any one habitat. Common garden tests consisting of two replicates of randomized complete block design were established, and seedling heights were measured after two years.

From this study (Rehfeldt 1974b), analysis of variance tests indicated that 15.4 per cent of the variance was attributed to habitat types. Varying selection pressures related to habitat cause deviation in seedling performance.

Twelve Douglas-fir populations from northern Idaho were compared to determine local differentiation patterns (Rehfeldt 1974a). Populations were selected from two drainages, from both north and south aspects, at three elevations. Seedlings were grown in two contrasting environments.

Data collected included tree height after one and two years, date of terminal bud burst (day that developing leaves were first visible), date of terminal bud set (day that immature terminal bud was first visible), and total number of lateral branches. Multivariate canonical analyses were used to reduce the number of dimensions and account for highly correlated variables, together with univariate analysis. Univariate analysis indicated differentiation between drainages, but generally the patterns of variation appeared to be non-systematic and not easily related to landscape features associated with natural selection.

Another Douglas-fir study representing 56 populations from northern Idaho, Oregon, Montana and Washington was established (Rehfeldt 1979a). Two randomized complete blocks including 21 seedlings from each population were established in early May under conditions of natural daylength and optimal soil moisture levels in a greenhouse until late June when watering was stopped. Data collected included date of germination and the number of periods (1 or 2 -- those that set a terminal bud and then resumed growth) of epicotyl elongation. Analysis of variance was made on the proportion of seedlings that exhibited one period of epicotyl elongation. Multiple regression techniques related the mean performance of populations to geographic and ecological conditions of the seed source including latitude, longitude, elevation, and habitat types. Regression statistics of the percentage of seedlings displaying one period of epicotyl elongation showed that habitat types accounted for 23 per cent of the variation among populations.

Rehfeldt studied the genecology of Douglas-fir in western Montana (1982b), and in central Idaho(1983b) using similar cone collections and common garden tests. Phenological characters examined in these studies included: a) bud burst -- the day after April 1 by which 50 per cent of the seedlings of a seed source had burst terminal buds; b) bud set -- the week by which 50 per cent of the seedlings of any seed source had set terminal buds; c) two flushes -- the proportion of seedlings of any given seed source that flushed after setting a terminal bud; d) height; e) growth rate -- deviation from the regression of 3-year heights on 2-year heights to correct for any previous environmental effects; f) spring frost injury -- the proportion of seedlings of any given seed source damaged by spring frost; g) fall frost injury -- the proportion of any given seed source damaged by fall frost; and h) winter injury -- the proportion of seedlings displaying mechanical injury attributable to snow.

A number of independent variables were included in regression models to determine the patterns of variation displayed in the measured characters. Independent variables that were related to the population differentiation patterns included latitude, longitude, habitat type, and elevation, among others (Rehfeldt 1982b, 1983b). As well, analysis of variance tests were used to determine the amount of population differentiation.

The analyses of these trials illustrated intense physiologic relations between Douglas-fir populations and their environments (Rehfeldt 1982b, 1983b). From this work Rehfeldt (1983 c, d) determined seed transfer guidelines for this species in these regions. Contours independent of elevation were drawn on local maps. Contour intervals were scaled to half of the geographic distance at which differentiation between populations could be detected at the 80 per cent level. Also, elevational restraints reflecting the differences detected at the 80 per cent level were suggested. Seed transfer limits were suggested at ± 1 contour and ± 330 to 800 feet (100 m to 243 m), dependent upon portion of the range.

A number of genecological studies in the northwestern United States involving other commercially important species including western white pine (*P. monticola* Dougl.) (Rehfeldt 1979b, Rehfeldt *et al* 1984), lodgepole pine (Rehfeldt 1980a, Rehfeldt and Wykoff 1981, Rehfeldt 1983a, 1985a, b, c, 1986d, 1987a) Ponderosa pine (*P. ponderosa* Laws.) (Rehfeldt and Cox 1975, Rehfeldt 1980c, d, 1986b, c, 1987b), western larch (*Larix occidentalis* Nutt.) (Rehfeldt 1982a) and coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) (Campbell 1979, 1986, Campbell and Franklin 1981) have been published. Characters that displayed adaptive variation in these studies included many of those listed for Douglas-fir (Rehfeldt 1982b, 1983b). Other characters that have been used in genecological studies include the following: a) percentage of trees by provenance with straight stems (Rehfeldt 1980c); b) leaf length, c) percentage of trees by provenance producing multiple whorls, d) percentage of trees by provenance not exhibiting lammas growth, proleptic shoots, or long buds (Rehfeldt 1983a); e) percentage of seedlings by provenance displaying purple leaves, f) percentage of seedlings by provenance displaying grey (rather than brown-green) stems in the current year's growth (Rehfeldt 1985b); g) length of longest branch, h) total number of branches, i) crown width (Rehfeldt 1985c); j) xeric height reduction (the difference between the height of a seedling grown under xeric conditions and the mean height of its provenance grown under mesic conditions), k) drought mortality as a percentage of trees by provenance (Rehfeldt 1986c); l) disease and insect infestations (Rehfeldt 1987a); m) duration of shoot elongation (Rehfeldt and Wykoff 1981, Rehfeldt 1987b); n) germination rate, o) cotyledon number, p) stem diameter, and q) dry weight (Campbell 1979, Campbell and Franklin 1981).

As well, freezing tolerance of a number of species was tested (Rehfeldt 1980a, b, 1982b, 1983a, 1985a, 1986a, b, d, 1989). Many of the traits measured in various trials were highly correlated, thus a small number of variables could be used to describe the patterns of genetic variation in a species (Rehfeldt 1987b).

The methodology to determine date of shoot elongation initiation, cessation, and duration in days was reported by Rehfeldt and Wykoff (1981). Shoot elongation of seedlings can be expressed as the proportion (Y) of the total growth increment achieved at time X by the following logistic equation:

$$Y = \frac{1}{1 + be^{(-rX)}} .$$

This function does not pass through the origin and is symmetrical at the point of 50 per cent of total shoot elongation, but Rehfeldt and Wykoff (1981) found that growth curves for lodgepole pine were generally asymmetrical and passed through the origin. Thus they added a hyperbolic time term to the logistic equation to improve its expression of shoot elongation of individual seedlings:

$$Y = \frac{1}{1 + be^{(-rX+c/X)}} .$$

In order to use linear regression techniques to calculate the variables describing shoot elongation periodicity, the equation was expressed as follows:

$$\ln\left(\frac{1}{Y} - 1\right) = \ln(b) - rX + c\left(\frac{1}{X}\right).$$

This approach allowed Rehfeldt and Wykoff (1981) to calculate of the following variables:

1. initiation of growth -- the day on which 2 mm of growth had occurred;
2. cessation of growth -- the day on which all but 5 mm of growth had occurred;
3. duration of growth -- the number of days between initiation and cessation; and
4. growth rate -- elongation per day during the period of maximum elongation.

Adaptive Variation in Lodgepole Pine

The most closely related species to jack pine is lodgepole pine (Little and Critchfield 1969). Adaptive variation has been examined extensively in lodgepole pine throughout much of its range in the northwestern United States (Rehfeldt 1980a, Rehfeldt and Wykoff 1981, Rehfeldt 1983a, 1985a, b, c, 1986d, 1987a).

In cold acclimation tests in the northern Rocky Mountains, Rehfeldt (1980a) found that elevation and geographic region of seed origin accounted for 78 per cent of the variance in hardiness. Shoot elongation negatively correlated to altitude whereas periodicity in shoot elongation linked weakly to geographic region (Rehfeldt and Wykoff 1981).

Results from studies of the adaptation of lodgepole pine have been used to estimate the limits and the consequences of seed transfer in northern Idaho (Rehfeldt 1983a), in central Idaho (Rehfeldt 1985a), in Utah (Rehfeldt 1985b), in eastern Idaho and Wyoming (Rehfeldt 1986d), and in a more extensive study, in the inland northwest (Rehfeldt 1987a). In northern Idaho, elevation accounted for as much as 86 per cent of the variation displayed among populations (Rehfeldt 1983a). Strong positive correlations between variables reflecting growth potential and freezing injury indicate adaptation to the growing season conditions at seed origin.

In studies of periodicity in shoot elongation, Rehfeldt and Wykoff (1981) saw little variation in relation to geographic region of seed origin. Elevation correlated negatively to the amount, rate, duration and cessation of elongation (Rehfeldt and Wykoff 1981; Rehfeldt 1985a, b, 1986d). Initiation of growth appeared to be controlled by temperature at the planting site, rather than by seed origin (Rehfeldt and Wykoff 1981).

Rehfeldt (1984) describes lodgepole pine as a 'specialist'; that is, it displays steep adaptive clines that are negative for growth potential and positive for cold hardiness. This contrasts with species classified as 'generalists' whose individual genotypes are adapted to a broad range of environmental conditions.

Adaptive Variation in Eastern Conifers

Though environmental gradients are not as severe over such short distances in the eastern portion of the North American continent, environments throughout the range of many species are heterogeneous. Eastern species also display patterns of adaptive variation.

Joyce (1988) has examined the adaptive variation in cold hardiness of eastern larch (*Larix laricina* [DuRoi] K. Koch) primarily in northern

Ontario. He detected substantial variation among 66 eastern larch populations in the degree of freezing injury sustained in laboratory freezing tests of current year shoots. Latitude of seed sources was the best predictor of cold hardiness, with elevation and region of origin refining the model. This work suggests that to avoid maladaptation of planted stock, seed source control must be maintained such that the physiology of the planting stock is synchronized with the climate at planting site.

Genetic variation in growth and sylleptic branching among and within populations of eastern larch from northern Ontario were examined by Farmer *et al* (1993). The study area extended from Fort Severn, on the Hudson Bay coast, to North Bay. Half of the genetic variance in height was attributable to seed source. A north-south trend of increasing height was observed among populations grown in common garden tests, suggesting a photoperiodic response. The latitudinal variation in height was correlated to mean daily temperature and precipitation.

Studies of genetic variation in black spruce in Newfoundland revealed that a significant portion of the variance was attributable to seed origin. Khalil (1975) examined 29 provenances, and determined that 22 per cent of the variance seen in bud burst date, 10 per cent of the variance seen in bud set date, 32 per cent of the variance seen in juvenile heights, and 17 per cent of the variance seen in root collar diameter were attributable to seed source.

Morgenstern (1969a) examined 9 populations of black spruce ranging from southern Ontario to northern Alberta. Soil moisture at seed origin influenced the variation seen in a number of variables, including germination and early development, survival under drought, growth under intermittent drought, phenology , and growth. Geographic origin and temperature at origin also influenced juvenile performance of the seedlings. Morgenstern (1969b) reported variances attributable to provenances ranging from 1.0 per cent for 10 month height to 90 per cent for second year growth cessation. Growth cessation was significantly related to day length at seed origin, and temperature at seed origin.

Studies of black spruce from 75 sources in northwestern Ontario (Parker *et al* 1994) revealed that the portion of variance attributable to seed origin ranged from 0 per cent for elongation start date to 24.5 per cent for first year height. Patterns of differentiation corresponded to climatic conditions at seed origin which varied geographically in terms of latitude and longitude, but also were strongly influenced by the proximity of the seed origin to Lake Superior and Lake Nipigon.

Flushing date of white spruce and red spruce (*Picea rubens* Sarg.) was examined to determine susceptibility to spring frosts and spruce budworm (*Choristoneura fumiferana* [Clemens]) damage (Blum 1988). Variability illustrated that selection could be made on the basis of flushing date to improve the survival of these two spruces in areas susceptible to spruce budworm epidemics and late spring frosts.

Frost hardiness tests were used by Davradou (1991) to examine the pattern of variation in jack pine in northern Ontario. Significant differences were detected between the provenances tested, however, inconsistencies among the trials led to inconclusive results.

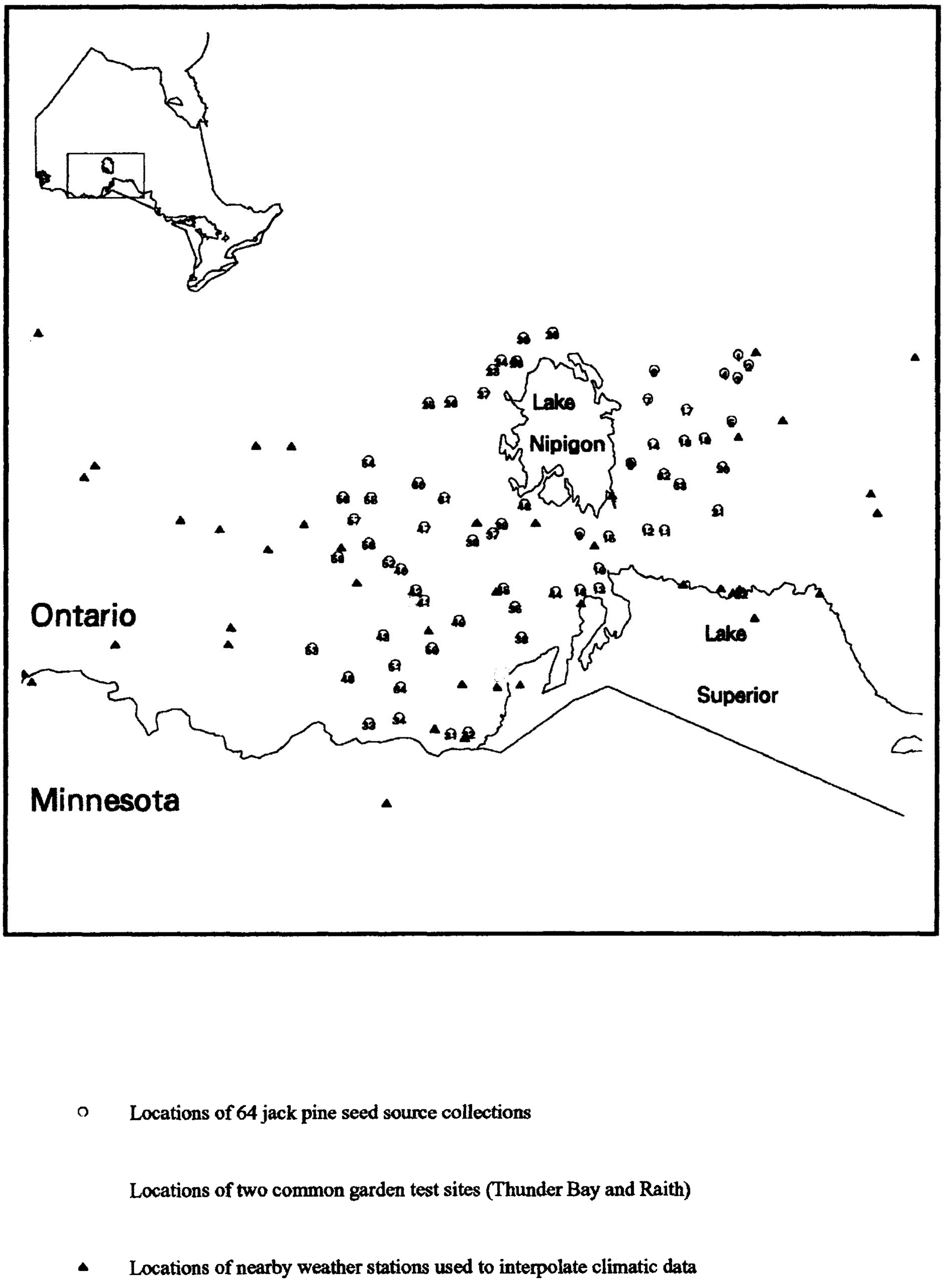
MATERIALS AND METHODS

SEED COLLECTION SITES AND PROCEDURES

Study Area Selection, Location, and Description

The study area is located in the province of Ontario, to the north and west of Lake Superior, both to the east and west of Lake Nipigon (Figure 2). All populations from which seed was collected are located between the longitudes of 86°47' and 90°54'. To the east of Lake Nipigon, the most southerly collection was near to Terrace Bay at a latitude of 48°47'. The Canada-United States border was the southern boundary of collection sites to the west of Lake Nipigon; the most southerly collection here was at a latitude of 48°05'. The northern-most collection site lies north of Lake Nipigon at 50°27'.

This portion of the range of jack pine was selected for a number of reasons. Maley (1990) began the studies of these sites. She lists the break in the pattern of clinal variation as reported by others (Yeatman 1966; Schoenike 1962; Schoenike 1976) as one of two major selection criteria. The second was the development of the Forest Ecosystem Classification (FEC) program within this area by the Ontario Ministry of Natural Resources (OMNR). Ecological data from the FEC program are a portion



○ Locations of 64 jack pine seed source collections

Locations of two common garden test sites (Thunder Bay and Raith)

▲ Locations of nearby weather stations used to interpolate climatic data

Figure 2: Location of the study area in Ontario (inset) and location of the 64 seed sources and two trial sites within the study area.

of the data base used in these studies. Also, Klein (1987 pers. comm.) indicated differences in growth and form between jack pine growing to the east and west of Lake Nipigon that were of interest to the OMNR.

The portion of the study area located to the west of Lake Superior, along the Canada - United States border, lies within the Great Lakes - St. Lawrence Forest Region, in the Quetico Forest Section. Rowe (1972) suggests that recent logging and fire behaviour have favoured the boreal species, including jack pine, in this area; though eastern white pine and red pine are still dominant in some portions. This area is described in the Thunder Bay Plains Ecoregion (Wickware and Rubec 1989) as having warm, dry summers and cold, snowy winters, with mean annual temperatures varying from 2.3° C near Lake Superior to 1.1° C further inland. Average annual precipitation ranges from 724 mm inland to 711 mm along the shore of Lake Superior. Jack pine sites include the dry, rapidly drained soils.

The larger portion of the study area, lying north of Lake Superior and to the east and west of Lake Nipigon, lies within the Boreal Forest Region (Rowe 1972) and encompasses three Ecoregions. The Nipigon Plains Ecoregion (Wickware and Rubec 1989) extends north and west of Thunder Bay and surrounds Lake Nipigon's shores to the north, south, and west. The climate is similar but cooler than that of the Thunder Bay Plains Ecoregion, with mean annual temperatures ranging from -1.1° C to 0.6° C. Total annual precipitation is 738 mm in the northern portion, and 798 mm in the western portion. In this region, jack pine occurs on well drained sites, on bedrock knobs, and on shallow sites.

The Superior Highlands Ecoregion lies along the north shore of Lake Superior (Wickware and Rubec 1989). Its climate is characterized by warm summers and long, cold winters. Total annual precipitation in this ecoregion exceeds that of any other ecoregion in this study, averaging 840 mm along the shore and 860 mm inland. Jack pine is found on dry, well-drained sites and on bedrock knobs throughout this ecoregion.

Portions of the Lake St. Joseph Plains Ecoregion (Wickware and Rubec 1989) within the study area include the area to the east of Lake Nipigon and to the north and west of the Nipigon Plains Ecoregion. Mean daily temperatures vary from -0.9° C in the west to -0.4° C in the east. Average total annual precipitation ranges from 760 mm in the west to 700 mm in the east. Well-drained sites, coarse textured soils, and shallow soil bedrock sites are inhabited by jack pine stands here.

Stand Selection and Seed Collection

Throughout the study area 64 stands were selected from which cones were collected throughout the summer of 1987. Stands were selected on the basis of their composition: jack pine was either the dominant or a co-dominant species. As well, stands had to be accessible by road, of natural fire origin, and were favoured if previously sampled by the FEC program (Maley 1990). The minimum distance between any two selected stands was approximately 8 km. The locations of the 64 collection sites are illustrated in Figure 1. Locations, elevations, and FEC types of the collection sites are presented in Appendix 1.

At each site, ten trees were selected from which to collect cones. Selection criteria are described by Maley (1990) and include criteria as follows: cone-bearing, free of obvious disease and insect damage, and easily felled. Selected trees were separated by at least 20 m to reduce the probability of selecting sibs. A minimum of ten cones was collected from each tree and stored in labeled paper bags. (Maley 1990).

SEEDLING CULTURE AND OUTPLANTING

Extraction of seed from cones was completed by the 19th of October, 1987. Seed from the ten trees at each collection site was bulked.

Stock to be outplanted was grown in commercial seedling containers. Spencer Lemaire Ferdinands (40 ml) were filled with a 1:1 mix (by volume) of peat and vermiculite, and soaked under misting irrigation for one night. Seeding was completed by the 27th of October, and the Ferdinand racks were set under intermittent misting irrigation in the greenhouse. First germinants appeared on the 30th of October, after which empty cells were filled with transplants germinated on petrie dishes until mid-November. Throughout the winter the seedlings were watered three times a week and fertilized at 50 ppm N with 11-41-8 soluble seedling starter fertilizer once a week to promote root growth. The fertilization was changed to 100 ppm N using 20-8-20 soluble seedling special fertilizer to encourage vegetative growth from the last week in January to the end of March.

In March of 1988, the seedlings were transplanted to Spencer Lemaire Tinus (500 ml) containers using a premixed commercial medium containing peat, vermiculite, limestone, and a wetting agent (Sunshine Special #3). From the first of April, fertilization occurred weekly at a rate of 65 ppm N using 8-20-30 soluble seedling finisher fertilizer to harden off the seedling. Watering and fertilization was continued in the greenhouse until the end of May. Throughout this culturing period 18 hours of light was provided, but this was reduced during the last two weeks of May. On the 30th of May the seedlings were moved outside into a shade house, where 30 per cent shading was provided using a shade cloth. The removal of artificial light and placement of the seedlings into a shade house after the risk of frost had passed served to harden off the seedlings and reduce the shock of outplanting.

The field sites for the trials at Raith and Lakehead University were prepared in May. The Raith site, located on a 1 ha cut block within a 75 year old jack pine stand at the Abitibi - Lakehead University Research Forest near Raith (N 48° 54', W 89°57') (Figure 2), was cleared of young jack pine and green alder (*Alnus crispa* (Ait.) Pursh.). The soil at this site was characterized by fine sandy loess deposits over coarser sands and was classified to FEC soil type S1. Vegetation in the surrounding forest was dominated by jack pine, with black spruce in the understory. Classification of this vegetation was to V32.

The Lakehead University (LU) field site, located behind the Physical Plant (N 48°24', W 89°19') (Figure 2) was cleared of red osier dogwood (*Cornus stolonifera* Michx.) and willows (*Salix* spp.). This site was on abandoned farm land. Examination of the soil led to the FEC soil-type classification of S1. As the land had been cleared for farming in the past, V-type could not be confirmed.

Both the LU and Raith areas were sprayed with Roundup™ at approximately 6 l/ha. The LU field site was ploughed in mid-June. Identifying pins were set up to mark the seedlings in each of three blocks at each test site.

Outplanting began at Raith on the 20th of June, 1988, and was completed on the 23rd. At the LU field site, planting began on the 28th of June and was completed on the 6th of July. In each of the three blocks at each site, ten seedlings from each of the 64 seed sources were planted in a completely randomized design at 0.5 m spacing. On the 7th and the 28th of July the LU field trial was irrigated due to a lack of precipitation. Unfortunately, the Raith trial could not be irrigated as no water sources were near. Throughout the summer months the LU field trial was weeded three times.

Six hundred and forty seedlings (ten from each of the 64 seed sites) were maintained at a shade house for the summer of 1988 under the 30 per cent shade cloth. In late September 1988 these were transplanted to three litre pots using the same premixed commercial medium, and arranged in a completely randomized design. The shade cloth was removed from the shade house in October, and snow fence was placed around the shade house to trap snow on the seedlings. At this location the seedlings were overwintered and then moved into the greenhouse in April of 1989.

DATA COLLECTION

Forest Ecosystem Classification (FEC) Data

Site classification of the forest stands from which cones were collected described the ecosystem of each provenance. For sites not previously surveyed, vegetation and soil classification information was collected using the methods outlined by the FEC program (Sims *et al.* 1987). If a survey had previously been done by OMNR personnel, vegetation and soil classification information were made available by the Technology Development Unit in Thunder Bay (Maley 1990). These data were summarized to produce twelve soil and vegetation variables listed in Table 1 (Maley 1990). Each seed source was classified by vegetation type and soil type, as listed in Appendix 1. The values of the twelve soil and vegetation variables for each of the 64 collection sites are included in Appendix 2.

Spatial and Climatic Data

Each seed collection location was further described by its geographic location (longitude, latitude, and elevation) (Appendix 1) and by the average climatic conditions of the last 30 years. Topographic maps were used to determine the spatial information (Maley 1990).

To determine average climatic conditions, data from 46 Canadian weather stations located in and around the study area as well as 10 American weather stations bordering the study area were summarized.

Table 1: Soil and vegetation Forest Ecosystem Classification (FEC) variables (after Maley 1990) determined for each of the 64 seed collection sites.

1. Soil depth (cm)
2. Proportion of conifer in the stand (per cent)
3. Proportion of hardwood in the stand (per cent)
4. Proportion of jack pine in the stand (per cent)
5. Proportion of black spruce in the stand (per cent)
6. Proportion of white spruce in the stand (per cent)
7. Proportion of lichen ground cover (per cent)
8. Proportion of bedrock exposed (per cent)
9. Proportion of feathermoss ground cover (per cent)
10. Proportion of sand in the soil (per cent)
11. Proportion of silt in the soil (per cent)
12. Proportion of clay in the soil (per cent)

Twelve climate variables describing annual and selected monthly mean temperatures, annual precipitation, frost free period, and heating and growing degree days (Table 2) were selected from data collected between 1951 and 1980 (Environment Canada 1982a, 1982b; Gale Research Company 1985a, 1985b) (Appendix 3). From this data, using Geographic Information Systems (GIS) Triangulated Irregular Network (TIN) techniques, interpolated estimates of the twelve climate variables were made for each of the 64 collection sites (Environmental Systems Research Institute 1987) (Appendix 4). Maps of the trends for each of the variables examined are included in Appendix 5.

Seedling Growth Data

Greenhouse Trial

The potted one year old seedlings were removed from the shade house and placed in the Lakehead University greenhouse on April 21, 1989, as they were free of snow and ice at this time. They were arranged in completely random order on two tables in the Main House, where watering occurred twice a day from overhead sprinklers.

Initial measurements of total seedling height and terminal long shoot ('candle') lengths were made on the 26th of April. Daily measures of the candles of this stock were made until May 11, 1989. Subsequent measures were made throughout the summer until the first of August at approximately weekly intervals.

Table 2: Climatic variables (after Maley 1990) from each of 56 weather stations in and around the study area, used in determining adaptive variation in jack pine.

1. July maximum (°C): Mean value of the daily maximum July temperatures.*
2. January minimum (°C): Mean value of the daily minimum January temperatures.*
3. Mean daily (°C): Mean value of the annual mean daily temperatures.*
4. Extreme maximum (°C): Record high temperature**.
5. Extreme minimum (°C): Record low temperatures**.
6. Snow (cm): Mean value of the annual snowfall.*
7. Total precipitation (mm): Mean value of the total annual precipitation.*
8. Heating degree days (°C-days): Mean value of annual heating degree days below 18°C.*
9. Growing degree days (°C-days): Mean value of annual growing degree days above 5°C.*
10. Frost free days (days): Mean value of the number of days between the last spring frost and the first fall frost.*
11. Spring frost (days): Mean value of the number of days after January 1st to the last spring frost.*
12. Fall frost (days): Mean value of the number of days after January 1st to the first fall frost.*

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* Normals are based on 30 years of data ending in 1980, however a number of stations have considerably shorter records, as noted in Appendix 3.

** Record high and low temperatures are based on recorded data of varying numbers of years, sometimes exceeding 30, as indicated in Appendix 3.

Initially, the candles were measured from the base of the current growth to their tips. As the axis elongated, the needles also began to elongate. Until the 20th of May these candles were measured to the tip of the needles but it became apparent that this was a very inconsistent measure. Later measures taken from this stock measure the stem portion of the current growth only.

Needle flushing, or needle emergence from the fascicles, was scored each day that candles were measured. Flushing scores for spruce, used by Nienstaedt and King (1969), were examined but found to be unsuitable for the flushing of jack pine seedlings. A great deal of elongation of the long shoot may occur in jack pine before the needles emerge from the fascicles. Therefore a new scoring system was developed, with scores ranging from 0 to 4 (Table 3). No sign of elongation of either long or short shoots was scored as 0 (Figure 3). Scores of 1, 2, or 3 indicated elongation of the long shoot with needle fascicles distinctly separate for a score of 2, and elongation between needle fascicles evident for a score of 3. A score of 4 indicated needle emergence from the fascicle (Figure 3).

The seedlings of the GH trial were moved out to a shadehouse in late June, and remained in the shadehouse to harden off. Needle colour was scored at weekly intervals through the months of September, October, and the beginning of November until the first snow. Seedlings were classified as being purple if at least half of the current foliage appeared to be purple. For purposes of analysis, percentages of the portion of seedlings of each source that had turned purple by November 9 were calculated.

Table 3: Flushing scores indicating degree of elongation and needle emergence.

0 -- Long shoot bud in the winter condition, more brown than green in appearance with no evident swelling or elongation.
1 -- Long shoot bud beginning to elongate, more green than brown.
2 -- Needle fascicle buds distinctly separate.
3 -- Elongation between fascicle buds evident.
4 -- First needle(s) emerging from fascicle(s) on elongating long shoot.

Figure 3: Sample buds in the winter condition (upper left), in the score 2 condition with needle fascicle buds distinctly separate (upper right), in the score 3 condition with elongation evident between fascicles (lower left), and in the score 4 condition with needles emerging from fascicles (lower right).

Lakehead University and Raith Field Trials

Total initial height of all the seedlings in the LU field trial was recorded on May 2 and May 3, 1989. At this time, flushing had not yet begun. On the 17th of May similar height data were collected at the Raith trial.

Candle lengths and flushing scores were first collected at the LU field trial on the 12th of May and two or three times a week after that until mid-June. Weekly measures were collected from then until mid-August. Final candle lengths and seedling heights were determined in late September.

Similarly, candle lengths and flushing scores were first collected at the Raith field trial on the 19th of May, 1989. Until the end of June these seedlings were measured and scored two to three times a week. Throughout July weekly measures were recorded. Final seedling heights for year two (1989) were determined in late September.

At weekly intervals in the fall of 1989 seedling colour was scored at block 2 of the LU field trial until there was snow on the ground. These scores were translated into percentage of seedlings of each seed source that had turned purple by the 9th of November.

Third year heights of all the seedlings in the three blocks of the LU field trial were measured in October of 1990. Similarly, third year heights were measured in November of 1990 at the Raith field trial.

Phenological Data Derivation

For each jack pine seedling in each trial, estimates of elongation initiation date, elongation cessation date, and duration of elongation in days were made. The candle measurements were entered on Macintosh™ computers using the software package Excel™, and verified. These candle measurements were fitted to a growth equation described by Rehfeldt and Wykoff (1981):

$$Y = \frac{1}{1 + be^{(-rx+c/X)}}$$

or

$$\ln\left(\frac{1}{Y} - 1\right) = \ln(b) - rX + c\left(\frac{1}{X}\right)$$

where Y is the proportion of the total elongation observed by day X, and ln (b), r, and c are regression coefficients. A multiple linear regression algorithm was developed by W. Parker following the methods of Sokal and Rohlf (1981) to calculate the regression coefficients, coefficients of multiple determination (r-squared), and plot the growth curves.

Regression of the elongation data for each seedling allowed estimates for the time of elongation initiation; i.e., the day on which 3 mm of cumulative growth had occurred, and the time of elongation cessation: i.e., the day on which all but 5 mm of the growth had occurred (Rehfeldt and Wykoff 1981). Duration was then calculated as the difference between these two estimated dates.

Initial examination of the fitted curves revealed that many of the seedlings at the LU field trial had two distinctive growth spurts, and the estimates of elongation initiation were poor because the curve fit was being skewed by the second growth spurt (Figure 4). Thus the curve was fitted to the first nine measurements to determine date of elongation initiation and to all the measurements to determine elongation cessation.

The date upon which the candle first scored a 4 (Table 3) marked the needle flushing date, the date that needle leaves had swelled to open their fascicles. This date was translated to the number of days after March 31 for the GH trial, and the number of days after April 30 for the LU and Raith field trials. In some cases, the needles may have flushed as many as two days earlier, as seedlings were not scored daily.

DATA ANALYSIS

Data were transferred to the MicroVAX II™ computer at Lakehead University from the Macintosh™ computers. Here the Statistical Package for the Social Sciences (SPSS-X™) was used for analysis (SPSS Inc. 1988). As well, Systat™ (Wilkinson 1989) was used on the Macintosh™ system.

Univariate Analysis

Mean values and standard deviations were calculated for each of the 64 seed sources for elongation initiation date, elongation cessation date, elongation duration, needle flushing date, and year end heights. The data were screened for homogeneity and normality.

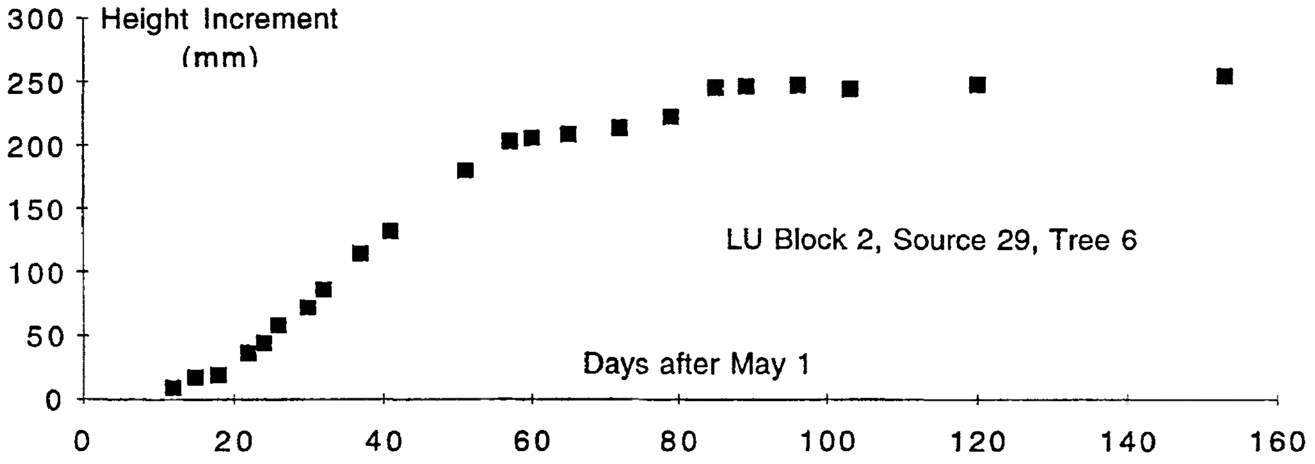

Figure 4: Example of a growth curve showing the discontinuous nature typical of many of the seedlings from the LU field trial.

One-way analysis of variance (ANOVA) tests were used to examine the amount of variation attributable to seed source in each of the trials (intraclass correlations). Two-way ANOVA tests were run to examine the significance of the blocks and the interaction of blocks and seed sources for the field trials.

Simple regression analyses were run for each of the variables (dependent) for which origin was a significant source of variation. The independent variables against which regressions were run included the climatic, spatial, and FEC data to evaluate the patterns of adaptive variation.

Each seedling was classified to a FEC vegetation type, according to the ecosystem at seed origin. Eight different FEC vegetation types were represented by seedlings in each of the trials. Numbers of seed sources classified to each of the eight vegetation types varied from 1 (V-type 25) to 27 (V-type 32) (Table 4). One-way ANOVA tests examined the differences among jack pine seedlings originating from these FEC vegetation types in each of the trials using a weighted mean of treatment means (Steel and Torrie 1980) to handle the imbalance in sample sizes. Multiple range tests (Least Significant Difference - LSD) examined which jack pine seedlings grouped by these vegetation types were significantly different. Standard deviations calculated for these comparisons accounted for the imbalanced design by including the numbers of observations of the two means being compared in the estimate algorithm (Steel and Torrie 1980). Geographic representation of vegetation types throughout the study area was not achieved; thus, these test results may be confounded with seed origin effects.

Table 4: Numbers of seed sources classified to eight Forest Ecosystem Classification vegetation types.

V-Type Number	V-Type Name	Number of Seed Sources
V17	Jack Pine Mixedwood /Shrub Rich	3
V18	Jack Pine Mixedwood /Feathermoss	7
V25	White Spruce - Balsam Fir /Feathermoss	1
V28	Jack Pine /Low Shrub	5
V29	Jack Pine /Ericaceous Shrub /Feathermoss	8
V30	Jack Pine - Black Spruce /Blueberry /Lichen	8
V31	Black Spruce - Jack Pine /Tall Shrub /Feathermoss	5
V32	Jack Pine - Black Spruce /Ericaceous Shrub /Feathermoss	27

Table 5: Numbers of seed sources classified to twelve Forest Ecosystem Classification soil types.

S-Type Number	S-Type Name	Number of Seed Sources
S1	Dry / Coarse Sandy	30
S2	Fresh / Fine Sandy	7
S3	Fresh / Coarse Loamy	3
S4	Fresh / Silty - Silt Loamy	1
S5	Fresh / Fine Loamy	3
S6	Fresh / Clayey	3
SS1	Discontinuous Organic Mat on Bedrock	5
SS2	Extremely Shallow Soil on Bedrock	2
SS3	Very Shallow Soil on Bedrock	2
SS5	Shallow - Moderately Deep / Sandy	4
SS6	Shallow - Moderately Deep / Coarse Loamy	3
SS7	Shallow - Moderately Deep / Silty - Fine Loamy - Clayey	1

Similarily, each seedling was classified to a FEC soil type, according to the ecosystem at seed origin. Twelve different FEC soil types were represented by the seed sources. Numbers of seed sources classified to each of the twelve soil types varied from 1 (S-type S4 and SS7) to 30 (S-type S1) (Table 5). One-way ANOVA tests examined the significance of differences among jack pine seedlings grouped by FEC soil types in each of the trials. Multiple range tests (Least Significant Difference - LSD) were used to determine which seedlings grouped by soil types differed significantly. Geographic representation of all soil types throughout the study area was not achieved; thus once again, these test results may be confounded with seed origin effects.

Relationships between each of the measured variables at each of the trials for which seed source was a significant source of variation, and each of the variables describing seed origin were examined. Simple linear correlations were determined to examine how the patterns of variation related to environment at seed origin.

Multivariate Analysis

The experimental unit for the purpose of multivariate statistics in this study was the seed source (Chatfield and Collins 1980). Mean values were calculated for each seed source in each trial for the phenological and morphological variables, and arcsine per cents were calculated for survival and purpling variables. Twenty-three variables were calculated for each of the 64 seed sources based on the seedlings grown at the three trials. In this manner, height at the end of the 1989 growing season was treated as three variables, one for each trial.

Stepwise backwards elimination multiple linear regression was used to determine whether the variation seen among seed sources based upon growth variables could be explained by the climatic and spatial data. Each variable for which seed source was a significant source of variation in the one-way and two-way ANOVA was regressed with the twelve climatic and twelve soil and vegetation variables, and latitude and elevation. Latitude was included in the regressions as the best estimate of photoperiod. Any variables not significant at the 5 per cent level were removed from the full (saturated) regression model in each step of the backwards elimination procedure until the significance of all remaining variables exceeded the 5 per cent level.

The correlations among the 23 variables were examined. As expected, they were generally high, thus principal components analysis (PCA) was used to transform the original set of variables for which seed source was a significant source of variation into a new set of uncorrelated variables. The first principal component accounted for the maximum variation seen in the original data. Each subsequent component accounted for the maximum amount of variation left after the generation of the previous component (Chatfield and Collins 1980). This new data set of PCA factor scores was used for subsequent regression analysis.

Simple regression analyses were run for each of the factor scores of the significant components (dependent variables) against the climatic, spatial, and FEC data (independent variables). This allowed patterns of variation which correlated with the environment at seed source to be examined.

The factor scores of the significant components were further regressed with the twelve climatic and twelve soils and vegetation variables, and latitude and elevation, using the backwards stepwise multiple linear regression. Once again, any variables not significant at the 5 per cent level were removed from the full (saturated) regression model in each step of the backwards elimination procedure until the significance of all remaining variables exceeded the 5 per cent level. Using these regression models that explain the adaptive variation, new factor scores were predicted for each of the 64 seed sources.

Trend Surface Diagrams

Trend surface diagrams using ARC/INFO (Environmental Systems Research Institute 1987) GIS techniques were generated for each of the variables showing significant differentiation among seed sources (5 per cent level) at each of the trials and for the PCA factor scores generated based on seed source means and per cents. These diagrams make use of isograms to display the trends in variation throughout the study area.

Thematic maps were constructed for the seed sources. The average performance of the seedlings of each seed source or the PCA factor score of each seed source was attributed to that seed source as a value in the third dimension. From these, three dimensional models were produced using the sub-package TIN (Triangulated Irregular Network) of ARC/INFO (Environmental Systems Research Institute 1987).

Interpolation of the point data in the third dimension allows the TIN software to draw contour intervals using isograms.

Similarly, trend surface diagrams were produced for the predicted PCA factor scores of each seed source, based on the models derived from backwards stepwise multiple linear regressions with the climatic, spatial, and FEC data. In this way the adaptive variation was included in the geographic model only. These were compared to the diagrams produced by the actual PCA factor scores.

Peaks and valleys on these trend surface maps indicate the performance of each of the seed sources in the common garden tests. These maps were compared and contrasted with the trend surface diagrams produced by the work of Maley (1990) in this same study area.

RESULTS

UNIVARIATE ANALYSIS

Means and standard deviations of phenological variables (dates of elongation initiation, cessation, duration, needle flush) and growth variables (heights, height increments) were calculated for each of the 64 seed sources in each trial. The means for the greenhouse, LU field, and Raith trials are presented in Appendix six, together with the percentage of seedlings of each seed source displaying fall purpling at the LU field trial and the greenhouse trial, and the percentage survival at the Raith trial. When original data were plotted in histograms, normal distributions were displayed by phenological and growth variables.

Analysis of Variance

Greenhouse Trial

One-way ANOVA tests revealed that seed source was a significant source of variation for three of the six variables: 1988 height, 1989 height increment, and the needle flushing date (Table 6). The portion of the total variance attributable to seed source varies from 0.8 per cent for elongation initiation, a non-significant result, to 24.7 per cent for the 1988 height.

Table 6: Portion of the total variance attributable among and within seed sources.

Variable*	Mean	Standard Deviation	Seed Source (%)	Error (within) (%)
GH-88	95.05 mm	36.75	24.7 **	75.3
GH-89	100.57 mm	32.35	15.4 **	84.6
GH-IN	26.88 (April 27)	1.63	0.8	99.2
GH-CS	81.00 (June 20)	11.16	3.0	97.0
GH-DR	54.12 days	11.25	2.8	97.2
GH-NF	30.39 (May 1)	1.91	15.5 **	84.5
LU-88	101.57 mm	40.69	25.6 **	74.4
LU-89	330.73 mm	104.88	30.0 **	70.0
LU-90	768.08 mm	197.72	19.6 **	80.4
LU-IN	13.25 (May 13)	0.69	5.4 **	94.6
LU-CS	87.80 (July 27)	13.15	4.0 **	96.0
LU-DR	74.56 days	13.20	4.2 **	95.8
LU-NF	27.65 (May 28)	3.58	4.4 **	95.6
R-88	66.11 mm	33.93	13.1 **	86.9
R-89	151.93 mm	76.76	18.4 **	81.6
R-90	279.58 mm	133.88	16.7 **	83.3
R-IN	23.17 (May 24)	5.23	1.4	98.6
R-CS	74.94 (July 14)	11.35	5.3 **	94.7
R-DR	51.76 days	12.53	4.7 **	95.3
R-NF	33.40 (June 3)	6.58	4.6 **	95.4

*

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-IN: Greenhouse Elongation Initiation
GH-CS: Greenhouse Elongation Cessation
GH-DR: Greenhouse Elongation Duration
GH-NF: Greenhouse Needle Flushing
LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing
R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-IN: Raith Elongation Initiation
R-CS: Raith Elongation Cessation
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing

** Significant at the 1 per cent level.

Examination of the seed source means revealed that the seedlings with the greatest elongation in 1989 came from sources 33, 32, and 35 respectively, with elongation ranging from 141.7 mm to 127.44 mm (Table 7). Sources 32 and 33 originated in the southwest portion of the study area, while source 35 originated in the south central portion of the study area, between Thunder Bay and Lake Nipigon. These three seed sources were the earliest to initiate elongation, however elongation cessation for these three sources was variable, with seedlings from source 33 averaging second earliest to cease elongation, and those of source 35 being second last to cease elongation. Flushing dates likewise were variable for these sources, with source 33 being among the latest to flush and source 32 flushing ahead of average.

