THE EFFECT OF PHOTOPERIOD ON APICAL GROWTH CESSATION IN TAMARACK (*Larix laricina*) AND BALSAM POPLAR (*Populus balsamifera*) PROVENANCES FROM NORTHERN ONTARIO

by
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ABSTRACT

Charrette, P. D. 1990. The effect of photoperiod on apical growth cessation in tamarack (*Larix laricina*) and balsam poplar (*Populus balsamifera*) provenances from northern Ontario.

Keywords: tamarack, *Larix laricina* (Du Roi) K. Koch, balsam poplar, *Populus balsamifera* L., photoperiod, growth cessation, bud set

The effects of four photoperiods (i.e. 6, 10, 14, and 18 hours) on the rate of apical growth cessation and apical bud primordia production were studied in controlled environment experiments using tamarack (*Larix laricina* (Du Roi) K. Koch) seedlings and rooted cuttings, and balsam poplar (*Populus balsamifera* L.) rooted cuttings from provenances in northern Ontario. The objectives of this study were to investigate 1) the effect of photoperiod on shoot growth and the rate of growth cessation among provenances of tamarack and balsam poplar, 2) the variation in the rate of growth cessation between species from northern Ontario, and 3) the effect of different photoperiods on apical bud primordia production among tamarack provenances. First-year tamarack seedlings from four provenances in northern Ontario, balsam poplar rooted cuttings from five provenances ranging from Rhinelander, Wisconsin to Hudson Bay, and two-year old tamarack rooted cuttings from five provenances in northern Ontario were tested. Tamarack provenances displayed significant variation in the critical daylength for inducing growth cessation, but did not vary in the rate of growth cessation. Tamarack seedlings produced twice as many axial needle primordia in apical buds under a 10 hour photoperiod than a six hour photoperiod. Balsam poplar displayed clinal variation in the critical daylength for inducing growth cessation and in the rate of growth cessation. The variation in the rate of growth cessation during short photoperiods was seen as an adaptation to an increasing rate of change in daily photoperiod with increasing latitude.

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1. INTRODUCTION

This study investigates the patterns of variation in apical growth cessation (i.e. bud set) of tamarack (*Larix laricina* (Du Roi) K. Koch.), and balsam poplar (*Populus balsamifera* L.) populations from northern Ontario, and their response to different light environments. At the present time detailed information is not available on variation in growth cessation of tamarack or balsam poplar from northern Ontario.

The existence of provenance variation in the photoperiodic response of tamarack was demonstrated by Vaartaja (1959) using two widely different sources. Pauley (1965) observed through range-wide seed source testing of tamarack, that northern provenances set bud earlier than southern provenances. A genecology study on tamarack in Wisconsin by Rehfeldt (1970) showed the existence of clinal variation in bud set times within the state with northern sources setting bud before southern sources. The variation in bud set timing was strongly correlated to the approximate length of the growing season at each location. Results from other common garden trials of regional population samples indicate that there are significant differences in growth and survival among tamarack provenances (Jeffers, 1975; Cech *et al.*, 1977). Cheliak *et al.* (1988) examined isozyme variation in natural populations of tamarack obtained from a range-wide sample. Their results suggest a high level of genetic variation within tamarack populations and more variation among tamarack populations than populations of other more continuously distributed conifers species. Recent work by Joyce (1988) on the pattern of variaton in cold hardiness for tamarack populations from throughout northern Ontario showed that tamarack may be physiologically specialized to relatively small geographic and elevational areas, with population differentiation correlated to the latitude, longitude, and elevation of a source. Joyce (1988) suggested that tamarack requires careful control of seed movement within the region, and that additional study with other adaptive traits is necessary to refine seed transfer guidelines.

Although balsam poplar has been used as breeding stock for producing hybrid poplar clones within Ontario (Zsuffa, 1979), there is a lack of information on the patterns of adaptive variation within its native range. Pauley and Perry (1954) reported on the existence of variation among provenances in photoperiodic response of balsam poplar, using unidentified sources. The work of Pauley and Perry (1954) with balsam poplar and

other *Populus* species, was among the first reports of genetic variation in the photoperiodic response based on changes in latitude, or elevation of a particular source. Farmer and Reinholt (1986) examined the release from dormancy for five balsam poplar populations from northern Wisconsin through northern Ontario to Hudson Bay. They found that the largest portion of the variation in bud break was among clones within populations with little variation among populations. The lack of a strong clinal pattern in chilling requirements among the five balsam poplar provenances studied was in contrast to the results of forcing studies with other species in which chilling requirements were correlated to current environmental conditions at each population (Campbell and Sugano, 1979; Donselman and Flint, 1982). Research using material from the same five balsam poplar provenances on rooting characteristics (Farmer *et al.*, 1988b), isozyme variation (Farmer *et al.*, 1988a), and assimilation and growth rates (Schnekenburger and Farmer, 1989), also display little geographic differentiation among populations with a high level of within population variation.

The photoperiodic induction of growth cessation has been studied in detail in several tree species (Downs and Borthwick, 1955; Wareing, 1956; Heide, 1974; Habjørg, 1972, 1978; Nooden and Weber, 1978). Much of this work has concentrated on the critical photoperiod (i.e. the longest photoperiod during which height growth cessation still occurs (Habjørg, 1972)) for triggering growth cessation in different populations. Habjørg (1972) studied in detail the effects of photoperiod and temperature on growth and development of three latitudinal and three altitudinal populations of *Betula pubescens* Ehrh. Among his results, he reported that the time from growth cessation to the induction of dormancy was shorter in northern and high elevational populations than southern and low elevational populations. This indicates that the rate of the response to photoperiods shorter than the populations critical photoperiod was faster in northern sources than southern sources. However, there are few detailed accounts available concerning the rate of apical growth cessation among populations.

The induction of growth cessation in container grown seedlings by short photoperiods has been reported for several tree species (e.g. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) van den Driessche, 1970; McCreary *et al.* , 1978; MacDonald and Owens, 1987b; Western hemlock (*Tsuga heterophylla* (Raf) Sarg.) Arnott *et al.*, 1988; Scots pine (*Pinus sylvestris* L.) Christersson, 1978; Rosvall-Ahnebrink, 1982; Norway spruce (*Picea abies* (L.) Karst.) Christersson, 1978; black spruce (*Picea mariana* (Mill.) B.S.P.) Colombo *et al.*, 1982; D'Aoust, 1981; white spruce (*Picea glauca* (Moench) Voss.) Hawkins and Draper, 1988; Engelmann spruce (*Picea engelmannii* Parry) Hawkins and Draper, 1988). Several experiments on the effect of short days have used a constant eight hour

photoperiod to induce height growth cessation and bud set (e.g. van den Driessche, 1970; McCreary *et al.*, 1978; Columbo *et al.*, 1981, MacDonald and Owens, 1987b; Arnott *et al.*, 1988). Pollard and Logan (1977) initiated bud development under eight hours, but after bud scale initiation was complete they exposed young spruce seedlings to a range of photoperiods to determine if photoperiod affected needle initiation. They found that there was no response to photoperiods between 6 and 15 hours. There are few data available concerning the optimum photoperiod for the induction of apical growth cessation and apical bud primordia production in containerized tree seedlings.

Hawkins and Draper (1988) used 'dynamic' photoperiods (i.e. photoperiods which parallel the natural ephemeris of the area) to control height growth in white spruce (*Picea glauca* (Moench) Voss.), Engelmann spruce (*Picea engelmannii* Parry), and a naturally occurring hybrid between white spruce (*Picea glauca* (Moench) Voss.) and Sitka spruce (*Picea sitchensis* (Bong) Carr.) indentified as, *Picea lutzii* Little. They found dynamic photoperiod treatments (nominal 15 and 13 hour daylengths) to induce similar responses as constant 8 or 10 hour short day treatments. They suggested that dynamic photoperiod treatments enhanced seedling response to shortened days. However, they did not present data comparing seedlings treated by constant day-lengths of comparable length to the dynamic day-lengths used. They also suggested that, "seedlings not only respond to the absolute day-length but to the rate at which the day-length is changing, i.e. the 'dynamic day'."

The use of abruptly or gradually decreasing photoperiods from long to short days was studied by MacDonald and Owens (1987b). Using first year Douglas-fir seedlings they found that seedlings grown under abruptly decreased photoperiods: 1) initiated and developed bud scales faster, 2) started and completed leaf primordium initiation earlier, 3) produced more leaf primordia, 4) completed leaf primordium elongation earlier, and 5) final leaf primordium length was longer than on seedlings grown under a gradually decreased photoperiod. Abruptly decreasing photoperiods were used in the present study.

A number of research programs have recently been initiatied by the forest industry and government agencies in eastern Canada to investigate the potential of fast growing *Larix* and *Populus* species as alternatives to traditional species for wood fibre production (Lucas, 1981; Sayward, 1981; O.M.N.R., 1983; Nicks, 1986). Selection and breeding programs to improve the form and growth rate of tamarack are presently being conducted in several areas of eastern Canada (Sayward, 1981; Simpson, 1983), including northern Ontario (Nicks, 1986). Zsuffa (1979) suggested the possible use of northern Ontario sources of balsam poplar as breeding stock in the development of fast growing hybrid poplar clones suited to northern conditions. Some balsam poplar derived hybrid clones are presently

being used in short rotation projects within Ontario (O.M.N.R., 1983), including a cooperative trial in northwestern Ontario (Palmer, 1986).

The objectives of this study were to investigate 1) the effect of different photoperiods on shoot growth and the rate of growth cessation among provenances of tamarack and balsam poplar from northern Ontario, 2) the variation in the rate of growth cessation between tamarack and balsam poplar from northern Ontario, and 3) the effect of different photoperiods on apical bud primordia production among tamarack provenances.

The most important factor in inducing apical growth cessation and bud set in tamarack and balsam poplar appears to be photoperiod. This environmental factor was selected for detailed study on height growth and growth cessation among populations of tamarack and balsam poplar. The use of two species allowed for the comparison of the photoperiodic response between two known light-sensitive species (Vaartaja, 1959; Pauley and Perry, 1954) from the same region. The use of tamarack seedlings and rooted cuttings allowed for a greater latitudinal range of material to be tested and also included material of different ages (i.e. first-year seedlings and rooted cuttings taken from wildings generally 5 years old).The examination of this factor (i.e. photoperiod) will provide information regarding variations in the rate of growth cessation among tamarack and balsam poplar provenances, and the photoperiodic regime for controlling bud set and apical bud primordia production in tamarack seedlings.

2.LITERATURE REVIEW

BUD DORMANCY

Bud dormancy is essentially an adaptation for the survival of plants during unfavourable climatic conditions, such as low temperatures (Wareing, 1969). The onset of dormancy is the result of an adaptation to the environmental conditions that prevail where a species originates (Vegis, 1964). The development, maintenance, and release of dormancy in buds involves a complex interaction of a number of factors ranging from environmental to genetic (Nooden and Weber, 1978).