Sources that showed least elongation included number 20, a source from the eastern boundary of the study area, source 36, which was located immediately south of source 35 and north of Thunder Bay, and source 55, from near the western boundary of the study area. These sources were generally late to initiate elongation and early to cease elongation. The flushing dates for these sources were variable, ranging from April 30 to May 2 (Table 7).

One-way ANOVA tests of the growth and phenological data revealed that seedlings of seed sources grouped by eight FEC vegetation types varied significantly for the same three variables: 1988 height, 1989 height increment, and the needle flushing date (Table 8). Seedlings of type 28 displayed the greatest mean height in 1988 (108.6 mm) and 1989 height increment (117.1 mm) (Figure 5). In both cases seedlings of type 28 differed significantly from those of four other vegetation types. Jack

Table 7: Greenhouse seed source means (ranked).

Rank	Seed Source	GH-88	Seed Source	GH-89	Seed Source	GH-NF
1	15	139.6	33	141.7	13	28.5
2	27	134.3	32	138.9	14	29.0
3	38	133.0	35	127.4	6	29.1
4	33	131.9	14	126.1	30	29.1
5	25	131.8	13	123.4	44	29.1
6	46	131.2	25	123.2	12	29.3
7	60	130.3	48	120.7	26	29.4
8	23	120.4	18	120.4	1	29.5
9	58	120.2	15	120.0	10	29.5
10	57	119.0	34	119.6	22	29.5
11	61	119.0	12	119.2	55	29.6
12	9	112.1	16	119.0	4	29.6
13	50	111.6	9	117.8	23	29.6
14	16	110.8	41	115.9	40	29.6
15	37	110.6	38	115.1	41	29.6
16	2	110.2	5	114.9	18	29.7
17	56	109.9	28	110.3	19	29.7
18	63	108.1	27	108.9	32	29.7
19	29	107.2	30	107.8	5	29.8
20	34	107.0	21	107.6	15	29.8
21	35	106.4	11	107.0	17	29.8
22	18	105.8	58	106.1	28	29.8
23	36	105.6	26	105.9	54	29.8
24	48	105.2	3	104.3	3	30.0
25	41	102.2	46	103.4	9	30.0
26	21	101.6	53	102.3	25	30.0
27	31	99.4	42	101.4	42	30.0
28	17	99.3	50	101.0	45	30.0
29	26	96.4	61	100.2	27	30.1
30	49	95.5	2	99.2	35	30.1
31	3	93.5	43	98.9	16	30.1
32	44	93.1	39	98.5	34	30.2
33	13	93.1	37	97.5	36	30.2
34	39	92.8	57	97.0	8	30.3
35	19	91.9	23	96.7	48	30.3
36	5	91.5	47	96.3	62	30.3
37	10	90.1	52	96.3	21	30.4
38	53	88.4	31	95.0	52	30.4
39	62	87.2	62	94.3	7	30.7
40	4	86.6	22	93.7	11	30.7
41	30	85.0	24	93.7	59	30.7
42	32	84.4	7	92.7	24	30.8
43	14	84.3	6	92.4	39	30.8
44	64	83.9	44	92.1	53	30.8

Table 7 (cont'd): Greenhouse seed source means (ranked).

Rank	**Seed Source**	**GH-88**	**Seed Source**	**GH-89**	**Seed Source**	**GH-NF**
45	7	82.6	4	91.9	29	30.9
46	42	81.3	19	91.8	43	30.9
47	28	80.9	29	90.0	20	31.0
48	8	80.4	17	89.0	37	31.0
49	43	80.0	56	87.8	47	31.0
50	24	78.0	54	87.6	56	31.0
51	54	75.6	60	86.0	58	31.0
52	45	75.1	8	84.2	2	31.1
53	11	74.6	45	83.6	57	31.1
54	12	70.7	1	83.6	51	31.4
55	20	69.8	59	83.1	61	31.4
56	51	68.8	10	83.0	50	31.5
57	59	68.2	49	82.3	38	31.7
58	6	66.9	63	81.9	60	31.7
59	52	65.4	64	81.8	46	31.8
60	1	64.8	51	80.3	31	32.0
61	47	64.2	40	76.9	33	32.2
62	40	61.8	55	76.3	64	32.2
63	22	61.6	36	74.7	63	32.7
64	55	59.8	20	71.3	49	33.2

GH-88: Greenhouse Height 1988

GH-89: Greenhouse height increment 1989

GH-NF: Greenhouse needle flushing

Table 8: Significance of differences among seed source groups classified according to FEC Vegetation Types (Sims *et al* 1989).

Variable*	**Significance of Vegetation Type**
GH-88	0.001
GH-89	0.000
GH-NF	0.000
LU-88	0.000
LU-89	0.000
LU-90	0.000
LU-IN	0.002
LU-NF	0.035
R-88	0.004
R-89	0.002
R-90	0.054
R-NF	0.017

*

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-NF: Greenhouse Needle Flushing
LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-NF: LU Needle Flushing
R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-NF: Raith Needle Flushing

a. 1988 height (Grand Mean = 95.1)

Mean (mm)	V-Type	# Rep	V25	V30	V31	V18	V17	V32	V29	V28
64.2	25	10								
86.7	30	78								
88.7	31	50								
88.8	18	70	√							
93.4	17	28	√							
98.1	32	267	√	√						
98.5	29	79	√	√						
108.6	28	49	√	√	√	√				

b. 1989 height increment (Grand Mean = 100.6)

Mean (mm)	V-Type	# Rep	V18	V31	V29	V25	V32	V17	V30	V28
91.8	18	70								
93.1	31	49								
95.0	29	79								
96.3	25	10								
100.8	32	263	√							
105.5	17	28								
106.4	30	77	√	√	√					
117.1	28	49	√	√	√		√			

c. Needle flushing date (Grand Mean = 30.39)

Mean	V-Type	# Rep	V17	V18	V28	V32	V31	V30	V25	V29
29.64	17	28								
29.93	18	70								
29.96	28	49								
30.34	32	264								
30.43	31	49								
30.57	30	77	√	√						
31.00	25	10								
31.25	29	79	√	√	√	√	√	√		

Figure 5: Pairs of vegetation types at the greenhouse trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height increment, and c) needle flushing date.

pine seedlings of seed sources classified to vegetation type 25 ranked lowest for 1988 height (64.2 mm) and differed significantly from seedlings of five other vegetation types. Seedlings of sources classified to vegetation type 25 ranked below average in 1989 height increment, however they did not differ significantly from those of any other vegetation type. The seedlings of FEC vegetation type 18 ranked lowest in growth increment in 1989 (91.8 mm) (Figure 5). These displayed below average height in 1988, but were significantly taller than those of type 25. Tests for homogeneity of variance were not significant.

Mean needle flush dates varied from 29.6 (April 30) for jack pine seedlings of vegetation type 17 to 31.3 (May 2) for those of vegetation type 29 (Figure 5). These results may be misleading; unequal replications may play a significant part in these results. Tests for homogeneity of variances were highly significant for the flushing dates.

One-way ANOVA tests of the growth and phenological data revealed that seed sources grouped by FEC soil type also varied significantly for the same three of the six variables: 1988 height, 1989 height increment, and the needle flushing date (Table 9). Of the twelve soil types represented, seedlings classified to type SS 3 displayed the greatest mean height in 1988 (133.1 mm); this mean was significantly greater than that of seedlings from any other soil type (Figure 6). Seedlings of this type ranked second, on average, in growth increment in 1989, and were significantly different from those of the nine lowest ranking soil types. Seedlings of soil type SS 7 ranked lowest for 1988 height (75.6 mm) and 1989 height increment (87.6 mm) and differed significantly from the means of seedlings of the same three top-ranked soil types in each year (Figure 5). Seedlings originating from stands classified as soil type SS 2

Table 9: Significance of differences among seed source groups classified according to FEC Soil Types (Sims *et al* 1989).

Variable*	**Significance of Soil Type**
GH-88	0.000
GH-89	0.000
GH-NF	0.020
LU-88	0.000
LU-89	0.000
LU-90	0.000
LU-IN	0.000
LU-CS	0.008
LU-NF	0.000
R-88	0.000
R-89	0.000
R-90	0.000
R-CS	0.014
R-NF	0.006

*

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-NF: Greenhouse Needle Flushing
LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-NF: LU Needle Flushing
R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-CS: Raith Elongation Cessation
R-NF: Raith Needle Flushing

a. 1988 height (Grand Mean = 95.1)

Mean (mm)	S- Type	# Rep	SS7	S4	S2	SS1	S3	S5	S1	SS6	SS5	S6	SS2	SS3
75.6	SS7	10												
78.0	S4	10												
83.4	S2	69												
86.6	SS1	48												
90.4	S3	30												
93.3	S5	30												
96.1	S1	297			√									
96.4	SS6	30												
98.4	SS5	38			√									
104.3	S6	30	√	√	√	√								
108.7	SS2	20	√	√	√	√								
133.1	SS3	19	√	√	√	√	√	√	√	√	√	√	√	

b. 1989 height increment (Grand Mean = 100.6)

Mean (mm)	S- Type	# Rep	SS7	S2	S4	SS5	S3	S1	SS6	SS1	S5	S6	SS3	SS2
87.6	SS7	10												
91.1	S2	69												
93.7	S4	10												
94.1	SS5	38												
95.0	S3	29												
98.7	S1	294												
102.4	SS6	29												
103.3	SS1	48		√										
107.4	S5	30		√										
114.2	S6	28	√	√		√	√	√						
125.3	SS3	20	√	√	√	√	√	√	√	√	√			
127.0	SS2	20	√	√	√	√	√	√	√	√	√			

c. Needle flushing date (Grand Mean = 30.39)

Mean (days)	S- Type	# Rep	S3	SS7	S5	S1	SS1	S2	SS2	SS5	S6	S4	SS3	SS6
29.79	S3	29												
29.80	SS7	10												
29.83	S5	30												
30.27	S1	294												
30.36	SS1	47												
30.39	S2	69												
30.70	SS2	20												
30.71	SS5	38												
30.72	S6	29												
30.80	S4	10												
31.15	SS3	20	√		√	√								
31.43	SS6	30	√	√	√	√	√	√						

Figure 6: Pairs of soil types at the greenhouse trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height increment, and c) needle flushing date.

showed the greatest growth increment in 1989, on average, though it was not significantly different from those of SS 3. The ranks of the means of seedlings from each of the soil types generally remained constant for the 1988 height and the 1989 height increment. However seedlings of type SS 1 were significantly shorter than those of the tallest soil type for 1988 height, and performed below average, but their average height increment in 1989 was above average. In this multiple range test it was significantly taller than the seedlings of shorter soil types (Figure 6). Tests for homogeneity of variances were not highly significant.

Multiple range tests for needle flush indicate significant difference (5 per cent level) between seedlings of various soil types (Figure 6). Mean flush dates varied from 29.7 (April 30) for seedlings of soil type S 3 to 31.4 (May 2) for those of soil type SS 6. Comparisons of flushing dates and heights do not show any consistent pattern. Tests for homogeneity of variances were significant for flushing dates.

Lakehead University Field Trial

Findings of the one-way ANOVA tests for each of the seven variables determined for the LU field trial data are presented in Table 6. Seed source was a highly significant source of variation in every case. The portion of the total variance attributable to seed source varied from 30.0 per cent for 1989 final height to 4.0 per cent for elongation cessation. The portion of variance attributable to seed source for the LU field trial data for each of the seven variables is consistently greater than those of the same variables at both the Greenhouse trial and the Raith field trial. As seen in the Greenhouse trial, the portion of variance attributable to the seed source was greater for the growth variables than for the phenological variables.

Examination of the means revealed that the tallest seedlings originated from source 33, averaging 979.5 mm after three years (Table 10). On average, seedlings of this source were the earliest to initiate elongation, among the later to cease elongation, and the very latest to flush their needles. Source 33 was collected from the southwest portion of the study area. By 1990, second tallest seedlings came from source 53; a source also located in the southwest portion of the study area. Likewise, seedlings of this source, on average, were early to initiate elongation, the very latest to cease elongation, and second latest to flush. Seedlings of source 48, originating from between sources 33 and 53, performed very similarly for all measured traits, being sixth in height after three years, eighth to initiate elongation, and fourth latest to flush, on average. Elongation cessation was average for seedlings of this seed source.

By 1990, seedlings from seed source number 20 were shortest, on average, at 560.4 mm (Table 10). Seedlings of this source were among the shortest three sources in the first and second year as well. Elongation initiation, on average, was late for this seed source, and cessation was six days later than the earliest source. Average needle flushing date was very near the trial mean for this source. Other seed sources whose seedlings averaged among the shortest were sources 24, 40, and 22. Seedlings of sources 24 and 40 were among the latest sources to initiate elongation, while source 22 was slightly later than the trial average. Elongation cessation, on average, was earliest among seedlings from seed source 22. Source 20 originated from the central eastern edge of the study area, north of Lake Superior while seed source 22 originated from the southeast

Table 10: Lakehead University field trial seed source means (ranked).

	Seed Srce	LU-88	Seed Srce	LU-89	Seed Srce	LU-90	Seed Srce	LU-IN	Seed Srce	LU-CS	Seed Srce	LU-DR	Seed Srce	LU-NF
1	60	155.7	33	462.3	33	979.5	33	12.9	22	78.5	22	65.2	1	25.5
2	52	152.7	60	444.3	53	969.3	25	12.9	21	81.0	21	67.5	12	25.9
3	34	140.2	53	437.7	34	920.7	64	12.9	7	81.8	7	68.5	5	25.9
4	50	130.6	48	428.1	41	910.8	42	12.9	55	82.2	55	68.9	25	26.1
5	46	127.1	34	426.0	60	904.8	53	12.9	28	82.9	19	69.6	57	26.2
6	25	126.8	41	416.8	48	898.8	45	13.0	19	82.9	28	69.6	28	26.4
7	13	125.8	32	416.2	32	882.8	16	13.0	12	83.0	24	69.7	22	26.6
8	33	124.9	16	414.2	46	880.9	48	13.0	24	83.3	12	69.8	29	26.6
9	16	124.8	52	406.4	49	875.6	18	13.0	61	83.5	61	70.3	19	26.7
10	15	119.7	25	397.1	64	874.3	38	13.1	30	83.7	30	70.5	6	26.7
11	58	118.7	58	390.3	16	861.1	26	13.1	8	83.8	8	70.6	4	26.8
12	37	118.6	13	389.1	38	858.7	58	13.1	10	83.9	10	70.7	62	26.9
13	5	118.5	50	385.3	15	848.9	39	13.1	27	84.2	13	70.7	9	27.0
14	38	118.4	64	384.0	52	845.0	60	13.1	13	84.2	11	70.9	44	27.0
15	53	118.3	15	382.8	5	838.7	46	13.1	11	84.3	27	71.0	45	27.0
16	29	115.4	38	378.1	42	837.9	59	13.1	20	84.6	20	71.2	17	27.1
17	32	114.1	46	377.9	50	836.5	6	13.1	47	85.3	47	71.8	54	27.1
18	41	113.8	42	368.0	58	833.2	49	13.1	38	85.4	38	72.4	13	27.1
19	48	113.6	5	367.9	18	830.3	31	13.1	16	85.8	4	72.7	14	27.2
20	54	112.2	26	366.9	25	823.6	61	13.1	4	85.9	16	72.9	20	27.3
21	61	110.1	61	363.9	6	810.7	5	13.1	45	86.2	3	73.2	2	27.3
22	35	109.8	18	363.9	37	806.9	10	13.2	48	86.5	45	73.2	16	27.3
23	57	109.6	37	355.1	13	804.9	8	13.2	3	86.8	40	73.3	38	27.3
24	28	109.5	54	348.8	39	803.8	12	13.2	52	86.8	48	73.5	3	27.3
25	64	108.8	49	347.5	26	799.7	43	13.2	40	86.9	52	73.6	59	27.3
26	26	108.4	45	338.6	57	796.1	34	13.2	1	87.1	62	73.7	64	27.4
27	7	108.1	12	337.8	54	794.9	27	13.2	44	87.1	1	73.7	7	27.4
28	23	107.9	6	335.4	45	781.5	41	13.2	62	87.4	44	73.8	8	27.4
29	45	107.6	2	333.2	35	780.5	37	13.2	43	87.9	50	74.5	40	27.4
30	39	107.2	57	329.6	43	777.6	15	13.2	42	87.9	17	74.7	56	27.4
31	56	104.0	43	328.2	56	774.0	56	13.2	50	87.9	63	74.7	60	27.4
32	4	103.6	9	326.9	61	766.5	52	13.2	17	87.9	43	74.7	27	27.5
33	49	103.4	28	325.6	28	762.9	54	13.2	63	88.0	57	74.9	35	27.5
34	9	102.9	39	324.5	59	758.8	4	13.2	57	88.3	42	74.9	30	27.5
35	12	102.3	4	317.1	12	757.0	30	13.3	35	88.6	35	75.0	39	27.6
36	8	101.6	56	313.7	10	756.7	17	13.3	59	88.6	15	75.4	58	27.7
37	2	99.5	59	312.2	51	744.5	63	13.3	15	88.6	59	75.5	51	27.7
38	17	98.7	35	309.4	9	742.1	2	13.3	64	88.9	18	75.9	49	27.8
39	42	98.0	31	308.4	29	733.9	7	13.3	18	88.9	23	75.9	24	27.8
40	31	97.5	21	308.4	17	730.8	55	13.3	41	89.2	64	76.0	11	28.0
41	43	96.1	10	306.1	2	730.1	22	13.3	6	89.4	41	76.0	15	28.0
42	59	95.7	17	305.8	31	727.7	14	13.3	23	89.5	6	76.3	55	28.0
43	51	95.6	44	302.7	44	726.2	9	13.3	31	89.6	31	76.5	21	28.1
44	63	95.3	29	300.5	23	724.3	28	13.3	2	90.0	2	76.7	42	28.1

Table 10 (cont'd): Lakehead University field trial seed source means (ranked).

Rank	Seed Srce	LU-88	Seed Srce	LU-89	Seed Srce	LU-90	Seed Srce	LU-IN	Seed Srce	LU-CS	Seed Srce	LU-DR	Seed Srce	LU-NF
45	44	94.3	51	295.7	55	720.1	57	13.3	14	90.0	14	76.7	41	28.1
46	18	92.1	7	294.5	14	716.6	32	13.3	9	90.1	9	76.8	36	28.1
47	21	91.0	23	292.4	21	711.8	19	13.4	37	90.4	37	77.2	26	28.2
48	10	89.2	8	290.7	36	693.3	44	13.4	60	90.5	34	77.3	47	28.2
49	55	89.0	3	286.1	4	691.5	1	13.4	34	90.5	56	77.3	63	28.3
50	6	85.3	62	284.2	8	687.4	11	13.4	56	90.6	60	77.4	46	28.3
51	27	84.2	63	283.9	1	685.9	47	13.4	58	90.8	58	77.8	18	28.3
52	62	82.6	14	283.2	7	682.8	50	13.4	25	91.0	36	77.9	32	28.3
53	11	76.2	27	279.4	27	682.7	51	13.4	26	91.1	54	78.0	50	28.3
54	36	75.7	55	274.5	62	676.9	29	13.4	54	91.2	26	78.1	31	28.4
55	30	75.4	1	270.0	63	660.9	21	13.5	36	91.6	25	78.2	43	28.5
56	1	73.8	36	265.6	19	658.6	20	13.5	33	92.0	29	78.9	37	28.5
57	3	73.6	19	256.1	3	657.3	13	13.5	29	92.4	33	79.1	23	28.6
58	14	71.0	30	253.5	11	654.9	40	13.6	49	92.4	49	79.3	61	28.7
59	19	70.2	11	251.6	30	642.1	24	13.6	46	92.6	32	79.3	10	28.8
60	24	67.1	47	232.9	47	634.0	23	13.6	32	92.7	51	79.4	52	28.8
61	47	64.5	40	224.1	22	609.9	3	13.6	51	92.8	46	79.5	48	29.7
62	20	61.1	20	223.8	40	605.0	35	13.6	5	93.5	5	80.3	34	29.8
63	22	58.3	22	217.4	24	589.3	62	13.7	39	93.9	39	80.8	53	30.1
64	40	52.8	24	215.6	20	560.4	36	13.7	53	94.4	53	81.5	33	30.8

LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing

corner of the study area, near Terrace Bay and Lake Superior. Seed source 24 was collected northwest of Lake Nipigon, and seed source 40 was collected in the west-central portion of the study area (Figure 2).

Two-way ANOVA tests indicated seed source as a very significant source of variation for each of the seven variables measured (Table 11) when tested against the interaction of seed source with blocks. Blocks were generally significant to very significant in each case, but the significance of the interaction of block and seed source was variable. The interaction was a very significant source of variation in the test of 1988 seedling heights. Variation in elongation cessation and duration, two highly correlated variables, also showed interaction effects. The interaction of block and seed source was insignificant for all other variables.

One-way ANOVA tests of the growth and phenological data by FEC vegetation type (Sims *et al* 1989) revealed significant differences between seedlings originating from different types of associations (Table 8). Vegetation type was a very significant source of variation in all tests except those involving elongation cessation and duration. The ranking of the means of seedlings of the eight vegetation types in the multiple range tests (Figure 7) revealed that seedlings of vegetation types 28 and 29, the tallest in 1988 (122.5 mm and 111.4 mm) and 1989 (387.7 mm and 351.6 mm), showed average elongation initiation (13.2 = May 14) and average needle flush dates (27.8 = May 28 and 28.1 = May 29). Those of vegetation type 25 were consistently poor, on average, for height (64.5 mm, 232.9 mm and 634 mm in 1988, 1989 and 1990 respectively) followed by those of vegetation type 18 in most cases (95.2 mm, 313.5 mm and 744.7 mm in 1988, 1989, and 1990 respectively). Seedlings of type 25 were, on average, the latest to initiate elongation and the latest to flush. Seedlings of

Table 11: Significance of variation revealed by two-way ANOVA tests for the LU and Raith field trials.

Variable	Source of Variation		
	Block	Seed Source	Interaction
LU-88	0.055	0.000	0.001
LU-89	0.035	0.000	0.207
LU-90	0.000	0.000	0.118
LU-IN	0.000	0.000	0.359
LU-CS	0.000	0.000	0.027
LU-DR	0.000	0.000	0.031
LU-NF	0.000	0.000	0.167
R-88	0.020	0.000	0.100
R-89	0.003	0.000	0.004
R-90	0.000	0.000	0.217
R-IN	0.125	0.206	0.970
R-CS	0.600	0.000	0.047
R-DR	0.890	0.001	0.052
R-NF	0.000	0.000	0.511

*

LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing

R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-IN: Raith Elongation Initiation
R-CS: Raith Elongation Cessation
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing

a. 1988 height (Grand Mean = 101.6)

Mean (mm)	V-Type	# Rep	V25	V17	V18	V32	V31	V30	V29	V28
64.5	25	30								
94.8	17	90	√							
95.2	18	209	√							
96.9	32	809	√							
103.1	31	150	√							
106.1	30	240	√	√	√	√				
111.4	29	240	√	√	√	√	√			
122.5	28	150	√	√	√	√	√	√	√	

b. 1989 height (Grand Mean = 330.7)

Mean (mm)	V-Type	# Rep	V25	V18	V32	V31	V17	V30	V29	V28
232.9	25	30								
313.5	18	208	√							
314.8	32	803	√							
331.3	31	150	√							
344.6	17	89	√	√	√					
349.9	30	240	√	√	√					
351.6	29	236	√	√	√					
387.7	28	149	√	√	√	√	√	√	√	

c. 1990 height (Grand Mean = 768.1)

Mean (mm)	V-Type	# Rep	V25	V18	V32	V31	V29	V17	V30	V28
634.0	25	30								
744.7	18	208	√							
746.5	32	798	√							
779.4	31	149	√							
786.2	29	236	√	√	√					
798.1	17	87	√	√	√					
801.7	30	239	√	√	√					
831.8	28	149	√	√	√	√	√			

d. Elongation initiation (Grand Mean = 13.25)

Mean (day)	V-Type	# Rep	V17	V30	V29	V28	V31	V18	V32	V25
13.13	17	90								
13.14	30	240								
13.17	29	236								
13.21	28	150								
13.24	31	150								
13.29	18	208		√						
13.31	32	804	√	√	√					
13.42	25	30	√	√						

e. Needle flush (Grand Mean = 27.65)

Mean (day)	V-Type	# Rep	V30	V18	V32	V28	V17	V29	V31	V25
27.11	30	240								
27.40	18	208								
27.59	32	806								
27.78	28	150								
27.79	17	90								
28.10	29	236	√	√						
28.21	31	150	√	√						
28.23	25	30								

Figure 7: Pairs of vegetation types at the LU field trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height, c) 1990 height, d) elongation initiation, and e) needle flush.

type 18, however, averaged just slightly late for elongation initiation and slightly early for needle flushing. The replicate numbers of seedlings in each vegetation type vary from 30 (1 seed source) to 810 (27 seed sources). Tests for homogeneity of variances were significant for all variables tested.

Growth and phenological variables were also tested by FEC soil types (Sims *et al* 1989), using one-way ANOVA. Highly significant differences between seed source groups classified by soil type were expressed by all variables except elongation duration (Table 9). Multiple range tests were used to examine the differences (Figure 8).

Seedlings of soil type SS 2 were consistently among the tallest, averaging 116.2 mm in 1988, 397.2 mm in 1989, and 870.7 mm in 1990 (Figure 8). By 1989, average seedling height of seedlings of SS 6 was top-ranked at 403.5 mm, and remained the tallest in 1990 at 914.7 mm. Average seedling height of seedlings of these two soil types were never significantly different from one another, however, in 1990 seedlings of all other soil types were significantly shorter than those of SS 6. The shortest seedlings consistently came from S 4; they averaged 67.1 mm, 215.6 mm, and 589.3 mm in 1988, 1989, and 1990 respectively, and were always significantly shorter than all other soil types. Seedlings from shallow soils (SS types) generally were taller than seedlings from deeper soils (S types). Once again tests for homogeneity of variances were significant.

Elongation initiation dates also displayed significant differences between seed sources groups classified according to FEC soil types (Figure 8). The average flushing date for seedlings of all soil types was May 14. Seedlings of shallow soil types generally flushed earlier than deep soil types. The mean elongation cessation date was 87.81, or July 27.

a. 1988 height (Grand Mean = 101.6)

Mean (mm)	S- Type	# Rep	S 4	S 2	S 3	S 5	S 1	S S 1	S S 3	S S 5	S S 6	S S 7	S 6	S S 2
67.1	S4	30												
94.0	S2	210	√											
96.9	S3	90	√											
99.0	S5	89	√											
100.1	S1	899	√	√										
104.3	SS1	150	√	√										
104.5	SS3	60	√											
106.8	SS5	120	√	√										
111.8	SS6	90	√	√	√	√	√							
112.2	SS7	30	√	√										
115.8	S6	90	√	√	√	√	√	√						
116.2	SS2	60	√	√	√	√	√							

b. 1989 height (Grand Mean = 330.7)

Mean (mm)	S- Type	# Rep	S 4	S 2	S 3	S 1	S 5	S S 5	S S 1	S 6	S S 7	S S 3	S S 2	S S 6
215.6	S4	30												
290.1	S2	208	√											
302.4	S3	90	√											
327.5	S1	889	√	√	√									
333.3	S5	89	√	√	√									
334.9	SS5	120	√	√	√									
341.8	SS1	150	√	√	√									
346.7	S6	90	√	√	√									
348.8	SS7	30	√	√	√									
372.4	SS3	59	√	√		√	√	√	√					
397.2	SS2	60	√	√	√	√	√	√	√	√	√			
403.5	SS6	90	√	√	√	√	√	√	√	√	√			

c. 1990 height (Grand Mean = 768.1)

Mean (mm)	S- Type	# Rep	S 4	S 2	S 3	S 1	S S 5	S S 1	S 5	S S 7	S 6	S S 3	S S 2	S S 6
589.3	S4	29												
704.8	S2	206	√											
731.0	S3	90	√											
756.5	S1	885	√	√										
778.1	SS5	119	√	√										
778.3	SS1	150	√	√										
787.2	S5	89	√	√	√									
794.9	SS7	30	√	√										
808.4	S6	89	√	√	√	√								
831.1	SS3	60	√	√	√	√								
870.7	SS2	60	√	√	√	√	√	√	√					
914.7	SS6	89	√	√	√	√	√	√	√	√	√	√		

Figure 8: Pairs of soil types at the LU field trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height, c) 1990 height, d) elongation initiation, e) elongation cessation, and f) needle flushing date.

d. Elongation initiation date (Grand Mean = 13.25)

Mean (days)	S-Type	# Rep	SS3	SS6	SS1	S5	SS2	SS7	SS5	S1	S3	S6	S2	S4
13.02	SS3	60												
13.03	SS6	90												
13.06	SS1	150												
13.17	S5	88												
13.19	SS2	60												
13.23	SS7	30												
13.27	SS5	120	√	√	√									
13.28	S1	893	√	√	√									
13.30	S3	90	√	√	√									
13.32	S6	89	√	√	√									
13.33	S2	208	√	√	√									
13.59	S4	30	√	√	√	√	√	√	√	√	√			

e. Elongation cessation date (Grand Mean = 87.81)

Mean (days)	S-Type	# Rep	S4	S2	SS1	S3	S1	SS3	S5	SS2	S6	SS5	SS6	SS7
83.33	S4	30												
85.72	S2	208												
86.69	SS1	150												
86.76	S3	90												
87.57	S1	893												
88.10	SS3	60												
88.95	S5	88	√											
89.04	SS2	60												
89.59	S6	89	√	√										
90.22	SS5	120	√	√	√		√							
91.10	SS6	90	√	√	√	√	√							
91.24	SS7	30	√	√										

f. Needle flushing date (Grand Mean = 27.65)

Mean (days)	S-Type	# Rep	SS1	SS7	S2	S3	S1	SS5	S5	SS2	S4	S6	SS3	SS6
26.88	SS1	150												
27.07	SS7	30												
27.14	S2	209												
27.36	S3	90												
27.57	S1	893	√											
27.73	SS5	120	√											
27.75	S5	88												
27.80	SS2	60												
27.83	S4	30												
28.58	S6	90	√	√	√	√	√							
29.12	SS3	60	√	√	√	√	√	√	√	√				
29.20	SS6	90	√	√	√	√	√	√	√	√				

Figure 8 (cont'd): Pairs of soil types at the LU field trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height, c) 1990 height, d) elongation initiation, e) elongation cessation, and f) needle flushing date.

Seedlings of soil type S 4 stopped elongating at 83.33 days, or by July 23. This was significantly earlier than seedlings of five other soil types (Figure 8). Seedlings of soil type SS 7 and SS 6 were the latest to cease elongation at 91.24 and 91.10 respectively (July 31).

Needle flushing dates expressed significant differences among seedlings of different soil types (Figure 8). Seedlings from sources classified to SS 1 were among the earliest to flush at 26.88, or May 27. This differed significantly from those soil types whose seedlings flushed on the 29th and 30th of May. Seedlings of three soil types, S 6, SS 3, and SS 6, flushed on or after May 29, and were not significantly different from each other. However, seedlings of the seed sources that flushed on average on May 30 (SS 3 and SS 6) differed significantly from those of the eight earliest flushing soil types (Figure 8). Tests for homogeneity of variances were significant for each of these three phenological variables.

Raith Field Trial

One-way ANOVA tests of each of the seven variables measured at the Raith trial are included in Table 6. Seed source was a very significant source of variation in all cases except that of elongation initiation. The portion of total variance attributable to seed source at the Raith field trial varies from 1.4 per cent (non-significant) for elongation initiation to 18.4 per cent for the 1989 height. As with the Greenhouse and the LU field trial, the portion of variance attributable to seed source was greater for growth variables than for phenological variables.

Growth at this trial was considerably less than at the LU field trial, with mean heights of 66 mm (LU = 102 mm), 152 mm (331 mm), and 279 mm (768 mm) in 1988, 1989, and 1990 respectively. The average duration of growth at Raith was approximately three weeks less than at the LU field trial as well (Table 6) with elongation initiation dates averaging 11 days later, and cessation elongation dates averaging 13 days earlier. Flushing dates averaged six days later than those of the LU field trial.

Seedlings of seed source 42 were the shortest for each of the first three years, at 42.9 mm, 95.0 mm, and 190.1 mm in 1988, 1989, and 1990 respectively (Table 12). At the LU field trial this source showed average height performance in 1988, but by 1990 it ranked in the top 25 per cent. This source originated from the western-central portion of the study area. Seedlings from seed source 22, originating near Terrace Bay, also consistently ranked low in terms of height. This performance corresponds to its height performance at the LU field trial. Other poor height performers on average were seedlings from source 32 (near Lake Superior and the Minnesota border) and source 27 (west of the north end of Lake Nipigon). By 1990, seedlings of source 32 ranked second shortest at the Raith trial, while at LU they ranked seventh tallest. At the greenhouse trial seedlings from source 32 ranked second in the average growth elongation in 1989. At the Raith trial, elongation initiation was not significantly different among seed sources. Elongation cessation for seedlings of these shorter sources aoccured earlier than the mean cessation date for the entire trial., Similar findings were observed in the elongation duration data. Needle flushing date for these four seed sources was generally later than average, with the Terrace Bay source, number 22, being the exception to the rule.

The tallest seedlings at the Raith field trial, on average, originated from seed source 33, at 107.8 mm, 279.8 mm, and 478.8 mm in 1988, 1989, and 1990 respectively (Table 12). This seed source, from the southwestern corner of the study area, near the Minnesota border (Figure 2), had the tallest seedling height in all trials. Seedlings of seed source seven (from the northeastern portion of the study area) ranked second tallest throughout the study, while those of source 45 (north of Thunder Bay) ranked third after two and three years. By year three, seedlings of first-ranked source 33 averaged almost 100 mm taller than those of third-ranked source 45 (Table 12). Elongation cessation, and the closely correlated duration, occurred later and lasted longer than average for seedlings of these three sources. Source 33 seedlings ceased elongation last, followed by those of source 7. Average needle flushing dates for seedlings of these sources were near average or earlier, with source 7 ranked among the first ten. All seedlings of the seed sources from the northeastern corner of the study area were among the first in needle flushing date.

Two-way ANOVA tests showed seed source to be a very significant source of variation in the height measures for each of the three years, in cessation and duration of elongation, and in needle flushing (Table 11). Elongation initiation showed no significant differences between seed sources. Blocks were a very significant source of variation in three cases: 1989 height, 1990 height, and needle flushing. The blocks explained a less significant amount of variation in the 1988 height measures, and were not a significant source of variation for elongation initiation, cessation or duration. The interaction of seed source and blocks was a very significant source of variation in 1989 heights, and a less significant source of

Table 12: Raith field trial means (ranked).

Rank	Seed Srce	R-88	Seed Srce	R-89	Seed Srce	R-90	Seed Srce	R-CS	Seed Srce	R-DR	Seed Srce	R-NF
1	33	107.8	33	279.8	33	478.8	39	66.3	39	38.4	6	29.9
2	7	104.3	7	252.3	7	458.0	28	67.6	55	43.3	1	30.0
3	21	95.4	45	220.6	45	375.5	59	68.6	36	43.6	20	30.1
4	45	88.6	6	205.4	6	369.7	4	68.9	53	43.8	8	30.4
5	56	87.3	60	201.4	5	367.0	14	68.9	28	44.1	24	30.8
6	36	86.0	15	198.5	1	355.1	57	69.0	51	44.5	3	31.0
7	52	81.8	56	197.1	41	352.4	36	69.1	14	44.9	25	31.0
8	63	78.9	1	195.1	18	351.6	24	69.7	57	44.9	5	31.2
9	16	78.6	5	194.7	60	347.8	27	69.7	59	45.0	7	31.6
10	60	78.1	58	188.4	17	340.4	8	69.8	27	45.4	22	31.6
11	25	78.0	3	186.7	46	338.4	2	70.1	4	45.5	14	31.6
12	18	76.4	16	186.5	56	337.1	22	70.5	2	46.4	4	31.9
13	44	74.1	21	186.0	15	337.0	50	70.5	22	46.8	12	31.9
14	1	73.3	41	185.6	11	336.0	26	70.8	50	46.9	23	32.0
15	11	72.9	49	185.2	49	330.9	53	71.6	8	47.0	41	32.0
16	38	72.8	17	183.6	16	330.8	23	72.0	26	47.2	2	32.1
17	15	72.5	18	183.4	58	328.0	55	72.0	32	47.5	18	32.1
18	13	72.2	11	181.5	3	327.9	44	72.0	24	48.3	60	32.2
19	54	70.3	12	180.0	13	324.1	43	72.1	29	48.4	19	32.3
20	5	69.3	54	177.6	12	322.6	51	72.1	54	48.9	63	32.3
21	41	67.3	46	175.4	21	318.1	30	72.3	44	49.0	35	32.6
22	46	67.2	63	171.5	8	311.5	29	72.3	30	49.5	58	32.6
23	17	66.3	13	170.2	54	305.1	48	72.5	38	49.6	30	32.6
24	35	66.1	52	169.5	35	304.3	34	72.7	43	49.7	52	32.6
25	29	66.0	36	168.8	20	303.5	32	72.7	48	49.7	46	32.6
26	31	65.3	25	166.2	25	303.4	54	72.8	23	49.9	26	32.7
27	57	65.1	64	165.3	63	300.8	58	72.9	15	50.1	16	32.8
28	58	65.0	8	164.5	64	299.6	1	73.0	10	50.6	33	32.8
29	51	64.9	20	164.3	36	298.8	40	73.0	34	50.6	62	32.9
30	48	64.3	44	163.0	19	296.5	37	73.7	40	50.7	21	33.0
31	12	64.2	35	162.8	44	293.6	38	74.1	42	50.8	54	33.1
32	8	64.1	62	158.6	38	293.1	42	74.6	9	50.9	36	33.1
33	6	63.3	37	158.4	30	291.5	49	74.6	1	51.1	13	33.1
34	64	62.9	30	156.6	62	289.0	19	74.7	60	51.5	11	33.5
35	27	62.7	38	156.1	10	288.9	15	74.7	58	51.8	17	33.7
36	49	62.6	48	155.9	61	283.4	52	75.0	47	51.8	38	33.7
37	37	62.2	4	155.3	48	281.7	60	75.0	25	51.9	61	33.7
38	3	62.0	31	150.4	52	280.5	47	75.2	52	52.1	53	33.7
39	20	61.7	34	149.0	31	274.4	9	75.4	11	52.1	45	33.8
40	30	61.0	61	148.6	34	272.6	63	75.6	5	52.2	44	34.0
41	10	60.4	19	148.6	9	272.6	5	75.9	37	52.6	28	34.0
42	34	59.4	10	147.4	4	268.2	10	76.0	20	52.7	29	34.1
43	2	59.3	2	141.5	14	264.1	45	76.1	49	52.8	57	34.4
44	50	57.7	43	140.5	37	262.9	21	76.3	19	52.9	56	34.8

Table 12: Raith field trial means (ranked).

Rank	Seed Srce	R-88	Seed Srce	R-89	Seed Srce	R-90	Seed Srce	R-CS	Seed Srce	R-DR	Seed Srce	R-NF
45	26	57.6	39	140.0	29	262.5	13	76.6	31	52.9	43	35.2
46	9	57.2	14	138.1	55	259.3	64	76.6	21	53.0	59	35.3
47	62	57.0	57	137.5	2	256.0	35	76.6	13	53.1	32	35.3
48	23	55.4	26	134.1	57	255.2	11	76.7	45	53.3	55	35.5
49	59	54.0	9	132.7	39	254.9	25	76.8	63	53.5	10	35.5
50	55	53.7	59	132.0	47	249.6	31	77.1	56	53.7	50	35.5
51	24	53.3	51	128.7	26	248.2	18	77.1	35	53.7	49	35.6
52	28	53.2	50	127.8	53	247.9	56	77.3	61	54.5	47	35.7
53	47	53.2	47	127.3	51	247.4	20	77.4	64	54.8	9	35.8
54	43	53.1	24	124.8	43	244.6	61	77.7	3	54.8	40	35.9
55	39	52.6	32	123.5	23	239.1	6	77.7	6	55.1	27	36.1
56	19	50.5	53	121.9	50	236.9	3	78.3	18	55.2	37	36.3
57	14	49.6	23	121.4	40	232.2	12	78.4	46	55.6	51	36.3
58	32	49.4	29	120.7	24	228.2	16	78.6	41	56.3	42	36.5
59	4	48.6	28	120.6	28	221.3	62	78.6	62	56.4	15	36.6
60	61	47.6	40	115.6	59	219.9	41	81.2	12	56.8	64	36.8
61	22	46.1	22	114.1	22	216.1	46	81.2	33	58.1	34	37.2
62	40	44.3	27	112.8	27	212.6	17	81.3	7	58.6	48	37.6
63	53	43.8	55	111.3	32	206.9	7	81.5	17	58.9	31	37.9
64	42	42.9	42	95.0	42	190.1	33	83.3	16	59.2	39	38.1

R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-CS: Raith Elongation Cessation
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing

variation in elongation cessation and duration times. The interaction was not a significant source of variation for any other variable.

One-way ANOVA tests of the growth and phenological data by FEC vegetation type (Sims *et al* 1989) revealed significant differences between progeny originating from different types of associations for four variables, though these are not as pronounced as those of the LU field trial or greenhouse trial (Table 8). Vegetation type was a significant or very significant source of variation for heights of all years, and also for needle flushing date.

Multiple range tests were used to determine which groups of seedlings from various vegetation types differed significantly from one another for each of the three height variables, and for needle flushing date (Figure 9). Average height for seedlings of vegetation type V 29 (76 mm, 168 mm, and 296 mm in 1988, 1989, and 1990 respectively) was significantly different from those of other vegetation types most often, and was consistently the tallest. Seedlings of this type were ranked among the tallest at the LU field trial (Figure 7). Seedlings of V 28 were tallest at the LU field trial and the greenhouse trial on average, and also ranked consistently among the tallest at the Raith trial; the average was never significantly shorter than the taller types, but was significantly taller than the shortest type. The shortest seedlings came from vegetation type V 25 (53 mm, 115 mm, and 219 mm in 1988, 1989, and 1990 respectively); this was also seen at the LU field trial.

The latest seedlings to flush originated from types V 25 (35.7 = June 5) and V 31 (35.4 = June 5) (Figure 9). This pattern was also seen at the LU field trial, however at the greenhouse the flushing date for seedlings of V 31 averaged much closer to the mean flushing date. The earliest flushing seedlings originated from types V 32 and V 18. Seedlings of these types were also among the earliest to flush at the LU field trial. Counts in each vegetation type ranged from 17 to 552. Tests for the homogeneity of variances showed significant differences among the vegetation groups in all three height measures thus these results must be interpreted with caution.

Similarly, one-way ANOVA tested the differences between seedlings classified to the 12 FEC soil types. Significant differences among seedlings associated with soil types were expressed for five of the seven variables, including the three annual heights, elongation cessation, and needle flushing (Table 9). Multiple range tests determined seedlings of which soil types differed significantly from one another (Figure 10).

The tallest seedlings consistently represented soil type SS 3, at 96 mm, 218 mm, and 386 mm in 1988, 1989, and 1990, respectively. These average annual heights for seedlings of SS 3 were significantly greater than those of all other soil types in each of the three years (Figure 10). SS 1 seedling average height was consistently the second tallest, and was significantly different from most shorter soil type seedlings. At LU, seedlings of SS 3 performed above average, though they were significantly shorter than the tallest soil type seedlings by 1990. SS 1 seedlings, however, performed very close to average at LU and often were significantly shorter than the tallest soil type seedlings (Figure 8). At the LU field trial, the tallest seedlings on average originated from soil types SS 6 and SS 2; these displayed below average heights at the Raith trial (Figure 10). As at the LU field trial, the shortest seedlings on average were those from sources classified to S 4, with heights of 53 mm, 114 mm, and 216

a. 1988 height (Grand Mean = 66.1 mm)

Mean (mm)	V-Type	# Rep	V25	V18	V31	V32	V17	V30	V28	V29
53.2	25	17								
60.3	18	129								
62.9	31	65								
64.5	32	451								
65.5	17	53								
68.5	30	162		√						
69.3	28	78								
76.0	29	133	√	√	√	√				

b. 1989 height (Grand Mean = 151.9 mm)

Mean (mm)	V-Type	# Rep	V25	V31	V17	V18	V32	V28	V30	V29
115.3	25	22								
133.5	31	85								
142.8	17	55								
148.8	18	152								
149.3	32	552	√							
153.1	28	104	√							
163.7	30	177	√	√			√			
167.6	29	165	√	√	√	√	√			

c. 1990 height (Grand Mean = 279.6)

Mean (mm)	V-Type	# Rep	V25	V31	V18	V17	V32	V28	V30	V29
218.5	25	22								
248.5	31	82								
272.0	18	148								
275.7	17	51								
279.1	32	533	√							
285.0	28	100	√							
292.8	30	172	√	√						
296.0	29	162	√	√						

d. Needle flush day (Grand Mean = 33.4 days)

Mean (day)	V-Type	# Rep	V32	V18	V29	V17	V30	V28	V31	V25
32.78	32	504								
33.18	18	144								
33.32	29	151								
33.63	17	52								
33.74	30	176								
34.15	28	94								
35.54	31	76	√	√	√		√			
35.71	25	21	√							

Figure 9: Pairs of vegetation types at the Raith field trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height, c) 1990 height, and d) needle flush.

a. 1988 Height (Grand Mean = 66.1 mm)

Mean (mm)	S-Type	# Rep	S4	S2	SS6	S3	S5	S6	SS2	S1	SS5	SS7	SS1	SS3
53.2	S4	16												
57.1	S2	117												
57.3	SS6	40												
61.1	S3	40												
62.1	S5	48												
64.2	S6	53												
64.3	SS2	22												
66.2	S1	532		√										
67.3	SS5	56												
70.3	SS7	15												
73.7	SS1	113	√	√	√	√	√			√				
96.5	SS3	36	√	√	√	√	√	√	√	√	√	√	√	

b. 1989 Height (Grand Mean = 151.9 mm)

Mean (mm)	S-Type	# Rep	S4	SS2	S2	SS5	S3	SS6	S5	S6	SS7	S1	SS1	SS3
113.6	S4	21												
126.1	SS2	32												
126.8	S2	136												
137.0	SS5	70												
138.1	S3	55												
139.0	SS6	44												
144.6	S5	66												
145.0	S6	63												
154.9	SS7	21												
155.8	S1	639	√	√	√	√								
176.6	SS1	123	√	√	√	√	√	√	√	√		√		
218.2	SS3	42	√	√	√	√	√	√	√	√	√	√	√	

c. 1990 Height (Grand Mean = 279.6 mm)

Mean (mm)	S-Type	# Rep	S4	SS2	S2	SS5	SS6	SS7	S6	S3	S5	S1	SS1	SS3
215.8	S4	18												
231.8	SS2	30												
238.6	S2	134												
249.4	SS5	66												
258.5	SS6	43												
264.5	SS7	22												
268.0	S6	63												
268.3	S3	52												
273.8	S5	64												
286.3	S1	619	√	√	√	√								
317.6	SS1	118	√	√	√	√	√		√	√	√	√		
385.7	SS3	41	√	√	√	√	√	√	√	√	√	√	√	

Figure 10: Pairs of soil types at the Raith field trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height, c) 1990 height, d) elongation cessation date, and e) needle flush.

d. Elongation cessation date (Grand Mean = 74.9)

Mean (days)	S-Type	# Rep	S4	S2	SS6	SS5	SS2	S5	S1	S6	SS7	SS1	S3	SS3
69.7	S4	16												
72.7	S2	114												
73.2	SS6	41												
73.3	SS5	57												
73.5	SS2	29												
74.0	S5	58												
75.0	S1	567		√										
75.5	S6	55												
75.6	SS7	18												
77.0	SS1	110	√	√		√								
78.3	S3	41	√	√	√	√								
79.1	SS3	39	√	√	√	√	√	√	√					

d. Needle flushing date (Grand Mean = 33.40)

Mean (days)	S-Type	# Rep	S4	S1	SS7	SS1	S2	S5	SS3	SS2	S3	SS5	SS6	S6
30.81	S4	16												
32.73	S1	594												
33.05	SS7	19												
33.18	SS1	119												
33.56	S2	126												
33.78	S5	60												
33.79	SS3	39												
34.44	SS2	32												
34.68	S3	47	√	√										
34.77	SS5	65	√	√										
35.60	SS6	40	√	√		√								
35.67	S6	61	√	√		√	√							

Figure 10 (cont'd): Pairs of soil types at the Raith field trial whose seedling averages differed significantly at the 5 per cent level for a) 1988 height, b) 1989 height, c) 1990 height, d) elongation cessation date, and e) needle flush.

mm in 1988, 1989, and 1990 respectively. Tests for the homogeneity of variances were significant for all three of the annual height variables.

Elongation cessation date was also significantly different among seedlings classified to the twelve FEC soil types (Figure 10). Seedlings of type SS 3 ceased elongation latest, on average, at 79.1 days, or by July 19. Seedlings of this type, which elongated significantly later than those of seven other soil types, were consistently the tallest on average at Raith. Similarly, the type whose seedlings averaged earliest elongation cessation, S 4 at 69.7 days, or by July 9, had the shortest seedlings on average at the Raith trial. Seedlings of S 4 were also the first to cease elongation at LU; however, those of SS 3 ceased elongation at approximately the average date at the LU field trial. Tests for homogeneity of variance were not significant, but the unequal representation of seed sources among soil types, compounded by the geographical proximity of some of these seed sources of a given soil type, may be causing some of the results seen here.

Needle flushing date was earliest at Raith for seedlings of type S 4, averaging May 31st, and latest for those of S 6, averaging June 5 (Figure 10). At LU, average needle flushing date of seedlings of S 4 was among those that flushed after the average date of the entire trial, and average needle flushing date of seedlings of soil type S 6 was among the last to flush. Seedlings of SS 1, the earliest to flush on average at LU, also flushed ahead of the trial average at Raith. The latest to flush at LU, seedlings of SS 6, were also among the latest to flush at Raith on average. Tests for homogeneity of variances were not significant.

Simple Correlation Analysis

Relationships between measured variables and environmental variables were examined using simple correlation analysis. These correlations measure the relationship between two variables where pairs of observations are drawn at random.

Few environmental variables were strongly correlated to heights at the greenhouse trial (Table 13). Height in 1988 was significantly correlated to extreme maximum temperature (positive) and total annual precipitation (negative). Height increment in 1989 was related to association at origin; prevalence of black spruce (positive) and prevalence of feather moss (negative) were significantly related to 1989 height increment. Date of needle flush was significantly correlated to many environmental variables (Table 13). Significant positive correlations were seen between needle flushing date and the following variables: average maximum July temperature, average number of growing degree days, longitude, and elevation, while significant negative relationships were determined for average date of the first fall frost, latitude, and soil depth. Percentage of fall purpling at the green house trial was significantly positively correlated to average number of heating degree days, latitude, and prevalence of lichen at seed origin (Table 13). This percentage was significantly negatively correlated with average minimum January temperature, average mean daily temperature, and average annual number of growing degree days.

Simple linear correlations between measured LU field trial variables and environmental variables showed the most significant relationships (Table 14). Three climatic variables were significantly correlated to all eight LU field trial variables. These three were average maximum July temperature, extreme maximum temperature, and average annual number of growing degree days. Also, the spatial variable, longitude, was very significantly correlated to all eight LU field trial variables. Height in 1988 was significantly correlated to four climatic variables, one spatial variable, and three plant association variables at seed origin. Heights in 1989 and 1990 were significantly correlated to six climatic variables. Both latitude and longitude were associated with 1989 and 1990 heights, and elevation was correlated with 1990 heights. Of the variables describing plant association and soil conditions at origin, four were correlated with 1989 height, and five were correlated with 1990 height (Table 14). Elongation initiation was correlated with three climatic variables, one spatial variable, and two plant and soil variables. Elongation cessation and duration were correlated to the same environmental variables, including the three climatic variables, longitude, elevation, and the soil composition at seed origin. Needle flush at the LU field trial was highly correlated with environment at seed origin. Eight of the climatic variables were significantly correlated to needle flush date, as were all three spatial variables. Two of the three soil variables, and the prevalence of black spruce at seed origin were likewise significantly related to needle flush (Table 14). Purpling at the LU field trial was significantly correlated to five climatic variables, to latitude and longitude, and to three plant association variables at seed origin.

Of the seven measured variables at the Raith trial which showed significant variation due to seed source, needle flush was the only one significantly correlated to numerous variables describing seed origin

Table 13: Simple correlations between measured greenhouse variables and environmental variables.

	GH 88	GH 89	GH-NF	GH-R
Maximum July Temp	0.196	0.099	**0.289**	-0.152
Minimum Jan. Temp	-0.051	0.124	0.050	**-0.289**
Mean Daily Temp	0.015	0.181	0.134	**-0.360**
Extreme Maximum Temp	**0.295**	0.076	0.172	-0.050
Extreme Minimum Temp	-0.029	0.062	0.134	-0.084
Snow	-0.054	0.065	0.107	0.008
Total Precipitation	**-0.245**	-0.017	-0.197	0.054
Heating Degree Days	0.025	-0.219	-0.122	**0.334**
Growing Degree Days	0.076	0.180	**0.271**	**-0.386**
Last Spring Frost	0.040	0.083	0.166	0.193
First Fall Frost	-0.089	-0.140	**-0.271**	-0.130
Frost Free Period	-0.065	-0.117	-0.224	-0.161
Latitude	0.005	-0.155	**-0.296**	**0.302**
Longitude	0.124	0.016	**0.332**	-0.155
Elevation	-0.047	-0.071	**0.382**	-0.130
Soil Depth	0.023	-0.120	**-0.261**	0.009
% Conifer	0.004	0.099	-0.034	0.035
% Hardwood	-0.002	-0.066	-0.100	-0.041
% Jack Pine	-0.007	0.033	-0.058	0.021
% Black Spruce	0.097	**0.281**	-0.024	0.065
% White Spruce	0.077	0.087	0.083	-0.120
% Lichen	-0.067	0.059	0.186	**0.437**
% Bedrock	-0.115	0.021	0.213	0.003
% Feather Moss	0.018	**-0.266**	0.060	-0.023
% Sand	-0.036	-0.144	-0.087	-0.043
% Silt	0.021	0.186	-0.007	0.049
% Clay	0.037	0.055	0.174	0.034

GH-88:	Greenhouse height 1988	GH-NF:	Greenhouse needle flushing
GH-89:	Greenhouse height increment 1989	GH-R:	Greenhouse Purpling %

Bold print indicates significance at the 5% level.

Table 14: Simple linear correlations between measured LU field trial variables and environmental variables.

	LU 88	**LU 89**	**LU 90**	**LU-IN**	**LU-CS**	**LU-DR**	**LU-NF**	**LU-R**
Maximum July Temp	**0.426**	**0.470**	**0.508**	**-0.331**	**0.488**	**0.499**	**0.399**	**-0.381**
Minimum Jan. Temp	0.097	0.202	0.216	-0.082	-0.066	-0.061	**0.265**	-0.242
Mean Daily Temp	0.220	**0.355**	**0.388**	-0.188	0.116	0.125	**0.435**	-0.378
Extreme Maximum Temp	**0.430**	**0.405**	**0.437**	**-0.344**	**0.306**	**0.321**	**0.365**	**-0.311**
Extreme Minimum Temp	0.105	0.135	0.140	-0.022	-0.054	-0.052	0.118	-0.105
Snow	-0.105	-0.086	-0.103	-0.039	0.156	0.156	-0.064	0.088
Total Precipitation	**-0.251**	**-0.290**	**-0.341**	0.189	-0.203	-0.211	**-0.384**	0.110
Heating Degree Days	-0.145	**-0.299**	**-0.331**	0.133	-0.069	-0.076	**-0.431**	**0.350**
Growing Degree Days	**0.320**	**0.465**	**0.522**	**-0.281**	**0.396**	**0.406**	**0.543**	**-0.459**
Last Spring Frost	0.058	0.102	0.116	-0.087	0.104	0.107	0.172	-0.034
First Fall Frost	-0.122	-0.190	-0.208	0.130	-0.182	-0.187	**-0.258**	0.085
Frost Free Period	-0.094	-0.152	-0.167	0.112	-0.145	-0.149	-0.220	0.064
Latitude	-0.221	**-0.381**	**-0.442**	0.202	-0.173	-0.181	**-0.510**	**0.363**
Longitude	**0.409**	**0.435**	**0.516**	**-0.344**	**0.346**	**0.361**	**0.487**	**-0.407**
Elevation	0.153	0.231	**0.280**	-0.152	**0.246**	**0.251**	**0.381**	-0.124
Soil Depth	-0.096	-0.066	-0.180	-0.094	-0.185	-0.177	-0.194	0.024
% Conifer	**0.324**	**0.363**	**0.252**	-0.201	0.040	0.051	0.086	**-0.375**
% Hardwood	-0.183	-0.156	-0.146	0.057	-0.186	-0.186	-0.185	0.177
% Jack Pine	**0.316**	**0.307**	0.180	-0.171	0.018	0.027	-0.013	**-0.272**
% Black Spruce	0.155	**0.307**	**0.346**	-0.051	0.100	0.101	**0.308**	**-0.282**
% White Spruce	-0.030	-0.037	-0.021	0.005	0.007	0.007	0.154	-0.083
% Lichen	0.084	0.046	0.114	-0.030	-0.040	-0.038	-0.194	0.093
% Bedrock	-0.118	-0.127	-0.064	0.032	-0.045	-0.046	0.047	0.186
% Feather Moss	**-0.254**	**-0.362**	**-0.392**	**0.303**	0.003	-0.013	-0.177	**0.260**
% Sand	-0.122	-0.167	**-0.266**	0.241	**-0.321**	**-0.329**	**-0.251**	0.133
% Silt	0.164	0.202	**0.321**	-0.175	**0.326**	**0.331**	**0.268**	-0.156
% Clay	0.039	0.102	0.160	**-0.267**	**0.246**	**0.257**	0.186	-0.104

LU-88:	LU height 1988	LU-CS:	LU elongation cessation	
LU-89:	LU height 1989	LU-DR:	LU elongation duration	Bold print indicates
LU-90:	LU height 1990	LU-NF:	LU needle flushing	significance at the 5%
LU-IN:	LU elongation initiation	LU-R:	LU purpling %	level.

Table 15: Simple linear correlations between measured Raith trial variables and environmental variables.

	R88	R89	R90	R-CS	R-DR	R-NF	R-SU
Maximum July Temp	-0.086	-0.067	-0.077	-0.034	-0.067	**0.449**	**-0.256**
Minimum Jan. Temp	0.150	0.122	0.062	0.116	0.039	**0.266**	-0.009
Mean Daily Temp	0.131	0.099	0.048	0.129	0.026	**0.416**	-0.130
Extreme Maximum Temp	-0.057	-0.085	-0.079	-0.125	-0.151	**0.291**	-0.220
Extreme Minimum Temp	0.184	0.137	0.087	0.200	0.095	0.159	0.048
Snow	-0.155	-0.023	-0.007	0.050	0.054	0.065	-0.015
Total Precipitation	-0.151	-0.066	-0.115	-0.027	0.002	-0.137	0.045
Heating Degree Days	-0.094	-0.090	-0.042	-0.134	-0.062	**-0.388**	0.061
Growing Degree Days	0.049	0.088	0.040	0.095	0.011	**0.512**	-0.201
Last Spring Frost	**-0.326**	**-0.307**	**-0.280**	-0.125	-0.055	0.154	-0.053
First Fall Frost	**0.264**	0.241	0.225	0.058	0.010	**-0.248**	0.077
Frost Free Period	**0.296**	**0.274**	**0.253**	0.088	0.029	-0.207	0.064
Latitude	-0.061	-0.037	0.015	-0.120	-0.046	**-0.519**	0.164
Longitude	-0.060	-0.194	-0.243	-0.155	-0.223	**0.550**	**-0.451**
Elevation	0.061	0.007	-0.055	0.003	-0.032	**0.249**	-0.162
Soil Depth	-0.026	-0.053	-0.060	-0.002	0.041	-0.157	-0.093
% Conifer	0.149	0.045	-0.043	-0.004	-0.005	0.120	-0.109
% Hardwood	-0.145	-0.035	0.023	0.017	0.073	-0.094	0.092
% Jack Pine	0.181	0.065	-0.019	-0.030	-0.009	0.061	-0.087
% Black Spruce	0.063	0.048	0.075	0.142	0.023	-0.101	-0.003
% White Spruce	-0.048	-0.001	-0.056	0.027	0.048	**0.292**	-0.026
% Lichen	-0.016	0.014	-0.021	-0.144	-0.059	0.073	0.242
% Bedrock	0.091	0.166	0.176	0.096	0.070	0.040	0.180
% Feather Moss	0.012	0.087	0.043	0.047	0.053	**-0.354**	-0.038
% Sand	0.170	0.129	0.076	0.081	0.240	**-0.420**	0.218
% Silt	-0.211	-0.189	-0.106	-0.130	**-0.298**	**0.399**	**-0.286**
% Clay	-0.083	-0.022	-0.012	0.012	-0.099	**0.326**	-0.070

R88: Raith height 1988
R89: Raith height 1989
R90: Raith height 1990

R-CS: Raith elongation cessation
R-DR: Raith elongation duration
R-NF: Raith needle flushing
R-SU: Raith survival %

Bold print indicates significance at the 5 per cent level.

(Table 15). Seven climatic variables were highly correlated to needle flush at Raith, as were latitude, longitude, and elevation. All the variables describing soil texture at seed origin were correlated to needle flush, as were the prevalence of feather moss and white spruce at seed origin (Table 15). Other significant correlations were seen between both the average date of the last spring frost and frost free period, with heights for 1988, 1989, and 1990. The average date of the first fall frost was correlated to height in 1988 as well. No significant correlations were seen between elongation cessation at Raith and conditions at seed origin. Prevalence of silt in the soil at seed origin correlated with elongation duration. Survival at Raith was correlated to average maximum July temperature, longitude, and proportion of silt in the soil at seed origin (Table 15).

MULTIVARIATE ANALYSIS

Variable Correlations

Many of the variables examined in this study were highly correlated. The Pearson correlation matrix based on the mean values for each of the variables measured in each of the trials is presented in Table 16.

Positive correlations were consistently displayed between growth variables within each trial, as expected. Generally, growth variables were positively correlated with date of elongation cessation and duration of elongation within each trial as well (Table 16). Significant correlations between growth variables and date of elongation initiation within trials was always negative, meaning that seed sources whose seedlings initiated elongation earlier were taller, on average. For the trials in which purpling was examined, its relationship to growth variables was negative; seed sources with taller than average seedlings had lower percentages of seedlings purpled. Higher survival rates were seen among seedlings of seed sources with taller than average seedlings at the Raith trial. The relationship between growth variables and needle flushing was inconsistent among trials, with positive correlations displayed at the greenhouse and LU field trials, and negative correlations displayed at the Raith trial (Table 16).

The dates of average elongation cessation were consistently positively correlated to the average elongation duration within each trial (Table 16). No other consistent relationships were seen between phenological variables within the trials. While the average date of elongation initiation was positively correlated to elongation cessation at the greenhouse trial, it was negatively correlated at the LU field trial, and at the Raith trial average elongation initiation was negatively correlated to elongation duration (Table 16).

Greenhouse height and height increment for 1988 and 1989 respectively were positively correlated with all three LU growth variables, but only 1988 greenhouse height was significantly positively correlated with 1988 Raith height (Table 16). Other growth varibles showed minimal correlation among trials. Average timing of the needle flushing of seed sources was positively correlated among all three trials, as was the proportion of purpling at the greenhouse trial and the LU field trial (Table 16). Other consistent trends between variables among the trials are not evident.

Table 16: Pearson's correlation matrix of the variables measured in the Greenhouse, Lakehead University field, and Raith trials.

	GH-88	GH-89	GH-IN	GH-CS	GH-DR	GH-NF	GH-R	LU-88
GH-88								
GH-89	.4189 **							
GH-IN	-.1427	-.4496 **						
GH-CS	.0297	.2317	.0493					
GH-DR	.0484	.2913 *	-.0842	.9911 **				
GH-NF	.3173 *	-.2216	.2568 *	-.1838	-.2176			
GH-R	-.3859 **	-.2044	.0510	.1482	.1411	-.1514		
LU-88	.5171 **	.3591 **	-.0262	.1052	.1083	.2444	-.2246	
LU-89	.4825 **	.5251 **	-.2083	-.0475	-.0196	.1778	-.2968	.8685 **
LU-90	.4422 **	.4725 **	-.2349	-.0234	.0080	.2229	-.2183	.8100 **
LU-IN	-.2390	-.2264	.0317	.0264	.0220	-.2315	.1158	-.4749 **
LU-CS	.3201 **	.1229	-.1806	.0687	.0926	.2917	-.1263	.4150 **
LU-DR	.3289 **	.1341	-.1796	.0660	.0899	.3002 **	-.1310	.4356 **
LU-NF	.2252	.2059	-.1544	-.3558 **	-.3343 **	.3223 **	-.3555 **	.2610 *
LU-R	-.3345 **	-.5178 **	.1296	-.0186	-.0358	-.0157	.3292 **	-.5977 **
R-88	.3041 **	.0997	.3032 *	-.1101	-.1506	.1933	-.2093	.3117 *
R-89	.1834	.1331	.2789 *	-.1444	-.1815	.1299	-.1799	.2000
R-90	.2053	.1413	.2828 *	-1281	-.1658	.0776	-.1636	.1678
R-IN	.0563	.0418	-.0600	.0672	.0749	-.0278	-.0260	.0285
R-CS	.1033	.1567	.1560	-.1151	-.1359	.1197	-.0494	.1361
R-DR	.0736	.1303	.1637	-.1368	-.1585	.1051	-.0324	.1053
R-NF	.1009	-.0015	-.1411	-.1004	-.0813	.2639 *	-.0395	.1587
R-SU	-.1915	.2095	.1359	-.0146	-.0327	-.2033	.0620	-.0960

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-IN: Greenhouse Elongation Initiation
GH-CS: Greenhouse Elongation Cessation
GH-DR: Greenhouse Elongation Duration
GH-NF: Greenhouse Needle Flushing
GH-R: Greenhouse Percent Reddening

LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing
LU-R: LU Percent Reddening

R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-IN: Raith Elongation Initiation
R-CS: Raith Elongation Cessation
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing
R-SU: Raith Percent Survival

*Significant at the 5 % level.

**Significant at the 1 % level.

Table 16 (Continued): Pearson's correlation matrix of the variables measured in the Greenhouse, Lakehead University field, and Raith trials.

	LU-89	LU-90	LU-IN	LU-CS	LU-DR	LU-NF	LU-R	R-88	R-89
GH-88									
GH-89									
GH-IN									
GH-CS									
GH-DR									
GH-NF									
GH-R									
LU-88									
LU-89									
LU-90	.9537 **								
LU-IN	-.6460 **	-.6505 **							
LU-CS	.4728 **	.5633 **	-.2426						
LU-DR	.5021 **	.5915 **	-.2954 *	.9985 **					
LU-NF	.3939 **	.4179 **	-.2168	.2099	.2191				
LU-R	-.7613 **	-.7515 **	.5580 **	-.3504 **	-.3767 **	-.3672 **			
R-88	.2287	.1863	-.1312	.0204	.0275	.0510	-.0877		
R-89	.2247	.1883	-.1989	-.0360	-.0241	-.0478	-.0773	.7892 **	
R-90	.2000	.1731	-.1807	-.0539	-.0427	-.0694	-.0541	.7501 **	.9768 **
R-IN	.0247	.0882	.0134	.1245	.1215	.1153	-.0381	.0184	-.2063
R-CS	.2125	.1733	-.1424	-.0654	-.0561	.0858	-.1305	.4821 **	.6540 **
R-DR	.1728	.1100	-.1248	-.1350	-.1255	.0253	-.0965	.4457 **	.6863 **
R-NF	.1768	.2707 *	-.1766	.2141	.2206	.3879 **	-.2264	-.2285	-.4122 **
R-SU	-.0555	-.1190	.0105	-.2627 *	-.2591 *	-.3155 *	.0885	.3131 *	.6445 **

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-IN: Greenhouse Elongation Initiation
GH-CS: Greenhouse Elongation Cessation
GH-DR: Greenhouse Elongation Duration
GH-NF: Greenhouse Needle Flushing
GH-R: Greenhouse Percent Reddening

LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing
LU-R: LU Percent Reddening

R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-IN: Raith Elongation Initiation
R-CS: Raith Elongation Cessation
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing
R-SU: Raith Percent Survival

*Significant at the 5 % level.
**Significant at the 1 % level.

Table 16 (Continued):Pearson's correlation matrix of the variables measured in the Greenhouse, Lakehead University field, and Raith trials.

	R-90	R-IN	R-CS	R-DR	R-NF
GH-88					
GH-89					
GH-IN					
GH-CS					
GH-DR					
GH-NF					
GH-R					
LU-88					
LU-89					
LU-90					
LU-IN					
LU-CS					
LU-DR					
LU-NF					
LU-R					
R-88					
R-89					
R-90					
R-IN	-.1717				
R-CS	.6852 **	-.0084			
R-DR	.7032 **	-.3582 **	.9337 **		
R-NF	-.4679 **	.1973	-.2079	-.2752	
R-SU	.6351 **	-.2450	.4839 **	.5471 **	-.4814 **

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-IN: Greenhouse Elongation Initiation
GH-CS: Greenhouse Elongation Cessation
GH-DR: Greenhouse Elongation Duration
GH-NF: Greenhouse Needle Flushing
GH-R: Greenhouse Percent Reddening

*Significant at the 5 % level.

LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing
LU-R: LU Percent Reddening
**Significant at the 1 % level.

R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-IN: Raith Elongation Initiation
R-CS: Raith Elongation Cessation
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing
R-SU: Raith Percent Survival

Principal Components Analysis

Because so many of the variables measured in these trials were highly correlated, principal components analysis (PCA) was used to examine the patterns of variation displayed. Variables that showed a significant portion of the total variance attributable to seed source population (Table 6) were included in the PCA, together with the percentages of survival at the Raith trial, and purpling at the LU field trial and at the greenhouse. As date of elongation initiation and date of elongation cessation led to the calculation of elongation duration, only two of these three variables were included in the PCA. Thus the means of eight growth variables, six phenological variables, and three percentage variables (transformed using arcsine transformation) were included in the PCA (Table 17).

PCA of these 17 variables generated four significant principal components (eigenvalues > 1) that accounted for 70.8 per cent of the variation (Table 17). The first component, with its eigenvalue of 5.62 and accounting for 33.1 per cent of the variance, had high positive loadings for most variables. Highest positive loadings were displayed by LU field trial heights for all three years. Negative loadings were seen for three variables: LU purpling, LU elongation initiation, and greenhouse purpling (Table 17). That these three variables showed negative loadings was not unexpected, as they often were negatively correlated to those variables that showed strong positive loadings (Table 16). This component appeared to describe growth potential among seed sources.

The second component displayed high loadings by the Raith variables; all except needle flushing date had strong negative loadings

Table 17: Principal components analysis results for 17 growth and phenological characters.

	Components				
	1	2	3	4	5
Eigenvalue	5.620	3.654	1.583	1.181	0.946
% of Variance	33.061	21.494	9.309	6.946	5.566
Cumulative %	33.061	54.555	63.864	70.810	76.376
Variable*	**Component Loadings**				
GH-88	0.617	0.068	0.159	-0.319	-0.447
GH-89	0.532	0.025	-0.583	-0.367	-0.050
GH-NF	0.317	0.108	0.771	0.161	0.071
GH-R	-0.460	0.020	-0.185	0.667	0.011
LU-88	0.815	0.170	-0.053	0.165	-0.208
LU-89	0.920	0.195	-0.197	0.116	-0.000
LU-90	0.895	0.267	-0.139	0.206	0.021
LU-IN	-0.646	-0.123	0.096	-0.385	-0.301
LU-DR	0.527	0.342	0.162	0.290	-0.366
LU-NF	0.452	0.358	0.307	-0.379	0.443
LU-R	-0.752	-0.268	0.341	0.054	-0.181
R-88	0.468	-0.635	0.307	-0.042	-0.135
R-89	0.527	-0.784	0.163	0.047	0.010
R-90	0.480	-0.810	0.134	0.057	0.012
R-DR	0.347	-0.687	0.003	-0.005	0.296
R-NF	0.142	0.655	0.261	0.000	0.316
R-SU	0.024	-0.759	-0.272	0.066	0.186

*

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-NF: Greenhouse Needle Flushing
GH-R: % Purpling at Greenhouse
LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height 1990
LU-IN: LU Elongation Initiation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing
LU-R: % Purpling at LU
R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-DR: Raith Elongation Duration
R-NF: Raith Needle Flushing
R-SU: % Survival at Raith

(Table 17). The correlation matrix showed significant negative relationships between needle flush at Raith and other variables of this trial (Table 16), thus its strong positive loading when other Raith variables showed strong negative loadings for this component were not unusual. This component had an eigenvalue of 3.65 and accounted for 21.49 per cent of the variance (Table 17). It appears to reflect the drought hardiness and competitiveness of the seed sources.

The third component was dominated by performance at the greenhouse trial, with strong loadings from greenhouse needle flushing (positive) and greenhouse height increment in 1989 (negative) (Table 17). The relationship between these two variables was shown to be negative (Table 16). The third component had an eigenvalue of 1.58, and accounted for 9.31 per cent of the total variance (Table 17).

Highest loading for the fourth component was displayed by LU purpling (Table 17). Phenological variables, including elongation initiation (negative) and needle flushing date (negative) from the LU field trial also contributed to this component The eigenvalue for this component was 1.18 and the portion of variance accounted for by this component was 6.95 per cent.

Multiple Regression Analysis

Variable Means and Percentages

Backward stepwise multiple linear regression analysis was used to examine the relationship between the summary variables including the means and percentages of the growth, phenological, survival, and fall purpling variables (dependent) and the environment at seed source as described by the FEC and weather variables and elevation (independent). Only those variables that showed significant amounts of variance attributable to seed source population (Table 6) were examined using these techniques.

Significant regressions were generated for one of the three greenhouse variables that showed significant differences between seed source populations (Table 18) as well as for per cent purpling. The coefficient of determination (r^2) for needle flushing at the greenhouse was 0.19, and that of the percentage of seedlings of each source that were purple was 0.32.

Fall frost date and frost free period were the only environmental variables included in the regression equation of needle flushing date. FEC variables were more prevalent among the six environmental variables retained in the equation for the proportion of purpled seedlings (Table 18). FEC variables retained in this equation included prevalence of conifers, prevalence of jack pine, black spruce, and white spruce, and prevalence of lichen at seed origin. Also included in the equation for purpling was mean number of growing degree days at seed origin.

All the variables from the LU field trial were significantly related to the environment at seed origin with r^2 values ranging from 0.18 for both 1988 height and elongation initiation date, to 0.57 for needle flushing date (Table 19). The trend illustrated by the height variables at the LU field trial showed increasing provenance differentiation explained by environmental variables over time, with a r^2 of 0.18 in 1988, of 0.40 in 1989, and 0.41 in 1990. Height variation among provenances in 1988, 1989 and 1990 was explained consistently by maximum July temperature.

Table 18: Regression coefficients, intercepts, and r-squares associated with climatic and FEC variables for three of the measured variable means and the purpling at the greenhouse test.

Regression Statistic	**GH-88**	**GH-89**	**GH-NF**	**GH-R**
Intercept	13.357	121.471	95.337	143.613
Maximum July Temp				
Minimum Jan. Temp				
Mean Daily Temp	16.926			
Extreme Maximum Temp				
Extreme Minimum Temp				
Snow				
Total Precipitation				
Heating Degree Days				
Growing Degree Days				-0.072
Last Spring Frost	34.422			
First Fall Frost.	-39.711		-0.320	
Frost Free Period	36.860		0.163	
Latitude	24.103			
Elevation		-0.009		
Soil Depth				
% Conifer	-3.641			2.002
% Hardwood				
% Jack Pine	3.823			-2.011
% Black Spruce	1.656	0.338		-0.568
% White Spruce	2.156			-1.035
% Lichen				0.201
% Bedrock	-0.415			
% Feather Moss		-0.217		
% Sand				
% Silt				
% Clay				
r-square	0.257	0.105	0.194	0.315
Significance	0.118	0.099	0.001	0.002

*

GH-88: Greenhouse Height 1988
GH-89: Greenhouse Height Increment 1989
GH-NF: Greenhouse Needle Flushing
GH-R: Greenhouse % purpling(Arcsine)

Table 19: Regression coefficients, intercepts, and r-squares associated with climatic and FEC variables for each of the measured variable means in the LU field test.

Regression Statistic	LU-88	LU-89	LU-90	LU-IN	LU-CS	LU-DR	LU-NF	LU-R
Intercept	-168.70	-236.38	-294.69	13.25	17.00	4.75	27.10	180.10
Maximum July Temp	11.556	34.564	47.764		3.723	3.742	-0.547	-6.732
Minimum Jan. Temp							-0.438	
Mean Daily Temp							1.439	
Extreme Maximum Temp					-0.731	-0.695	0.236	
Extreme Minimum Temp		5.174						
Snow								
Total Precipitation								
Heating Degree Days								
Growing Degree Days								
Last Spring Frost					7.762	7.762		
First Fall Frost.					-7.675	-7.590	-0.034	-1.770
Frost Free Period					7.718	7.627		0.860
Latitude								7.593
Elevation		-0.014					0.001	0.008
Soil Depth								
% Conifer								
% Hardwood								
% Jack Pine		0.912						-0.093
% Black Spruce		1.603	3.113					-0.118
% White Spruce								
% Lichen							-0.012	
% Bedrock							-0.012	
% Feather Moss		-0.689	-1.344	0.003				
% Sand								
% Silt								
% Clay				-0.007				
r-square	0.182	0.402	0.405	0.180	0.387	0.389	0.572	0.310
Significance	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.004

*

LU-88: LU Height 1988
LU-89: LU Height 1989
LU-90: LU Height l 1990
LU-IN: LU Elongation Initiation

LU-CS: LU Elongation Cessation
LU-DR: LU Elongation Duration
LU-NF: LU Needle Flushing
LU-R: LU % Purpling (Arcsine)

A number of climatic and site factors including extreme minimum temperature, elevation, and prevalence of each of jack pine, black spruce, and feather moss at seed origin were included in the equation for 1989 height. Only black spruce and feather moss prevalence were added to the equation for 1990 height. The 1989 greenhouse height increment was explained by some of the same independent variables as the 1989 LU field trial height, including prevalence of black spruce and feather moss, and elevation of seed origin.

Phenological variables ranged in their relation to environmental variables with r^2 values ranging from 0.18 for elongation initiation to 0.57 for needle flushing date. Prevalence of feather moss and clay in the soil were associated with elongation initiation. Variation among provenances in elongation cessation and duration, highly correlated variables, was explained by frost dates and periods, as well as extreme maximum temperature. Eight of the environmental variables were retained in the regression equation for needle flushing, with temperatures figuring prominently (Table 19).

The proportion of seedlings that turned purple at the LU trial was explained by seven independent environmental variables, including mean maximum July temperature, mean fall frost date and frost free period, latitude, elevation, and the prevalence of jack pine and black spruce at seed source. The r^2 for this regression equation was 0.31 (Table 19).

Backwards stepwise multiple linear regression was run for the six dependent variables at the Raith trial that showed significant differences among seed sources when examined by one-way ANOVA (Table 6) and for the dependent variable of percentage of seedlings surviving with the 12 climate variables, two spatial variables, and 12 FEC variables. Significant

Table 20: Regression coefficients, intercepts, and r-squares associated with climatic and FEC variables for six of the measured variable means and the survival percentages in the Raith field test.

Regression Statistic	R-88	R-89	R-90	R-DR	R-NF	R-SU
Intercept	45.40	115.30	226.73	319.10	161.59	-578.98
Maximum July Temp.						17.204
Minimum Jan. Temp.					-0.394	14.813
Mean Daily Temp.						-32.188
Extreme Max. Temp.						-5.860
Extreme Min. Temp.						
Snow						
Total Precipitation						-0.170
Heating Degree Days						-0.048
Growing Degree Days						
Last Spring Frost				-1.386		
First Fall Frost.						
Frost Free Period	0.254	0.582	0.866	-0.632		
Latitude					-2.745	25.569
Elevation						
Soil Depth						
% Conifer					-0.227	
% Hardwood						
% Jack Pine					0.264	
% Black Spruce						
% White Spruce					0.225	
% Lichen						
% Bedrock						
% Feather Moss						
% Sand				0.117	-0.063	
% Silt						
% Clay						
r-square	0.088	0.075	0.064	0.144	0.621	0.320
Significance	0.017	0.028	0.043	0.057	0.000	0.002

*

R-88: Raith Height 1988
R-89: Raith Height 1989
R-90: Raith Height 1990
R-CS: Raith Elongation Cessation

R-DR: Raith Elongation Duration
R-NF: Raith Needle Flush
R-SU: Raith Survival (arcsine)

amounts of provenance variation were explained by environmental variables in six cases; no equation was derived for elongation cessation (Table 20). The variable for which most variation could be explained by environmental variables was needle flushing, with an r^2 value of 0.62. This was the highest displayed by any of the regression equations in all trials. Coefficients of determination were generally low for all other variables.

Comparison among like variables assessed in all three trials showed weak trends (Tables 18, 19, and 20). Frost free period was prevalent in equations for Raith heights, while July temperature dominated LU field trial heights. Needle flushing dates were predicted by an assortment of climatic and ecological variables, with first fall frost occurring in equations at both the greenhouse and the LU trials.

Factor Scores

The PCA factor scores based on the means and percentages of 17 variables from all three trials were regressed with the FEC, spatial, and climatic variables using backwards stepwise multiple linear regression (Table 21). Significant regression equations were generated for each of these sets of factor scores whose eigenvalues exceeded 1, with coefficients of determination (r^2) ranging from 0.20 to 0.43.

Backwards stepwise multiple linear regression for factor one retained average annual July maximum temperatures together with latitude (used to estimate photoperiod), in the equation (Table 21). The prevalence of conifers at the seed origin, further described by prevalence of each of jack pine, black spruce, and white spruce were also included in the

Table 21: Regression coefficients, intercepts, and coefficients of determination associated with climatic and FEC variables for four factor scores.

Regression Statistic	Factor 1	Factor 2	Factor 3	Factor 4
Intercept	18.243	-29.190	51.697	-0.716
Maximum July Temp.	0.498			
Minimum Jan. Temp.				
Mean Daily Temp.		1.609		
Extreme Max. Temp.				
Extreme Min. Temp.				
Snow				
Total Precipitation				
Heating Degree Days		0.003		
Growing Degree Days				
Last Spring Frost		0.080	1.697	
First Fall Frost.			-1.958	
Frost Free Period			1.837	
Latitude	-0.604			
Elevation			0.001	
Soil Depth				
% Conifer	-0.082			0.181
% Hardwood				
% Jack Pine	0.093			-0.168
% Black Spruce	0.052		-0.032	-0.064
% White Spruce	0.042			-0.109
% Lichen				0.018
% Bedrock				
% Feather Moss			0.018	
% Sand		-0.047		
% Silt				
% Clay		-0.069		
r-square	0.323	0.429	0.405	0.204
Significance	0.003	0.000	0.000	0.030

prediction of factor one scores. The r^2-value was 0.32. LU variables dominated the loadings for this component, which accounted for 33 per cent of the variation seen among the seed sources.

The regression equation for the second factor had the highest r^2-value, at 0.43 (Table 21). Environmental variables retained in this equation included mean daily temperature, heating degree days, average date of the last spring frost, and prevalence of sand and clay in the soil at seed source. This component had high negative loadings for many Raith variables, and accounted for 21 per cent of the variation seen among seed sources

The r^2-value for the regression equation of the third factor was 0.41 (Table 21). The portion of variation among seed sources accounted for by this component was nine percent. Climatic and ecological variables retained in this equation included all three variables relating to frost as well as elevation, and the prevalence of black spruce and feather moss at the seed source. This component was dominated by performance at the greenhouse trial, as seen from the loadings.

The fourth set of factor scores accounted for 7 per cent of the variation seen among seed sources. The r^2-value for the regression equation generated by these scores was 0.20 (Table 21). Only FEC variables were retained in the equation generated by backwards multiple linear regression for scores of factor four. These included all the measures of the prevalence of conifers at seed origin, and the prevalence of lichen at seed origin.

Trend Surface Diagrams

For each of the phenological and growth variables at each of the greenhouse, LU Field, and Raith trials, maps were generated using GIS techniques. These maps, based on the mean values for each variable at each seed source, are included in Appendix 7.

Trend surface diagrams of four sets of factor scores from the PCA based on the seed source means and percentages of 17 variables are presented in Figures 11 through 14. For each seed source, the factor score has been calculated using PCA techniques, and gives a z-value.

The trend illustrated by the first set of factor scores shows a longitudinal effect (Figure 11). Scores were generally negative to the east, north, and south of Lake Nipigon, with the lowest scores originating from the southeast portion of the study area. However, a band of positive scores ran along the east of Lake Nipigon, at a longitude of approximately 88°. Two pockets of positive scores occurred to the east of this band as well. In the western portion of the study area, west of Lakes Nipigon and Superior, scores were generally positive, with the highest scores occurring in the southwest portion of the study area. This western portion of the study area also showed variability, with negative scores located in a circular pattern in the midwestern portion of the area.

The scores of the second factor are illustrated in Figure 12. Scores to the east of Lake Nipigon were generally negative, with the extreme negative value occurring to the east of the northern portion of the lake. Except for the portion to the northeast of Lake Nipigon, the lake is encircled by positive scores. The southwest was also generally characterized by positive scores, though the most southwesterly portion of the study area shows a negative score. The extreme positive score occurs in this southwest portion of the study area as well.

Scores for the third principal component showed a broad band of positive scores running from the Ontario - Minnesota border through Lake Nipigon (Figure 13). Pockets of negative scores occurred within this area at the interception of the border and the Lake Superior shore, and in the west-central portion of the study area. To the east of Lake Nipigon the scores were primarily negative, with a large pocket of positive scores to the north of Lake Superior. The seed source displaying the extreme negative score and the one displaying the extreme positive score are both found in this area, relatively close to one another.

The scores of the fourth factor for each of the seed sources are presented in Figure 14. Negative scores run along the shore of Lake Superior and up to Lake Nipigon. A broad band of positive scores extends from the southwest of Lake Nipigon, as well as to the northeast and east of Lake Nipigon. An extensive pocket of positive scores occurs to the northwest of Lake Nipigon.

Factor scores were predicted based upon the regression equations developed using the spatial and climatic data. These new factor scores reflect the adaptive variation displayed as explained by these models.