Due to the complex and varying nature of bud dormancy in woody plants, there are several definitions of dormancy, and a wide array of terminology used to describe it (Romberger, 1963). The term dormancy was applied by Doorenbos (1953) to, "any case in which a tissue predisposed to elongate does not do so." Romberger (1963) suggested that more specific terminalogy than 'dormancy' may be required to adequately define specific physiological states or conditions of a plant. This study will use the definition for dormancy given by Perry (1971) in which a dormant plant is defined as having two attributes:

(i) a period of reduced growth rate with few, or in some cases no, cell divisions in the terminal and lateral meristems of the plant

(ii) a winter chilling requirement

Because of the second attribute, even when exposed to a favourable environment, a dormant plant will not grow without first receiving a period of chilling. The three distinct phases in bud development are; 1) steady state shoot growth, 2) physiological dormancy, and 3) imposed dormancy (Smith and Kefford, 1964). It is during the transition from the steady state shoot growth phase to the physiological dormancy phase that growth cessation and dormancy induction occur.

ENVIRONMENTAL FACTORS AFFECTING BUD DORMANCY

Many environmental factors influence the development of bud dormancy, such as, photoperiod, temperature, water supply, nutritive condition, and the quality of light (Vegis, 1964; Nooden and Weber, 1978). Of these factors, photoperiod and temperature appear to be of overriding importance. Photoperiod is generally more important in inducing dormancy, and temperature is more important in breaking dormancy. In general, long days promote vegetative growth while short days cause growth cessation and the induction of dormancy (Downs and Borthwick, 1955). This response of plants to the relative length of day and night and its changes throughout the year is called photoperiodism.

Studies on photoperiodism in plants began as long ago as 1852 when Henfrey (1852) suggested that the natural distribution of plants was partly due to latitudinal variations in summer daylength. Experiments by Tournois (1912, 1914) and Klebs (1913) were the first to recognize that daylength was a major factor in the regulation of flowering (Vince-Prue, 1975). However, it was the work of Garner and Allard (1920, 1923) that clearly indicated flowering, and many other plant responses, could be affected by daylength. These authors classified many plants into photoperiodic groups, and introduced the terms photoperiod, and photoperiodism (Vince-Prue, 1975). Since that time many studies have been conducted which have attempted to further characterize the photoperiodic response in plants.

For many tree species apical growth cessation is induced by short photoperiods. However, the induction of growth cessation by short photoperiods is not universal for all species. For some tree species which have a dormant state, the induction of growth cessation is not affected by photoperiod (e.g. *Fraxinus excelsior* L. and *Malus* spp. Vince-Prue, 1975). Early work on the photoperiodic response of northern tree species by Vaartaja (1957), using two widely different photoperiods (i.e. long vs short), showed that the induction of dormancy in a single tamarack source was dependent upon the length of photoperiod. He demonstrated that short days induce growth cessation and bud set, and that long days cause vegetative growth. Similarly, European larch (*Larix decidua* Mill.) grown under long days was maintained in a state of continuous growth (for up to 18 months), whereas, short daylengths quickly caused growth cessation (Wareing, 1954; Simak, 1970). Japanese larch (*Larix leptolepis* (Sieb. & Zucc.) Gord) also stopped growth in response to short days (Downs, 1962). Van der Veen (1951) studied the effect of daylength on dormancy in one year old cuttings and seedlings of 8 different *Populus* taxa (*Populus alba* L., *P.* x *robusta* C. K. Schneid., *P. marilandica* Bosc ex Poir., *P. tremula* L., *P. trichocarpa* Hook., *P. serontina* T. Hartig., *P. nigra* L., and *P. lasiocarpa* Oliv.). For all taxa bud set occurred under short day photoperiods (9 and 12 hours) while

all plants given long days (16 hours and continuous light) continued to grow after 3 months of exposure.

The induction of apical growth cessation by short photoperiods operates through the phytochrome system of a plant (Downs, 1962). Light is absorbed by the phytochrome pigment. The protein phytochrome exists in two forms, one (Pr) absorbing red light (peak wavelength 660 nm), and the other (Pfr) absorbing far-red light (peak wavelength 735 nm) (Vince-Prue, 1975). The Pfr form is considered to be the physiologically active form of the pigment. The two forms are photochemically interconvertible. Absorption of light at the appropriate wavelength readily converts one form into the other. In addition, the Pfr form slowly converts to the Pr form in the dark (Vince-Prue, 1975).The photoperiodic induction of growth cessation results primarily from the length of the dark period. Under daylight conditions the naturally predominent red light produces more than 70 percent of the photochrome pigment in the active Pfr form. However, during the dark period the active Pfr form slowly reverts to the Pr form. If the dark period is long enough only 10 percent will remain in the active Pfr form (Downs, 1962). If the Pr form exists during the dark period for a substantial time growth cessation and dormancy induction will result due to inadequate levels of the biologically active Pfr form.

There exist two main hypotheses to explain the mechanism of time measurment in plants. The first is known as the physiological clock, and is based upon an endogenous circadian rhythm (Bünning, 1960, 1973). The second is known as the hourglass, which is based upon phytochrome conversion during the dark period, as previously described. There appears to be mounting evidence to support the interaction of phytochrome with the circadian rhythm over the simple hourglass type of phytochrome dark conversion (Vince-Prue, 1975). Heide (1977) proposed a theoretical model for photoperiodic time measurement in higher plants based upon the interaction of phytochrome with a circadiam rhythm in membrane functioning and configuration. In this system phytochrome acts to synchronize the rhythm with the external light stimuli through its binding to the membrane.

The locus for the perception of photoperiod in woody plants appears to reside mainly in the leaves, primarily the youngest fully, or partially expanded leaves of a plant (Vince-Prue, 1975). However, the apical bud in some species has also been shown to be responsible for the perception of light (Wareing, 1954).

Temperature has been shown to interact with, and modify the effect of photoperiod in the induction of dormancy (Dormling *et al.*, 1968; Habjørg, 1972; Heide, 1974). In species that have dormancy induced by short days, the critical day-length may vary with temperature (Heide, 1974). This may be expected since the critical day-length is to a certain extent also determined by the phytochrome conversion rate which is highly temperature

dependent (Devlin, 1975). In European larch Simak (1970) found that the formation of terminal buds was initiated by short days, but that bud development was dependent upon temperature. Fluctuating day and night temperatures have also been found to influence dormancy (Perry, 1962; Nooden and Weber, 1978; Junttila, 1980).

In an attempt to reconcile the variation between years in the duration, and the heat sum accumulation of the thermal growing season, Koski and Srevanen (1984), proposed that growth cessation is not regulated by a fixed system, such as photoperiodic responses or an accumulation of constant heat sum, but is based on a consistent relationship between heat sum and night length. They believe this is in accordance with the idea of flexibility, and present an empirical model for growth cessation.

PROVENANCE VARIATION IN BUD DORMANCY

Dormancy of forest trees is frequently investigated within the context of provenance studies. Sylven (1940) was the first to demonstrate provenance variation in the photoperiodic response in forest trees. Since then genetic variation in growth cessation and subsequent dormancy has been demonstrated in a number of tree species (Pauley and Perry, 1954; Vaartaja, 1959; Habjørg, 1972; Hiede, 1974; Vince-Prue, 1975; Nooden and Weber, 1978; Donselman and Flint, 1982). Populations become adapted to different photoperiods to regulate their entrance into dormancy in response to the length of the growing season that prevail where they originate. In general, the induction of growth cessation and dormancy differs depending on the latitude and elevation of a particular source (Nooden and Weber, 1978). In the northern hemisphere, trees from more northerly latitudes, or higher elevations generally become dormant at longer photoperiods than trees from more southern latitudes, or lower elevations.

Populations may differ in their photoperiodic response due to fluctuating day and night temperatures. Fluctuating day and night temperatures with low night temperatures (approximately below 10° C) appear to interact with photoperiod (Perry, 1962; Junttila, 1980). There appears to be an increase in the sensitivity to fluctuating day and night temperatures with an increase in latitude. Northern red maple (*Acer rubrum* L.) populations set bud under long days (16 hours) when grown with night temperatures below 10° C and a day temperature at 23° C, but maintained growth with night temperatures above 10° C. Southern sources did not form a terminal under the same night temperatures (Perry, 1962). Junttila (1980) found that a northern *Salix pentandra* L. source had bud set induced by alternating day/night temperatures even when grown under continuous light, while a southern *Salix pentandra* L. source continued to grow under the same conditions.

3. MATERIALS AND METHODS

MATERIALS

Tamarack

Tamarack seed and seedling ortets were collected in 1984 from locations throughout northern Ontario (Figure 3.1). At each collection area two separate stands were sampled (Table 3.1). The first two digits of the site number (Table 3.1) identify the collection area and the last two digits indentify the stand within the collection area that was sampled. A description of each collection site (e.g. stand composition, age, height, associated vegetation, *etc.*) appears in Appendix IX. After cone collection and seed extraction, all seed were stored by family in plastic containers at 3° C. Seedlings used in Experiment 1 were grown from seed collected at four locations; North Bay, Thunder Bay, Fort Frances, and Red Lake (Table 3.1).

Table 3.1. Geographic location of tamarack provenances.

SOURCE	SITE NO.	LATITUDE	LONGITUDE	MATERIAL
Big Trout Lake	12 01	53° 50' N	89° 52' W	seedling ortets
	12 02	53° 50' N	89° 52' W	seedling ortets
Red Lake	07 01	51° 50' N	93° 50' W	seed and seedling ortets
	07 03	51° 50' N	93° 50' W	seed and seedling ortets
Kenogami River	09 01	51° 35'N	84° 15'W	seedling ortets
	09 02	51° 35'N	84° 26'W	seedling ortets
Fort Frances	06 01	48° 43' N	94° 51' W	seed
	06 03	48° 47' N	94° 59' W	seed
Thunder Bay	05 02	48° 25' N	89° 16' W	seed and seedling ortets
	05 03	48° 25' N	89° 16' W	seed and seedling ortets
North Bay	01 01	47° 39' N	80° 45' W	seed and seedling ortets
	01 02	46° 38' N	80° 58' W	seed and seedling ortets

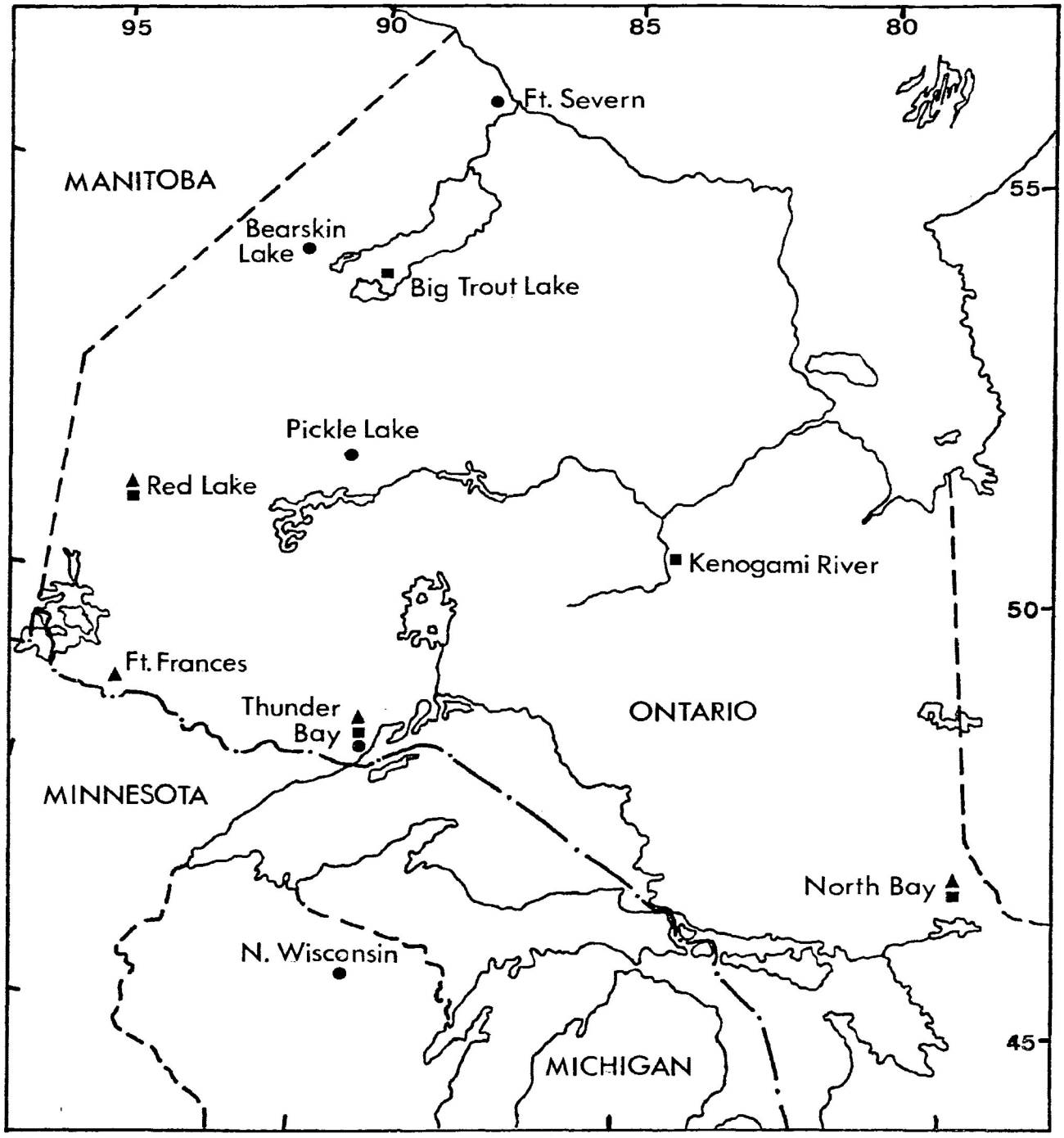

Figure 3.1. Location of balsam poplar (●) and tamarack seed (▲) and seedling (■) collection areas from Northern Ontario.

The two year old rooted cuttings used in Experiment 3 were propagated from wild seedling ortets collected from five locations; North Bay, Thunder Bay, Kenogami River, Red Lake, and Big Trout Lake (Table 3.1). Wild seedlings of undetermined age, but generally less than 5 years, were dug up in the field with their root systems intact, and transported to the greenhouse where they were transplanted into 6 L containers.

Balsam Poplar

Balsam poplar cuttings from five provenances (Figure 3.1), were established at the Lakehead University nursery between 1982 and 1984. The cuttings were collected from approximately 50 seedling ortets (generally less than 20 years old) at each location. Collection sites ranged from roadside stands in Wisconsin to stands along the banks of the Severn River, with a wide range of soil and vegetation types. Provenances were located along a transect from Rhinelander, Wisconsin, north to Thunder Bay, Pickle Lake, Bearskin Lake, and Fort Severn, Ontario (Table 3.2). Seedling ortets within each location were selected at least 1 km apart to reduce the possibility of selecting more than one ortet from a single, naturally occurring clone. The distance between clones, and the number of clones collected at each site resulted in the latitudinal ranges for each location represented in Table 3.2. Cuttings were initially propagated in the greenhouse before being outplanted to the nursery.

Table 3.2. Geographic location of balsam poplar provenances.

SOURCE	LATITUDE	LONGITUDE
Fort Severn, Ontario	55-56° N	88° W
Bearskin Lake, Ontario	53-54° N	91° W
Pickle Lake, Ontario	50-51° N	90° W
Thunder Bay, Ontario	48-49° N	89° W
Rhinelander, Wisconsin	45-46° N	90° W

PROPAGATION

Tamarack Seedlings

The production of tamarack seedlings, and the testing of tamarack seedlings and rooted cuttings followed the schedule in Table 3.3. Seeds were stratified for two weeks in

polyurethane bags at 3° C in the dark. After stratification, family seedlots were placed on moistened filter paper in 9 cm petri dishes. All petri dishes were labelled and placed in one growth chamber where seed germination took place. The growth chamber was set at 30° C during an 18 hour day and 20° C during a 6 hour night. Germinants (radicle greater than 2 mm) were transferred to peat and vermiculite (1:1 ratio by volume) filled Spencer-Lemaire 'Tinus' containers (350 ml volume) located under intermittent misting nozzles in an adjacent greenhouse. A total of four seedlings per family and four families for each of four provenances (Red Lake, Fort Frances, Thunder Bay, and North Bay) were tested in each photoperiod treatment of Experiment 1. For the first and third replications of Experiment 1, seedlings were individually located on the greenhouse bench and tagged. For the second replication, container booklets of four seedlings per family were randomized on the bench and tagged. After approximately seven days under intermittent misting, all seedlings were moved to another greenhouse and grown under 18 hours of light (natural photoperiod supplemented with light from 400 watt high-pressure sodium lamps), and a 25°-15° C day and night temperature regime. Seedlings were watered regularly, and fertilized with 100 ppm soluble 20-20-20 (N-P-K) complete fertilizer once a week. The greenhouse growing period for seedlings was about three months (Table 3.3).

Table 3.3. Tamarack seedling and rooted cutting propagation and testing schedule.

STOCK TYPE	STRATIFICATION PERIOD (2 weeks)	SEEDLING GROWTH (approx. 3 mon.)	PHOTOPERIOD TREATMENT (approx. 1.5 mon.)
Seedlings (Rep. 1)	mid-January to late January	February to end of April	May to mid-June
Seedlings (Rep.2)	early March to mid-March	mid-March to mid-June	mid-June to end of July
Rooted Cuttings	Not Applicable	mid-June to end of July	August to mid-September
Seedlings (Rep. 3)	early June to mid-June	mid-June to mid-September	mid-September to end of October

Tamarack Rooted Cuttings

In March 1986, ten potted seedling ortets were selected from each of the five tamarack provenances (Table 3.2), and brought into the greenhouse for forcing. The ortets were grown under greenhouse conditions (long days, and optimum water and nutrients) until large enough to furnish 12, four cm long cuttings each. The cuttings were struck into peat and vermiculite (1:1 ratio by volume) filled Spencer-Lemaire 'Tinus' containers (350 ml volume), and rooted under intermittent misting (Farmer *et al.*, 1986). The rooted cuttings (ramets) were then grown in a greenhouse under 18 hour photoperiods until early August when they were moved outdoors into the shadehouse to harden-off, and subsequently over-winter. In the spring of 1987, after an initial growing period outdoors, the ramets were brought into the greenhouse under the same greenhouse conditions as described above for tamarack seedlings (Table 3.3). Before being exposed to experimental light treatments, ramets were randomized within each treatment.

Balsam Poplar Rooted Cuttings

In late March 1987, dormant branches were removed from 10 clones of each of the five balsam poplar provenances in the Lakehead University nursery. The nursery cuttings were stored by clone in polyurethane bags at 3° C. During propagation only those cuttings required for one replication of the experiment were removed from the cooler at one time. Branch cuttings were cut into approximately 10 cm long sections and soaked in a benomyl solution before being struck into peat and vermiculite (1:1 ratio by volume) filled Spencer-Lemaire 'Super 45' containers (750 ml volume). Initially, two cuttings were struck per container, but one was later cut out after rooted cuttings were established. The rooted cuttings (ramets) were maintained in one greenhouse under an 18 hour photoperiod (natural photoperiod supplemented with light from 400 watt high-pressure sodium lamps), and a 25° C day and 15° C night temperature regime. The ramets were watered regularly, and fertilized with 100 ppm soluable 20-20-20 (N-P-K) complete fertilizer once a week. Ramets were periodically treated with benomyl during early growth stages.

Balsam poplar photoperiod testing (Experiment 2) followed the same time schedule as tamarack seedling testing (Experiment 1) outlined in Table 3.3. For the first replication of the experiment, balsam poplar ramets were started in the greenhouse in April, and grown for approximately one month before receiving light treatments in May. Material for the second replication was started approximately three weeks after the first replication, and material for the third replication was started two weeks after the second. Both of these latter

replications were grown for approximately one month in the greenhouse, but were then pruned back to approximately 8-10 cm in height. The pruned ramets were grown for approximately another month and a half before receiving light treatments starting in mid-June, and mid-September, respectively.

LIGHT TREATMENTS

After the greenhouse growing period, actively growing seedlings and/or rooted cuttings were transferred into one of four growth chambers to receive one of the following photoperiod treatments; 6, 10, 14, or 18 hours of light per day. All growth chambers had a day temperature of 20° C. and a night temperature of 10° C. The tamarack seedlings and the balsam poplar ramets used in Experiments 1 and 2 were placed in the growth chambers together for each of their three replications.

Of the four growth chambers used in this study three were Conviron model E-7, and one was a Percival model PT-80. All of the chambers were refitted with new incandescent and florescent light bulbs before the start of light treatments. The light intensity in each chamber was measured at a constant distance from the light source, and all chambers measured near 200 $\mu E \cdot s^{-1} \cdot m^{-2}$ (appoximately 7 klx.), ranging from 192 to 210 $\mu E \cdot s^{-1} \cdot m^{-2}$. Light treatments were randomly assigned to each of the four chambers for each experiment.

MEASUREMENTS

Height

During the latter part of the greenhouse growing period, and throughout photoperiod treatments, seedling and/or ramet heights were measured approximately every three days. Tamarack seedlings were measured from root collar to the tip of the terminal needle cluster. Tamarack rooted cuttings were measured from the point of second year growth initiation to the tip of the terminal needle cluster. Height growth measurements of balsam poplar ramets were taken from the base of the initiating bud to the tip of the apical meristem.

Relative Height Growth

For Experiments 1 and 2, relative height growth was calculated using Evans (1972) formula:

$$\mathbf{RGR} = \frac{ln\ Ht_2 - ln\ Ht_1}{T_2 - T_1}$$

where;

RGR = relative growth rate ($cm \cdot cm^{-1} \cdot day^{-1}$).
T_1 = time one: days from the start of light treatments until the first height measurement.
T_2 = time two: days from the start of light treatments until the second height measurement.
$ln\ Ht_1$ = the natural logarithm of the seedling and/or ramet height at time one.
$ln\ Ht_2$ = the natural logarithm of the seedling and/or ramet height at time two.