The trend surface diagram produced by the set of scores predicted for the first component is seen in Figure 15. Negative scores were predicted for the north and northeast, and positive scores for the southwest, generally showing gentle clinal variation. The extreme negative score predicted for the extreme southeast collection influenced the trend displayed along the eastern edge of the study area and the north shore of Lake Superior.

Comparison of the actual factor scores (Figure 11) and the predicted factor scores (Figure 15) illustrate the smoothing effect of modeling when clinal variables such as average maximum July temperature and latitude are used in the prediction of the scores. The first factor scores, before regression, show the pattern of adaptive variation as well as variation which cannot be accounted for by this adaptive variation model. The unexplained variation is removed by the regression techniques, and while the same general trends are displayed, a number of irregularities are removed. This model accounted for 32.3 per cent of the variation as described by the first factor scores.

The predicted factor scores for the second component are illustrated in Figure 16. Because of unavailable data, predicted factor scores were not made for a number of the seed sources. The zero isogram circles most of Lake Nipigon, and much of the western portion of the study area. Within this isogram and bordering Lake Nipigon are the positive scores. Negative scores were predicted to the east of Lake Nipigon and along the north shore of Lake Superior. A narrow band of negative scores extend from the south of Lake Nipigon southwesterly to the wetern study area boundary. Extreme positive scores were predicted in the southwest portion of the study area.

A comparison of Figure 12, the second set of factor scores, and Figure 16, the predicted factor scores described by mean daily temperature, heating degree days, date of last spring frost, and proportion of sand and clay at seed origin, illustrates that general trends remain. The modeling removes the irregularities to a great extent, and displays the portion of the variation which is explained by climatic, spatial, and FEC variables included in this study. This model accounted for 42.9 per cent of the variation among seed sources displayed by the second factor scores.

Predicted factor scores for the third component were negative surrounding all but the southwest shores of Lake Nipigon and along the north Shore of Lake Superior. Bands of positive and negative scores running along north-south axis disseminated from this central feature (Figure 17). Extreme positive score for the third component was predicted for seed source 36 located to the north of Thunder Bay. The extreme negative scores were predicted in two locations, one to the immediate northwest of Lake Nipigon, and a second north of Lake Superior's Black Bay.

Likewise, the factor scores (Figure 13) and predicted factor scores (Figure 17) for the third principal component show similar trends, with 40.5 per cent of the variation among seed sources explained by the model. This model included the three frost variables, elevation, and two FEC variables.

Predicted scores for the fourth factor were described by FEC variables which are less clinal in nature, thus the patterns are weak. Lowest scores were predicted for two sites to the southeast of Lake Nipigon, and one site to the northeast of Lake Nipigon (Figure 18). Highest scores were predicted for a site to the northeast of Lake Nipigon, and one site along the northwest boundary of the study area. Comparison of the actual factor scores (Figure 14) and the predicted factor scores for the fourth set of factors shows little smoothing in the predicted scores, as the FEC variables used in the predictions are not continuous as the climatic variables used in the predictions of the first three sets of factor scores are..

Most of the factor scores, particularly those of the first and second component, indicate differences between sources in the southwest of the study area, and those in the southeast and eastern portions of the study area. This reflects the high simple linear correlations seen for individual variables with latitude (Tables 13, 14, and 15).

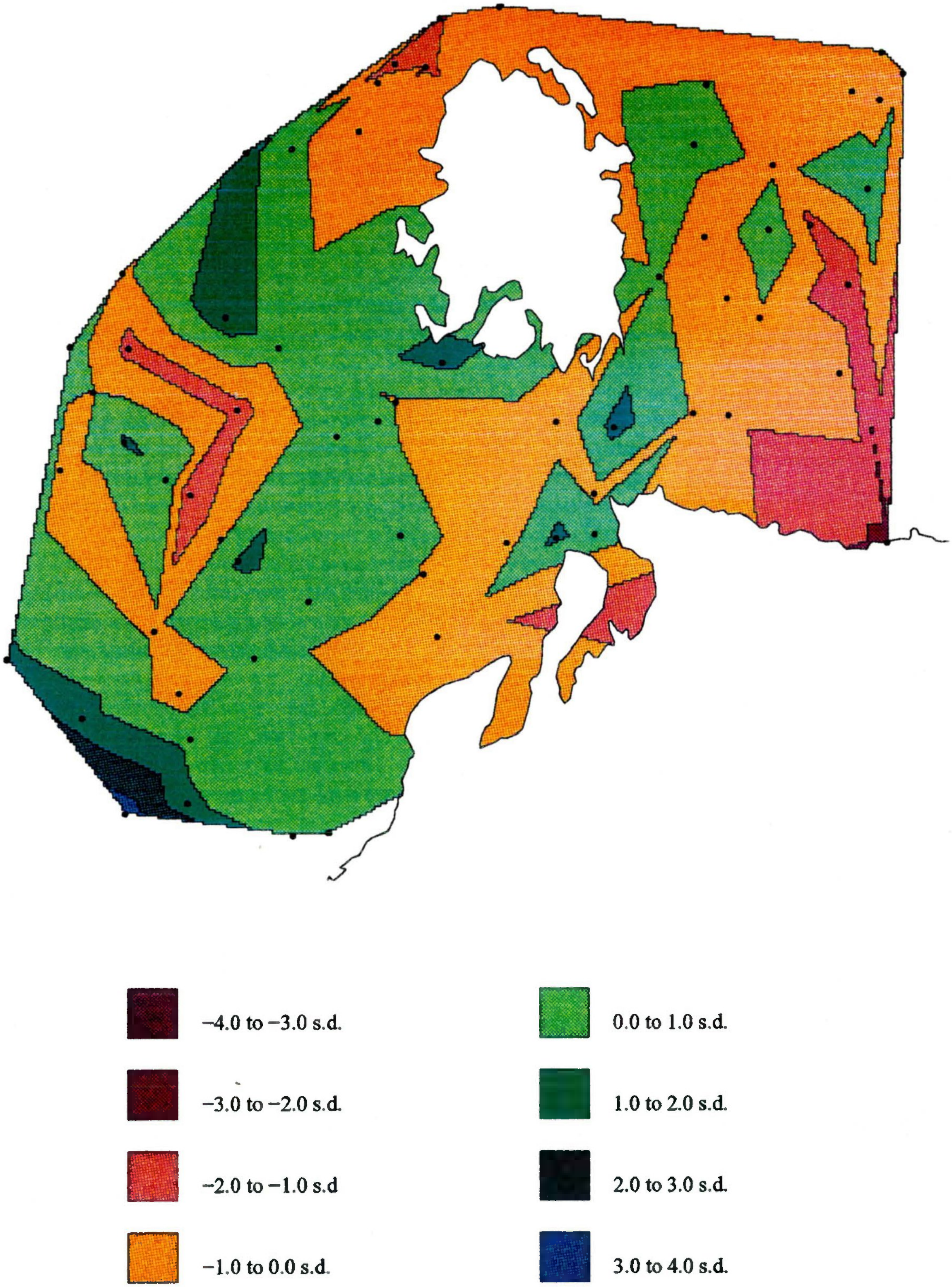

Figure 11: Trend surface diagram of the 64 factor scores of the first principal component.

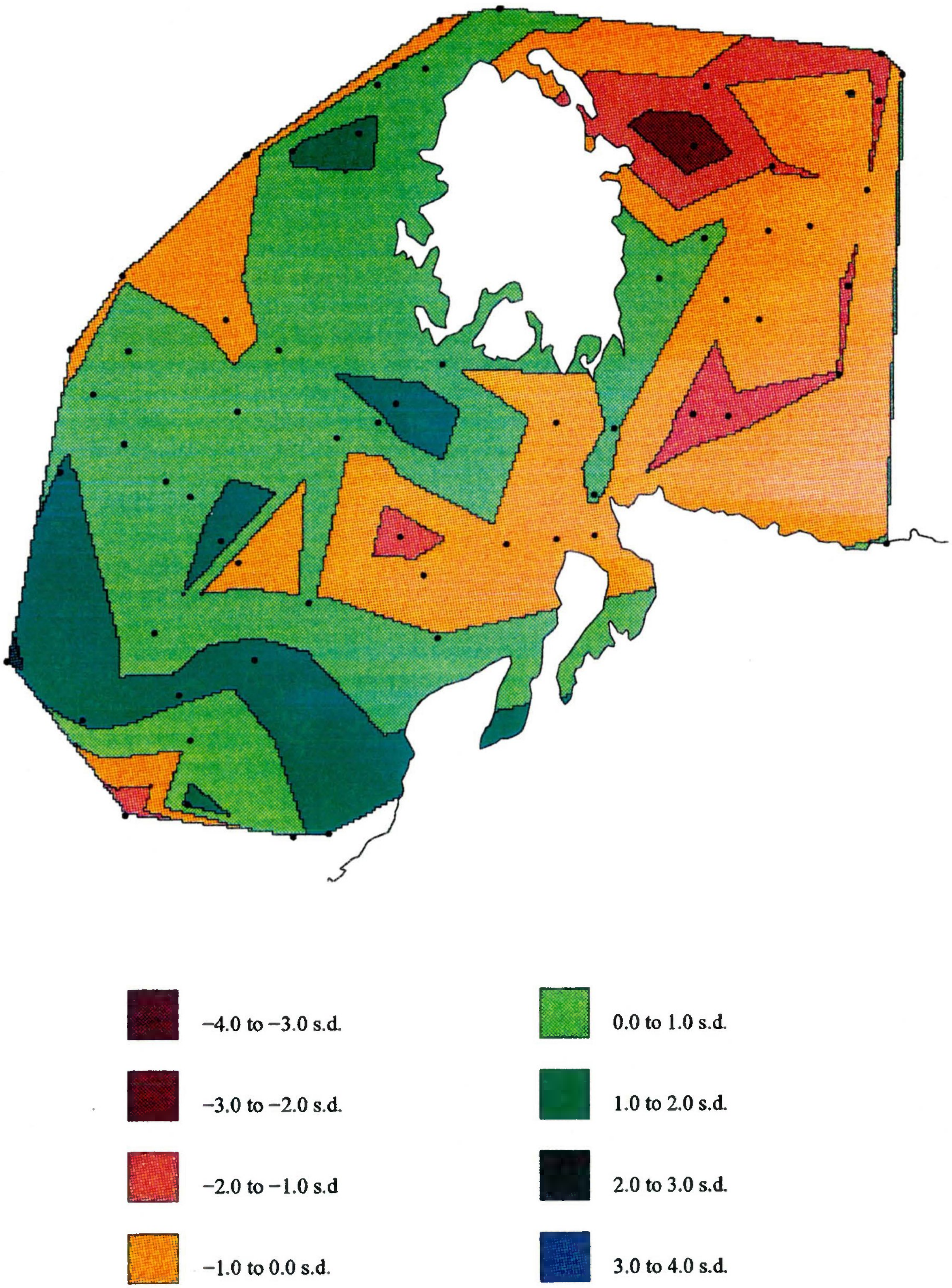

Figure 12: Trend surface diagram of the 64 factor scores of the second principal component.

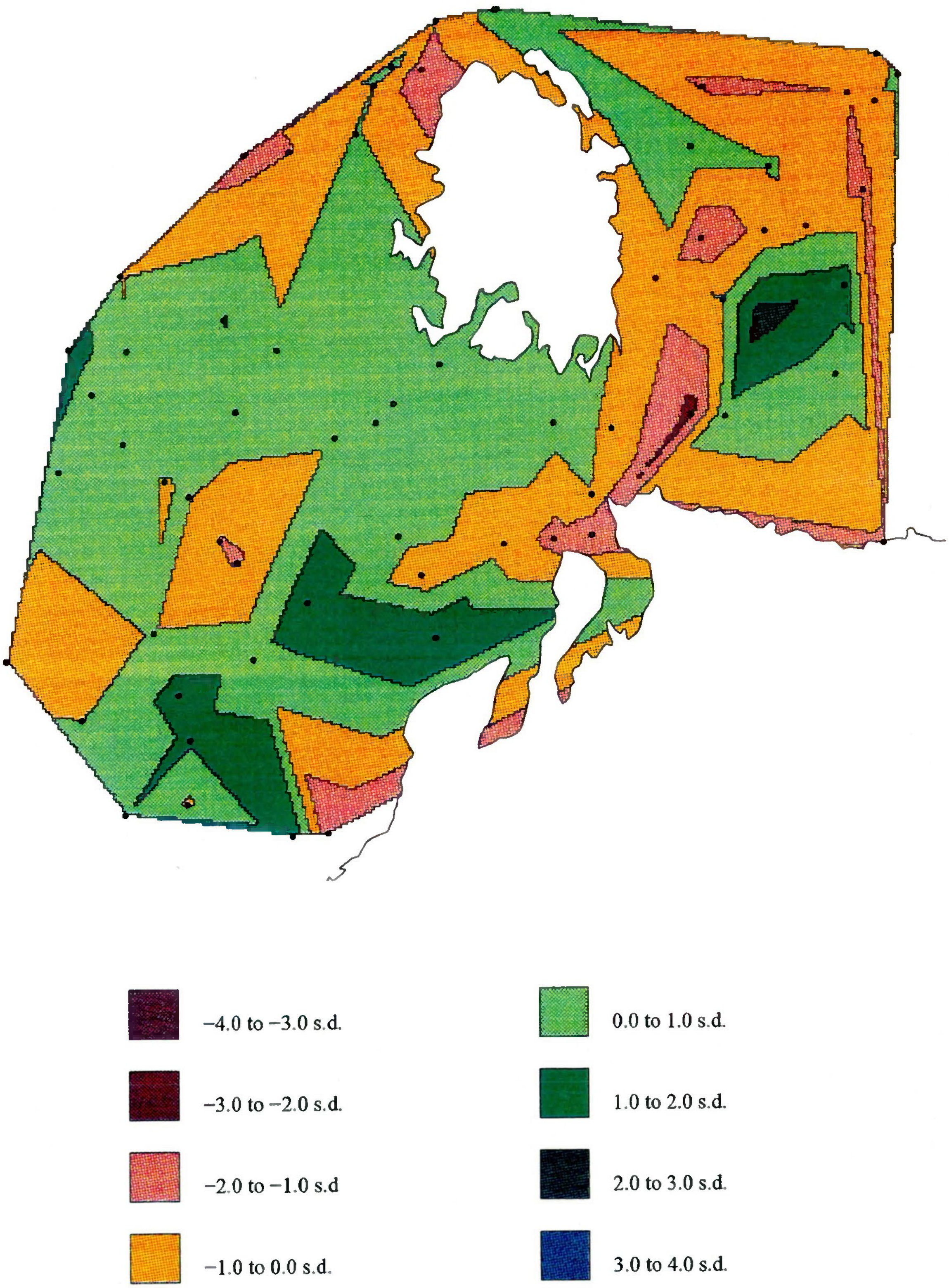

Figure 13: Trend surface diagram of the 64 factor scores of the third principal component.

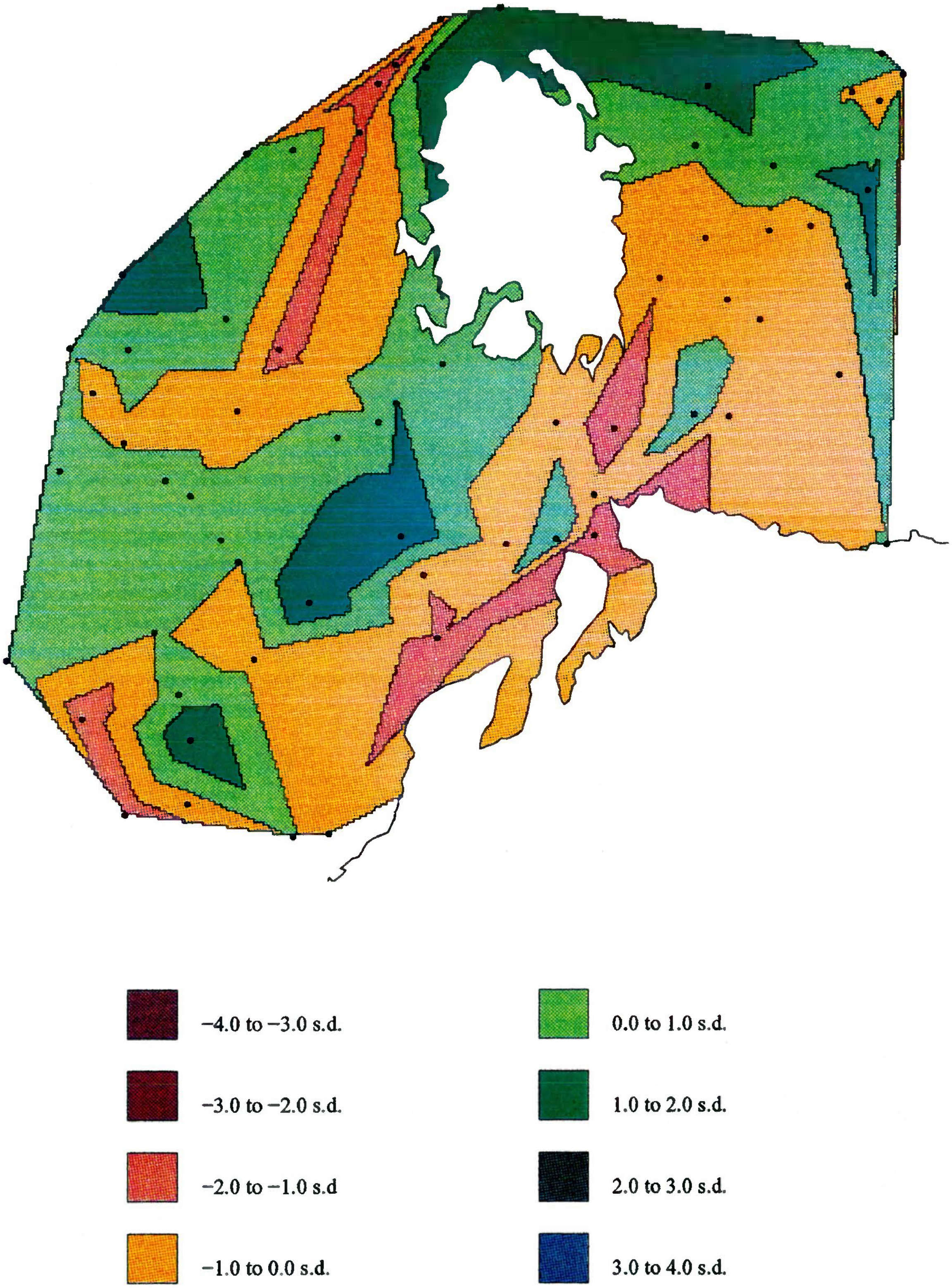

Figure 14: Trend surface diagram of the 64 factor scores of the fourth principal component.

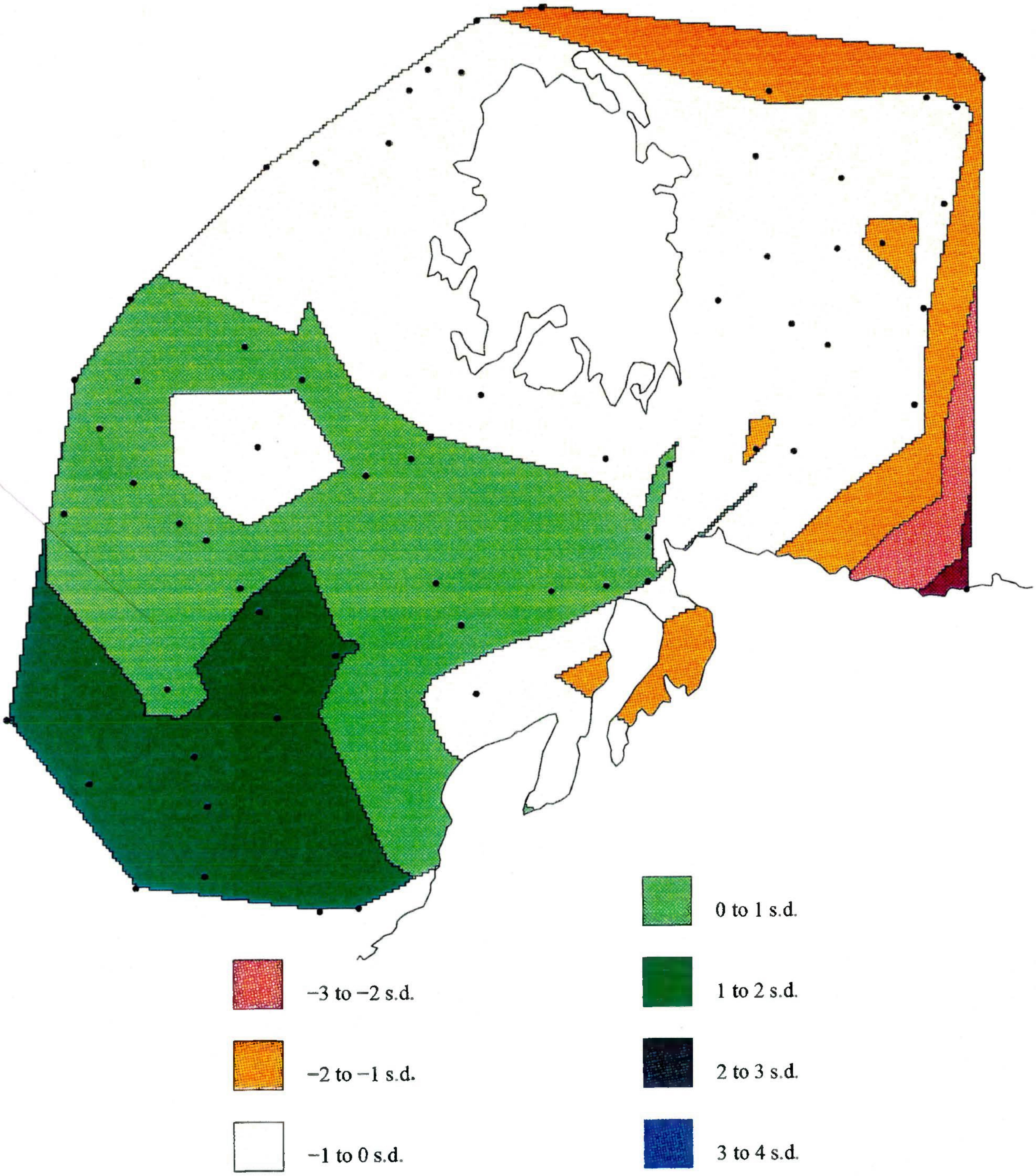

Figure 15: Trend surface diagram of the 64 predicted factor scores of the first principal component.

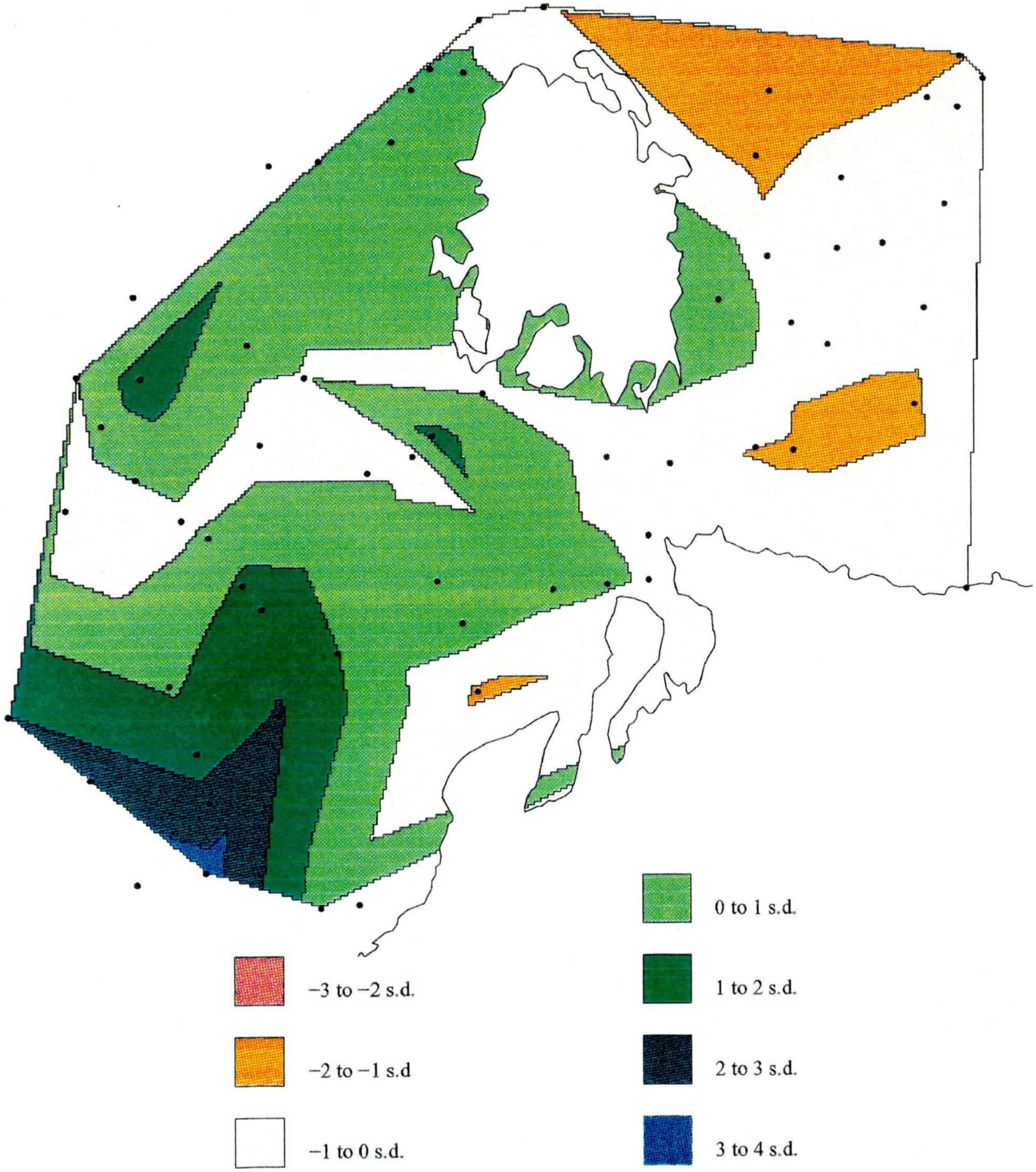

Figure 16: Trend surface diagram of the 64 predicted factor scores of the second principal component.

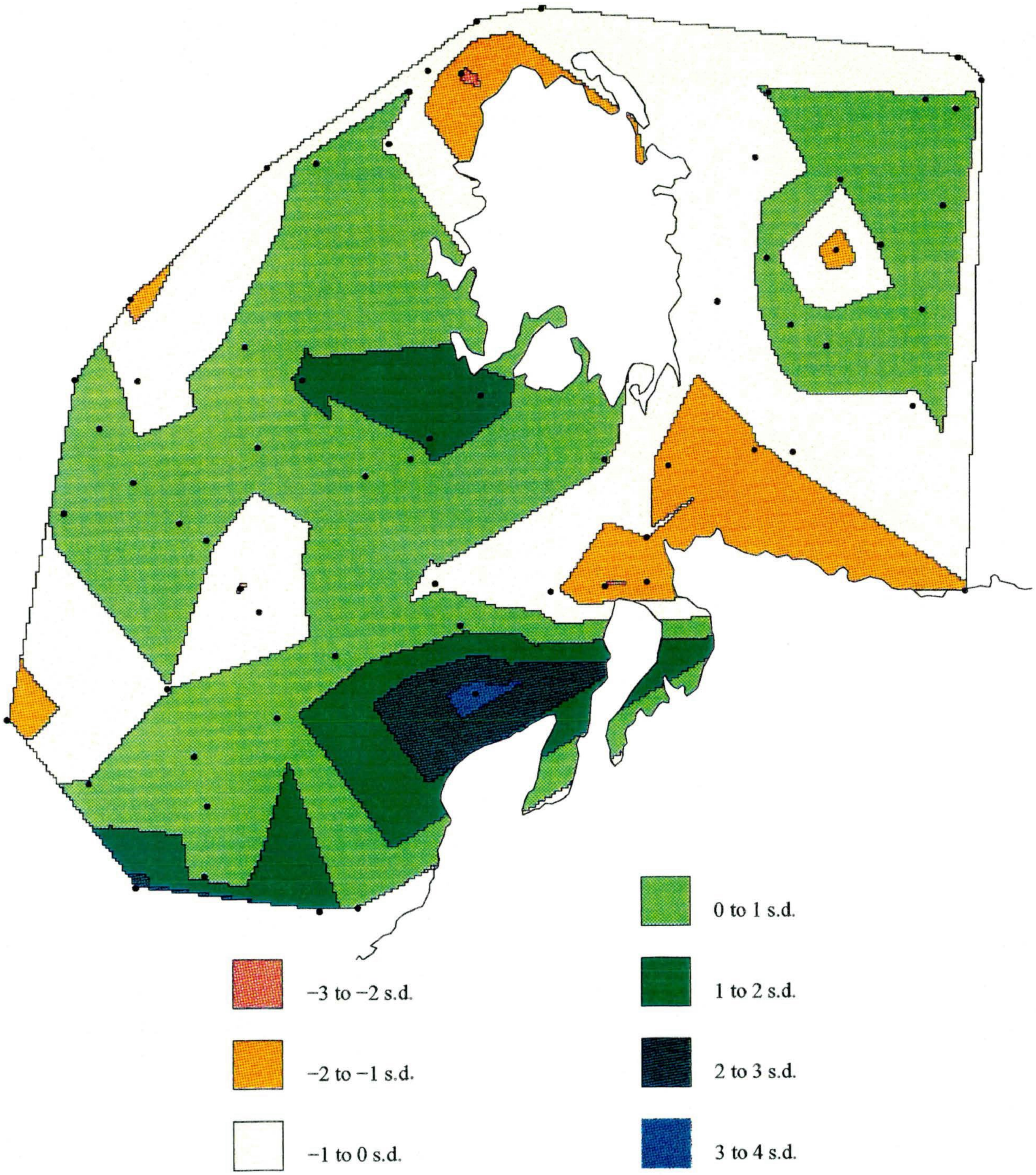

Figure 17: Trend surface diagram of the 64 predicted factor scores of the third principal component.

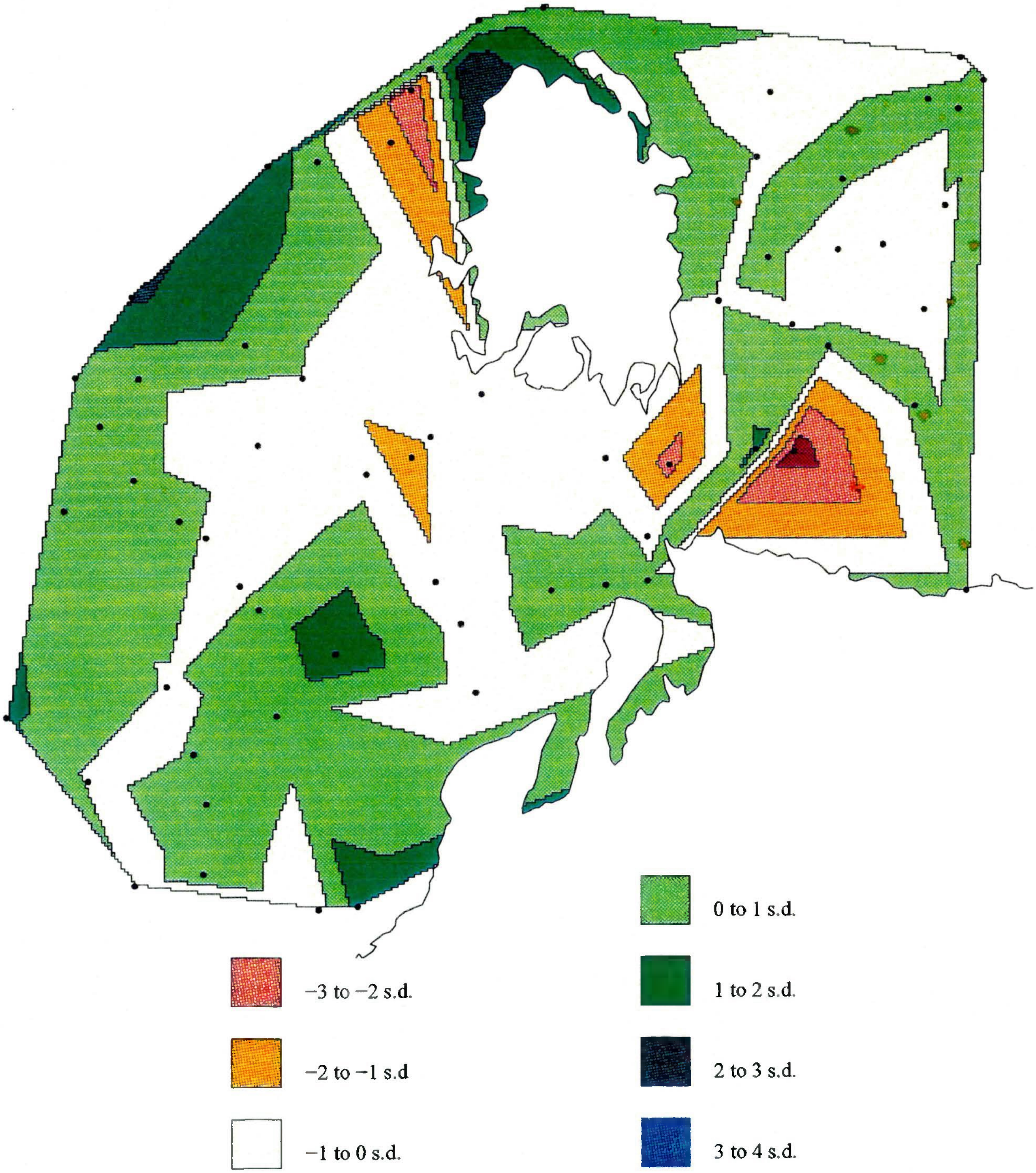

Figure 18: Trend surface diagram of the 64 predicted factor scores of the fourth principal component.

DISCUSSION

PATTERNS OF GENETIC VARIATION

Differences between Seed Sources

Significance of Source

Provenance studies of jack pine have shown that significant differences in performance were related to seed source (Magnussen and Yeatman 1989, 1987a, Rudolph and Yeatman 1982, Rudolph 1980, Yeatman 1976, Giertych and Farrar 1962, Jensen *et al* 1960). The intensive provenance trial results reported in this thesis reinforce these findings; many of the variables measured showed significant portions of observed variance due to seed source.

Most phenological and all growth traits showed differentiation among seed sources. Comparison of the types of traits consistently showed that growth traits (heights and increments) were associated with larger portions of variation attributable to seed source. This result may reflect phenotypic plasticity for phenological traits or may be a result of poorer quality data for phenological traits, particularly the elongation data.

The elongation data, including time of initiation, cessation, and duration, were derived from repeated measurements taken throughout the growing season. Linear regression techniques (Rehfeldt and Wykoff 1981) were applied to interpolate dates of initiation and cessation. As noted in the case of many seedlings in the LU trial, the growth equation poorly described the initial growth of the seedlings. Adjustments were made to the equation to improve the fit; however, a more complex equation may be required for those seedlings that showed variable elongation rates throughout the growing season and lammas growth late in the season. Mistakes made within the repeated measurements, particularly in the slow-growing Raith field trial, further hampered the fit of the growth equation and affected the quality of the interpolated data.

The best phenological data were the needle flushing data collected in the greenhouse trial, since it was scored daily throughout most of the flushing period, rather than being interpolated, as elongation dates were, or scored every second or third day, as was the case in the field trials. This was reflected in the greater portion of variance for this phenotypic variable attributable to seed source.

Timing of first needle flush was relatively unpredictable from long shoot development in individual jack pine seedlings. Intuition suggests that needle flushing date, the date that the first needle emerged from a fascicle along the developing long shoot, and elongation initiation date of that same long shoot would be strongly correlated. In the greenhouse trial a significant positive correlation was seen, whereas a significant negative correlation was seen at the LU field trial between these variables. This study supported the findings of Rudolph and Yeatman (1982) that growth initiation in the spring depended on the temperature of the planting site, since elongation initiation was significantly different among seed sources only for the LU field trial. In this case, 5 per cent of the variation seen in initiation data was attributable to seed source. Needle flushing appeared to be more strongly controlled by the adaptations of populations to the conditions at seed origin. Portions of variance attributable to seed source for elongation cessation were likewise small; however, they were significant for both the LU field trial and the Raith field trial.

Schoenike (1976) in a range-wide study found that 37 per cent of the variance measured in traits of crown form, bark, wood, foliage, and cones was associated with the geographic locations of the seed sources. In the present study, portions of variance attributable to seed source varied from 4.0 per cent to 30.0 per cent for traits in which seed source was a significant source of variation. For the study area used here Maley (1990) reported portions of variance associated with source ranging from 1.62 per cent to 18.85 per cent for needle and cone traits. The portion of variance attributable to source for growth traits (heights and increments) in the present study averaged 20 per cent. This exceeds the portion of variance attributable to seed source for any needle or cone characteristics measured for these same sources by Maley (1990). She examined needle shape by measuring lengths, widths, thicknesses, vascular bundle and resin canal shapes, and radial distances. Cone traits examined in her work included length, width, depth, cone scale measures, and seed measures.

The differences in the portion of variance attributable to seed source may reflect the difference in the scope of these studies. When the range of the tested provenances is increased, the total phenotypic variance is expected to increase, as is that portion of the variance attributable to seed source. Schoenike (1976) examined the entire range of jack pine, which is characterized by a great deal of diversity of climate and geography, and thus the amount of phenotypic variation observed in the species at that scale might be considerably greater. This study and Maley's study (1990) examined only a small portion of the entire range of the species by comparison. Furthermore, the type of study undertaken in the present work is that of a common garden, thus the effects of environment were minimized. In Schoenike's (1976) and Maley's (1990) studies phenotypic variation was examined in that measures were made from material gathered at each seed source thus environmental effects are greater.

The pattern of variation displayed by jack pine in the north central region of Ontario is generally clinal. The factor scores, derived from 17 measured variable means, are new variables that maximize the variation among seed sources. Examination of the trend surface diagrams produced from the first two sets of factor scores (Figures 11 and 12) showed no steep clines, though irregularities abound. The high scores seen for the first set of factor scores (Figure 11) in the southwest portion of the study area reflect sources whose seedlings grew tallest and initiated elongation early at the LU trial (source 33). The low score seen for seed source 22 in the southeast portion of the study area reflects shorter seedlings and late initiation of elongation. The highest scores seen for the second set of factor scores (Figure 12) are seen for sources whose seedlings were shorter than average at the Raith field trial, and had poorer survival percentages at that trial. These sources prevailed to the southwest of Lake Nipigon. Lowest scores were seen for seed sources whose seedlings were tall, on average, and had higher survival levels. Sources with negative scores prevailed to the east of Lake Nipigon. These two sets of factor scores account for 55 per cent of the variation seen within the factor scores data set, and the maps indicate that a significant contrast in performance between seedlings from the east of Lake Nipigon and the southwest portion of the study area exists.

The pattern of variation seen by Schoenike (1962, 1976) in his range wide studies was reported as a cline, with the most distinctive clinal pattern in the area from the Lake States to the Northwest. Maley and Parker (1993) found a very steep cline in cone characteristics as well as needle characteristics in the area to the south of Lake Nipigon, at a longitude of 88° 15'. The clinal gradient in the present study, though not as steep as that reported by Maley and Parker (1993) shows a similar trend along the north shore of Lake Superior.

Rank and Proximity

Findings of range-wide provenance tests planted in Ontario and Quebec typically showed that local sources or those of equivalent latitude ranked among the best in tree height average after ten years (Yeatman 1976). In the study reported here, no seed sources were collected in the vicinity of the LU trial; however, three collections were made to the west, at approximately the same latitude: sources 48, 51, and 64. By year three seedlings of these sources were taller than average at the LU field trial, with two sources ranked near the top. Of the two collection sources originating near the Raith field trial, sources 41 and 42, one ranked among the best height performers at that test, and another ranked worst. Collection sites of the same latitude generally performed average to slightly above average in height at this trial as well. However, in all trials the best height performance was seen in seedlings of a southern source, 33, originating near the Minnesota-Ontario border.

These findings appear to discredit the maxim of local seed source performance; however, juvenile height growth is only part of the picture.

Frost hardiness and long term survival would certainly be included in the evaluation of seed source performance. Studies which verify the local seed source performing best have generally been range-wide provenance studies with low sampling intensities while studies with greater sampling intensities have reported performances of nearby sources exceeding height performance of the local source (Schantz-Hansen and Jensen 1969).

Correspondence with Environmental Variation

As the desirable rotation for jack pine exceeds 40 years, the species must have the genetic fortitude either individually or as populations to withstand fluctuations of environment in time. The degree to which populations have adjusted their phenology to the amplitude of the local environmental conditions describes adaptive or genecological variation.

A portion of the variation seen among seed sources examined in this study reflects adaptive variation and has been measured using regression techniques. Selection forces that direct patterns of adaptive variation in plants include site factors and climate. These forces are generally variable in both space and time. Regressions for individual variables measured in this study showed correlations with a wide variety of independent environmental variables. Of the 26 site factors and climate variables examined, 23 were included in one or more of the equations.

Climatic and Spatial Factors

Certain climatic characteristics are highly variable over time (MacIver and Whitewood 1991). Precipitation is known to fluctuate drastically between years. Variability of climatic variables within the study area generally displays gradients though some steeper clines occur.

Schoenike (1962, 1976), in his examinations of 90 populations of jack pine across the range of the species, determined that environmental factors that correlated with measured traits included latitude, elevation, mean annual temperature, and mean annual precipitation. In the present study, each of these factors also played a role in one or more of the regression equations derived for the individual variables and the PCA factors by backwards stepwise multiple linear regression.

Davradou (1991) examined the tolerance to freezing of seedlings of the 64 seed sources used in the present study. Significant differences were detected among the seed sources for all the freezing tests. Frost hardiness appeared to be associated with extreme minimum temperatures, snowfall, and mean daily temperature. Snowfall was one of three independent variables not included in regression equations in the present study.

Patterns of variation described by Davradou (1991) were inconsistent among trials; however, she reported that sources to the north of Lake Nipigon (30, 28, and 23) showed no higher levels of frost hardiness than those from the more southerly seed sources. In contrast, first factor scores of the present study showed these sources from north of Lake Nipigon had extreme negative values, as opposed to those in the southwest portion of the range. The predicted factor scores likewise showed that these sources displayed less growth potential. Growth potential of seedlings of southerly seed sources was considerably greater than of those of northerly sources. Predictions of the second factor scores also suggest that survival of seedlings from northerly sources was better than of seedlings originating in the southwest portion of the study area.

Maley (1990) examined relationships of summary variables describing cone and needle data for the 64 collection sites used in the present study. Regression equations included latitude, elevation, various mean temperatures, and precipitation. Precipitation was retained in all the predictive equations developed for the summary variables of the cone and needle data (Maley 1990). Bark thickness and needle length varied with precipitation according to the findings of Schoenike (1962, 1976). The role of precipitation in predicting variation seen among seed sources in the present study was minimal; it was not retained in any equations for the prediction of PCA factor scores but was retained to predict survival at Raith, where lack of precipitation after planting led to reduced survival.

Average July maximum temperature together with latitude, predicted the first factor scores to a great extent in the present study. These findings concur with earlier work which showed that shoot development in jack pine responded to temperature regimes, as is true for many species (Kozlowski 1971).

The broad spectrum of independent variables used in this study to describe environment at seed origin was chosen by Maley (1990) from a collection of many. The very best climatic variables may not have been selected for this work; greater portions of the variation observed among seed sources may be explained with different variables. Also, the TIN algorithm used to interpolate climatic variables for the 64 collection sites of this study has limitations. TIN constructs triangles between geographic points, and the surfaces of the triangles become the surfaces of the three dimensional trend surface upon which interpolations occur. Other approaches including splining and kriging procedures can also be used to interpolate data, and some of these may produce more accurate results than the TIN subroutine. At present, the most direct interpolation technique was desired. Coefficients of determination seen in this work suggest that the approximations of climate variables are acceptable, though known to be imperfect.