The use of relative growth rate allows for the comparison of growth among plants of different size and ontogeny (Kramer and Kozlowski, 1979). For each experiment, height increment from a nine day period (three measurements) of constant growth (i.e. before the start of growth cessation) was used to determine provenance relative growth values within each photoperiod treatment. The same growth period for all treatments within each experiment was used for relative height growth analysis. Relative height growth values were then subjected to an analysis of variance using the designs given in Table 3.4 for Experiment 1, and in Table 3.6 for Experiment 2.

Determination of Bud Set

Observations of terminal bud development were also recorded approximately every three days. The number of days from the start of photoperiod treatments until terminal bud set was determined in tamarack by the ocular detection of bud scales, and in balsam poplar when the bud scales fully enclosed the apical meristem. Experiments were terminated, and final heights were recorded when the stock growing under the 14 hour photoperiod set bud (approximately 1 to 1.5 months).

Terminal Bud Needle Primordia

To evaluate the effect of different photoperiods on the developmnent of preformed needles within terminal buds of tamarack seedlings, needle primordia were counted in seedlings from the final replication of Experiment 1. Terminal buds were removed from all seedlings. Buds were stored in glass vials by family and were fixed with 6% glutaraldehyde in 0.05 M (K^+) PO_4 buffer for four days to ensure effective penetration through bud scale layers. After fixing, buds were washed in, and subsequently maintained in 0.05 M (K^+) PO_4 in sealed vials, and stored in a refrigerator. Buds scales were removed

under a dissecting microscope (x50) for viewing preformed axial and basal primordia.

Work by Remphrey and Powell (1984), and Owens and Molder (1979) on bud development in *Larix* , tamarack and western larch (*Larix occidentalis* Nutt.) respectively, indicate that there are differences in size and position between axial and basal primordia. Generally, basal primordia are long (arch over axial primordia), and born on a broad cup-shaped receptacle just above the bud scales. Axial primordia are short and occur on the conical axis of the bud. The number of preformed axial, and basal needle primordia was determined by multiplying the number of contact parastichies (i.e. spirals around the bud) with the average number of axial or basal primordia within a spiral (Pollard and Logan, 1973). The average number of primordia within a contact parastichy was determined by counting the number of primordia (axial or basal) in all spirals, and deriving the average number.

EXPERIMENTAL DESIGN AND ANALYSIS

Experiment 1

Seedling Height and Bud Set Data Analysis

The objective of Experiment 1 was to study the effect of four photoperiods on height increment and days until bud set of three-month-old tamarack seedlings from 4 provenances in northern Ontario. The experiment was executed in a nested-split plot design and was performed three times to provide a statistical test of the photoperiod treatment (Table 3.4). For each photoperiod treatment, four seedlings from each of five families per provenance were tested from each of the four provenances.

The linear model for experiment 1 was as follows:

$$Y_{ijklm} = \mu + R_i + \delta_{(i)} + L_j + RL_{ij} + \omega_{(ij)} + P_k + RP_{ik} + LP_{jk} + RLP_{ijk} + F_{(k)l} + RF_{i(k)l} + LF_{j(k)} + RLF_{ij(k)l} + \varepsilon_{(ijkl)m}$$

where;

Y_{ijklm} = the variable to be analysed from the m^{th} seedling in the l^{th} family in the k^{th} provenance in the j^{th} light treatment in the i^{th} replication
μ = the overall mean
R_i = the random effect of the i^{th} replication of the experiment
$\delta_{(i)}$ = the first restriction error (Anderson and McLean 1974)
L_j = the fixed effect of the j^{th} light treatment

RL_{ij} = the interaction of the i^{th} replication and the j^{th} light treatment
$\omega_{(ij)}$ = the second restiction error
P_k = the random effect of the k^{th} provenance
RP_{ik} = the interaction of the i^{th} replication and the k^{th} provenance
LP_{jk} = the interaction of the j^{th} light treatment and the k^{th} provenance
RLP_{ijk} = the interaction of the i^{th} rep. and the j^{th} light treatment and the k^{th} prov.
$F_{(k)l}$ = the random effect of the l^{th} family in the k^{th} provenance
$RF_{i(k)l}$ = the interaction of the l^{th} family in the k^{th} provenance and the i^{th} replication
$LF_{j(k)l}$ = the interaction of the l^{th} family in the k^{th} prov. and the j^{th} light treatment
$RLF_{ij(k)l}$ = the interaction of the l^{th} family in the k^{th} provenance and the i^{th} replication and the j^{th} light treatment
$\varepsilon_{(ijkl)m}$ = the random eror due to the m^{th} seedling in the l^{th} family in the k^{th} provenance in the j^{th} light treatment in the i^{th} replication

Height increment, number of days until bud set, and relative height growth values were analysed as for the design outlined in Table 3.4. From the Expected Mean Squares (EMS) in Table 3.4 it can be seen that some of the effects cannot be tested by means of the usual mean square ratio (e.g. Light). To overcome this problem a quasi-F ratio (F') was used to generate an appropriate error term as described by Winer (1971).

Table 3.4. Model for the analysis of variance of data from Experiment 1.

SOURCE	D.F.	EXPECTED MEAN SQUARES
Replication (R_i)	2	$\sigma^2 + 4\,\sigma^2_{RF} + 20\,\sigma^2_{RP} + 80\,\sigma^2_{\delta} + 80\,\sigma^2_{R}$
Restriction error ($\delta_{(i)}$)	0	$\sigma^2 + 4\,\sigma^2_{RF} + 20\,\sigma^2_{RP} + 80\,\sigma^2_{\delta}$
Light (L_j)	3	$\sigma^2 + \sigma^2_{RLF} + 3\sigma^2_{LF} + 5\sigma^2_{RLP} + 15\sigma^2_{LP} + 20\sigma^2_{\omega} + 20\sigma^2_{RL} + 60\phi(L)$
Interaction (RL_{ij})	6	$\sigma^2 + \sigma^2_{RLF} + 5\,\sigma^2_{RLP} + 20\,\sigma^2_{\omega} + 20\,\sigma^2_{RL}$
Restriction error ($\omega_{(ij)}$)	0	$\sigma^2 + \sigma^2_{RLF} + 5\,\sigma^2_{RLP} + 20\,\sigma^2_{\omega}$
Provenance (P_k)	3	$\sigma^2 + 4\,\sigma^2_{RF} + 12\,\sigma^2_{F} + 20\,\sigma^2_{RP} + 60\,\sigma^2_{P}$
Interaction (RP_{ik})	6	$\sigma^2 + 4\,\sigma^2_{RF} + 20\,\sigma^2_{RP}$
Interaction (LP_{jk})	9	$\sigma^2 + \sigma^2_{RLF} + 3\,\sigma^2_{LF} + 5\,\sigma^2_{RLP} + 15\,\sigma^2_{LP}$
Interaction (RLP_{ijk})	18	$\sigma^2 + \sigma^2_{RLF} + 5\,\sigma^2_{RLP}$
Family within P ($F_{(k)l}$)	16	$\sigma^2 + 4\,\sigma^2_{RF} + 12\,\sigma^2_{F}$
Interaction ($RF_{i(k)l}$)	32	$\sigma^2 + 4\,\sigma^2_{RF}$
Interaction ($LF_{i(k)l}$)	48	$\sigma^2 + \sigma^2_{RLF} + 3\,\sigma^2_{LF}$
Interaction ($RLF_{ij(k)l}$)	96	$\sigma^2 + \sigma^2_{RLF}$
Within error ($\varepsilon_{(ijkl)m}$)	720	σ^2
Total	959	

Apical Bud Needle Primordia Analysis

The number of needle primordia (axial and basal primordia) in seedling apical buds was counted after the termination of the third replication of Experiment 1 to determine the effect of 3 photoperiods on primordia production. Only 3 photoperiod treatments, instead of 4, were examined because tamarack seedlings did not set bud under the 18 hour photoperiod. The primordia data were analysed in a split plot design (Table 3.5). The

whole plots were growth chambers and the whole plot treatments were three photoperiods (light treatments). Within the growth chambers the design was hierarchical with the following structure: provenance, family within provenance, and seedlings within family within provenance.

Table 3.5. Model for the analysis of variance of axial and basal primordia data.

SOURCE	D.F.	EXPECTED MEAN SQUARES
Light (L_i)	2	$\sigma^2 + 4\,\sigma^2_{LF} + 20\,\sigma^2_{LP} + 80\,\sigma^2_{\delta} + 80\,\phi(L)$
Restriction error ($\delta_{(i)}$)	0	$\sigma^2 + 4\,\sigma^2_{LF} + 20\,\sigma^2_{LP} + 80\,\sigma^2_{\delta}$
Provenance (P_j)	3	$\sigma^2 + 16\,\sigma^2_{F} + 80\,\sigma^2_{P}$
Interaction (LP_{ij})	6	$\sigma^2 + 4\,\sigma^2_{LF} + 20\,\sigma^2_{LP}$
Family within P ($F_{(j)k}$)	16	$\sigma^2 + 16\,\sigma^2_{F}$
Interaction ($LF_{i(j)k}$)	32	$\sigma^2 + 4\,\sigma^2_{LF}$
Within error ($\varepsilon_{(ijk)l}$)	180	σ^2
Total	239	

Experiment 2

The objective of Experiment 2 was to study the effect of 4 photoperiods on height increment, and days until bud set of balsam poplar rooted cuttings from five provenances ranging from Rhinelander, Wisconsin to the shore of Hudson Bay. The experiment was replicated three times in a nested-split plot design to provide a statistical test for photoperiod treatments (Table 3.6). One ramet from each of 10 clones per provenance (Fort Severn, Bearskin Lake, Pickle Lake, Thunder Bay, and Rhinelander) were tested in each replication of the four photoperiod treatments.

The linear model for Experiment 2 is as follows:

$$Y_{ijklm} = \mu + R_i + \delta_{(i)} + L_j + RL_{ij} + \omega_{(ij)} + P_k + RP_{ik} + LP_{jk} + RLP_{ijk} + C_{(k)l} + RC_{i(k)} + LC_{j(k)l} + RLC_{ij(k)l} + \varepsilon_{(ijkl)m}$$

where;

Y_{ijklm} = the variable to be analyzed from the m^{th} ramet in the l^{th} clone in the k^{th} provenance in the j^{th} light treatment in the i^{th} replication
μ = the overall mean
R_i = the random effect of the i^{th} replication of the experiment
$\delta_{(i)}$ = the first restriction error
L_j = the fixed effect of the j^{th} light treatment
RL_{ij} = the interaction of the i^{th} replication and the j^{th} light treatment
$\omega_{(ij)}$ = the second restiction error
P_k = the random effect of the k^{th} provenance
RP_{ik} = the interaction of the i^{th} replication and the k^{th} provenance
LP_{jk} = the interaction of the j^{th} light treatment and the k^{th} provenance
RLP_{ijk} = the interaction of the i^{th} replication and the j^{th} light and the k^{th} provenance
$C_{(k)l}$ = the random effect of the l^{th} clone in the k^{th} provenance
$RC_{i(k)l}$ = the interaction of the l^{th} clone in the k^{th} provenance and the i^{th} replication
$LC_{i(k)l}$ = the interaction of the l^{th} clone in the k^{th} provenance and the j^{th} light
$RLC_{ij(k)l}$ = the interaction of the l^{th} clone in the k^{th} provenance and the i^{th} replication and the j^{th} light treatment
$\varepsilon_{(ijkl)m}$ = random eror due to the m^{th} ramet in the l^{th} clone in the k^{th} provenance in the j^{th} light treatment in the i^{th} replication

As in Experiment 1, not all factors in this experiment could be tested by the usual mean square ratios as seen in the EMS table (Table 3.6). Quasi-F ratios were generated as outlined by Winer (1971) and used for testing.

Table 3.6. Model for the analysis of variance of Experiment 2.

SOURCE	D.F.	EXPECTED MEAN SQUARES
Replication (R_i)	2	$\sigma^2 + \sigma^2_{RLC}+4\sigma^2_{RC}+10\sigma^2_{RLP}+40\sigma^2_{RP}+50\sigma^2_{\omega}+200\sigma^2_{\delta}+200\sigma^2_{R}$
Restriction error ($\delta_{(i)}$)	0	$\sigma^2 + \sigma^2_{RLC} + 4\sigma^2_{RC} + 10\sigma^2_{RLP} + 40\sigma^2_{RP} + 50\sigma^2_{\omega} + 200\sigma^2_{\delta}$
Light (L_j)	3	$\sigma^2+\sigma^2_{RLC}+3\sigma^2_{LC}+10\sigma^2_{RLP}+30\sigma^2_{LP}+50\sigma^2_{\omega}+50\sigma^2_{RL}+150\phi(L)$
Interaction (RL_{ij})	6	$\sigma^2 + \sigma^2_{RLC} + 10\,\sigma^2_{RLP} + 50\,\sigma^2_{\omega} + 50\,\sigma^2_{RL}$
Restriction error ($\omega_{(ij)}$)	0	$\sigma^2 + \sigma^2_{RLC} + 10\,\sigma^2_{RLP} + 50\,\sigma^2_{\omega}$
Provenance (P_k)	4	$\sigma^2 + 4\sigma^2_{RC} + 12\sigma^2_{C} + 40\sigma^2_{RP} + 120\sigma^2_{P}$
Interaction (RP_{ik})	8	$\sigma^2 + 4\,\sigma^2_{RC} + 40\,\sigma^2_{RP}$
Interaction (LP_{jk})	12	$\sigma^2 + \sigma^2_{RLC} + 3\,\sigma^2_{LC} + 10\,\sigma^2_{RLP} + 30\,\sigma^2_{LP}$
Interaction (RLP_{ijk})	24	$\sigma^2 + \sigma^2_{RLC} + 10\,\sigma^2_{RLP}$
Clone within P ($C_{(k)l}$)	45	$\sigma^2 + 4\,\sigma^2_{RC} + 12\,\sigma^2_{C}$
Interaction ($RC_{i(k)l}$)	90	$\sigma^2 + 4\,\sigma^2_{RC}$
Interaction ($LC_{i(k)l}$)	135	$\sigma^2 + \sigma^2_{RLC} + 3\,\sigma^2_{LC}$
Interaction ($RLC_{ij(k)l}$)	270	$\sigma^2 + \sigma^2_{RLC}$
Within error ($\varepsilon_{(ijkl)m}$)	0	σ^2
Total	599	

Experiment 3

The objective of Experiment 3 was to study the effect of four photoperiods on height increment and days until bud set in two year old tamarack rooted cuttings (ramets) from five provenances in northern Ontario. This experiment tests tamarack material from a wider latitudinal range in northern Ontario and older aged material than in Experiment 1. The experiment was executed in a split-plot design (Table 3.7). The whole plots were growth

chambers and the whole plot treatments were the four photoperiods. Within the growth chambers the design was hierarchical with the following structure: provenance, clones within provenance, and ramets within clone within provenance. For each photoperiod treatment, three ramets per clone and 10 clones per provenance (Big Trout Lake, Kenogami River, Red Lake, Thunder Bay, and North Bay) were tested. The experiment had the following linear model:

$$Y_{ijkl} = \mu + L_i + \delta_{(i)} + P_j + LP_{ij} + C_{(j)k} + LC_{i(j)k} + \varepsilon_{(ijk)l}$$

where;

Y_{ijkl} = the variable to be analyzed from the l^{th} ramet in the k^{th} clone in the j^{th} provenance in the i^{th} light treatment
μ = the overall mean
L_j = the fixed effect of the i^{th} light treatment
$\delta_{(i)}$ = restriction error
P_k = the random effect of the k^{th} provenance
LP_{jk} = the interaction of the i^{th} light treatment and the j^{th} provenance
$C_{(k)l}$ = the random effect of the k^{th} family in the j^{th} provenance
$LC_{i(k)l}$ = the interaction of the k^{th} clone in the j^{th} provenance and the i^{th} light
$\varepsilon_{(ijk)l}$ = random eror due to the l^{th} ramet in the k^{th} clone in the j^{th} provenance in the i^{th} light treatment

Table 3.7. Model for the analysis of variance of data from Experiment 3.

SOURCE	D.F.	EXPECTED MEAN SQUARES
Light (L_i)	3	$\sigma^2 + 3\,\sigma^2_{LC} + 24\,\sigma^2_{LP} + 80\,\sigma^2_{\delta} + 120\,\phi(L)$
Restriction error ($\delta_{(i)}$)	0	$\sigma^2 + 3\,\sigma^2_{LC} + 24\,\sigma^2_{LP} + 80\,\sigma^2_{\delta}$
Provenance (P_j)	4	$\sigma^2 + 12\,\sigma^2_{C} + 96\,\sigma^2_{P}$
Interaction (LP_{ij})	12	$\sigma^2 + 12\,\sigma^2_{C} + 24\,\sigma^2_{LP}$
Clone within P ($C_{(j)k}$)	45	$\sigma^2 + 12\,\sigma^2_{C}$
Interaction ($LC_{i(j)k}$)	135	$\sigma^2 + 3\,\sigma^2_{LC}$
Within error ($\varepsilon_{(ijk)l}$)	400	σ^2
Total	599	

4. RESULTS

EXPERIMENT 1: TAMARACK SEEDLINGS

Height Growth

Based upon the height measurements made every three days in Experiment 1, average height curves were produced for each provenance in each light treatment (Figure 4.1). Provenance average height values for each treatment were obtained from all seedlings within five families per provenance in each of the three replications (maximum of 60 seedlings per average value). Due to an electrical failure in one of the growth chambers during the first replication, the 14 hour light treatment was invalidated in this replication. Therefore, the growth curves for all provenances in the 14 hour treatment are based on averages from two replications instead of three (maximum of 40 seedlings). Provenance mean height growth, based on all three replications, range of family means, and coefficient of variation values, are given in Table 4.1.

The height growth curves (Figure 4.1) and provenance mean height growth values (Table 4.1) display little variation among the four provenances within photoperiod treatments, but show strong differences among light treatments. Family mean height growth (maximum of four seedlings per family), and coefficient of variation values for seedlings within family appear in Appendix I.

The initial height differences among provenances (i.e. North Bay tallest and Thunder Bay shortest) displayed in all photoperiods (Figure 4.1) may be due to differences in the ability of seed to germinate after two years of storage in unsealed containers stored at 3° C. Seed from North Bay germinated quickly and with a high percent germination, while seed from Thunder Bay was slow to germinate and had a low percent germination.

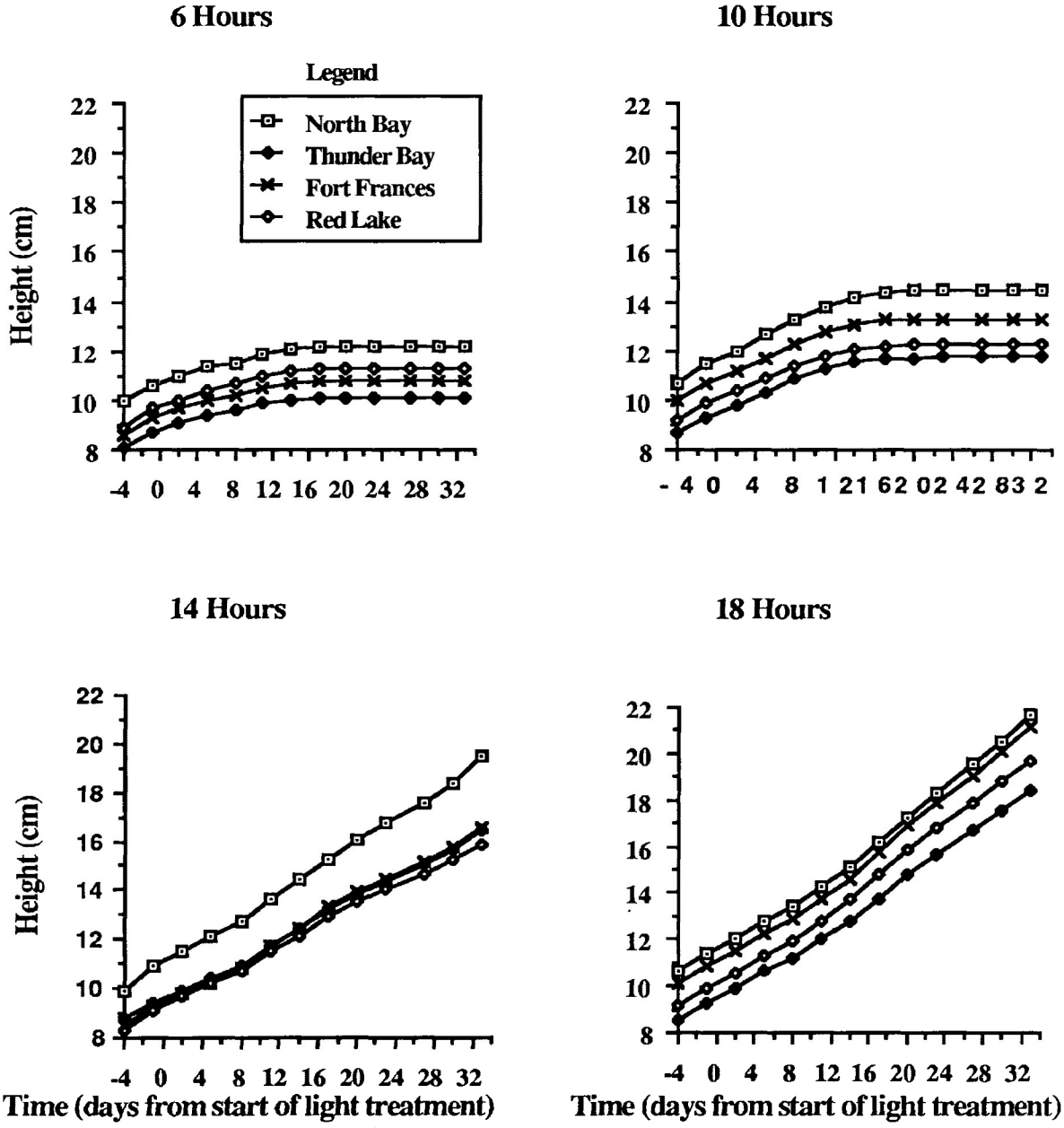

Figure 4.1. Average height growth of 3 month old seedlings from tamarack provenances grown under 6, 10, 14, and 18 hour photoperiods based on three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment three replications of Experiment 1.