Maley (1990) retained elevation in all the multiple regression equations of summary variables for needle and cone characters of the 64 seed source stands. Elevation was included in a number of similar regression models for the growth of black spruce in this same geographic area (Parker *et al* 1994) when the same TIN algorithm was used to derive climate variables. The regression models for jack pine in this study do not include elevation nearly so frequently. It was retained in predictive models for greenhouse heights and time of needle flushing and prevalence of purpling at the LU field trial. The inclusion of elevation in these types of models may improve the predictive values of the interpolated climatic variables, or may be a result of elevation's direct affect on natural selection and the resulting pattern of variation.

Rehfeldt (1983a) reported that as much as 86 per cent of the variation seen among populations of lodgepole pine, the western species most closely related to jack pine, could be explained by elevation. In the present study, elevation appeared to explain little of the variation seen among the 64 sources. Simple linear correlations with elevation resulted in significant relationships for only six out of 19 measured variables. It is likely that elevation is a very significant predictor of climate and vegetative association in the range of lodgepole pine. None of the present study regression models, even those including many independent variables, explained such a large portion of the variance seen among sources as Rehfeldt (1983a) reported for lodgepole pine.

Latitude is used in genecological studies as an estimate of photoperiod. Backwards stepwise multiple linear regression included latitude in the equation for the first set of factor scores. Simple linear correlations revealed that latitude was significantly correlated to 7 of the measured variables. Particularly significant relationships were seen between latitude and timing of needle flushing.

The proximity of all seed sources to Lake Superior and Lake Nipigon may overwhelm the geographic effects of latitude and elevation in this study area. These large bodies of water appear to influence the geographic gradients displayed by climatic variables, with irregularities appearing throughout, as illustrated on the weather maps in Appendix 5.

Soil and Vegetative Factors

The site factors examined in this study included the soil and the plant association at seed origin. Soil variables were variable from one seed source to another even over short geographic distances. Like the soil variables, plant associations were highly variable even between neighbouring seed sources. Both the soil and related plant associations may have influenced selection pressures which differ among various stand conditions. Though jack pine pollen is known to travel great distances, the bulk of the pollen involved in seed production on a site is likely from very local sources, thus though gene exchange over long distance is very possible, probabilities minimize its effect.

Significant differences in heights have been reported among geographically neighbouring (relatively speaking) jack pine provenances in Ontario. Yeatman (1976) describes this as 'chance variation among the provenances tested'. Much of the examination of provenance trials in the past has been related to the broad scale site region classifications of Hills (1961) and climatic gradients.

When soil variables have exuded significant selection pressure, ecotypes develop through natural evolutionary processes. Species that inhabit a broad range of sites within a climatic region may do so by developing races adapted to the various site types (Rehfeldt 1984). Jack pine for this study was collected from 12 FEC soil types (Sims *et al* 1987).

A plant association on a given site reflects the combination of underlying soil conditions, effects of local climate, effects of local topography as well as such chance factors as available seed source. Selection pressure from plant association may be minimal, but the vegetation type may measure other site factors that significantly affect race development within a species. The ecological amplitude of jack pine in this portion of the range is reflected in that collections represented eight vegetation types.

Examination of the present trials by FEC vegetation type and soil type determined significant differences among sources whose origins were varied. These results are confounded with seed origin because unequal geographical representation of each type was examined. However, some of these differences were attributable to finer-scale differences in soil type and the related vegetation type, as seen in the equations produced by backwards stepwise multiple linear regression. Of the 12 FEC soil and vegetation variables included in the regression equations, only soil depth and prevalence of hardwood in the overstory were not retained in any equations.

Nested analysis of variance, with seed sources nested within the FEC vegetation or soil types would have yielded cleaner interpretations of the results, as would use of the Bonferoni theorem with the least significant difference tests. The general findings, however, would have remained though fewer significant differences would have been detected if either statistical technique had been employed.

Further work examining the role of FEC types is necessary to fill in the complete adaptive variation story in jack pine. Rehfeldt (1979a) used dummy variables in his regressions to include the effect of habitat type in regression models. His regression equation for Douglas-fir included latitude, longitude, and elevation of seed origin, as well as constant terms (dummy variables) that coded five different habitat types. Standardized partial regression coefficients were calculated by Rehfeldt (1979a) for all independent variables using this technique. As some of the soil and vegetation types were represented by one seed source, similar calculations could not be made on the present data set.

Variation seen among jack pine seed sources that was not related to conditions at seed origin may reflect incomplete examination of conditions at seed origin, that is, the inadequate selection or measurement of independent variables. Other soil variables not included in this study, such as soil drainage or soil pH, might be selective forces in the adaptive variation seen in jack pine.

Not all the variation displayed among seedlings from these seed sources may be related to conditions at seed source. The movement of pollen and the outcrossing nature of jack pine may have led to highly variable offspring. Pollen from trees adapted to a given set of environmental conditions may travel over considerable distances to breed trees adapted to different environmental conditions, leading to seed, which when collected and planted, reflects a set of intermediate conditions. If this seed had regenerated the site of the maternal parents, those seedlings best adapted to the site, likely those of more local parents, would be the most successful. Selection pressures at the germination, seedling, and sapling stages would then operate to select these adapted individuals.

Comparison to Lodgepole Pine

Lodgepole pine was described by Rehfeldt as a 'specialist' in terms of its adaptive variation (1984). He described the development of specialization in a species as the result of natural selection forces altering the gene frequencies to produce distinct populations in response to environment differences, primarily in space. In such species the phenotype reflects the genotype, and selection forces therefore work directly on the genotype. Evidence that lodgepole pine is a specialist was seen in that it displays steep adaptive clines for growth potential and cold hardiness (Rehfeldt 1984).

Such steep adaptive clines and measures highly correlated with environmental variables were not detected in this jack pine study. Simple linear correlations with climatic, spatial, and FEC site variables rarely exceeded 0.5 for the measured variables. Coefficients of determination from backwards multiple linear regression indicate that the model accounts for more than 50 per cent of the variation only in the case of needle flushing date at LU and at Raith. These lower values suggest that jack pine is a 'generalist' as opposed to a 'specialist' in terms of adaptive variation in north-central Ontario. Rehfeldt (1984) describes this adaptive mode as the primary response to environmental variation over time. Species that display such phenotypic plasticity develop from a process of selection that favours alleles that tolerate a broad ecological range. Thus a single genotype may produce a variety of phenotypes for a given measured trait or a variety of genotypes may result in a single phenotype (Rehfeldt 1984).

The migrational history of jack pine as compared to lodgepole pine since the last glacial advance may explain much of the difference seen in adaptive variation for these two closely related boreal species. Lodgepole pine survived the glaciers within its present range in three areas, each resulting in distinctive races of lodgepole pine today (Critchfield 1985). Rehfeldt (1984) reported on lodgepole pine's adaptive variation in areas not covered by the last glacier, thus the species has had a much longer period of time in which to evolve and adapt to specific habitats. In contrast, jack pine in the north central portion of Ontario has had less than 10,000 years to become adapted to environment since post-glacial invasion (Critchfield 1985).

SEED MOVEMENT AND BREEDING ZONES

The suggested seed collection zones and guidelines for seed movement presented in the Tree Improvement Strategy (OMNR 1987b), are very conservative for jack pine. Collections for this study were taken from stands within the southern three seed collection zones in the Lake Nipigon North Breeding Zone, the western two seed collection zones of the Lake Nipigon East Breeding Zone, the western two seed collection zones in the Lake Superior Breeding Zone, the eastern two seed collection zones of the 4400 Breeding Zone, and all five seed collection zones of the Lake Nipigon West Breeding zone, for a total of 14 seed collection zones. The Tree Improvement Strategy calls for this restricted movement of seed until further information on population variation and its effect on seed movement in the former North Central Region, as reported in this study, is available.

The general pattern seen from the mapping of the first two predicted factor scores in this study support the restriction of movement of seed from one end of the study area to the other. New GIS techniques, together with the data base provided by this study and the data from Davradou (1991), should be used to establish seed movement guidelines for jack pine in north-central Ontario. Parker (1992) developed focal point seed zones; essentially floating seed zone boundaries dependent upon the conditions at the planting site. This approach does away with the discrete zones on a map, and allows the silvicultural forester to select from potential seed sources the one whose critical conditions best match that of the planting site. The results of this study, together with those of Davradou (1991) indicate which variables were critical to the description of the environment to which populations of jack pine are adapted, and what weights should be assigned to each.

The results of the present study indicate that mean annual July temperature together with latitude, were very critical variables and predicted a large portion of the variation seen in the first set of component scores. Mean daily temperature was included in the prediction of survival and height of the seedlings for the second set of component factor scores. A number of other variables also contributed to the prediction of the performance of these seedlings, reflecting their adaptive variation. If discrete seed collection zones are desirable for administrative purposes, these climatic variables should be the basis of their development.

The role played by site factors in the influence of adaptive variation seems consistently smaller than that of the climatic variables, as determined by the simple linear correlations. The results of this study do not suggest the presence of ecotypes; thus, based upon present information, it does not appear critical that site factors be included in seed collection zone boundary development. However, the poor growth of seedlings from vegetation type 25 (seed source 47 located in the west-central portion of the study area), a white spruce - balsam fir type, suggests that jack pine seed collections from stands not dominated by jack pine may lead to less than desirable growth performance. Species association likely reflects the different selection pressures which will likewise be reflected in the performance of seedlings from a seed source.

The study area has been divided into five breeding zones (OMNR 1987b) for the purpose of producing improved stock well-adapted to the zones. These zones have been determined based upon a number of climatic variables, including growing degree days, spring and fall frost dates, and latitude (photoperiod estimate) as well as Site Regions (OMNR 1987b) as originally described by Hills (1961). The present study supports the inclusion of these climatic variables, and additional variables: mean annual maximum July temperature and daily temperature, in the development of breeding zones for jack pine.

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APPENDIX I

Jack Pine Collection Site Locations, V-types, and S-types

Seed Source	Latitude	Longitude	Elevation	S-Type	V-Type
1	50°12'	86°52'	1050	S1	V32
2	50° 7'	86°47'	1080	S1	V29
3	50° 3'	86°54'	1150	S1	V32
4	50° 5'	87° 1'	1100	S1	V18
5	49°48'	87° 0'	1150	S1	V18
6	50° 9'	87°39'	1050	S1	V32
7	49°59'	87°44'	1050	S1	V32
8	49°11'	88°25'	950	S2	V32
9	49°37'	87°57'	1050	S3	V28
10	49° 1'	88°20'	950	S1	V18
11	49°12'	87°43'	1500	SS1	V30
12	49°13'	87°52'	1400	SS1	V30
13	48°54'	88°21'	650	S1	V28
14	49°43'	87°44'	1150	S1	V32
15	49°12'	88°13'	800	S1	V32
16	48°54'	88°31'	900	S1	V28
17	49°54'	87°24'	1100	S3	V31
18	49°43'	87°27'	1100	S1	V17
19	49°43'	87°16'	1100	S1	V18
20	49°33'	87°10'	1250	S1	V29
21	49°17'	87°13'	1300	S1	V32
22	48°47'	87° 6'	900	S2	V32
23	50°16'	89° 3'	1200	S1	V32
24	50°18'	89° 1'	1150	S4	V32
25	50° 4'	89°42'	1450	SS1	V30
26	50° 2'	89°29'	1350	S1	V32
27	50° 7'	89°13'	1100	SS3	V32
28	50°17'	88°53'	1050	S2	V30
29	50°26'	88°32'	1050	S2	V32
30	50°27'	88°42'	1050	S5	V32
31	48° 5'	89°47'	1100	S6	V29
32	48°10'	89°37'	1250	SS2	V30
33	48°14'	90°30'	1700	SS3	V29
34	48°14'	90°11'	1600	S6	V28
35	48°50'	89° 6'	1550	S6	V32
36	48°39'	89° 4'	1500	S1	V18
37	49°17'	89°14'	1350	SS5	V31
38	49°15'	89°25'	1450	SS2	V32
39	49°20'	89° 9'	1150	S5	V32
40	49° 7'	90° 3'	1550	S2	V32
41	48°55'	89°53'	1600	S5	V32

Seed Source	Latitude	Longitude	Elevation	S-Type	V-Type
42	48°59'	89°57'	1450	S1	V17
43	48°44'	90°15'	1600	S1	V18
44	48°54'	88°44'	1100	SS5	V17
45	48°57'	89°11'	1500	SS1	V30
46	49°26'	88°56'	750	S1	V32
47	49°21'	89°50'	1500	S2	V25
48	48°30'	90°36'	1600	SS6	V31
49	48°47'	89°36'	1500	SS6	V30
50	48°38'	89°51'	1450	S1	V32
51	48°35'	90° 9'	1500	SS5	V31
52	49°18'	90°11'	1600	S1	V29
53	48°41'	90°54'	1600	SS6	V32
54	49°46'	90°17'	1450	SS7	V18
55	49°33'	90°17'	1550	S3	V31
56	49°34'	90°32'	1600	S1	V29
57	49°26'	90°26'	1550	S1	V32
58	49°17'	90°20'	1550	SS5	V28
59	49°13'	90°37'	1550	S1	V29
60	49°37'	89°51'	1450	S2	V29
61	49°31'	89°38'	1500	S1	V32
62	49°32'	87°40'	1350	S1	V32
63	49°28'	87°32'	1450	S1	V32
64	48°25'	90° 8'	1450	SS1	V30

APPENDIX II

Jack Pine Collection Sites

FEC Data

Seed Source	Soil Depth (cm)	% Conifer	% Hard-wood	% Jack Pine	% Black Spruce	% White Spruce	% Lichen	% Bedrock	% Feather Moss	% Sand	% Silt	% Clay
1	100	40	0	40	0	0	1	0	68	91	4	5
2	100	60	0	60	0	0	1	0	83	91	4	5
3	100	60	0	60	0	0	1	0	86	91	4	5
4	100	60	10	60	0	0	na	na	na	91	4	5
5	100	56	0	56	0	0	na	na	na	91	4	5
6	100	40	0	40	0	0	1	0	90	91	4	5
7	100	60	0	60	0	0	0	0	75	91	4	5
8	100	50	0	30	0	20	0	0	78	91	4	5
9	100	60	0	60	0	0	0	0	38	60	5	35
10	100	50	0	50	0	0	0	0	56	91	4	5
11	15	15	0	15	0	0	30	50	0	91	4	5
12	0	40	0	40	0	0	40	50	10	na	na	na
13	100	70	0	70	0	0	0	0	20	91	4	5
14	100	70	0	70	0	0	0	0	86	91	4	5
15	100	62	0	40	0	15	0	0	60	91	4	5
16	100	80	0	80	0	0	5	0	1	91	4	5
17	100	95	0	70	20	5	0	0	88	82	6	12
18	100	40	40	40	0	0	0	0	1	91	4	5
119	100	na	na	na	0	0	1	0	80	91	4	5
20	100	50	0	50	0	0	0	0	91	91	4	5
21	100	65	0	50	15	0	1	0	86	91	4	5
22	100	32	0	28	4	0	0	0	93	91	4	5
23	100	19	0	15	4	0	1	0	87	91	4	5
24	100	60	0	50	10	0	0	0	80	91	4	5
25	20	40	0	40	0	0	60	10	25	na	na	na

Seed Source	Soil Depth (cm)	% Conifer	% Hard-wood	% Jack Pine	% Black Spruce	% White Spruce	% Lichen	% Bedrock	% Feather Moss	% Sand	% Silt	% Clay
26	100	70	0	70	0	0	1	0	85	91	4	5
27	20	na	0	na	0	0	0	0	85	na	na	na
28	100	70	0	70	0	0	85	0	1	91	4	5
29	100	45	0	45	0	0	5	0	85	91	4	5
30	100	60	0	60	0	0	1	0	85	33	34	33
31	100	30	0	30	0	0	1	0	90	18	65	17
32	3	4	0	4	0	0	83	10	0	na	na	na
33	9	27	0	27	0	0	3	0	68	na	na	na
34	77	70	0	70	0	0	1	0	3	60	5	35
35	40	25	0	15	10	0	1	0	96	60	5	35
36	100	50	5	35	15	0	0	0	80	82	6	12
37	90	75	0	60	0	15	0	0	35	91	4	5
38	3	30	0	30	0	0	1	0	70	na	na	na
39	100	35	0	35	0	0	0	0	70	10	34	56
40	100	40	0	40	0	0	1	0	85	91	4	5
41	100	70	0	55	15	0	1	0	65	33	34	33
42	100	40	0	40	0	0	0	0	5	82	6	12
43	100	38	10	45	3	0	1	0	60	91	4	5
44	70	70	0	70	0	0	1	0	15	82	6	12
45	10	25	0	25	0	0	0	20	0	na	na	na
46	100	52	0	30	15	0	0	0	80	91	4	5
47	100	50	0	15	0	35	0	0	60	82	6	12
48	35	55	0	40	15	0	1	40	10	na	na	na
49	45	45	0	40	5	0	65	10	20	67	15	18
50	75	60	0	60	0	0	1	0	60	91	4	5

Seed Source	Soil Depth (cm)	% Conifer	% Hard-wood	% Jack Pine	% Black Spruce	% White Spruce	% Lichen	% Bedrock	% Feather Moss	% Sand	% Silt	% Clay
51	65	65	0	65	0	0	0	0	40	82	6	12
52	100	75	0	75	0	0	1	0	90	91	4	5
53	65	65	0	40	25	0	0	0	37	42	17	41
54	30	70	0	40	30	0	1	0	65	na	na	na
55	100	82	0	75	7	0	0	0	5	60	5	35
56	100	75	0	75	0	0	1	0	85	91	4	5
57	na	na	na	na	na	na	na	na	na	na	na	na
58	25	75	0	75	0	0	0	0	5	na	na	na
59	100	80	0	80	0	0	1	0	74	91	4	5
60	100	na	na	na	na	na	na	na	na	91	4	5
61	100	60	0	60	0	0	0	0	85	91	4	5
62	100	60	0	60	0	0	0	0	82	91	4	5
63	100	70	0	70	0	0	0	0	85	91	4	5
64	20	70	0	70	0	0	1	25	25	na	na	na

APPENDIX III

Weather Station Locations and Data

Station Number	Station	Longitude	Latitude
101	Abitibi Camp 228	48 ° 56 '	89 ° 15 '
102	Abitibi Camp 230	49 ° 21 '	89 ° 22 '
139	Aguasabon	48 ° 47 '	87 ° 10 '
103	Armstrong A	50 ° 17 '	88 ° 54 '
104	Atikokan CLI	48 ° 44 '	91 ° 38 '
105	Beardmore	49 ° 37 '	87 ° 57 '
140	Black Sturgeon Lake	49 ° 19 '	88 ° 51 '
106	Cameron Falls	49 ° 9 '	88 ° 21 '
141	Caramat	49 ° 16 '	85 ° 50 '
126	Central Patricia	51 ° 30 '	90 ° 9 '
107	Dorion TCPL	48 ° 49 '	88 ° 31 '
127	Dryden	49 ° 46 '	92 ° 51 '
142	Dryden A	49 ° 50 '	92 ° 45 '
143	Ear Falls	50 ° 38 '	93 ° 13 '
108	Geraldton	49 ° 42 '	86 ° 57 '
109	Graham	49 ° 16 '	90 ° 35 '
138	Hornepayne	49 ° 14 '	84 ° 48 '
110	Kakabeka Falls	48 ° 24 '	89 ° 37 '
144	Lansdowne House	52 ° 14 '	87 ° 53 '
111	Longlac P and P	49 ° 46 '	86 ° 32 '
145	MacDiarmid	49 ° 26 '	88 ° 9 '
117	Manitouwadge	49 ° 9 '	85 ° 48 '
118	Marathon	48 ° 43 '	86 ° 24 '
146	Martin TCPL	49 ° 17 '	91 ° 14 '
119	Mattice TCPL	49 ° 35 '	83 ° 10 '
120	Mine Centre	48 ° 46 '	92 ° 38 '
147	Nagagami	49 ° 46 '	84 ° 31 '
112	Nakina	50 ° 11 '	86 ° 42 '
113	Nolalu	48 ° 9 '	89 ° 53 '
148	Pagwa A	50 ° 2 '	85 ° 16 '
121	Pays Plat	48 ° 52 '	87 ° 36 '
122	Pickle Lake	51 ° 28 '	90 ° 12 '
149	Pigeon River	48 ° 5 '	89 ° 38 '
150	Quorn	49 ° 25 '	90 ° 54 '
114	Raith	48 ° 44 '	89 ° 52 '
123	Red Lake A	51 ° 4 '	93 ° 48 '
115	Schreiber	48 ° 49 '	87 ° 16 '
151	Slate Island	48 ° 37 '	87 ° 0 '
152	Sturgeon Lake	49 ° 53 '	90 ° 58 '
153	Terrace Bay	48 ° 48 '	87 ° 6 '
116	Thunder Bay A	48 ° 22 '	89 ° 19 '

Station Number	Station	Longitude	Latitude
124	Upsula	49 ° 3 '	90 ° 28 '
154	Waboose Dam	50 ° 47 '	87 ° 59 '
155	Watcomb	49 ° 54 '	91 ° 17 '
156	Welcome Island	48 ° 22 '	89 ° 7 '
125	White River	48 ° 36 '	85 ° 17 '
128	Babbitt	47 ° 41 '	91 ° 55 '
129	Baudette	48 ° 43 '	94 ° 37 '
130	Bemidji	47 ° 30 '	94 ° 56 '
131	Cloquet	46 ° 42 '	92 ° 31 '
132	Grand Marais	47 ° 44 '	90 ° 21 '
133	Grand Rapids	47 ° 14 '	93 ° 30 '
134	Two Harbours	47 ° 1 '	91 ° 40 '
135	Virginia	47 ° 30 '	92 ° 33 '
136	Duluth	46 ° 50 '	92 ° 11 '
137	International Falls	48 ° 34 '	93 ° 23 '

Station No.	Max July Temp ~°C	Min January Temp ~°C	Mean Daily Temp ~°C	Extreme Max Temp ~°C[a]	Extreme Min Temp ~°C[a]	Snow ~cm	Total Precip ~mm	Heating Degree Days	Growing Degree Days	Last Spring Frost	First Fall Frost	Frost Free Period ~days[a]
101	24.2[b]	-25.0[b]	0.7[b]	37.2(8)	-42.8(9)	232.4[b]	734.8[b]	6357.1[b]	1364.3[b]	159	243	84(7)
102	23.8[b]	-25.6[b]	0.2[b]	37.8(10)	-43.9(10)	251.5[b]	734.4[b]	6531.0[b]	1306.0[b]	164	240	76(9)
139	19.2[b]	-19.7[b]	1.7[b]	28.9(21)	-40.6(22)	257.2[d]	852.8[d]	5934.6[b]	1096.4[b]	148	264	116(20)
103	23.6[c]	-28.2[c]	-1.1[c]	38.3(42)	-50.0(40)	262.0[c]	738.4[c]	6990.8[c]	1130.4[c]	178	228	50(30)
104	25.4[d]	-25.4[d]	1.9[d]	42.2(55)	-48.9(52)	237.4[b]	724.0[b]	5960.3[b]	1496.6[b]	165	246	81(21)
105	23.4[b]	-26.6[b]	0.2[b]	34.0(7)	-48.3(7)	335.7[b]	784.0[b]	6530.3[b]	1273.5[b]	163	243	80(7)
140	na	na	na	na	na	na	na	na	na	166	242	76(7)
106	23.6[c]	-22.3[c]	1.7[c]	38.9(52)	-46.1(54)	233.6[e]	793.3[e]	6005.0[e]	1361.4[e]	154	256	102(30)
141	23.5[b]	-24.7[b]	0.5[b]	38.3(15)	-49.4(13)	241.5[b]	760.4[b]	6413.3[b]	1359.0[b]	157	243	86(8)
126	23.6[d]	-27.9[d]	-1.4[d]	36.7(23)	-53.9(23)	321.9[d]	829.1[d]	7116.0[b]	1197.0[b]	177	220	43(22)
107	22.8[b]	-22.8[b]	1.4[b]	35.5(11)	-42.8(11)	168.6[b]	685.0[b]	6094.7[b]	1261.8[b]	162	246	84(11)
127	24.5[c]	-24.4[c]	1.6[c]	39.4(65)	-46.7(66)	170.8[e]	697.5[e]	6086.6[e]	1578.2[e]	142	262	120(30)
142	24.7[b]	-24.0[b]	1.7[b]	35.6(11)	-43.3(10)	225.9[b]	720.2[b]	6067.6[b]	1610.0[b]	137	263	126(10)
143	24.2[e]	-23.7[c]	1.3[e]	40.0(39)	-45.6(39)	186.0[e]	661.9[e]	6181.6[e]	1501.1[e]	149	264	115(30)
108	22.9[b]	-27.0[b]	-0.4[b]	36.1(13)	-47.8(13)	239.6[b]	697.0[b]	6752.7[b]	1219.1[b]	168	236	68(12)
109	23.4[b]	-26.1[b]	-0.1[b]	34.4(18)	-52.2(18)	268.1[b]	816.0[b]	6626.4[b]	1291.7[b]	159	248	89(16)
138	23.6[e]	-25.4[e]	0.2[e]	37.2(56)	-52.2(54)	274.7[e]	733.6[e]	6544.7[e]	1240.6[e]	166	238	72(29)
110	25.4[e]	-22.2[e]	2.5[e]	41.7(63)	-48.3(69)	191.6[e]	710.0[e]	5714.8[e]	1500.5[e]	153	247	94(26)
144	22.0[c]	-28.0[c]	-1.6[c]	36.7(40)	-47.8(38)	260.9[c]	666.4[c]	7198.9[c]	1205.0[c]	150	266	116(30)
111	23.6[b]	-27.3[b]	-0.1[b]	34.4(17)	-47.8(17)	268.7[b]	813.3[b]	6645.6[b]	1310.1[b]	156	249	93(17)
145	22.2[b]	na	na	35.6(17)	-43.3(10)	na	na	na	na	152	262	110(14)
117	24.0[e]	-23.5[e]	1.1[e]	39.4(25)	-42.2(25)	309.5[e]	861.7[e]	6215.5[b]	1410.3[b]	157	250	93(25)
118	18.3[e]	-19.1[e]	1.9[e]	32.2(28)	-36.1(28)	242.2[e]	838.4[e]	5899.8[b]	1117.5[b]	147	265	118(29)
146	24.1[b]	-24.5[b]	1.1[b]	36.7(10)	-41.1(11)	184.7[b]	750.7[b]	6248.4[b]	1451.0[b]	159	247	88(10)
119	23.6[b]	-25.7[b]	0.2[b]	37.2(13)	-48.9(14)	339.9[b]	845.6[b]	6566.6[b]	1301.2[b]	178	225	47(13)
120	25.5[c]	-23.7[c]	2.3[c]	41.7(65)	-47.2(66)	179.9[c]	706.2[c]	5825.4[e]	1628.4[e]	151	252	101(29)
147	na	na	na	na	na	na	na	na	na	176	238	62(5)
112	22.9[b]	-25.9[b]	-0.6[b]	35.0(29)	-46.7(27)	291.1[b]	810.9[b]	6815.5[b]	1166.0[b]	166	241	75(17)

[a] the number of years of record follow in brackets.

[b] adjusted normals based on 5 to 19 years, inclusive, from 1951 to 1980 and any other available data from 1931 to 1950.

[c] normal based on 30 years of data. [d] normal based on 20 to 24 years of data. [e] normal based on 25 to 29 years of data.

Station No.	Max July Temp ~°C	Min January Temp ~°C	Mean Daily Temp ~°C	Extreme Max Temp ~°C[a]	Extreme Min Temp ~°C[a]	Snow ~cm	Total Precip ~mm	Heating Degree Days	Growing Degree Days	Last Spring Frost	First Fall Frost	Frost Free Period ~days[a]
113	24.2[b]	-23.4[b]	1.4[b]	36.7(5)	-45.6(6)	369.8[b]	na	6096.3[b]	1320.4[b]	177	220	43(5)
148	24.0[b]	-25.1[b]	0.1[b]	37.2(26)	-46.7(26)	340.7[b]	902.0[b]	6594.9[b]	1299.8[b]	172	221	49(13)
121	21.2[b]	-21.1[b]	na	30.6(10)	-38.3(8)	217.0[b]	836.5[b]	na	na	148	259	111(7)
122	22.9[b]	-26.9[b]	-0.9[b]	40.0(34)	-51.1(34)	265.7[b]	760.9[b]	6911.8[b]	1276.4[b]	158	250	92(21)
149	24.6[b]	-21.2[b]	2.6[b]	36.1(9)	-40.0(8)	306.1[b]	924.1[b]	5695.9[b]	1460.5[b]	159	239	80(8)
150	24.0[b]	-25.8[b]	0.2[b]	40.6(40)	-49.4(41)	227.2[b]	796.3[b]	6674.4[b]	1221.7[b]	160	242	82(9)
114	24.1[b]	-25.2[b]	0.3[b]	36.7(10)	-46.7(10)	221.0[b]	749.8[b]	6489.9[b]	1225.2[b]	185	216	31(10)
123	23.7[b]	-26.5[b]	0.7[b]	37.2(24)	-45.6(28)	180.5[b]	588.5[b]	6350.2[b]	1519.9[b]	143	263	120(20)
115	19.6[d]	-20.2[d]	1.2[d]	32.8(63)	-42.8(63)	212.5[d]	860.2[d]	6129.2[d]	1090.3[d]	146	255	109(24)
151	15.7[b]	na	na	29.5(14)	na	na	na	na	na	144	278	134(14)
152	23.7[b]	-23.5[b]	1.5[b]	36.7(7)	-40.0(8)	254.9[b]	749.8[b]	na	na	139	270	131(8)
153	na	na	na	na	na	na	na	na	na	160	252	92(8)
116	24.3[c]	-21.3[c]	2.3[c]	37.2(39)	-41.1(39)	213.0[c]	711.8[c]	5767.9[c]	1425.4[c]	150	255	105(30)
124	23.5[d]	-25.4[d]	0.6[d]	35.6(25)	-45.6(24)	234.8[b]	798.2[b]	6395.0[b]	1345.8[b]	166	247	81(21)
154	na	na	na	na	na	na	na	na	na	154	256	102(5)
155	24.1[b]	-24.7[b]	0.7[b]	35.6(8)	-43.3(7)	191.4[b]	761.1[b]	na	na	157	250	93(8)
156	20.3[b]	na	na	30.0(14)	na	na	na	na	na	133	284	151(10)
125	23.1[e]	-25.8[e]	0.3[e]	38.3(84)	-51.7(88)	291.6[e]	823.3[e]	6479.2[e]	1206.7[e]	170	227	57(25)
128	25.2	-20.0	3.7	35.6	-40.6	135.6	711.2	5459.0	1904.0	140	264	124
129	26.4	-23.8	3.2	37.2	-43.3	104.4	573.8	5644.0	1956.0	142	262	120
130	26.3	-23.1	3.2	38.3	-44.4	102.1	577.1	5669.0	1932.0	141	262	121
131	26.6	-19.7	4.0	36.1	-40.6	173.5	761.0	5321.0	1893.0	153	257	104
132	21.4	-16.6	3.7	35.0	-36.1	143.0	670.6	5352.0	1511.0	135	273	138
133	26.6	-20.8	4.2	37.8	-41.7	145.5	669.5	5295.0	1989.0	146	259	113
134	24.1	-16.5	4.4	37.2	-37.2	130.8	723.9	5128.0	1719.0	138	273	135
135	26.3	-21.2	3.7	36.1	-43.3	157.2	688.1	5468.0	1911.0	150	255	105
136	24.7	-19.4	3.4	36.1	-39.4	na	753.9	5501.0	na	na	na	na
137	25.8	-23.9	1.3	36.7	-43.3	na	618.5	5891.0	na	na	na	na

[a] the number of years of record follow in brackets.

[b] adjusted normals based on 5 to 19 years, inclusive, from 1951 to 1980 and any other available data from 1931 to 1950.

[c] normal based on 30 years of data. [d] normal based on 20 to 24 years of data. [e] normal based on 25 to 29 years of data.

APPENDIX IV

Jack Pine Collection Sites

Weather Data

Seed Source	Max July Temp (°C)	Min January Temp (°C)	Mean Daily Temp (°C)	Extreme Max Temp (°C)	Extreme Min Temp (°C)	Snow (cm)	Total Precip (cm)	Heating Degree Days	Growing Degree Days	Last Spring Frost ***	First Fall Frost ***	Frost Free Period (days)
1	22.9	-26.1	-0.6	35.1	-46.9	288.5	801.6	6821.0	1166.8	165.0	242.5	77.5
2	23.0	-26.0	-0.6	35.0	-46.9	289.1	804.4	6801.8	1173.6	165.7	241.3	75.7
3	23.0	-26.3	-0.5	35.1	-47.2	286.7	791.9	6792.0	1183.7	165.4	241.5	76.1
4	23.0	-26.3	-0.5	35.0	-47.3	291.7	794.9	6793.4	1180.8	164.6	242.9	78.3
5	23.2	-27.6	-0.6	36.3	-48.4	244.0	690.6	6820.3	1222.6	169.1	235.1	65.9
6	23.2	-27.3	-0.8	35.9	-48.6	286.8	767.4	6862.8	1164.3	162.0	245.4	83.4
7	23.6	-27.5	-0.5	35.2	-49.6	324.9	774.6	6765.8	1217.2	163.6	242.8	79.3
8	23.7	-22.8	1.6	39.5	-46.5	245.9	792.1	6051.3	1379.5	155.9	254.4	98.5
9	23.4	-26.6	0.2	34.0	-48.3	335.7	784.0	6530.3	1273.5	163.0	243.0	80.0
10	23.3	-22.1	1.6	37.5	-44.6	208.6	768.3	6022.4	1317.6	156.7	251.9	95.2
11	22.4	-23.6	0.9	32.6	-42.6	263.6	804.3	6254.5	1235.9	155.3	251.1	95.8
12	22.0	-23.6	1.2	33.7	-41.7	266.6	800.6	6161.4	1282.1	150.5	260.3	109.8
13	23.0	-22.6	1.4	35.9	-43.1	180.1	716.5	6096.6	1259.8	161.1	246.6	85.5
14	23.5	-27.0	0.0	34.2	-48.9	340.6	783.2	6597.4	1262.5	163.4	242.3	78.9
15	23.3	-22.4	1.7	38.5	-45.8	243.7	801.8	6001.6	1359.4	151.3	260.0	108.7
16	23.2	-23.0	1.3	36.5	-43.4	180.8	703.8	6124.8	1275.9	162.4	245.3	82.9
17	23.4	-27.0	-0.3	34.8	-48.6	322.0	784.4	6712.3	1225.5	163.8	242.6	78.7
18	23.3	-27.1	-0.2	35.0	-48.4	296.1	739.4	6687.6	1238.5	165.8	239.1	73.3
19	23.1	-27.2	-0.4	35.7	-48.1	260.5	704.9	6754.6	1222.1	167.8	236.6	68.7
20	22.4	-25.9	-0.1	35.1	-46.4	239.1	717.4	6634.6	1200.4	165.4	238.8	73.5
21	21.8	-23.9	0.4	33.8	-43.9	232.4	772.3	6441.6	1167.2	158.7	245.0	86.3
22	19.0	-19.6	1.7	29.0	-40.4	258.6	855.2	5927.4	1090.3	159.4	253.0	93.6
23	23.6	-28.0	-1.0	38.4	-49.6	259.1	737.1	6982.4	1134.6	176.3	229.7	53.4
24	23.6	-28.1	-1.1	38.4	-49.9	260.5	737.6	6992.6	1132.8	177.4	228.5	51.2
25	23.7	-26.8	-0.3	38.3	-47.1	257.9	738.9	6918.6	1156.1	165.3	241.4	76.1
26	23.7	-27.3	-0.6	38.4	-47.9	257.1	737.1	6936.9	1146.3	169.1	237.3	68.2
27	23.7	-27.8	-0.8	38.4	-48.9	257.9	736.2	6954.1	1138.5	173.7	232.5	58.7
28	23.6	-28.2	-1.1	38.3	-50.0	262.2	738.5	6990.9	1130.1	178.1	227.9	49.8
29	23.5	-28.2	-1.3	38.0	-50.7	268.0	742.1	7015.9	1125.6	175.1	231.3	56.3
30	23.6	-28.2	-1.2	38.3	-50.5	264.4	739.3	7015.4	1128.6	178.8	227.0	48.3
31	24.6	-22.2	2.0	36.6	-42.7	337.3	900.0	5880.0	1394.8	167.6	229.5	61.9
32	24.6	-21.3	2.5	36.2	-40.3	304.1	916.8	5710.4	1451.5	158.7	239.8	81.1

*** Days after January 1.

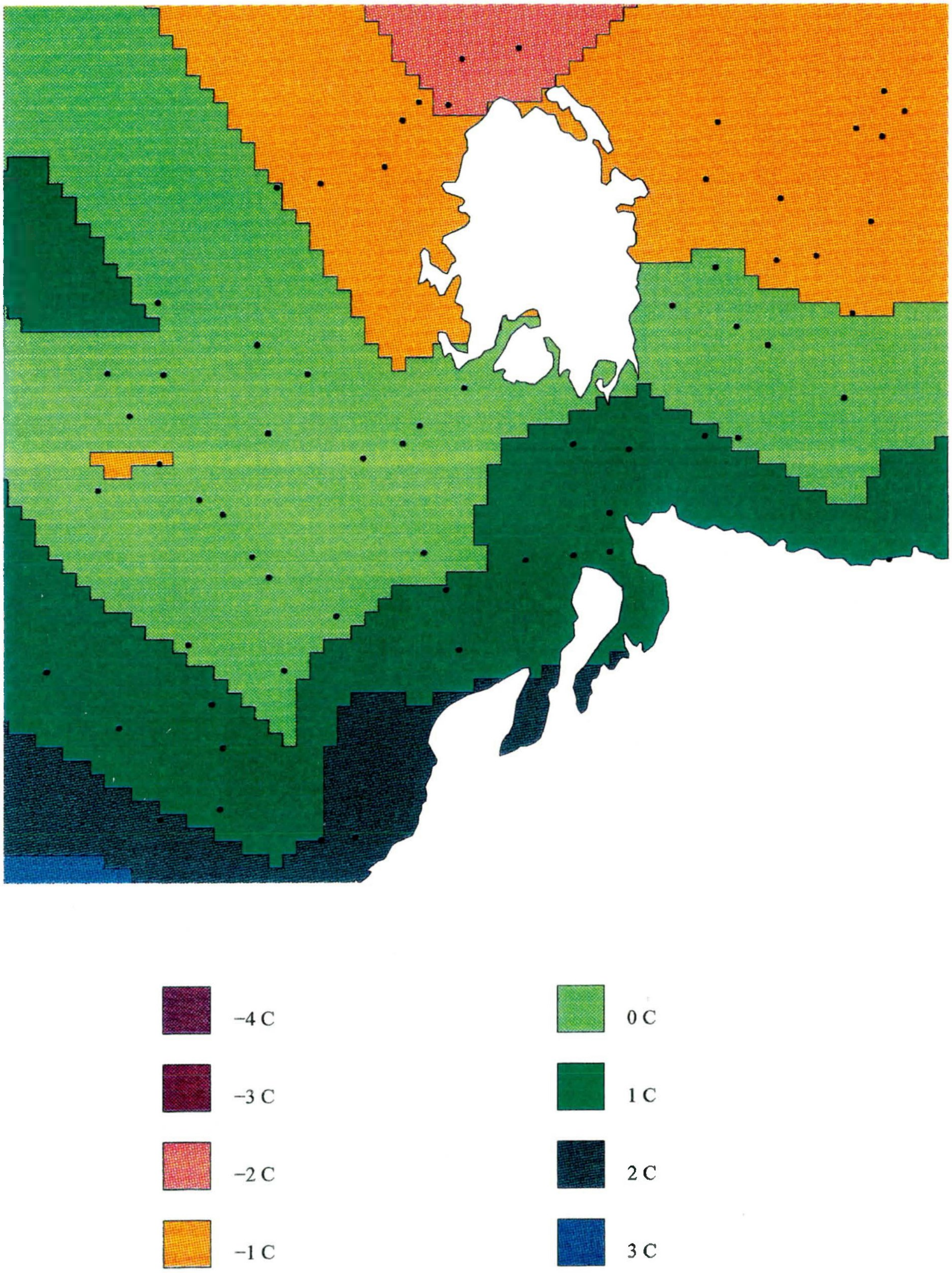
Seed Source	Max July Temp (°C)	Min January Temp (°C)	Mean Daily Temp (°C)	Extreme Max Temp (°C)	Extreme Min Temp (°C)	Snow (cm)	Total Precip (cm)	Heating Degree Days	Growing Degree Days	Last Spring Frost ***	First Fall Frost ***	Frost Free Period (days)
33	23.6	-22.6	1.9	37.1	-44.4	299.7	708.1	5955.8	1392.8	166.3	237.0	70.7
34	24.0	-23.4	1.5	37.0	-45.6	341.9	713.6	6086.0	1340.5	174.1	226.1	52.1
35	23.7	-24.1	1.1	36.4	-42.8	217.2	724.8	6217.7	1362.5	155.2	249.4	94.2
36	22.4	-22.8	1.6	34.0	-42.5	195.5	695.7	6008.2	1366.8	147.0	262.5	115.5
37	23.8	-25.4	0.3	37.9	-43.7	249.7	735.4	6471.1	1320.0	164.8	239.1	74.4
38	23.9	-25.5	0.3	37.7	-44.0	247.0	736.6	6489.7	1314.3	164.9	239.0	74.1
39	23.8	-25.4	0.3	38.0	-43.8	252.6	736.0	6474.1	1318.5	165.5	239.2	73.6
40	23.5	-25.6	0.3	35.6	-45.7	239.6	789.2	6493.7	1306.8	167.0	243.2	76.3
41	23.9	-25.6	0.1	36.3	-46.1	218.2	762.6	6573.5	1222.3	182.6	220.7	38.0
42	23.7	-25.7	0.1	35.9	-46.0	224.9	772.9	6558.5	1245.0	178.3	227.4	49.1
43	23.8	-24.8	0.9	36.2	-45.5	266.8	755.3	6302.2	1327.7	172.1	236.7	64.5
44	23.4	-23.5	1.2	36.7	-43.5	191.7	703.9	6165.1	1307.1	161.4	245.7	84.3
45	24.1	-24.9	0.7	37.1	-42.7	232.0	735.6	6350.2	1363.2	158.4	244.1	85.7
46	23.4	-25.7	0.2	38.0	-43.6	269.3	740.1	6508.4	1306.7	167.7	239.8	72.1
47	23.7	-25.8	0.0	36.5	-46.7	259.3	756.9	6603.8	1283.4	161.5	243.7	82.2
48	24.2	-24.2	1.5	38.0	-46.1	285.5	731.9	6099.2	1381.8	170.3	235.7	65.5
49	24.3	-25.0	0.6	37.4	-45.3	222.5	741.5	6398.4	1292.5	173.5	227.0	53.4
50	24.2	-24.8	0.5	37.1	-46.9	229.3	739.5	6403.4	1246.8	183.3	216.8	33.5
51	24.0	-24.4	1.1	36.7	-45.8	295.0	740.8	6230.0	1328.0	174.1	230.6	56.5
52	23.4	-25.6	0.3	35.3	-46.2	240.8	794.0	6503.8	1313.6	164.8	246.3	81.4
53	24.4	-24.7	1.5	38.7	-46.3	254.6	739.6	6100.3	1412.5	167.7	242.2	74.5
54	23.6	-24.9	0.7	37.2	-43.3	261.0	747.8	6801.8	1184.7	150.4	257.0	106.6
55	23.6	-25.3	0.4	36.5	-45.9	262.4	762.9	6752.4	1197.4	153.8	252.6	98.8
56	23.6	-25.1	0.5	36.2	-46.5	264.0	775.0	6746.0	1196.1	151.1	255.3	104.2
57	23.5	-25.8	0.1	35.3	-50.1	270.6	794.5	6722.3	1202.8	155.5	250.2	94.7
58	23.4	-26.2	-0.2	34.2	-52.6	278.5	811.1	6655.2	1280.0	159.1	247.4	88.3
59	23.4	-26.1	-0.1	34.2	-52.2	265.2	819.3	6597.5	1303.0	160.2	247.6	87.4
60	23.7	-25.6	0.2	37.5	-44.1	256.5	737.8	6739.0	1223.6	158.0	247.9	990.0
61	23.7	-25.7	0.1	37.6	-44.1	254.4	734.4	6651.0	1269.9	161.1	243.9	82.8
62	23.1	-26.0	0.3	33.8	-47.1	315.3	778.6	6498.4	1258.5	162.1	243.4	81.2
63	22.8	-25.2	0.3	33.8	-46.1	288.7	769.7	6484.6	1238.5	161.7	243.5	81.8
64	24.1	-24.1	1.2	37.0	-46.0	316.9	729.7	6172.5	1331.8	174.8	227.3	52.6