Table 4.1 Mean height growth (cm), coefficient of variation of family means within provenance (in brackets), and range of family means for each tamarack provenance by photoperiod treatment based on three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment in Experiment 1.

PROVENANCE	PHOTOPERIOD (hours) 6	10	14	18
North Bay	1.6 (14.1)	3.0 (18.0)	10.8 (5.5)	11.3 (5.5)
range of family means	1.3-1.9	2.2-3.6	10.2-11.6	10.2-11.8
Thunder Bay	1.4 (21.8)	2.4 (17.3)	7.6 (21.9)	10.2 (10.3)
range of family means	1.1-1.8	1.7-2.9	6.0-10.4	10.5-13.4
Fort Frances	1.5 (11.5)	2.6 (21.0)	8.4 (4.0)	11.4 (10.3)
range of family means	1.3-1.8	2.1-3.5	8.0-8.8	10.5-13.4
Red Lake	1.6 (5.9)	2.4 (8.0)	7.3 (16.4)	10.8 (7.0)
range of family means	1.5-1.8	2.1-2.6	5.4-8.7	9.5-11.3

The analysis of variance for tamarack seedling height growth was based on only the second and third replications of Experiment 1. In the second replication an experimental unit consisted of a Spencer-Lemaire booklet containing one family of four seedlings. Family booklets were randomized with one booklet per light treatment. In the third replication each of the four seedlings within a family were randomized within a treatment, so that each seedling was an experimental unit.

The analysis presented in Table 4.2 was produced from a two stage analysis because of the different experimental units used in the second and third replications. In the first stage, the third replication of Experiment 1 was analysed in order to obtain an estimate of experimental error. The second stage of the analysis used family means from replications two and three. By using the estimate for experimental error obtained from stage one with the analysis from stage two, the full analysis was produced (Table 4.2). The estimated mean squares for the analysis, presented in Table 3.4, give the initial error terms used. The F-ratios and error terms listed in Table 4.2 are those used in the final tests.

The ANOVA of tamarack seedling height growth indicates significant differences in growth due to light treatments, the light by provenance interaction, and families within provenance (Table 4.2). All other factors tested were non-significant.

Table 4.2 Analysis of variance of tamarack seedling height growth from replications two and three in Experiment 1.

SOURCE OF VARIATION	S. S.	D.F.	M. S.	F-RATIO	ERROR TERM
Replication	17.7	1	17.7		
Restiction Error ($\delta_{(i)}$)	N.A.	0	N.A.	N.A.	
Light	2906.5	3	968.8	179.2 **	Quasi-F ratio
Rep. x Light	6.3	3	2.1		
Restriction Error ($\omega_{(ij)}$)	N.A.	0	N.A.	N.A.	
Provenance	32.8	3	10.9	3.1 ns	Family w Provenance
Rep. x Provenance	5.9	3	1.9	1.3 ns	Rep. x Family w Prov.
Light x Provenance	36.7	9	4.1	3.1 **	Light x Family w Prov.
Rep x Light x Provenance	6.7	9	0.7	0.7 ns	Rep x Light x Fam w P
Family within Provenance	56.3	16	3.5	2.3 *	Rep. x Family w Prov.
Rep. x Family w Prov.	24.0	16	1.5	0.4 ns	Within
Light x Family w Prov.	62.4	48	1.3	0.4 ns	Rep x Light x Fam w P
Rep. x Light x Fam.w Prov.	54.4	48	1.1	0.3 ns	Within
Seedling within ($\varepsilon_{(ijkl)m}$)	826.0	220	3.8		

*= significant at α= 0.05 ** significant at α=0.01 ns = not significant

A Student-Newman-Keuls (SNK) multiple range test (Anderson and McLean, 1982) was used to determine significant differences in height growth among photoperiod treatments. The analysis indicated that each photoperiod was significantly different (α=0.05) from all other photoperiod treatments. Photoperiod treatments were ranked, based on apical height growth, from largest to smallest, as follows: 18, 14, 10 and 6 hours of light.

Relative Height Growth Rate

Relative height growth rate (RHGR) was computed for each seedling between the fifth and eleventh day after the start of photoperiod treatments (i.e. period of rapid height growth). Family average RHGR values are presented in Appendix III. RHGR values were subjected to the same analysis (i.e. two stage) as outlined earlier for the tamarack seedling height growth analysis (Table 3.4). The average RHGR values for each provenance based

on all replications are presented in Figure 4.2 and with the range of family means in Table 4.3. The bar graph shows a strong photoperiod treatment effect on RHGR, but little provenance effect.

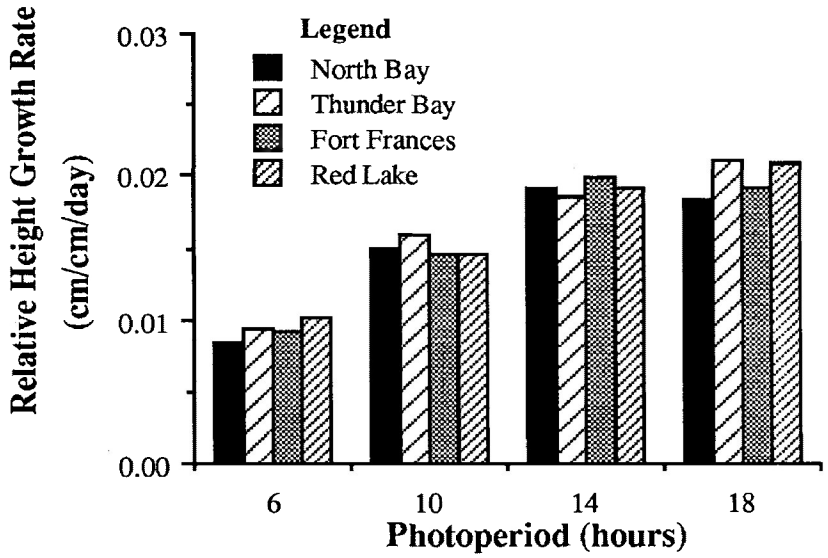

Figure 4.2. Average RHGR (cm/cm/day) for tamarack provenances, by photoperiod based on three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment in Experiment 1.

Table 4.3. Average RGHR (cm/cm/day) and range of family means for tamarack provenances based on three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment in Experiment 1.

		PHOTOPERIOD			
PROVENANCE		6 Hours	10 Hours	14 Hours	18 Hours
North Bay	Mean	0.0084	0.0150	0.0191	0.0183
range of family	means	0.005-0.012	0.011-0.018	0.016-0.023	0.013-0.022
Thunder Bay	Mean	0.0094	0.0158	0.0186	0.0210
range of family	means	0.005-0.016	0.011-0.025	0.010-0.022	0.015-0.032
Fort Frances	Mean	0.0092	0.0145	0.0198	0.0192
range of family	means	0.007-0.012	0.011-0.018	0.018-0.024	0.015-0.023
Red Lake	Mean	0.0101	0.0146	0.0191	0.0209
range of family	means	0.007-0.016	0.009-0.024	0.015-0.023	0.014-0.031

The analysis of variance of RHGR indicates a significant difference in RHGR due to light treatment (Table 4.4). All other factors in the analysis were non-significant. SNK multiple range test was used to determine significant differences (α=0.05) in RGHR

among photoperiod treatments. The analysis indicated that the RHGR in the 18 and 14 hour photoperiods were significantly larger than in the 10 and 6 hour photoperiods and that the RHGR in the 10 hour treatment was significantly larger than in the 6 hour photoperiod.

Table 4.4. Analysis of variance of tamarack seedling RGHR from replications two and three of Experiment 1.

SOURCE OF VARIATION	S. S.	D.F.	M. S.	F-RATIO	ERROR TERM
Replication	38.9	1	38.9		
Restriction Error ($\delta_{(i)}$)	N.A.	0	N.A.	N.A.	
Light	3674.5	3	1224.8	816.5 **	Quasi-F ratio
Rep. x Light	7.4	3	2.4		
Restriction Error ($\omega_{(ij)}$)	N.A.	0	N.A.	N.A.	
Provenance	30.5	3	10.2	1.4 ns	Family w Provenace
Rep. x Provenance	35.1	3	11.7	1.8 ns	Rep. x Family w Prov.
Light x Provenance	55.7	9	6.2	1.6 ns	Light x Family w Prov.
Rep x Light x Provenance	63.8	9	7.1	1.4 ns	Rep. x Light x Fam w P
Family within Provenance	117.7	16	7.4	1.2 ns	Rep. x Family w Prov.
Rep. x Family w Prov.	101.5	16	6.3	0.6 ns	Within
Light x Family w Prov.	187.5	48	3.9	0.8 ns	Rep. x Light x Fam w P
Rep x Light x Fam w Prov	235.8	48	4.9	0.4 ns	Within
Seedling within ($\varepsilon_{(ijkl)m}$)	2406.4	220	10.94		

** significant at α=0.01 ns = not significant

Days Until Bud Set

The number of days from the start of the light treatments to the ocular detection of bud scales was recorded as the time until bud set. The number of days until bud set for tamarack seedlings in each replication of Experiment 1 appear in Appendix V. Seedlings grown under the 18 hour light treatment did not set bud in any of the three replications, and therefore, were not included in the analysis of days until bud set. Except for the reduced number of light treatments, from four to three, the ANOVA was performed as outlined for tamarack seedling height growth (Table 3.4). The average number of days until bud set for each provenance in each of the three light treatments is shown in Figure 4.3 and with the range of family means in Table 4.5. The 6 hour and 10 hour photoperiods resulted in bud

set occurring at the same time in all provenances with little or no variation among families (Table 4.5). Variation among provenances in the 14 hour photoperiod generally follows the latitude of each provenance with North Bay growing for the longest period and Red Lake growing for the shortest period (Figure 4.3).