***Days after January 1.

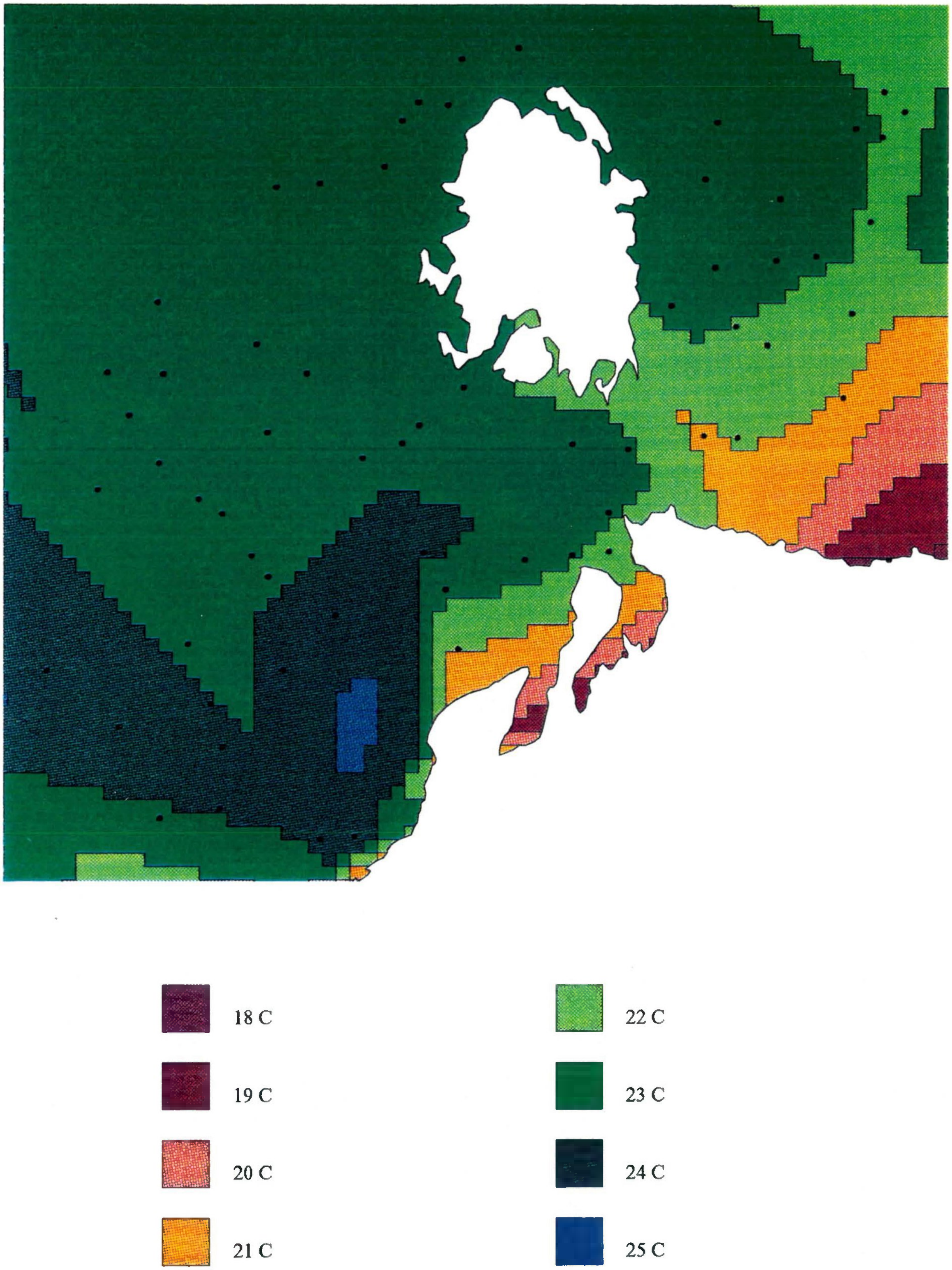
APPENDIX V

Study Area

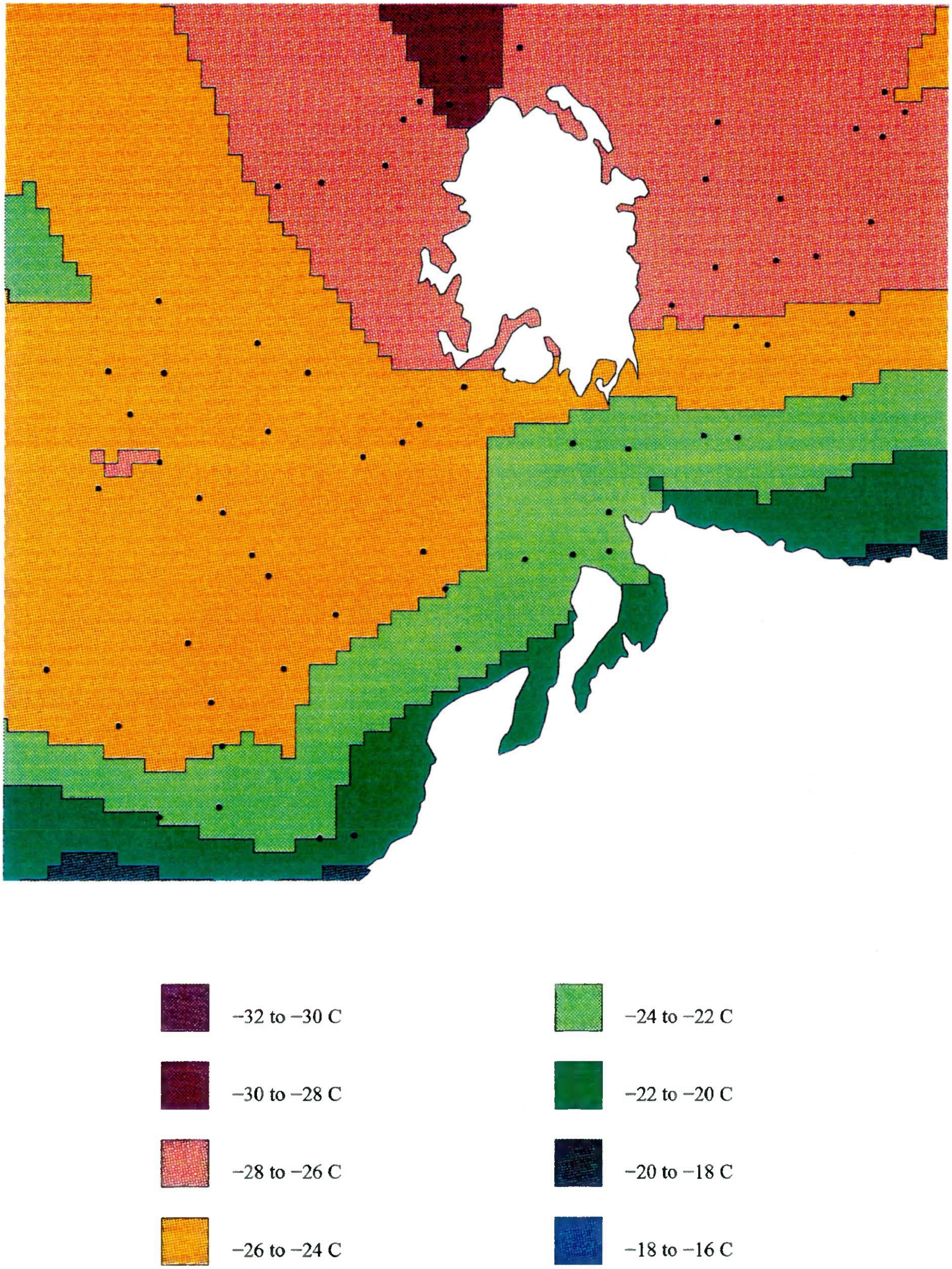
Weather Maps



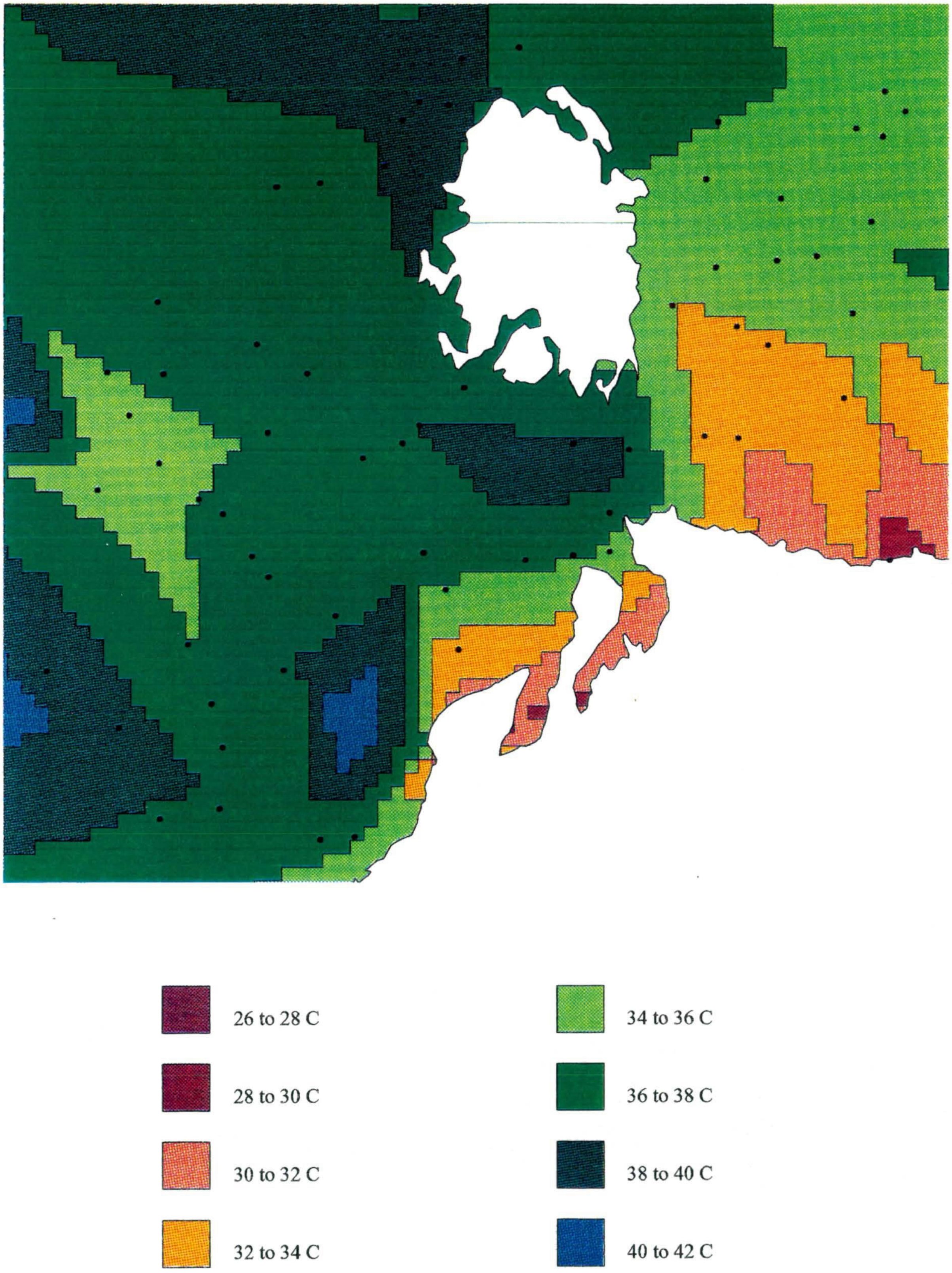
Mean Annual Temperature



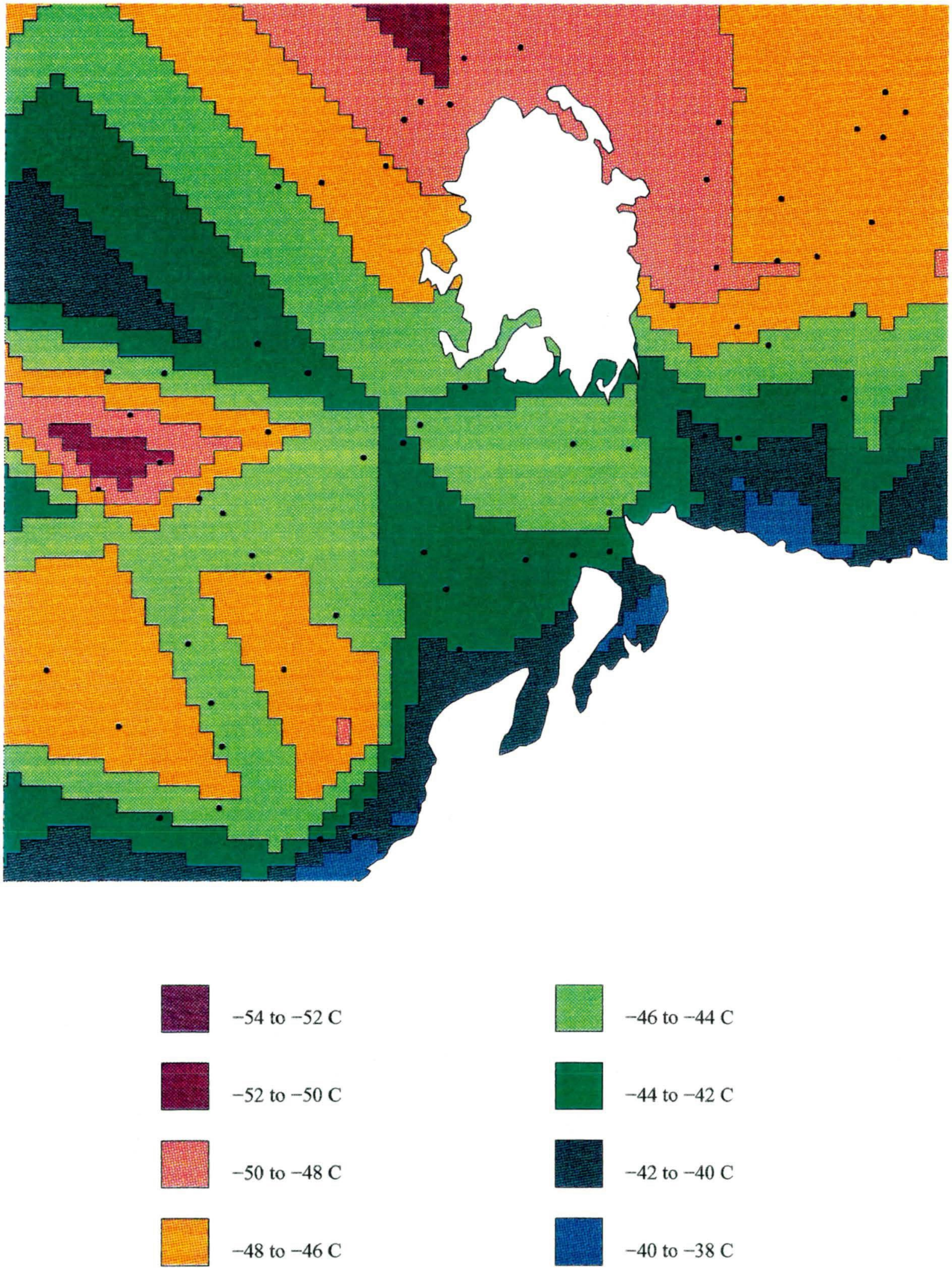
Average July Maximum Temperature



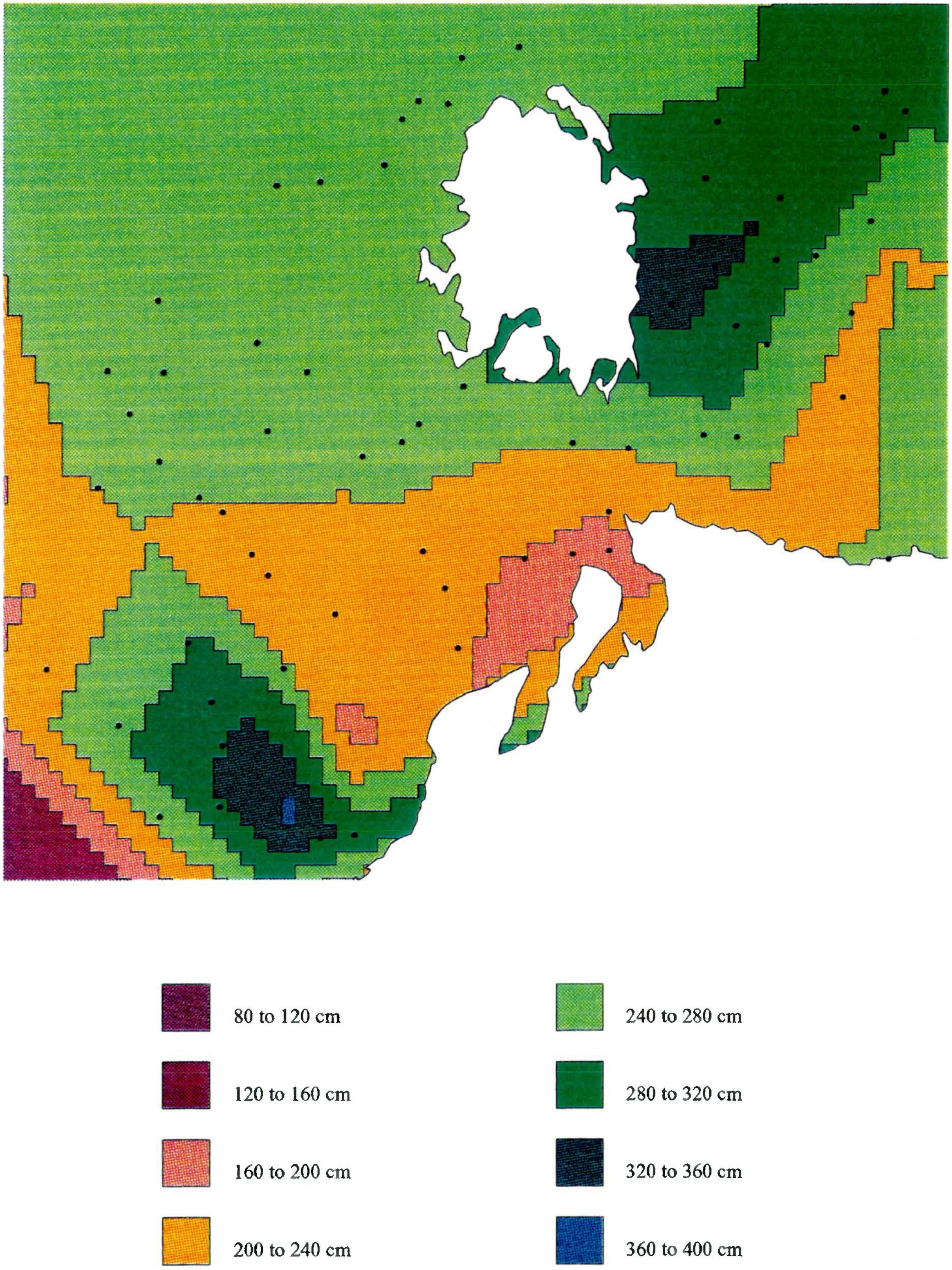
Average January Minimum Temperature



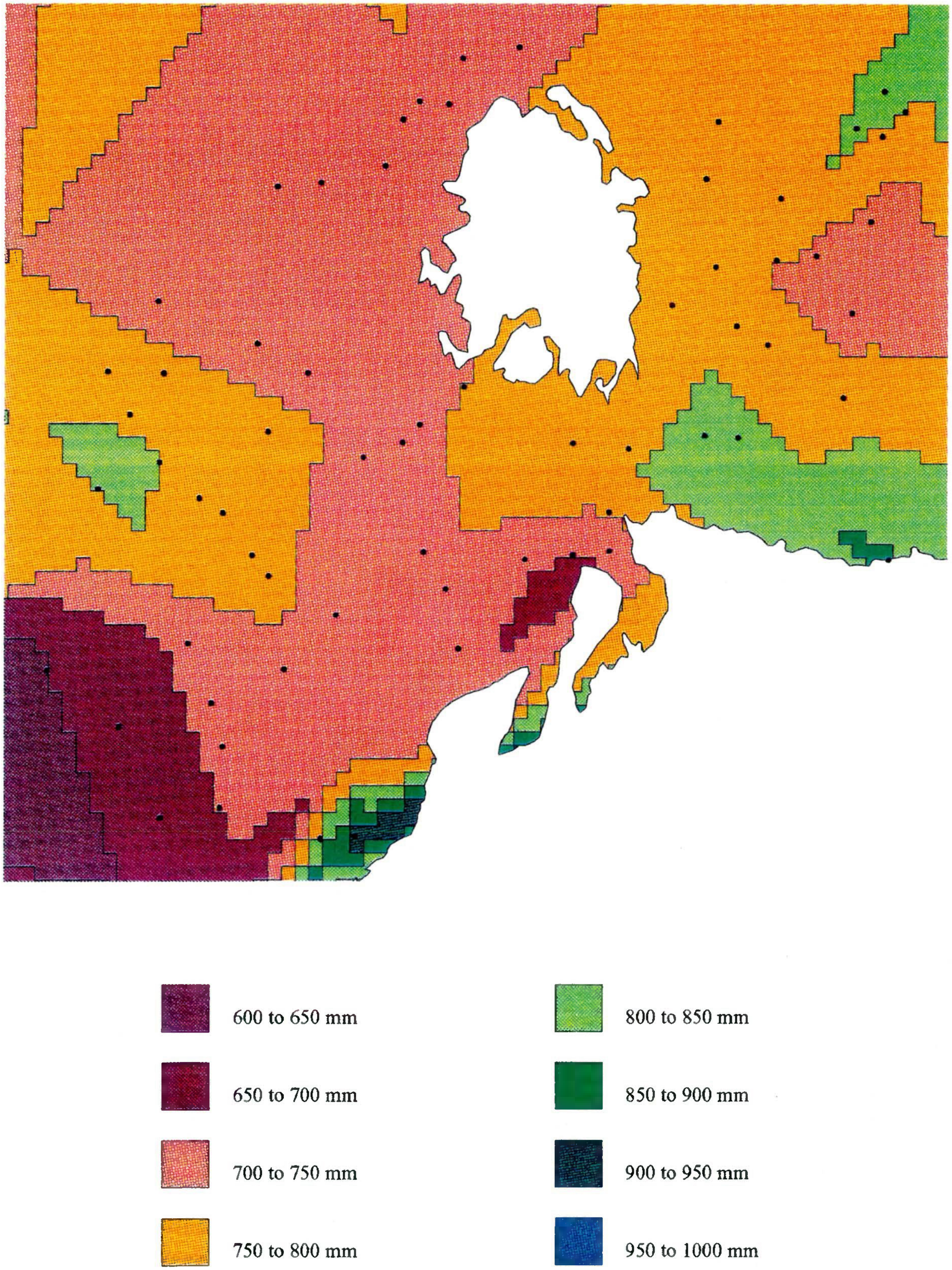
Maximum Temperature



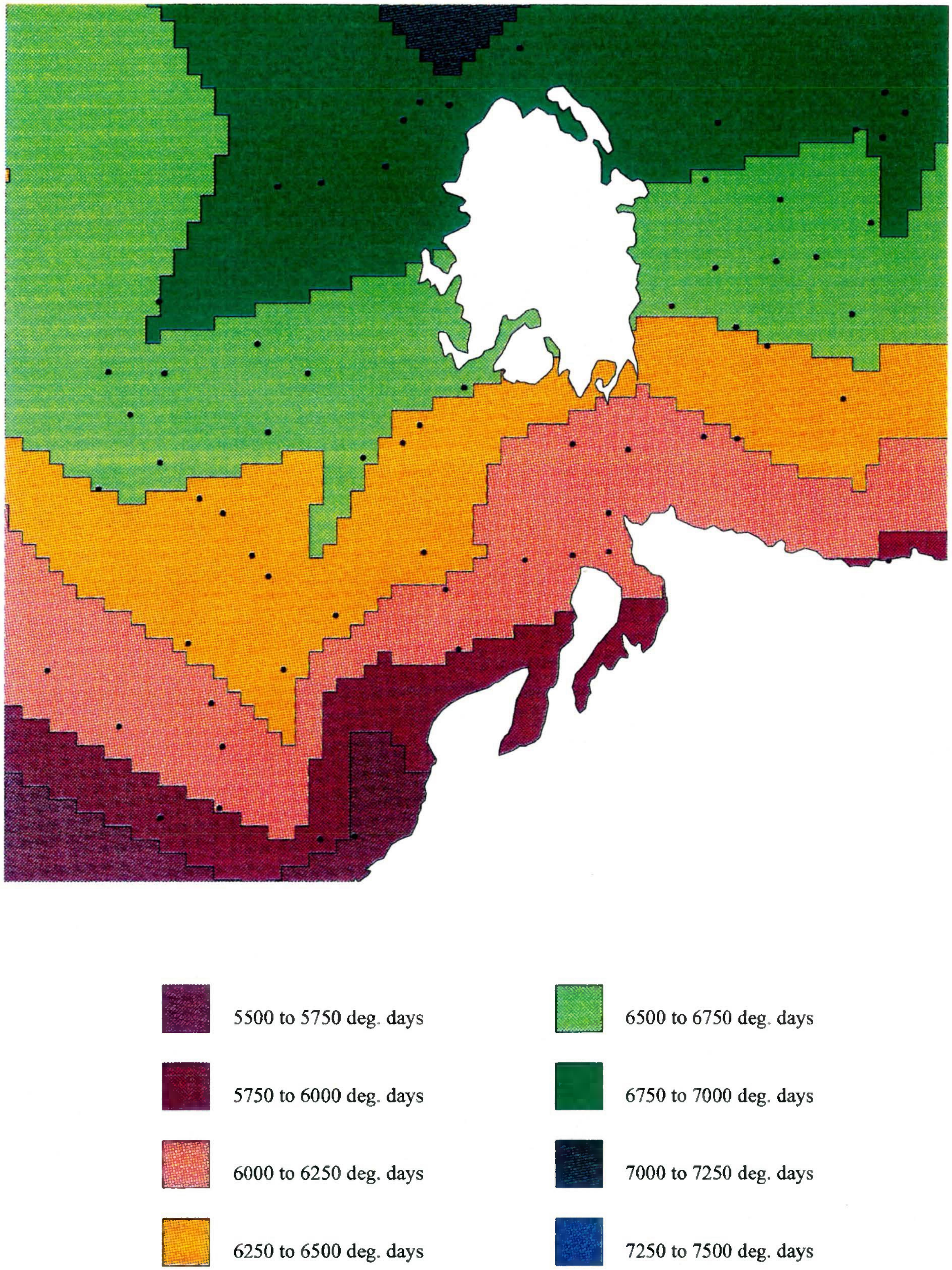
Minimum Temperature



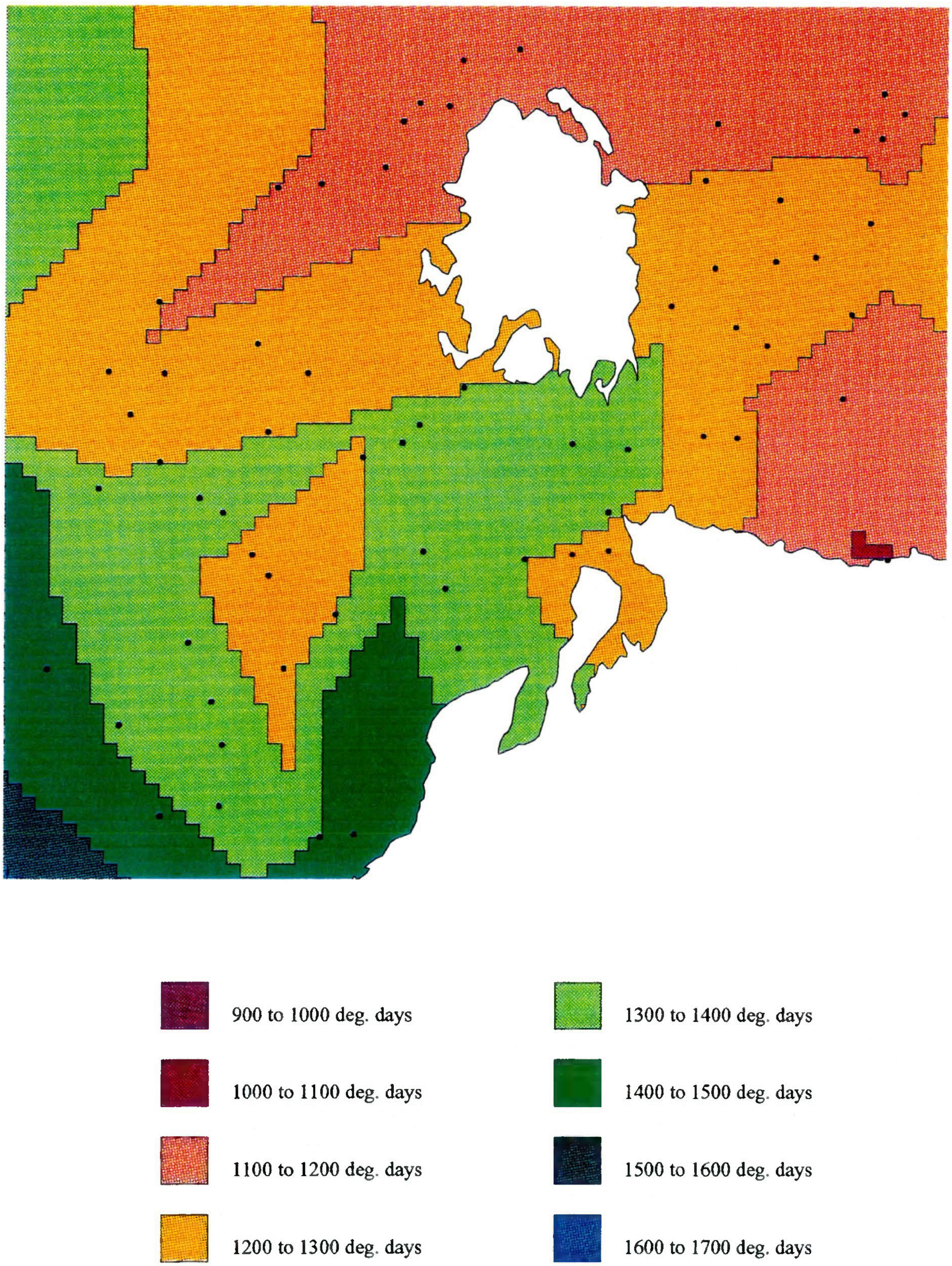
Mean Annual Snow Fall



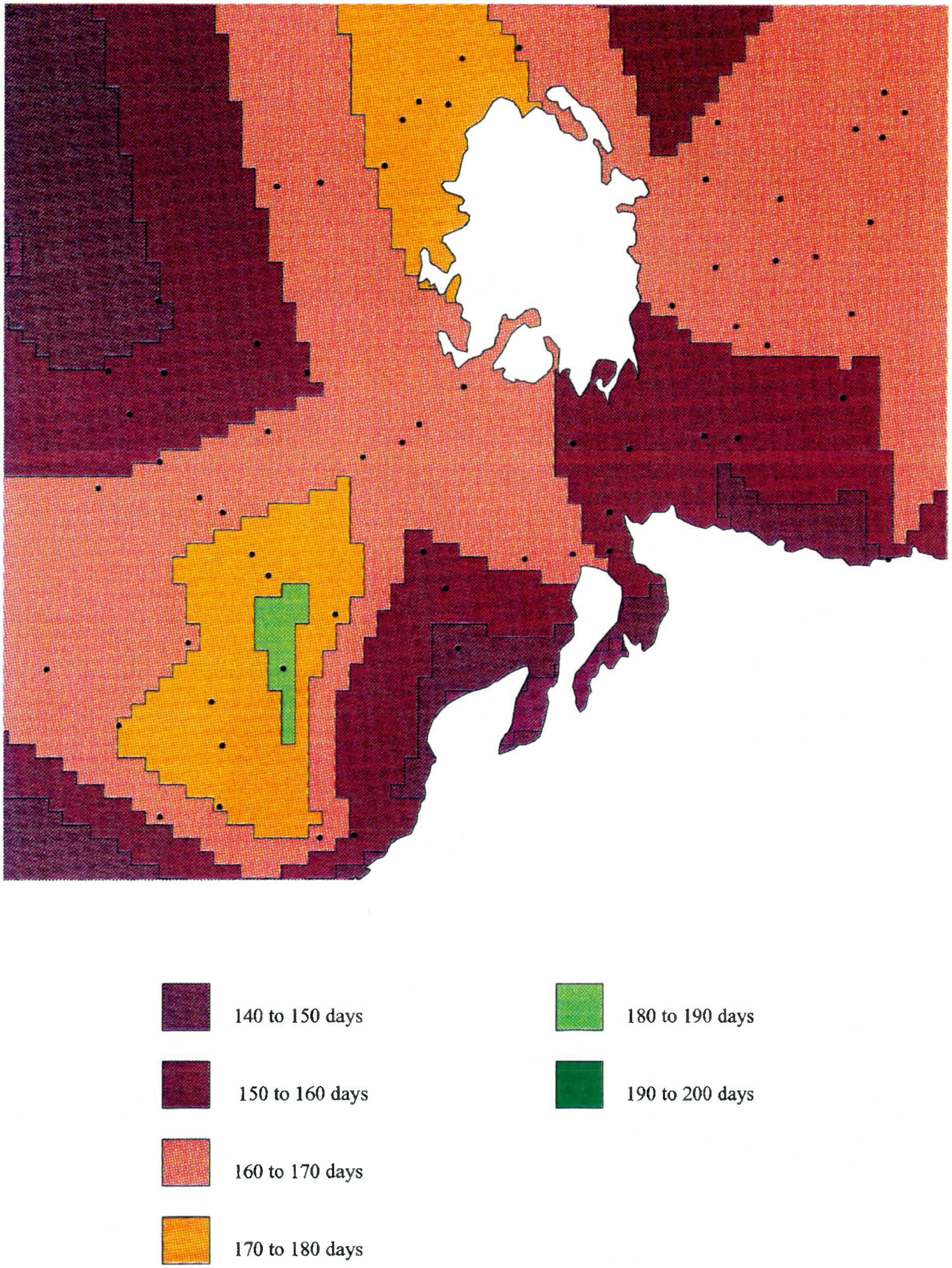
Mean Annual Precipitation



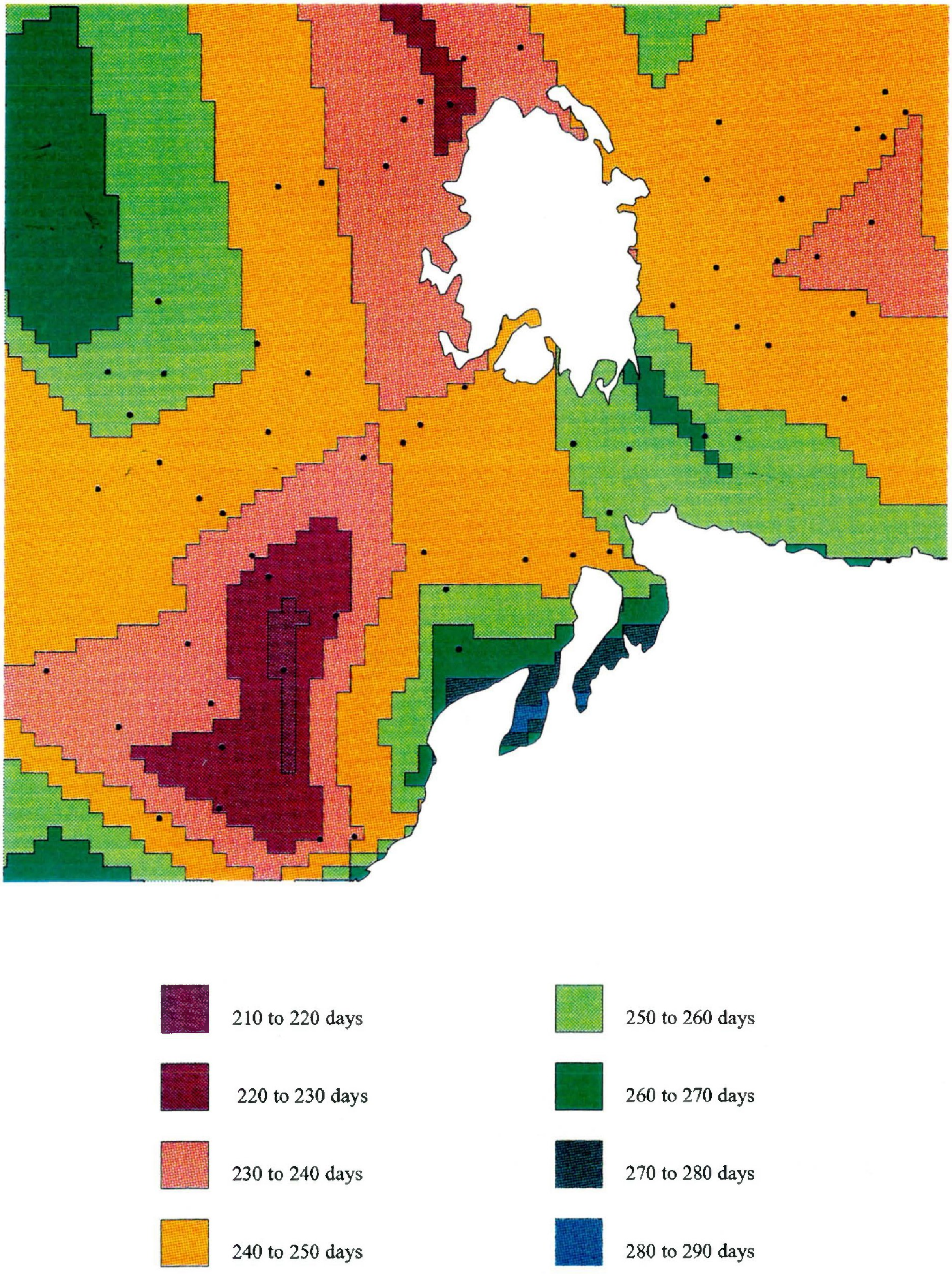
Mean Annual Heating Degree Days



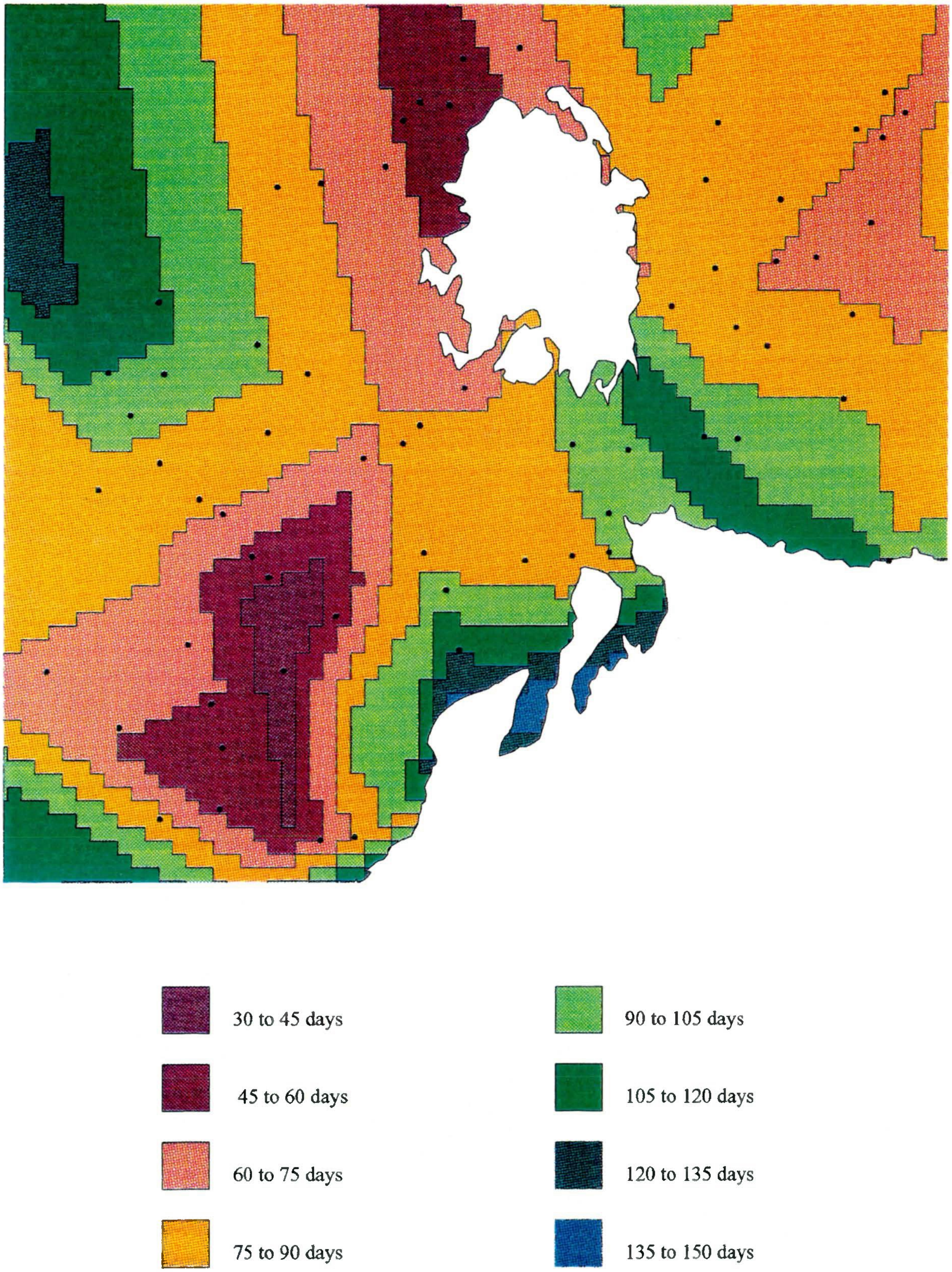
Mean Annual Growing Degree Days



Average Spring Frost Date



Average First Fall Frost Date



Average Frost Free Days

APPENDIX VI

Jack Pine Variable Means

Greenhouse Trial
LU Field Trial
Raith Trial

	GH88	GH89	GHIN	GHCS	GHDR	GHNF	GHR
1	64.80	83.59	27.19	79.87	52.70	29.50	50.77
2	110.20	99.20	26.98	84.41	57.43	31.10	45.00
3	93.50	104.30	26.76	81.17	54.42	30.00	56.79
4	86.60	91.90	26.96	81.76	54.81	29.60	45.00
5	91.50	114.90	26.55	84.00	57.45	29.80	56.79
6	66.90	92.40	26.75	78.38	51.61	29.10	63.44
7	82.60	92.70	30.43	85.43	54.99	30.67	56.79
8	80.40	84.20	27.23	83.14	55.91	30.30	39.23
9	112.10	117.80	26.78	89.28	62.47	30.00	45.00
10	90.10	83.00	27.11	70.79	43.69	29.50	45.00
11	74.60	107.00	26.57	82.42	55.83	30.67	50.77
12	70.67	119.20	26.47	83.55	57.06	29.30	63.44
13	93.10	123.40	26.35	78.32	51.97	28.50	33.21
14	84.30	126.11	26.52	86.94	60.41	29.00	56.79
15	139.60	120.00	26.54	85.60	59.05	29.80	26.57
16	110.78	119.00	26.66	80.44	53.81	30.11	61.87
17	99.30	89.00	26.69	79.29	52.61	29.80	63.44
18	105.80	120.40	26.39	80.79	54.40	29.70	50.77
19	91.90	91.80	26.97	82.46	55.51	29.70	50.77
20	69.78	71.30	27.30	74.20	46.89	31.00	56.79
21	101.60	107.60	26.67	77.78	51.12	30.40	63.44
22	61.60	93.70	26.75	81.77	55.01	29.50	71.57
23	120.40	96.70	26.78	81.32	54.55	29.60	39.23
24	78.00	93.70	27.06	81.14	54.10	30.80	50.77
25	131.78	123.20	27.31	83.98	56.67	30.00	39.23
26	96.40	105.90	26.67	76.52	49.86	29.40	71.57
27	134.33	108.90	26.77	85.91	59.14	30.10	56.79
28	80.90	110.30	26.61	80.19	53.59	29.80	90.00
29	107.22	90.00	27.03	83.10	56.06	30.89	90.00
30	85.00	107.80	26.44	82.47	56.03	29.10	63.44
31	99.40	95.00	26.82	76.24	49.39	32.00	50.77
32	84.40	138.90	26.33	82.48	56.14	29.70	45.00
33	131.90	141.70	26.22	71.78	45.55	32.20	18.44
34	107.00	119.59	26.76	78.59	51.81	30.20	50.77
35	106.40	127.44	26.30	88.42	62.13	30.10	56.79
36	105.60	74.69	26.94	74.73	47.80	30.20	45.00
37	110.60	97.50	26.64	81.41	54.77	31.00	56.79
38	133.00	115.10	26.83	85.16	58.32	31.70	63.44
39	92.80	98.50	26.77	84.77	58.00	30.80	56.79
40	61.80	76.90	26.77	74.94	48.17	29.60	71.57
41	102.20	115.90	26.58	82.27	55.70	29.60	50.77
42	81.30	101.40	26.55	86.33	59.78	30.00	56.79
43	80.00	98.90	26.97	76.55	49.57	30.90	50.77
44	93.13	92.13	26.59	80.01	53.44	29.13	45.00
45	75.10	83.60	27.48	78.89	51.42	30.00	63.44
46	131.22	103.44	26.96	83.64	56.67	31.78	61.87
47	64.20	96.30	26.89	79.08	52.17	31.00	56.79

	GH88	GH89	GHIN	GHCS	GHDR	GHNF	GHR
48	105.20	120.70	26.47	72.20	45.75	30.30	26.57
49	95.50	82.32	27.48	77.09	49.61	33.20	63.44
50	111.60	101.00	26.92	76.16	49.24	31.50	50.77
51	68.80	80.30	27.05	80.88	53.82	31.40	50.77
52	65.40	96.30	26.94	87.84	60.90	30.40	50.77
53	88.40	102.30	26.75	84.15	57.41	30.80	56.79
54	75.60	87.60	26.77	84.58	57.83	29.80	71.57
55	59.80	76.33	27.00	81.87	54.83	29.56	63.44
56	109.90	87.80	27.06	83.69	56.64	31.00	45.00
57	119.00	97.00	26.88	84.10	57.21	31.10	39.23
58	120.20	106.09	26.73	78.69	51.96	31.00	39.23
59	68.20	83.10	27.16	82.20	55.04	30.70	45.00
60	130.30	85.99	27.12	75.51	48.37	31.70	39.23
61	119.00	100.22	26.84	77.74	50.90	31.44	33.21
62	87.20	94.30	27.37	81.13	53.77	30.30	56.79
63	108.10	81.88	27.26	79.90	52.65	32.67	39.23
64	83.90	81.77	27.23	79.88	52.66	32.25	56.79

	LU88	LU89	LU90	LUIN	LUCS	LUDR	LUNF	LUR
1	73.80	270.03	685.93	13.40	87.14	73.74	25.53	52.54
2	99.47	333.20	730.13	13.29	89.96	76.67	27.27	50.77
3	73.63	286.14	657.31	13.60	86.77	73.17	27.33	55.55
4	103.60	317.10	691.50	13.25	85.94	72.69	26.80	35.06
5	118.50	367.93	838.67	13.14	93.49	80.35	25.93	36.87
6	85.27	335.37	810.70	13.12	89.42	76.30	26.70	33.21
7	108.13	294.47	682.80	13.30	81.82	68.52	27.40	35.06
8	101.57	290.66	687.38	13.16	83.80	70.64	27.40	53.73
9	102.90	326.90	742.13	13.32	90.09	76.77	27.00	36.87
10	89.24	306.14	756.66	13.16	83.86	70.70	28.77	33.21
11	76.17	251.60	654.93	13.41	84.35	70.93	28.00	60.67
12	102.33	337.77	756.97	13.17	82.99	69.83	25.87	33.21
13	125.83	389.10	804.87	13.51	84.24	70.73	27.13	33.83
14	70.97	283.20	716.62	13.31	89.99	76.68	27.20	36.87
15	119.67	382.80	848.87	13.21	88.63	75.42	28.00	28.66
16	124.77	414.20	861.07	12.98	85.85	72.87	27.27	26.57
17	98.70	305.80	730.83	13.27	87.94	74.68	27.07	50.77
18	92.07	363.90	830.28	13.04	88.90	75.87	28.30	37.47
19	70.17	256.07	658.60	13.37	82.92	69.55	26.67	54.33
20	61.07	223.79	560.39	13.46	84.64	71.19	27.25	67.21
21	91.00	308.38	711.79	13.45	80.98	67.53	28.07	41.55
22	58.30	217.37	609.90	13.31	78.48	65.17	26.57	50.77
23	107.87	292.37	724.31	13.60	89.51	75.91	28.63	42.71
24	67.10	215.63	589.35	13.59	83.33	69.74	27.83	50.77
25	126.80	397.07	823.63	12.87	91.04	78.17	26.13	26.57
26	108.43	366.86	799.72	13.06	91.12	78.06	28.17	33.21
27	84.20	279.41	682.73	13.18	84.23	71.05	27.47	43.85
28	109.50	325.55	762.86	13.32	82.88	69.55	26.40	52.54
29	115.43	300.47	733.93	13.43	92.35	78.92	26.60	50.77
30	75.41	253.54	642.14	13.25	83.74	70.49	27.52	47.87
31	97.50	308.40	727.67	13.14	89.64	76.50	28.43	42.71
32	114.07	416.20	882.80	13.33	92.66	79.32	28.33	14.18
33	124.87	462.30	979.50	12.86	91.97	79.11	30.77	21.13
34	140.17	426.00	920.72	13.18	90.52	77.34	29.83	39.23
35	109.80	309.37	780.53	13.65	88.61	74.96	27.47	46.72
36	75.72	265.61	693.32	13.71	91.65	77.93	28.14	53.13
37	118.63	355.13	806.93	13.21	90.43	77.22	28.53	35.06
38	118.43	378.13	858.67	13.05	85.42	72.37	27.27	39.23
39	107.17	324.48	803.83	13.09	93.93	80.84	27.62	46.72
40	52.80	224.10	605.04	13.58	86.86	73.28	27.40	48.45
41	113.77	416.80	910.80	13.18	89.18	76.00	28.10	33.21
42	98.00	367.97	837.86	12.95	87.90	74.95	28.07	33.21
43	96.13	328.20	777.57	13.17	87.88	74.71	28.47	39.23
44	94.27	302.67	726.21	13.39	87.15	73.76	27.00	35.06
45	107.60	338.60	781.53	12.96	86.19	73.23	27.03	52.54
46	127.13	377.86	880.87	13.10	92.59	79.48	28.27	36.87
47	64.50	232.90	634.03	13.42	85.26	71.84	28.23	48.45

	LU88	LU89	LU90	LUIN	LUCS	LUDR	LUNF	LUR
48	113.60	428.07	898.76	13.01	86.50	73.49	29.70	26.57
49	103.37	347.47	875.60	13.12	92.40	79.28	27.80	30.66
50	130.57	385.27	836.47	13.42	87.91	74.49	28.33	40.98
51	95.57	295.70	744.50	13.42	92.78	79.35	27.73	39.23
52	152.73	406.41	845.04	13.22	86.81	73.60	28.80	29.33
53	118.30	437.70	969.27	12.95	94.40	81.45	30.10	18.44
54	112.17	348.80	794.90	13.23	91.24	78.00	27.07	48.45
55	89.00	274.47	720.10	13.31	82.23	68.93	28.00	46.72
56	104.03	313.67	773.97	13.21	90.56	77.34	27.40	42.71
57	109.60	329.59	796.14	13.33	88.27	74.94	26.17	40.98
58	118.73	390.25	833.20	13.06	90.82	77.75	27.67	30.66
59	95.72	312.21	758.83	13.11	88.62	75.51	27.34	40.98
60	155.70	444.31	904.83	13.09	90.50	77.41	27.41	37.47
61	110.10	363.93	766.54	13.14	83.48	70.34	28.70	33.83
62	82.60	284.17	676.86	13.69	87.39	73.71	26.90	52.54
63	95.33	283.90	660.93	13.28	87.99	74.70	28.25	49.60
64	108.83	384.00	874.27	12.92	88.88	75.96	27.37	39.23

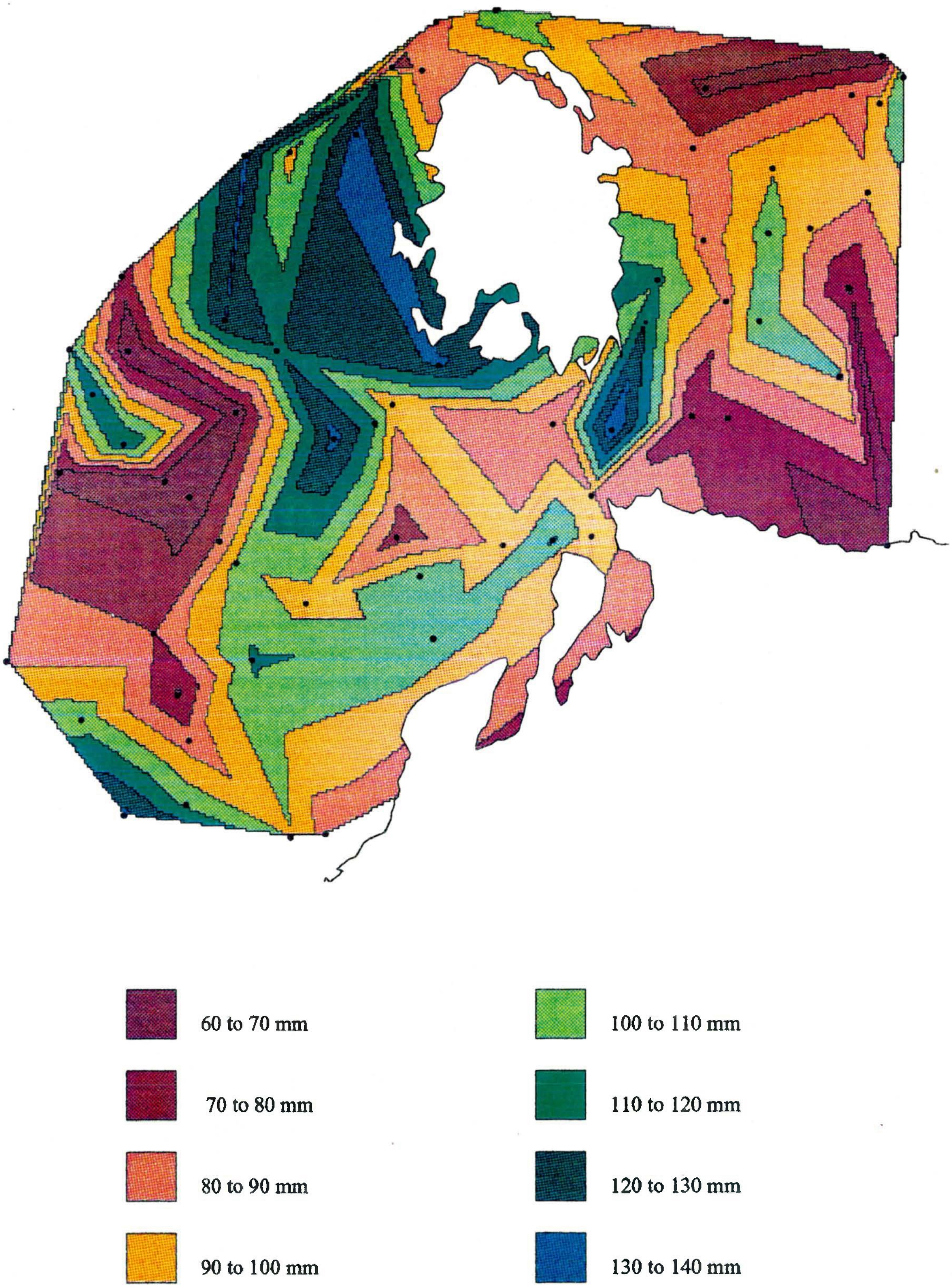
	R88	R89	R90	RIN	RCS	RDR	RNF	RSU
1	73.35	195.12	355.08	21.84	72.98	51.14	29.96	68.58
2	59.26	141.48	256.00	23.71	70.12	46.42	32.05	61.12
3	61.96	186.65	327.87	23.47	78.27	54.80	31.00	63.44
4	48.57	155.29	268.20	23.34	68.87	45.53	31.85	56.79
5	69.30	194.74	366.96	23.68	75.91	52.23	31.24	61.12
6	63.28	205.39	369.72	22.68	77.74	55.07	29.87	50.77
7	104.31	252.29	457.96	22.89	81.48	58.59	31.56	65.91
8	64.14	164.54	311.54	22.84	69.82	46.98	30.38	43.09
9	57.22	132.67	272.57	24.51	75.36	50.85	35.83	33.21
10	60.35	147.39	288.95	25.39	76.01	50.62	35.52	52.73
11	72.86	181.50	335.95	24.59	76.74	52.15	33.46	58.91
12	64.22	179.96	322.56	21.59	78.36	56.77	31.93	71.57
13	72.24	170.21	324.05	23.44	76.57	53.13	33.10	56.79
14	49.56	138.06	264.11	24.04	68.91	44.88	31.62	50.77
15	72.53	198.53	337.00	24.63	74.74	50.11	36.55	48.83
16	78.58	186.54	330.79	19.37	78.57	59.20	32.78	63.44
17	66.29	183.55	340.40	22.36	81.30	58.94	33.65	56.79
18	76.44	183.44	351.65	21.95	77.15	55.20	32.05	50.77
19	50.50	148.60	296.53	21.74	74.67	52.93	32.26	54.74
20	61.73	164.33	303.47	24.71	77.38	52.67	30.11	45.00
21	95.44	186.00	318.13	23.29	76.34	53.04	33.00	46.91
22	46.12	114.06	216.13	23.74	70.51	46.77	31.61	48.83
23	55.36	121.39	239.08	22.08	71.99	49.91	32.00	43.09
24	53.25	124.75	228.19	21.41	69.73	48.33	30.81	46.91
25	77.96	166.15	303.40	24.89	76.78	51.89	31.04	61.12
26	57.60	134.11	248.22	23.63	70.85	47.22	32.73	35.26
27	62.67	112.75	212.63	24.30	69.74	45.45	36.08	33.21
28	53.19	120.63	221.32	23.58	67.64	44.05	34.00	56.79
29	66.00	120.67	262.46	23.90	72.33	48.43	34.06	41.17
30	61.00	156.57	291.45	22.84	72.30	49.46	32.58	56.79
31	65.29	150.43	274.36	24.20	77.14	52.94	37.94	48.83
32	49.38	123.50	206.88	25.24	72.74	47.50	35.33	31.09
33	107.78	279.78	478.78	25.14	83.25	58.11	32.78	71.57
34	59.39	149.00	272.62	22.07	72.70	50.63	37.20	41.17
35	66.13	162.83	304.26	22.85	76.60	53.75	32.57	61.12
36	86.00	168.78	298.78	25.52	69.14	43.62	33.09	33.21
37	62.20	158.43	262.86	21.11	73.69	52.58	36.27	45.00
38	72.79	156.07	293.07	24.44	74.09	49.64	33.65	43.09
39	52.63	140.00	254.86	27.87	66.29	38.42	38.13	31.09
40	44.33	115.62	232.23	22.38	73.05	50.67	35.88	50.77
41	67.26	185.58	352.37	24.87	81.19	56.32	32.00	52.73
42	42.88	95.00	190.13	23.74	74.58	50.84	36.50	46.91
43	53.14	140.52	244.57	22.38	72.07	49.70	35.17	56.79
44	74.11	163.00	293.56	23.02	72.00	48.98	33.95	52.73
45	88.58	220.57	375.55	22.82	76.15	53.33	33.80	63.44
46	67.23	175.39	338.39	25.61	81.19	55.58	32.60	41.17
47	53.18	127.31	249.63	23.40	75.19	51.79	35.71	48.83

	R88	R89	R90	RIN	RCS	RDR	RNF	RSU
48	64.25	155.86	281.71	22.78	72.49	49.71	37.60	31.09
49	62.55	185.18	330.94	21.84	74.62	52.78	35.55	54.74
50	57.70	127.75	236.88	23.64	70.53	46.88	35.54	35.26
51	64.91	128.70	247.44	27.60	72.14	44.54	36.31	37.27
52	81.82	169.50	280.50	22.84	74.97	52.12	32.59	37.27
53	43.83	121.90	247.90	27.79	71.58	43.79	33.70	39.23
54	70.33	177.60	305.07	23.89	72.78	48.89	33.05	45.00
55	53.70	111.25	259.25	28.65	72.00	43.35	35.50	35.26
56	87.30	197.10	337.10	23.59	77.27	53.68	34.77	35.26
57	65.06	137.53	255.21	24.08	68.96	44.88	34.44	46.91
58	65.00	188.36	328.00	21.16	72.95	51.78	32.57	37.27
59	54.00	132.00	219.92	23.59	68.56	44.97	35.29	41.17
60	78.06	201.35	347.77	23.52	74.99	51.47	32.16	48.83
61	47.55	148.63	283.37	23.20	77.74	54.54	33.65	54.74
62	57.05	158.59	288.96	22.24	78.62	56.38	32.88	58.91
63	78.88	171.50	300.81	22.10	75.60	53.50	32.30	48.83
64	62.94	165.25	299.60	21.80	76.57	54.77	36.78	48.83

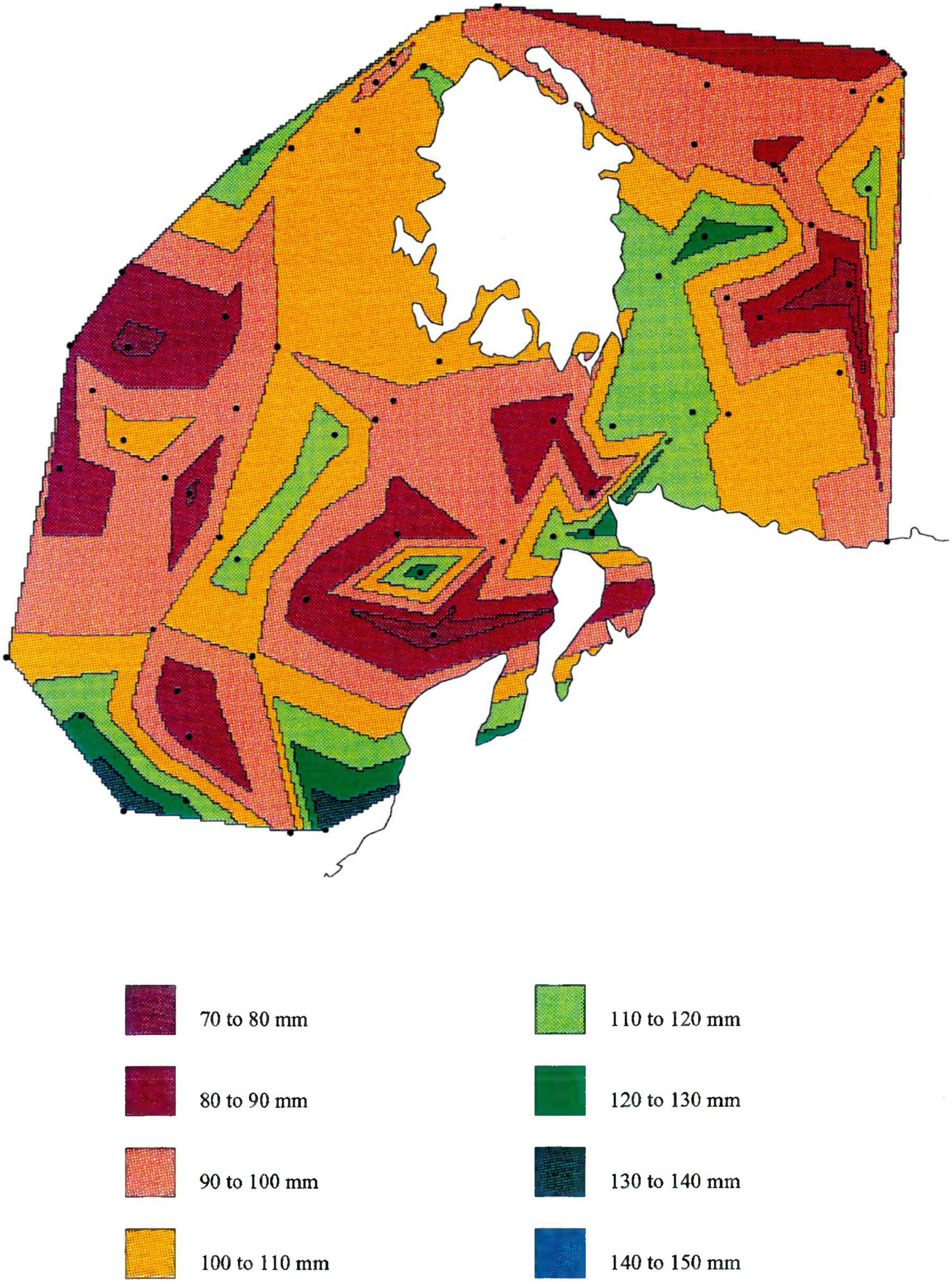
APPENDIX VII

Jack Pine Variable Maps

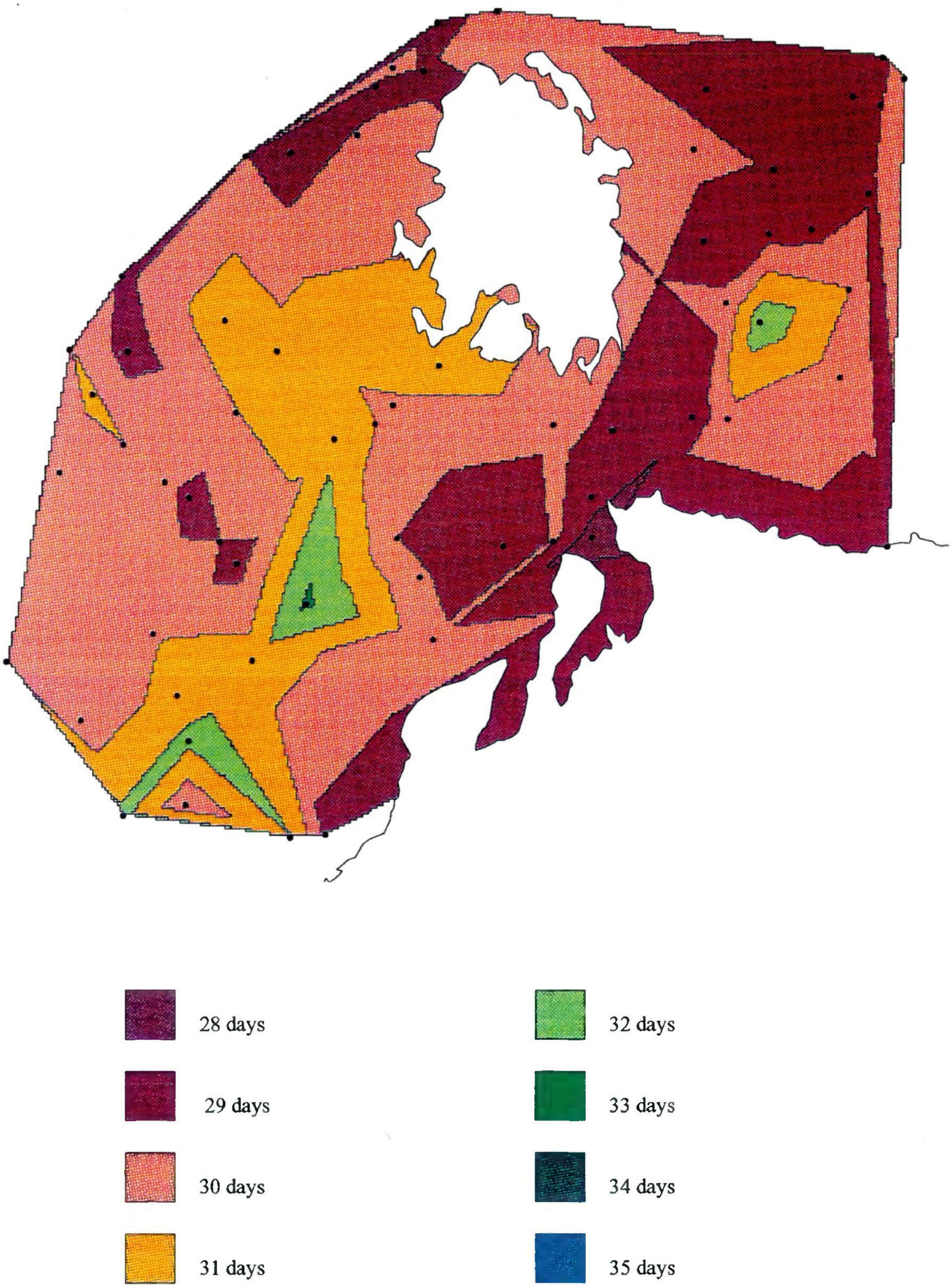
Greenhouse Trial
LU Field Trial
Raith Trial