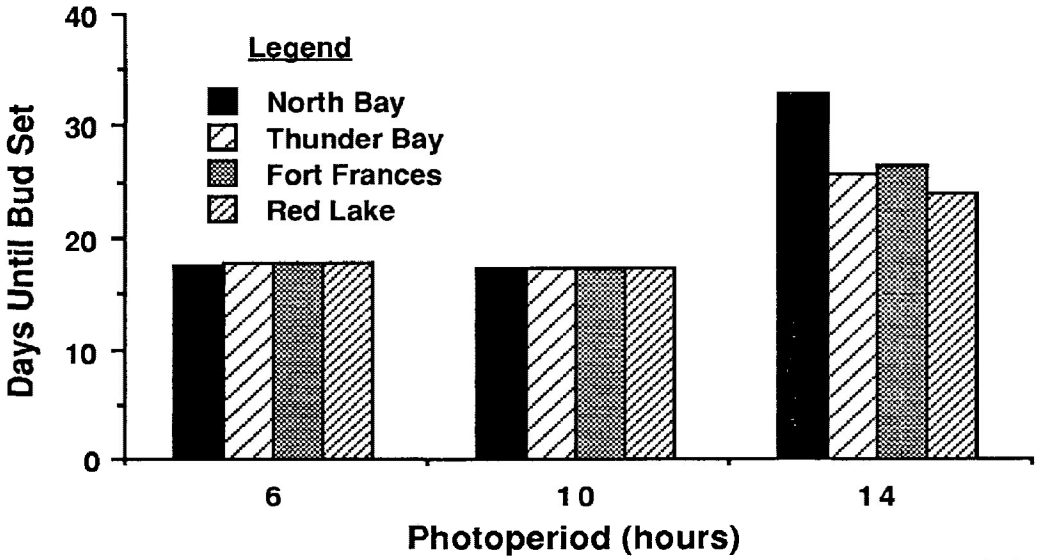

Figure 4.3. The average number of days until bud set for tamarack provenances, by photoperiod, from replications two and three in Experiment 1.

Table 4.5. Tamarack provenance mean days until bud set and range of family means, by photoperiod, from replications two and three in Experiment 1.

PROVENANCE	PHOTOPERIOD (hours) 6	10	14
North Bay	16	16	33
range of family means	16-18	16-16	31-35
Thunder Bay	16	16	26
range of family means	16-18	16-16	23-29
Fort Frances	17	16	27
range of family means	16-19	16-16	24-29
Red Lake	17	16	24
range of family means	16-18	16-16	21-29

The ANOVA of days until bud set for the three photoperiods indicates that light, provenance, and the light by provenance interaction were significant (Table 4.6). All other factors tested in the analysis were non-significant. The significant provenance and light x

provenance results (Table 4.6) relate to the large number of days until bud set for North Bay in the 14 hour photoperiod treatment. This photoperiod appears to be below the critical daylength of the three northern sources, but is close to the critical daylength for North Bay.

Table 4.6. Analysis of variance of the number of days until bud set for tamarack seedlings from replications two and three in Experiment 1.

SOURCE OF VARIATION	S. S.	D. F.	M. S.	F-RATIO	ERROR TERM
Replication	279.8	1	279.8		
Restiction Error (δ)	N.A.	0	N.A.	N.A.	
Light	3200.9	2	1600.5	14.6 *	Quasi-F ratio
Rep. x Light	132.5	2	66.2		
Restriction Error (ω)	N.A.	0	N.A.	N.A.	
Provenance	143.5	3	47.8	11.9 **	Family w Provenace
Rep. x Provenance	22.2	3	7.4	0.1 ns	Within
Light x Provenance	304.9	6	50.8	10.0 **	Light x Family w Prov.
Rep x Light x Provenance	42.9	6	7.2	0.1 ns	Within
Family within Provenace	64.4	16	4.0	1.2 ns	Rep. x Family w Prov.
Rep. x Family w Prov.	52.2	16	3.3	0.1 ns	Within
Light x Family w Prov.	162.4	32	5.1	1.8 ns	Rep x Light x Fam w P
Rep. x Light x Fam w Prov.	89.6	32	2.8	0.1 ns	Within
Within ($\varepsilon_{(ijkl)m}$)	30018.8	180	166.8		

* = significant at α=0.05 ** = significant at α=0.01 n.s. = not significant

SNK multiple range test was used to determine significant differences in the number of days until bud set among photoperiod treatments and provenances. The analysis of the number of days until bud set by photoperiod treatment indicated that the short day treatments (i.e. 6 and 10 hours) were the same, but that the 14 hour photoperiod was significantly (α=0.05) larger than both short day treatments. The analysis of the number of days until bud set by provenance produced the following results:

	PROVENANCE			
	North Bay	Thunder Bay	Fort Francis	Red Lake
Mean Days Until Bud Set	22a	19b	20b	19b

Provenance means followed by different letter suffixes are significantly different at α=0.05

Tamarack Needle Primordia

The analysis of primordia counts (axial and basal) was designed to have five families within each provenance, and four seedlings within each family (Table 3.5). However, due to the combination of poor seed viability, seedling mortality, and buds with indistinguishable primordia, the analysis was based upon only three families within each provenance, and three seedlings within each family. Because primordia were counted from only one replication of Experiment 1, the test for the effect of light treatment also includes the effect of the restriction on randomization due to growth chambers (i.e. restriction error). The number of axial and basal primordia in apical buds of tamarack seedlings from the third replication of Experiment 1 appear in Appendix VII. The average number of axial, and basal primordia for each provenance in each photoperiod (6, 10 and 14 hours) appears in Figures 3.4 and 3.5 respectively.

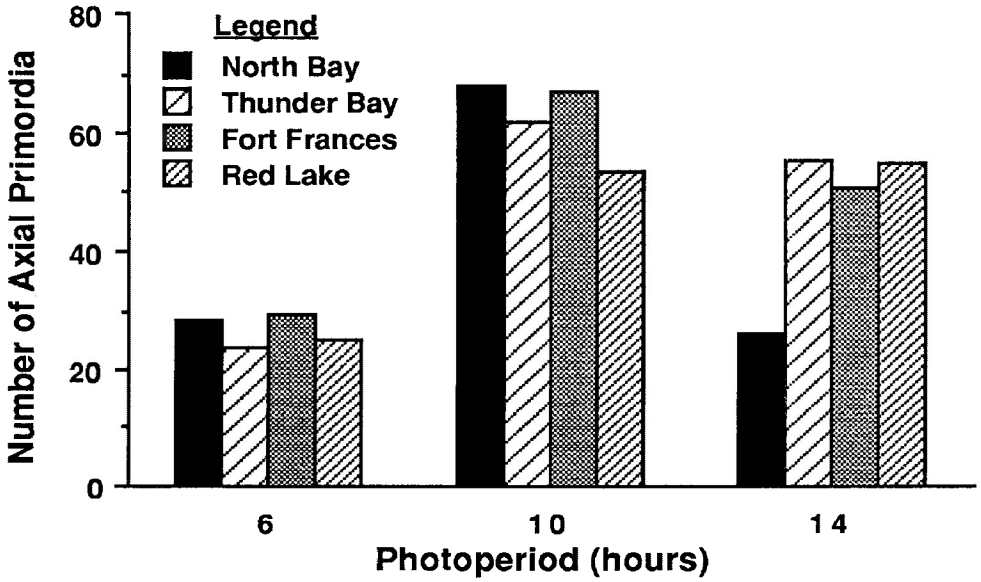

Figure 4.4. The average number of axial primordia for each tamarack provenance by photoperiod from replication three in Experiment 1.

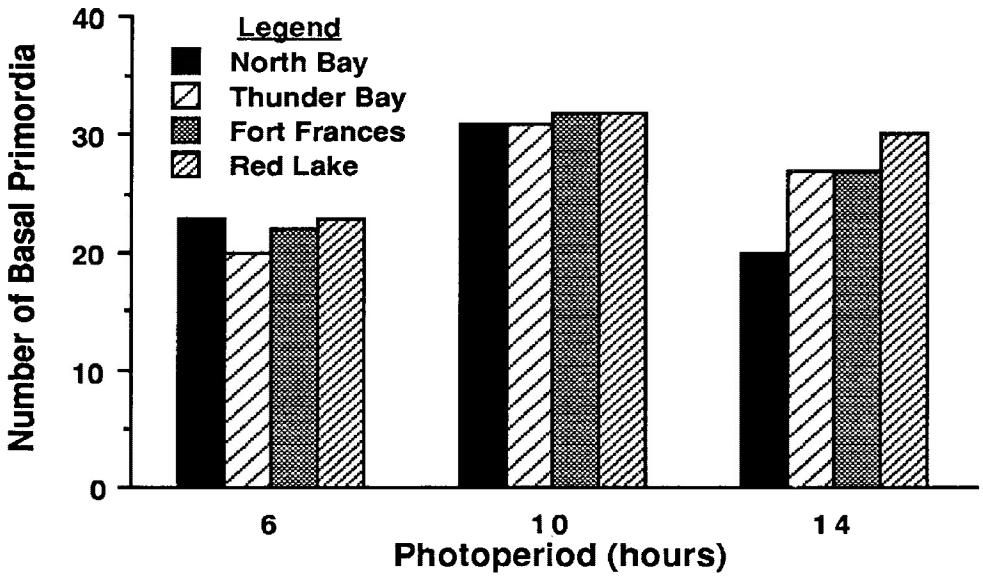

Figure 4.5. The average number of basal primordia for each tamarack provenance by photoperiod from replication three in Experiment 1.

The analysis of axial primordia counts (Table 4.7) indicates that the light treatment and/or restriction error, and the light by provenance interaction were significant. All other factors tested in the analysis including provenance, were non-significant. For each provenance, axial primordia production in the 10 hour treatment was twice that of the six hour treatment (Figure 4.4), despite having set bud at the same time (Figure 4.3). Average axial primordia production by photoperiod was as follows:

	Photoperiod		
	6	10	14
Number of Axial Primordia	29	64	48

In the 14 hour light treatment, North Bay seedlings had the longest growing period before setting bud (Figure 4.3), and therefore, the shortest period for primordia production. Consequently, North Bay seedlings developed small buds with few and poorly formed axial primordia (Figure 4.4). The significant light x provenance interaction (Table 4.7) may have resulted from the low number of axial primordia in North Bay seedlings due to the short bud development period for these seedlings in the 14 hour photoperiod.

Table 4.7. Analysis of variance of the number of axial primordia from tamarack seedlings in replication three of Experiment 1.

SOURCE OF VARIATION	S. S.	D.F.	M. S.	F-RATIO	ERROR TERM
Light	22176.00	2	11088.02	10.43 *[1]	Light x Provenance
Restriction Error ($\delta_{(i)}$)	N.A.	0	N.A.	N.A.	
Provenance	1132.67	3	377.56	2.44 ns	Family w Provenance
Light x Provenance	6380.00	6	1063.33	12.63 **	Light x Family w Prov.
Family within Prov.	1236.07	8	154.51	1.45 ns	Within
Light x Family w Prov.	1347.04	16	84.19	0.79 ns	Within
Seedling within ($\varepsilon_{(ijk)l}$)	7673.31	72	106.57		

* = significant at α=0.05 ** = significant at α=0.01 n.s. = not significant
[1] = Test of light and restriction error terms.

The analysis of basal primordia counts was performed as described above for axial primordia. The analysis indicated that provenance, and the light by provenance interaction were significant (Table 4.8). All other factors tested in the analysis were non-significant, including light and the restriction on light by growth chambers. The largest number of basal primordia was produced in the 10 hour photoperiod. There was little variation among provenances in the number of basal primordia for the 6 and 10 hour light treatments, but noticeable variation within the 14 hour photoperiod. The number of basal primordia produced by a provenance under the 14 hour photoperiod appears to be related to the number of days until bud set. Provenances which set bud early produced more basal primordia than late setting provenances. North Bay seedlings in the 14 hour photoperiod set bud shortly before the termination of light testing, and therefore, produced the lowest number of basal primordia. The low number of basal primordia for the North Bay provenance in the 14 hour photoperiod treatment appears to have resulted in the significant provenance and light by provenance effects (Table 4.8).