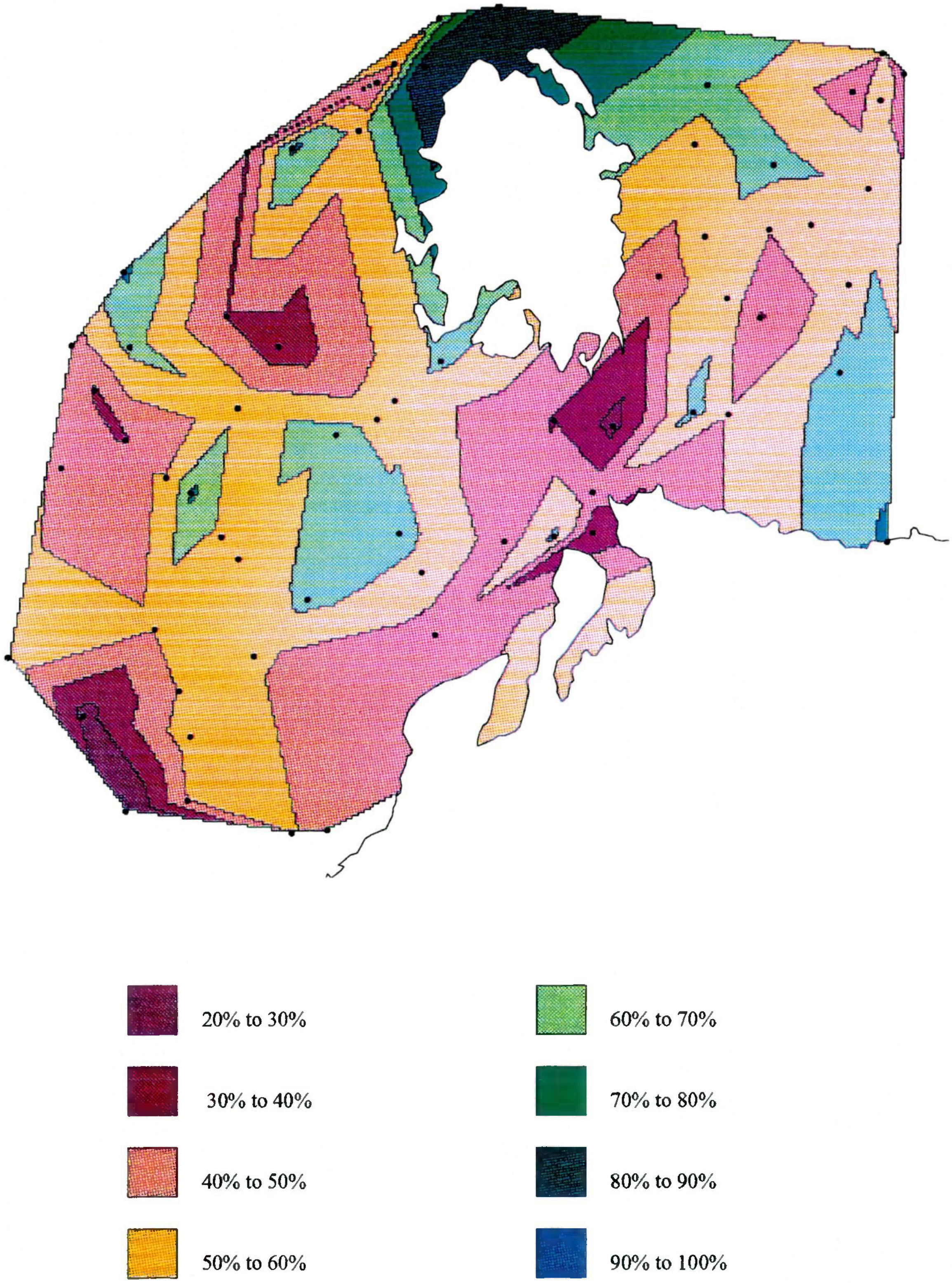
1988 Greenhouse Heights



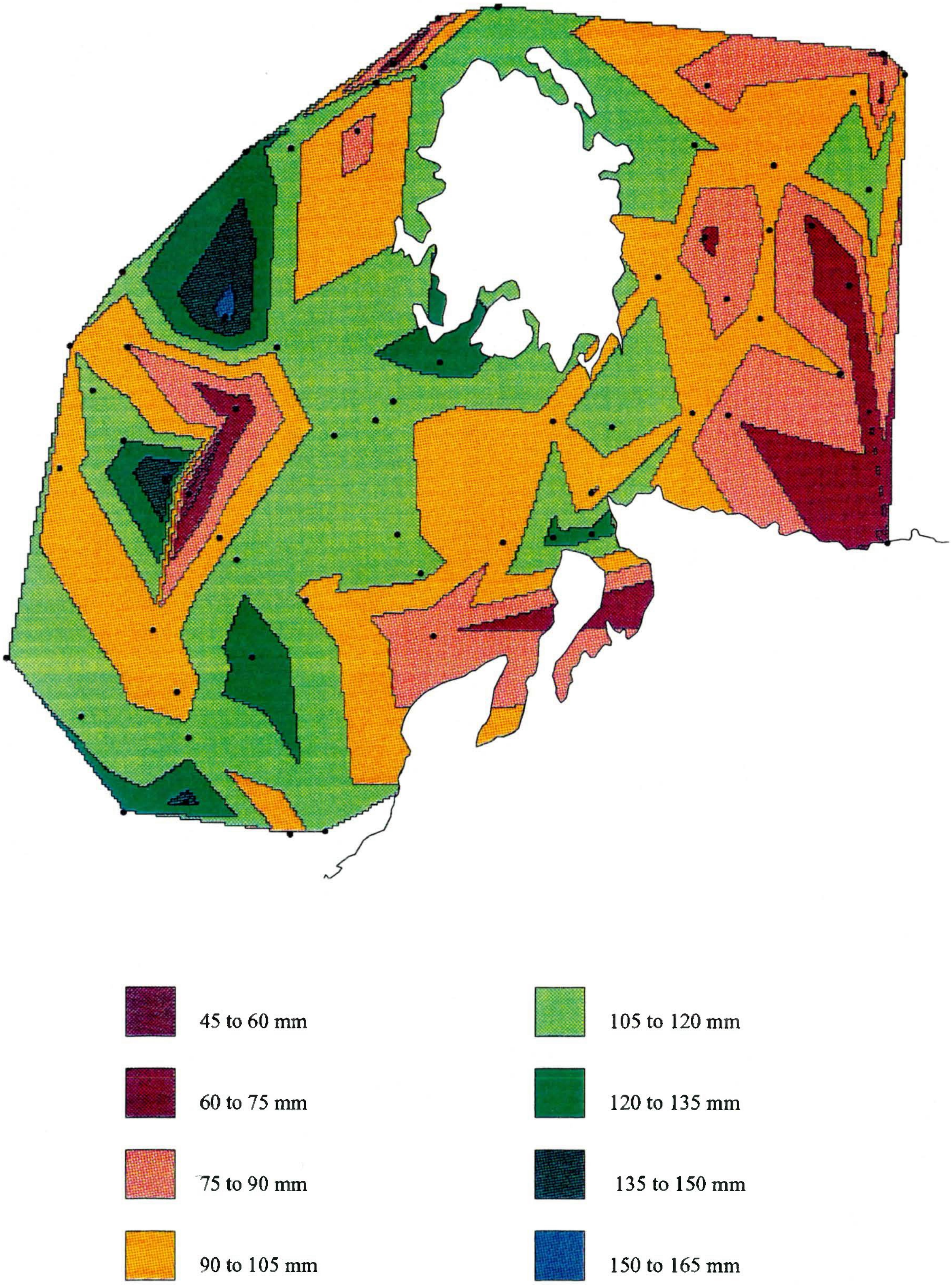
1989 Greenhouse Height Elongation



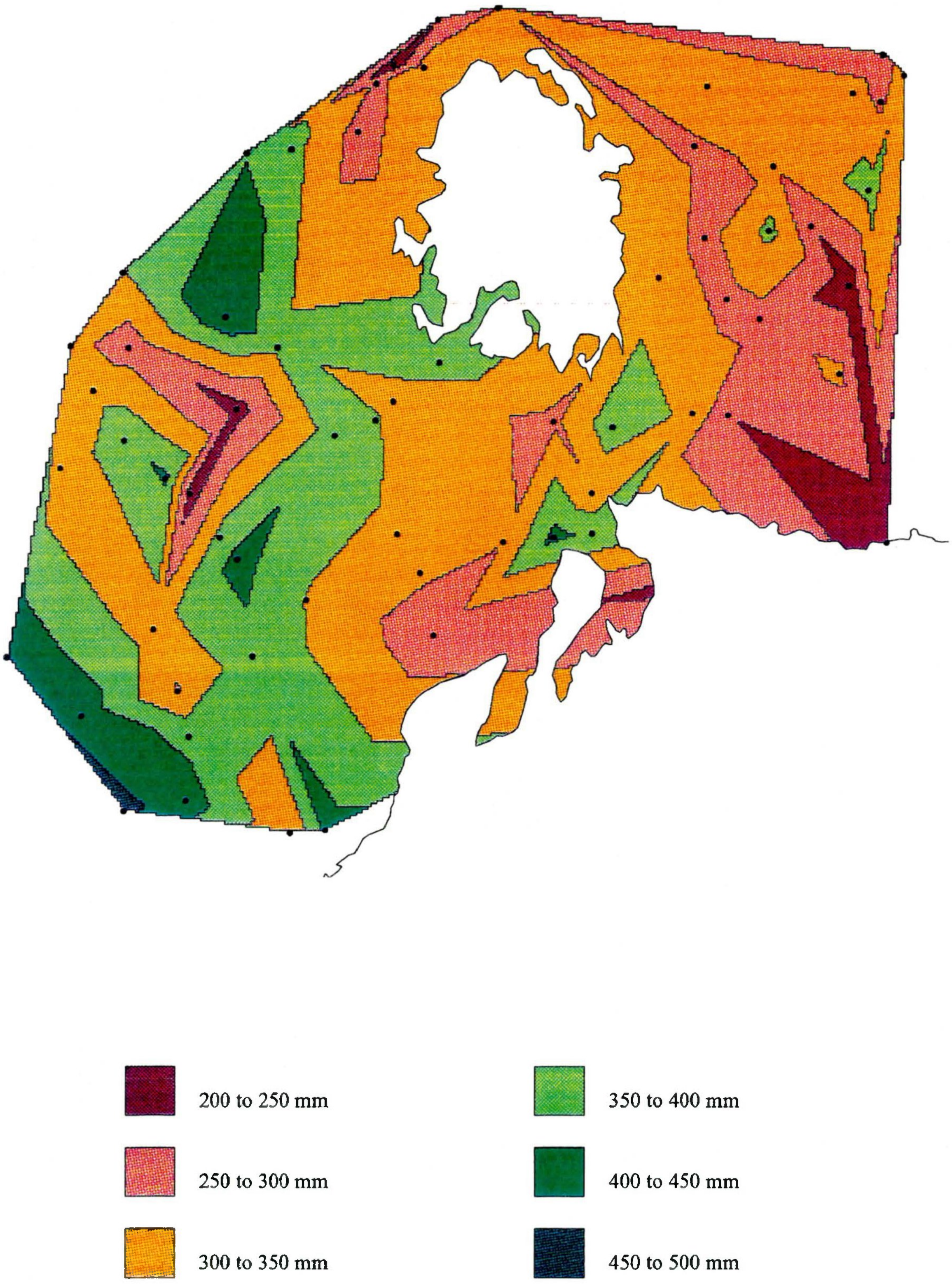
Greenhouse Trial Needle Flushing



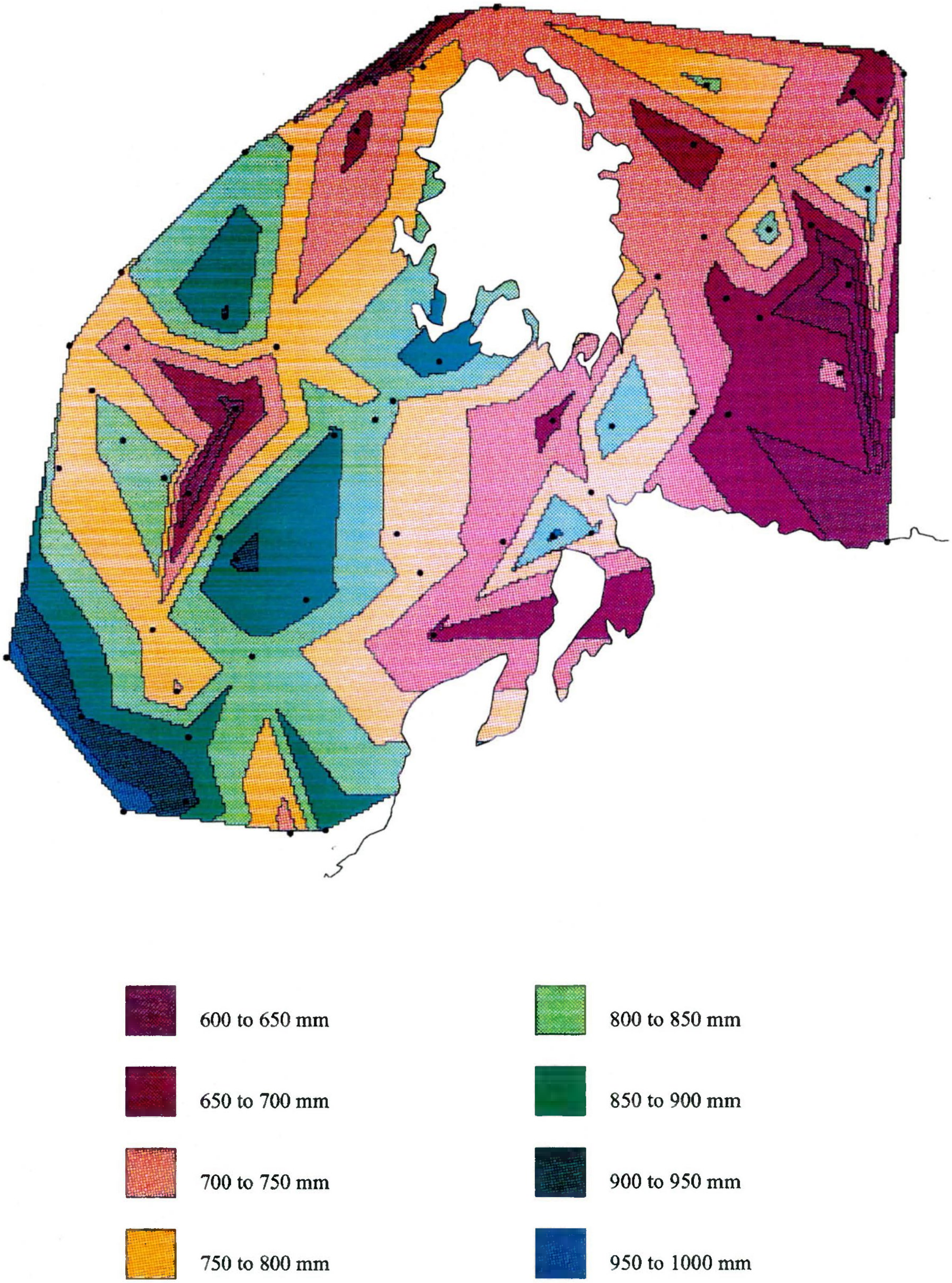
Greenhouse Purpling



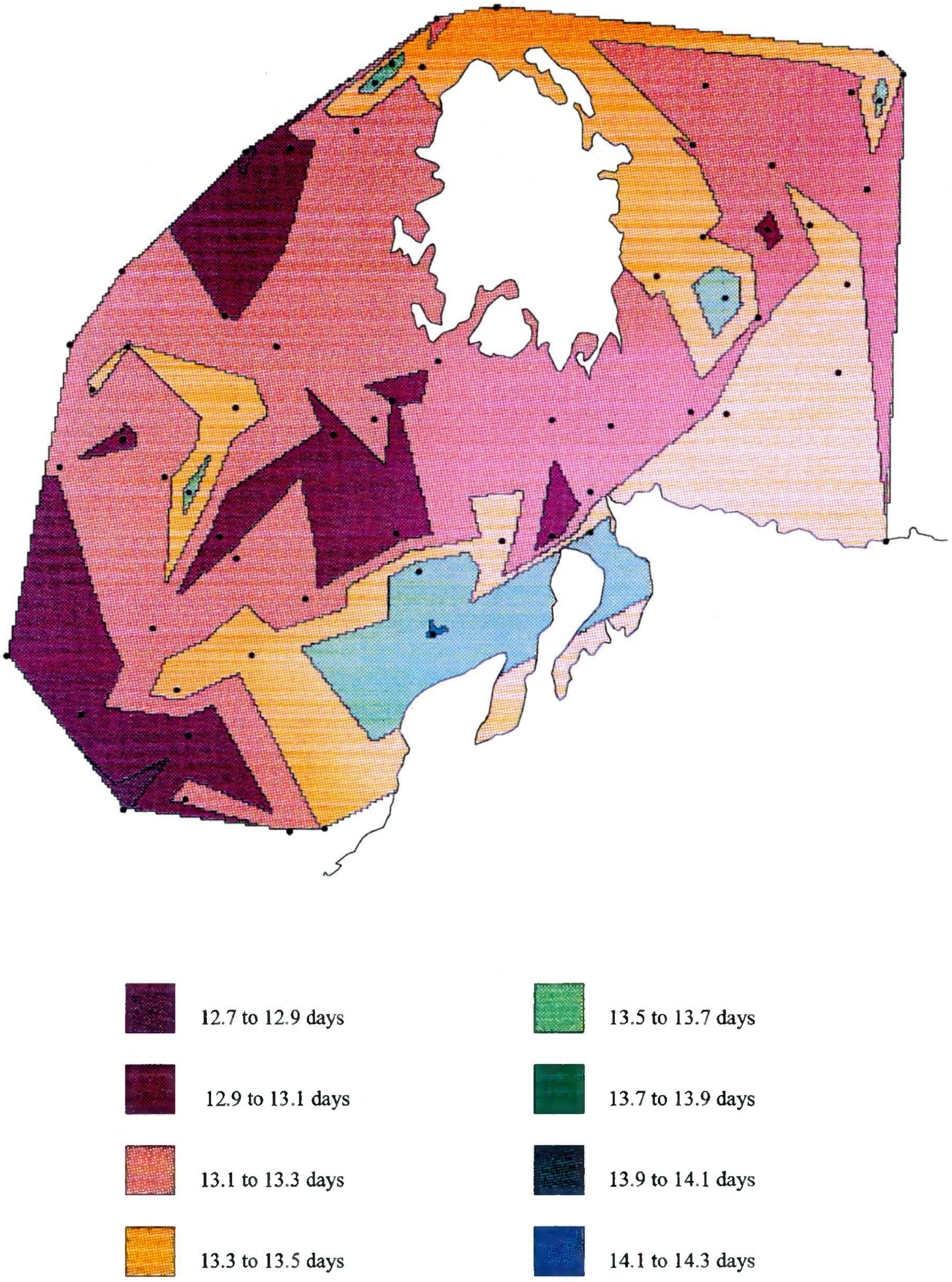
1988 LU Field Trial Height



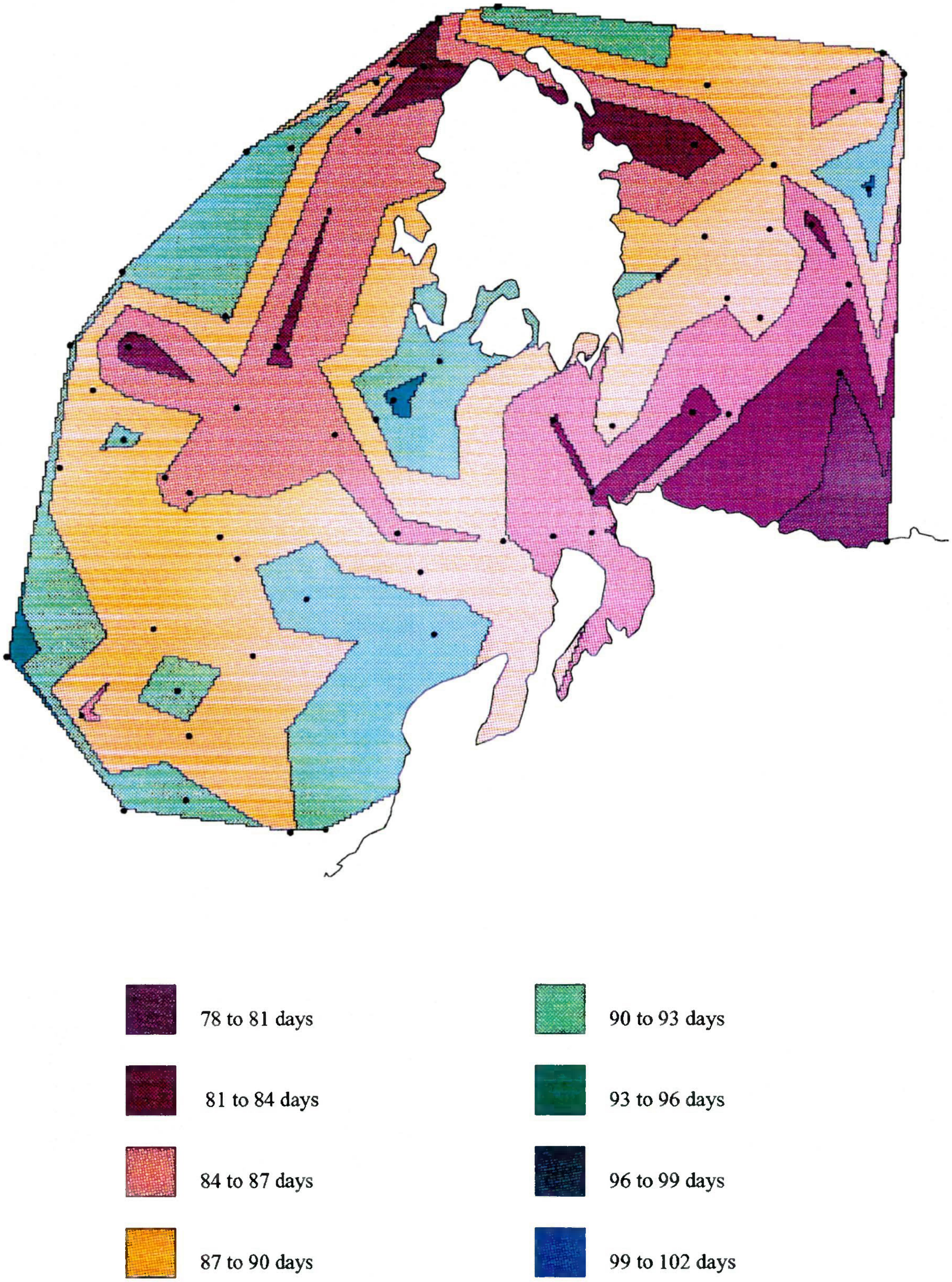
1989 LU Field Trial Height



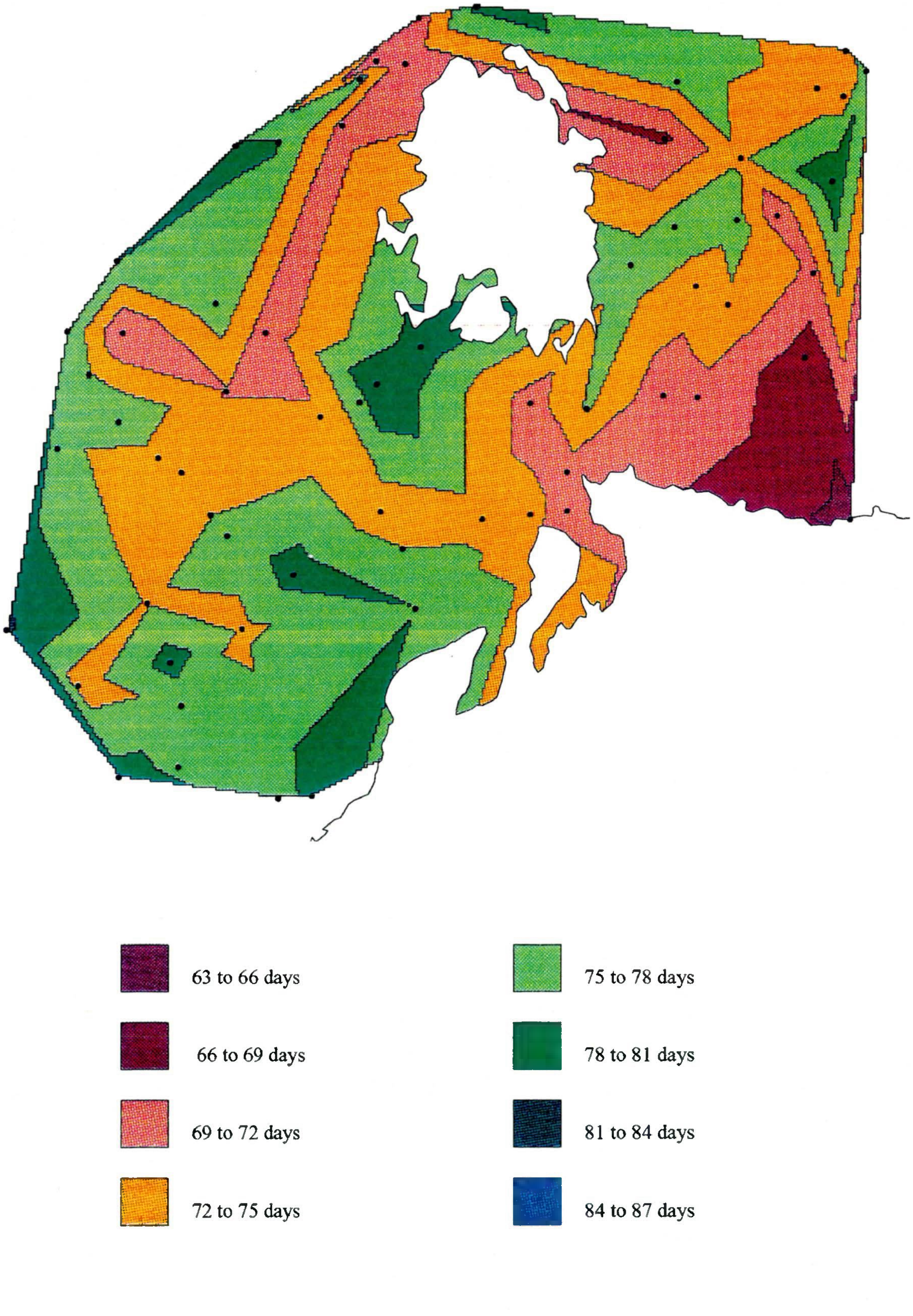
1990 LU Field Trial Heights



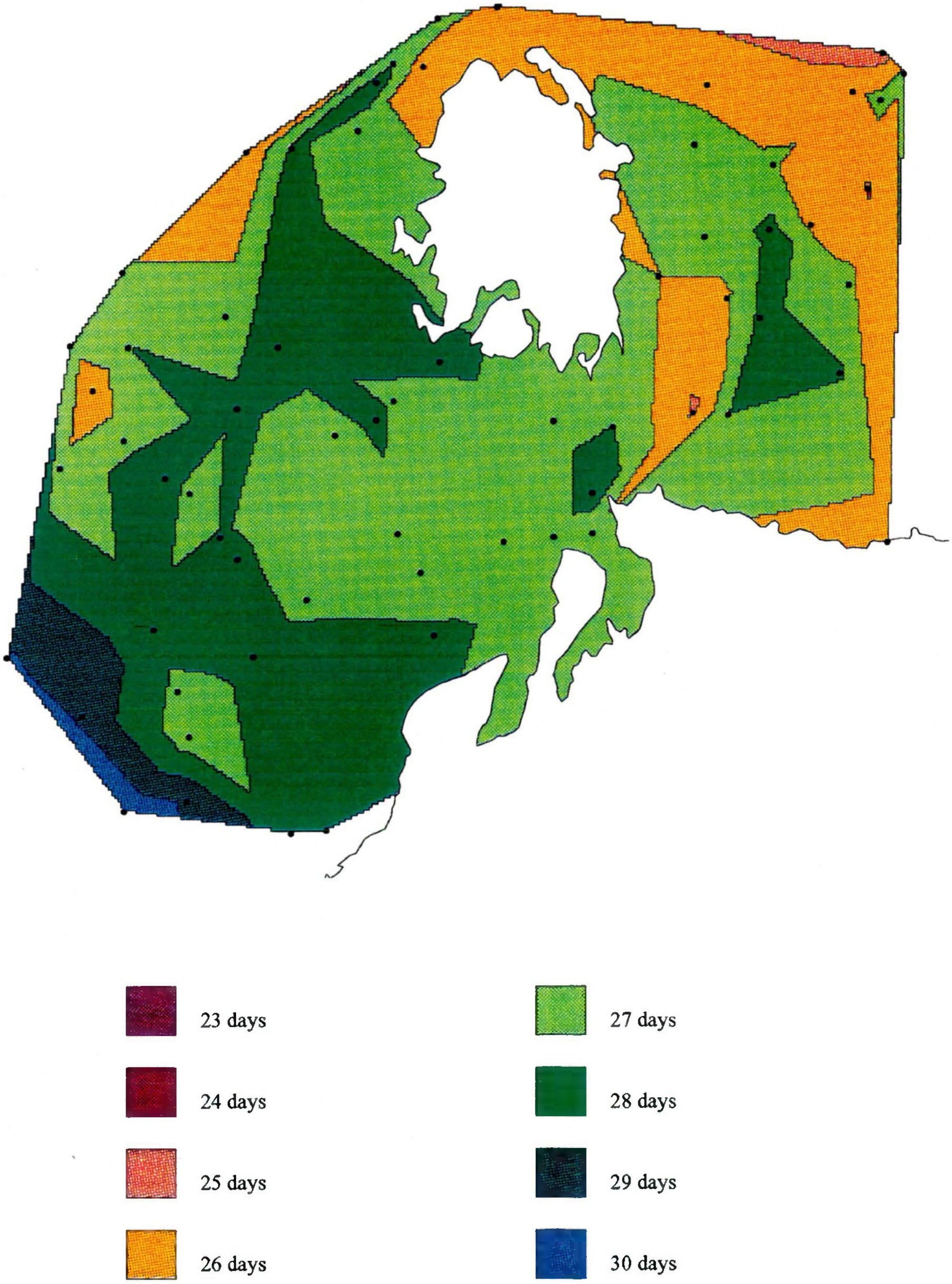
LU Field Trial Elongation Initiation



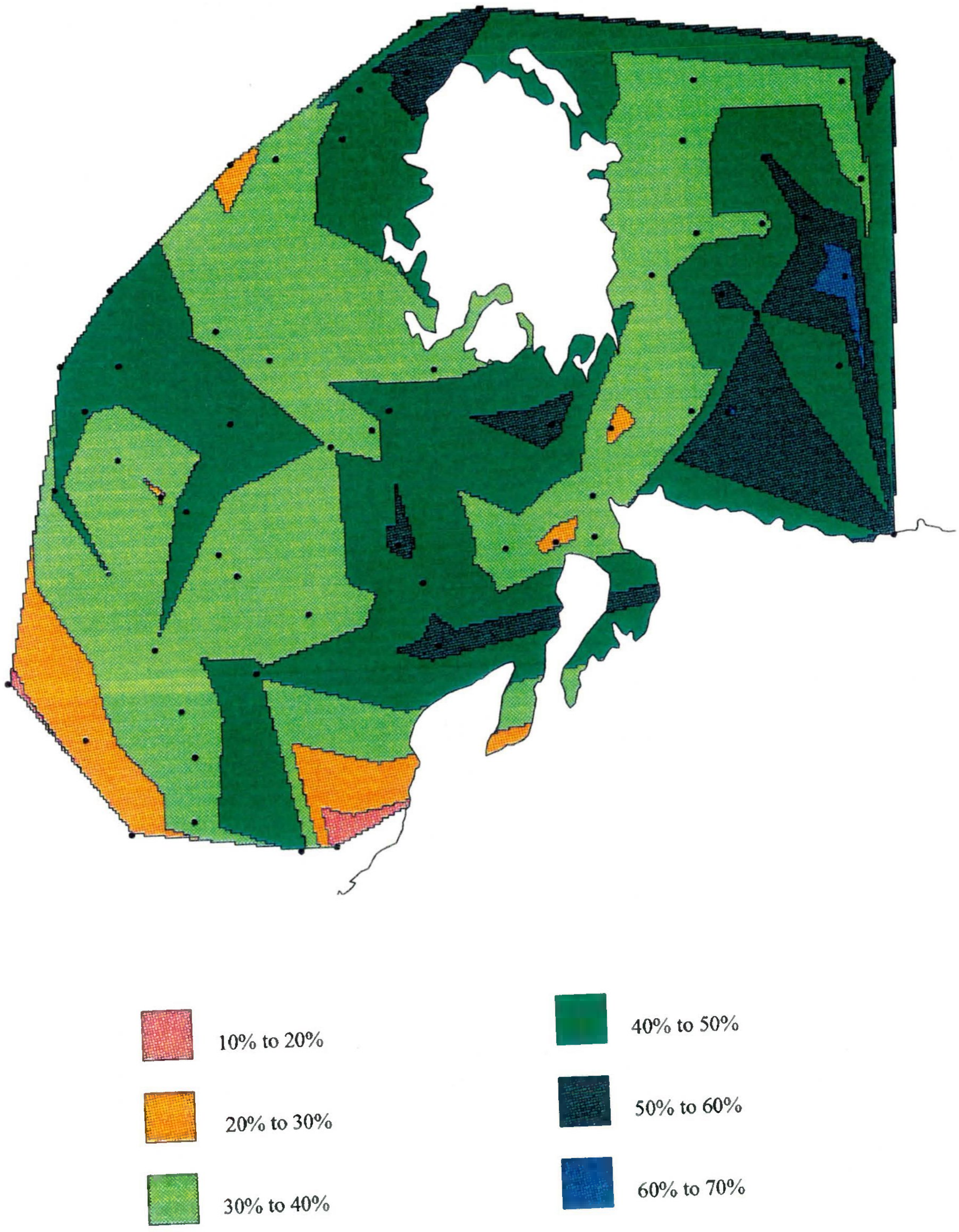
LU Field Trial Elongation Cessation



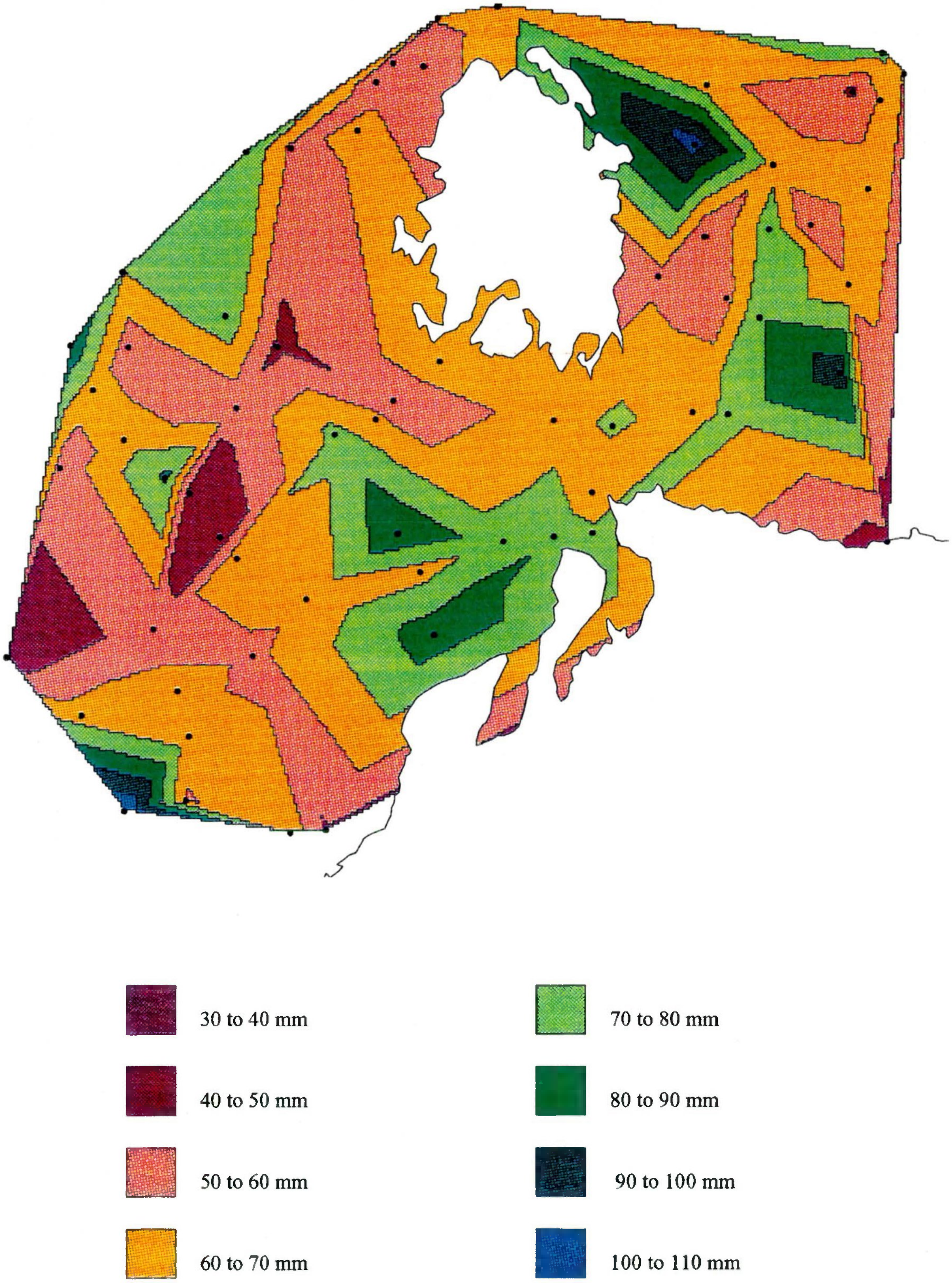
LU Field Trial Elongation Duration



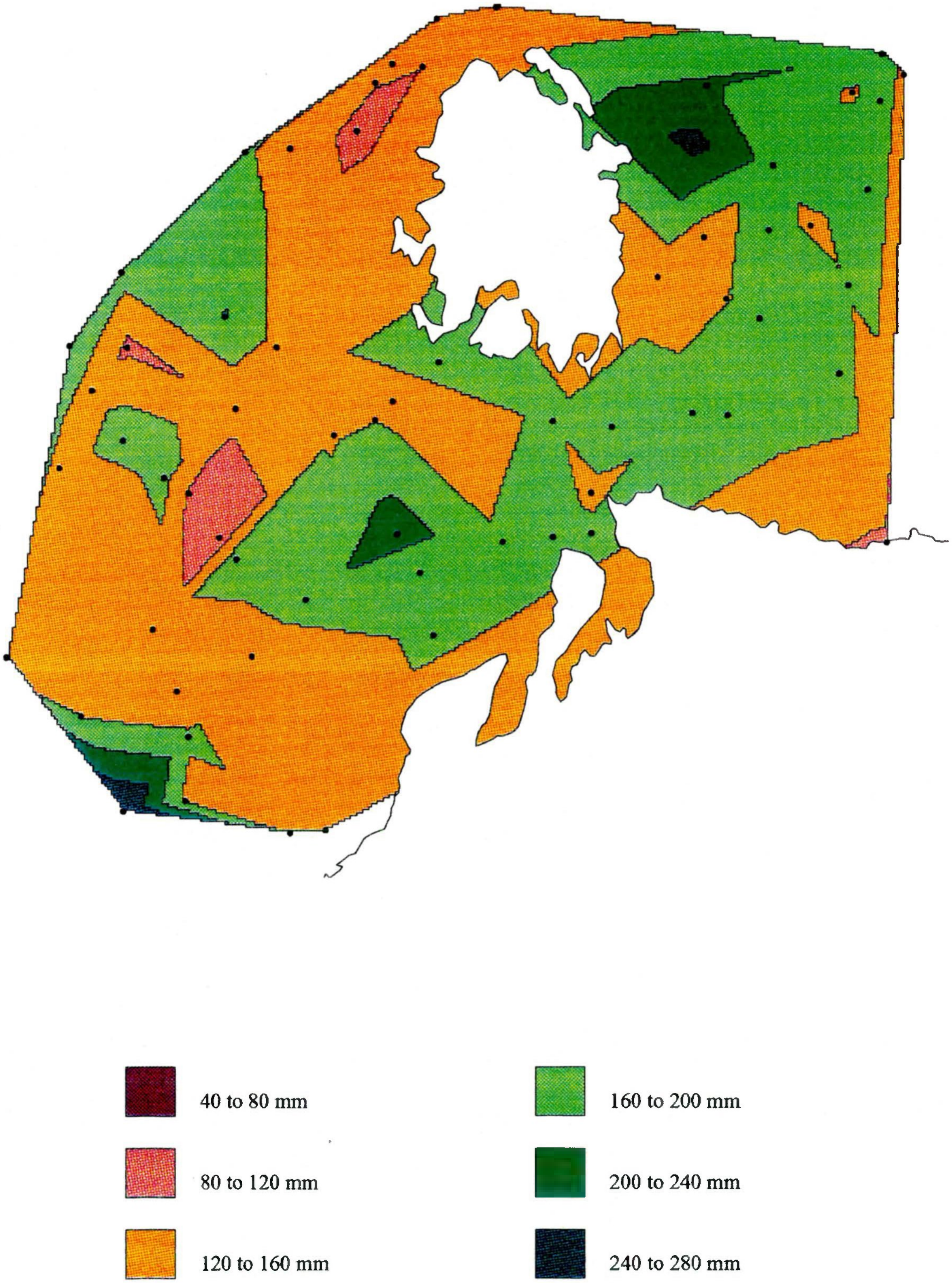
LU Field Trial Needle Flushing



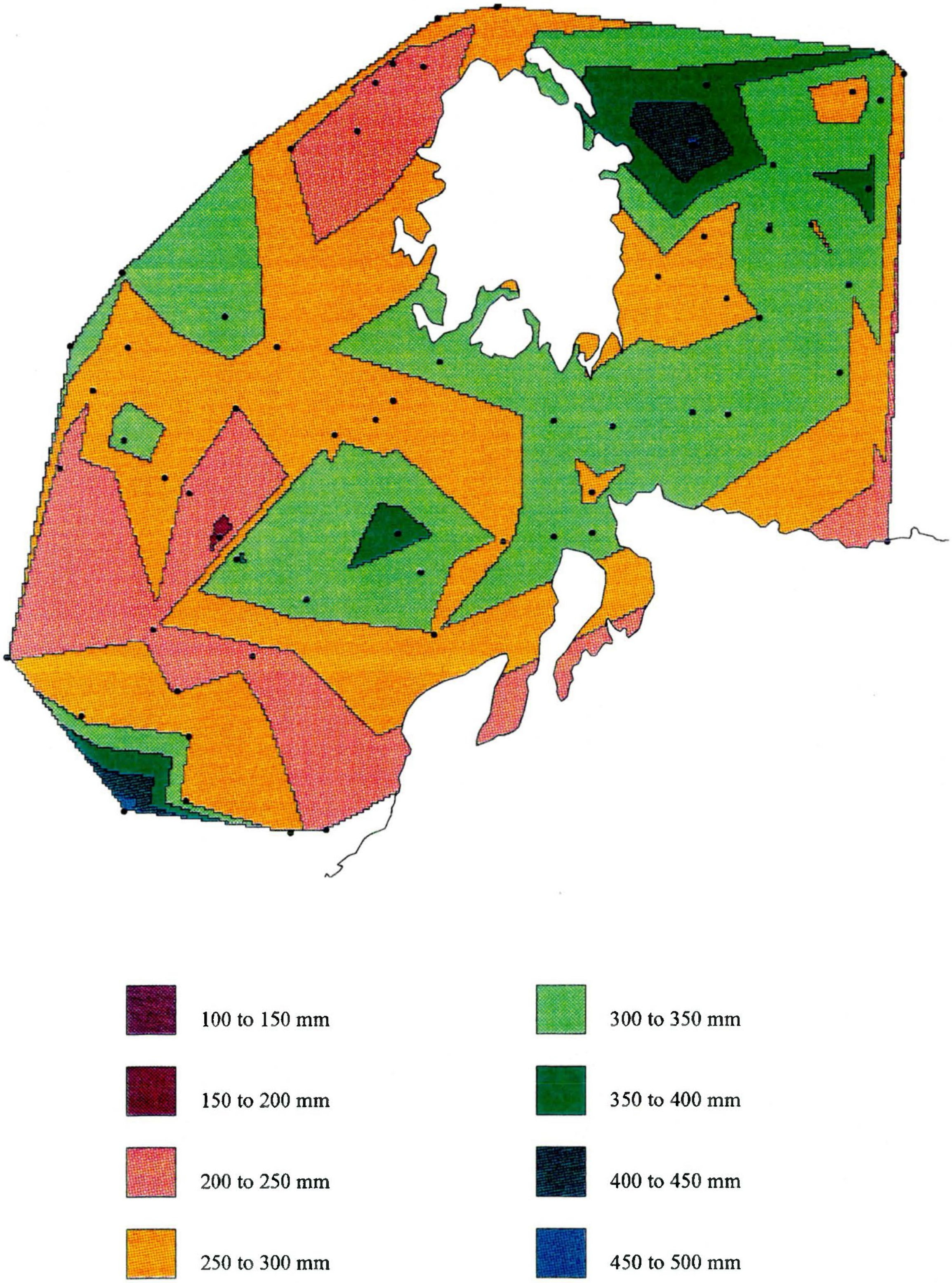
LU Field Trial Purpling



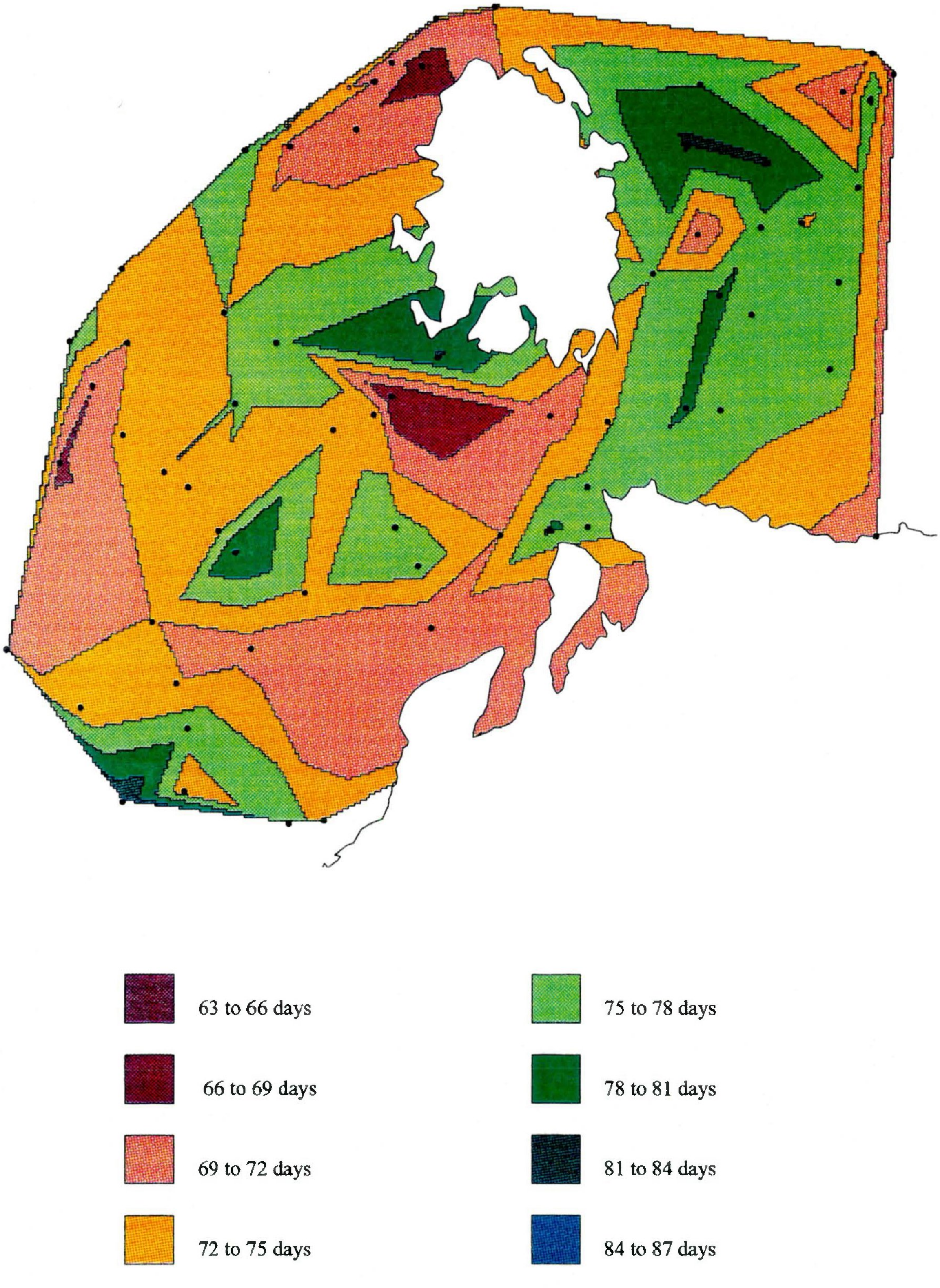
1988 Raith Trial Height



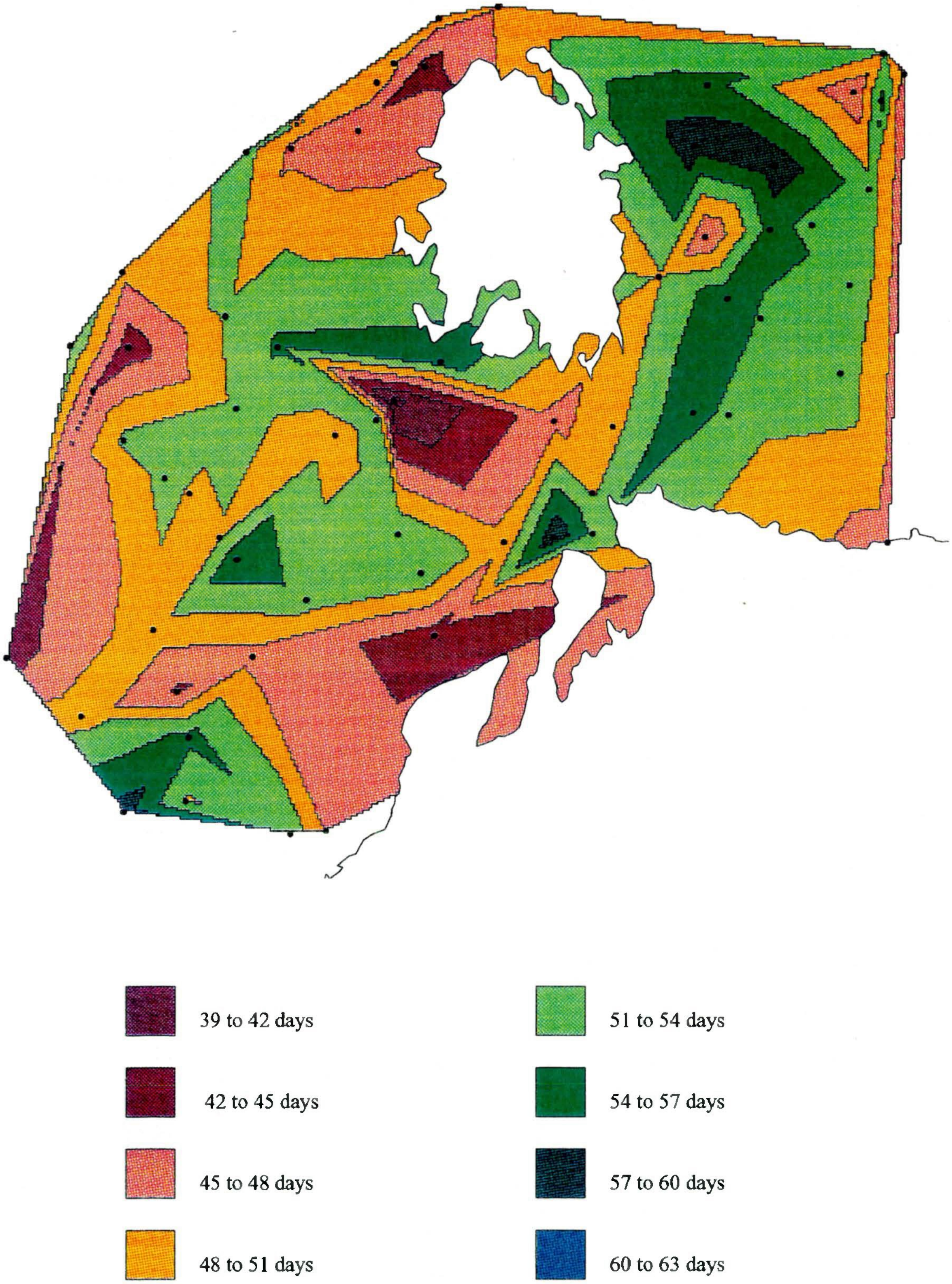
1989 Raith Trial Heights



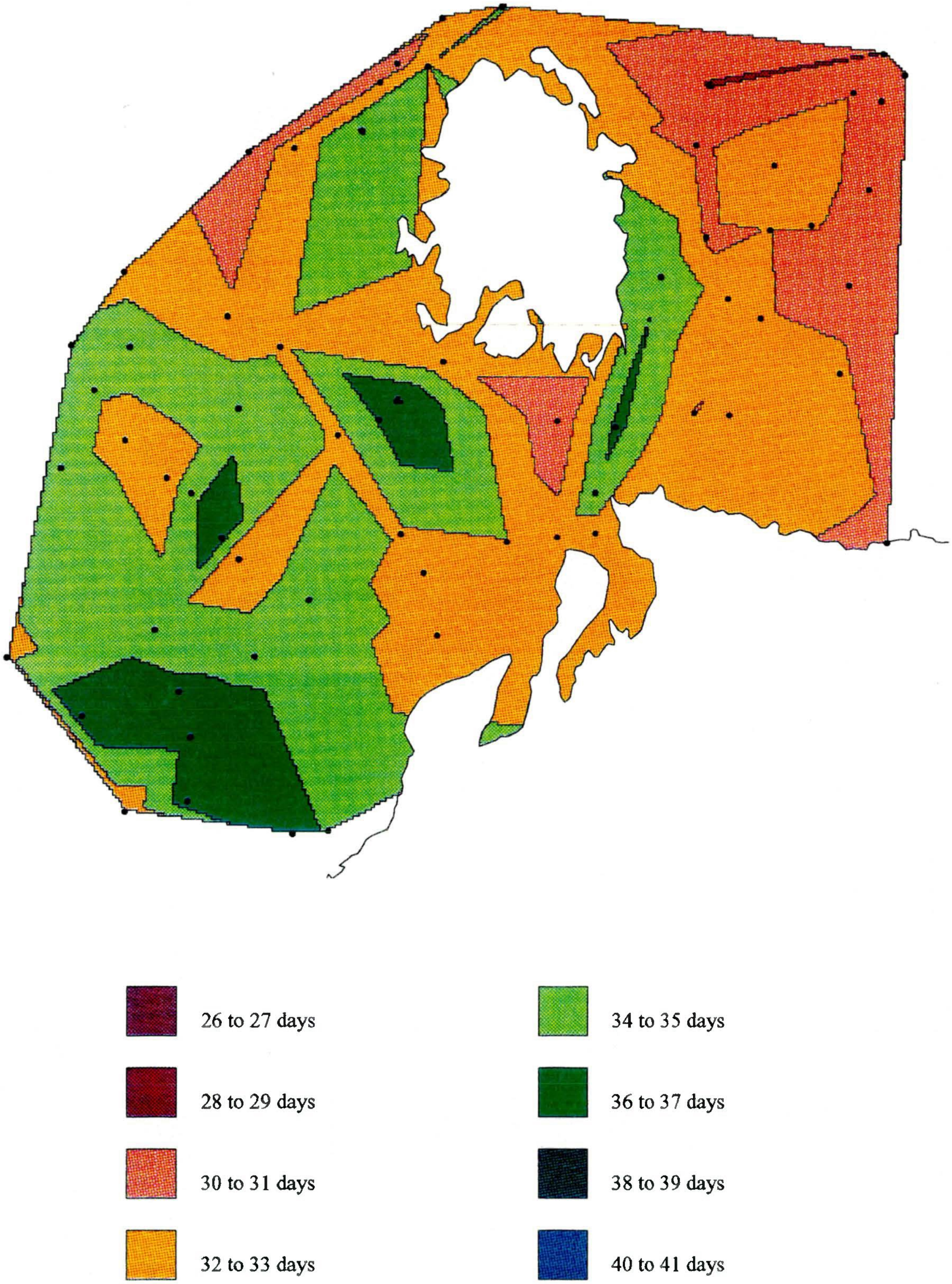
1990 Raith Trial Heights



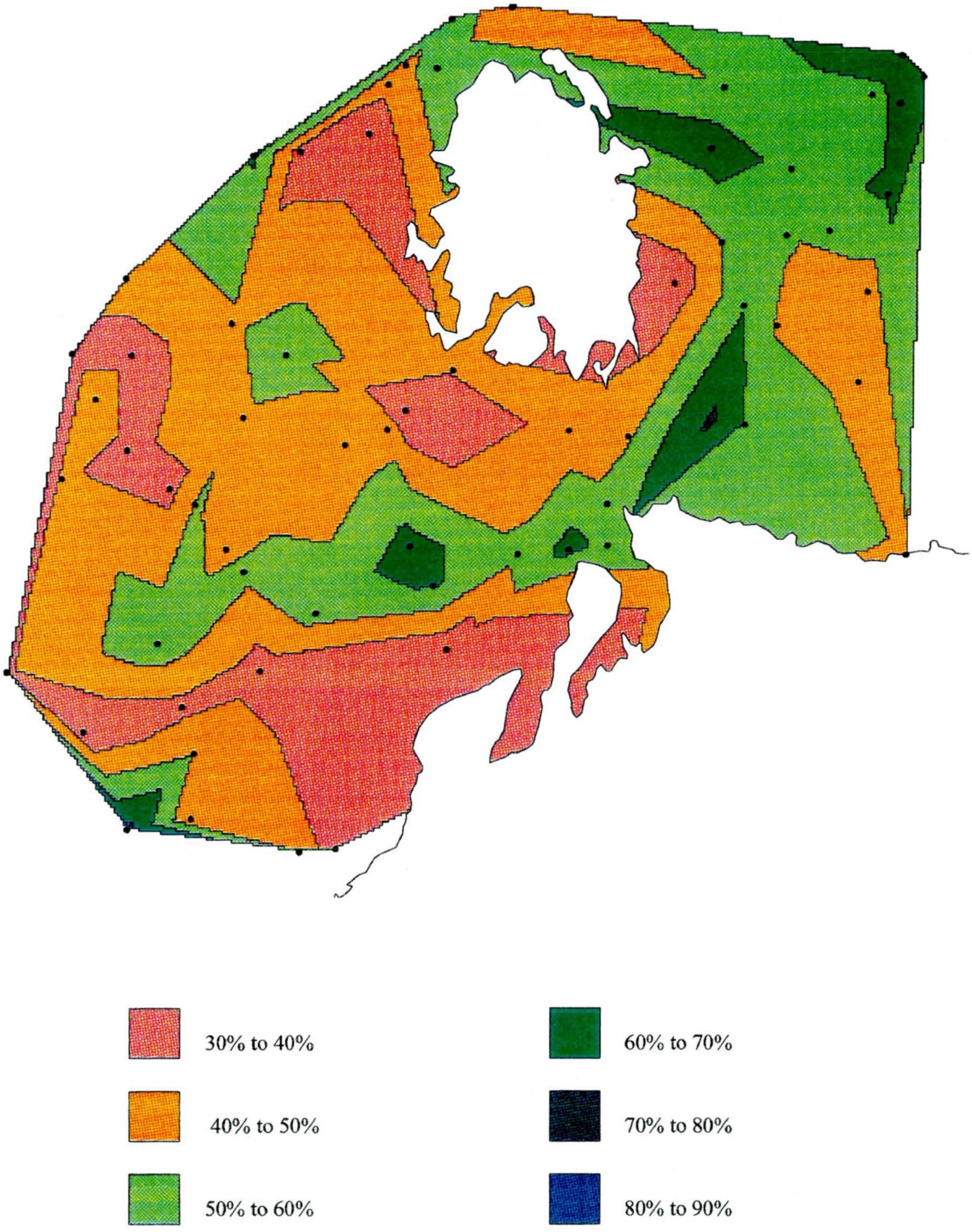
Raith Trial Elongation Cessation



Raith Trial Elongation Duration



Raith Trial Needle Flushing



Raith Trial Survival