Table 4.8. Analysis of variance for the number of basal primordia surrounding the apical bud in tamarack seedlings from replication 3 in Experiment 1.

SOURCE OF VARIATION	S. S.	D.F.	M. S.	F-RATIO	ERROR TERM
Light	1147.69	2	573.84	3.89 ns[1]	Light x Prov.
Restriction Error ($\delta_{(i)}$)	N.A.	0	N.A.	N.A.	
Provenance	300.67	3	100.22	5.10 *	Family w Prov.
Light x Provenance	884.61	6	147.44	6.69 **	Light x Family
Family within Provenance	157.18	8	19.65	1.26 ns	Within
Light x Family within Prov.	352.59	16	22.04	1.43 ns	Within
Seedling within ($\varepsilon_{(ijk)l}$)	112.67	72	15.59		

* = significant at α=0.05 ** = significant at α=0.01 n.s. = not significant
[1] = Test of light and restriction error terms.

EXPERIMENT 2: BALSAM POPLAR ROOTED CUTTINGS

Height Growth

Based on the height measurements made every three days, height growth curves were produced for each balsam poplar provenance by photoperiod treatment (Figure 4.6). Average height growth values for each provenance by light treatment, the range of clone means, and the coefficient of variation values, based on all three replications, are given in Table 4.9. The growth curves (Figure 4.6) and provenance mean height growth values (Table 4.9) are based on the average of 10 clones (one ramet per clone) within each provenance from each of the three replications of the experiment (maximum of 30 ramets per average value) (Appendix II). A breakdown in one growth chamber during the first replication of the experiment caused the invalidation of the 14 hour light treatment in this replication. Therefore, height growth values for the 14 hour light treatment are based on replications two and three only (maximum of 20 ramets per average value).

In all of the light treatments, except the 18 hour long day treatment, there appears to be a strong relationship between height growth and the latitude of a provenance (Figure 4.6). The general trend exhibited in the 6, 10, and 14 hour light treamtments was that northern provenances stopped height growth earlier than southern provenances.

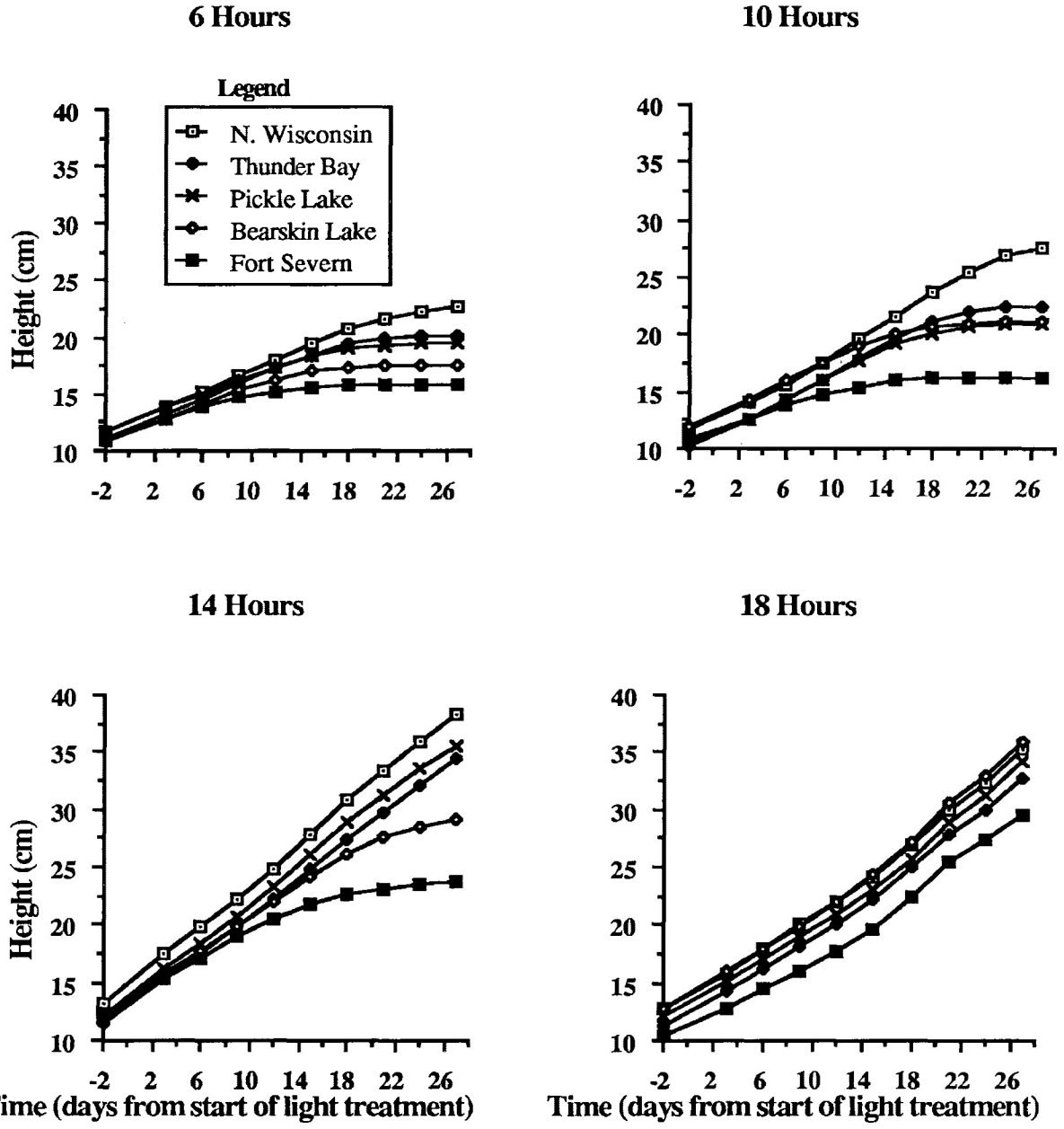

Figure 4.6. Average height growth of rooted cuttings from balsam poplar provenances grown under 6, 10, 14, and 18 hour photoperiods based on three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment in Experiment 2.

Table 4.9. Balsam poplar provenance mean height growth (cm), coefficient of variation percent of clones within provenance, and range of clone means, by photoperiod based on all three replications in Experiment 2.

PROVENANCE	PHOTOPERIOD (hours) 6	10	14	18
N. Wisconsin	10.9 (17.2)	15.8 (13.8)	23.6 (17.2)	21.4 (13.0)
range of clone means	8.3-13.5	11.2-18.3	18.0-32.4	16.4-25.7
Thunder Bay	8.9 (28.5)	12.3 (10.8)	21.8 (11.6)	20.5 (8.9)
range of clone means	6.4-12.6	9.8-14.5	17.5-25.2	18.0-23.6
Pickle Lake	7.7 (20.8)	10.6 (15.3)	21.6 (19.6)	21.2 (12.8)
range of clone means	5.3-9.3	7.5-12.7	13.4-26.2	18.0-27.3
Bearskin Lake	6.9 (21.1)	9.2 (26.5)	17.4 (30.5)	22.8 (17.5)
range of clone means	5.3-10.8	5.1-13.1	8.6-25.9	16.4-27.7
Fort Severn	5.0 (26.4)	5.4 (34.2)	11.9 (37.4)	17.8 (31.3)
range of clone means	2.4-7.4	2.0-7.7	6.7-18.9	4.7-26.9

The analysis of variance of balsam poplar height was performed with data from replications two and three due to the elimination of the 14 hour light treatment from the first replication. Due to a shortage of cuttings for propagation in some clones, and ramet mortality during the greenhouse growing stage, the analysis for Experiment 2 was limited to only five clones within each provenance. The ANOVA of balsam poplar height growth indicates that light, provenance and the interaction of light and provenance were significant (Table 4.10). All other factors tested in the analysis were non-significant . The significant light by provenance interaction may have resulted from the exceptional growth of Bearskin Lake clones within the 18 hour photoperiod where they were ranked first in height growth instead of the usual fourth ranking among the provenances in the other three photoperiods (Table 4.9). This indicates that, when excluding photoperiod effects, Bearskin Lake clones can grow as fast as clones from more southern provenances.

Table 4.10. Analysis of variance of balsam poplar height for 5 clones per provenance from replications two and three in Experiment 2.

SOURCE OF VARIATION	S. S.	D.F.	M. S.	F-RATIO	ERROR TERM
Replication	1499.3	1	1499.3		
Restriction Error ($\delta_{(i)}$)	N.A.	0	N.A.	N.A.	
Light	12124.6	3	4041.5	21.0 **	Quasi-F ratio
Rep. x Light	352.9	3	117.6		
Restriction Error ($\omega_{(ij)}$)	N.A.	0	N.A.	N.A.	
Provenance	2025.6	4	506.4	13.0 **	Clone within Provenace
Rep. x Provenance	9.8	4	2.4	0.1 ns	Rep x Clone w Prov.
Light x Provenance	1098.2	12	91.5	7.4 **	Light x Clone w Prov.
Rep x Light x Provenance	199.1	12	16.6	2.2 ns	Rep x Light x Clonew P
Clone within Provenance	778.0	20	38.9	1.6 ns	Rep x Clone w Prov.
Rep. x Clone w Prov.	476.6	20	23.8		
Light x Clone w Prov.	740.6	60	12.3	1.6 ns	Rep x Light x Clonew P
Rep x Light x Clonew Prov	453.4	60	7.6		
Ramet within ($\varepsilon_{(ijkl)m}$)	N.A.	0	N.A.		

** = significant at α=0.01 n.s. = not significant

SNK multiple range test was used to determine significant differences in height among photoperiod treatments and provenances. The analysis of height growth by photoperiod treatment indicated that each photoperiod was significantly different from all other photoperiod treatments. Photoperiod treatments were ranked, based on average height growth, in order of duration; 18, 14, 10 and 6 hours of light. The analysis of height growth by provenance indicated the following provenance ranking:

	PROVENANCE				
	Rhinelander	Thunder Bay	Pickle Lake	Bearskin Lake	Fort Severn
Height Growth (cm)	23.1a	18.4b	19.2b	17.9b	13.2c

Provenance means followed by different letter suffixes are significantly different at α=0.05.

Balsam Poplar Relative Height Growth Rate

Height growth between the fifth and twelfth days (i.e. period of most rapid growth) from the start of photoperiod treatments was used to determine the relative height growth

rate (RHGR). The RHGR of balsam poplar clones in each replication of Experiment 2 appear in Appendix IV. The average RHGR values for each provenance from all three replications, (only two replications for the 14 hour treatment) are shown in Figure 4.13 and with the range of family means in Table 4.11. The bar graph indicates possible differences among provenances, and among light treatments.

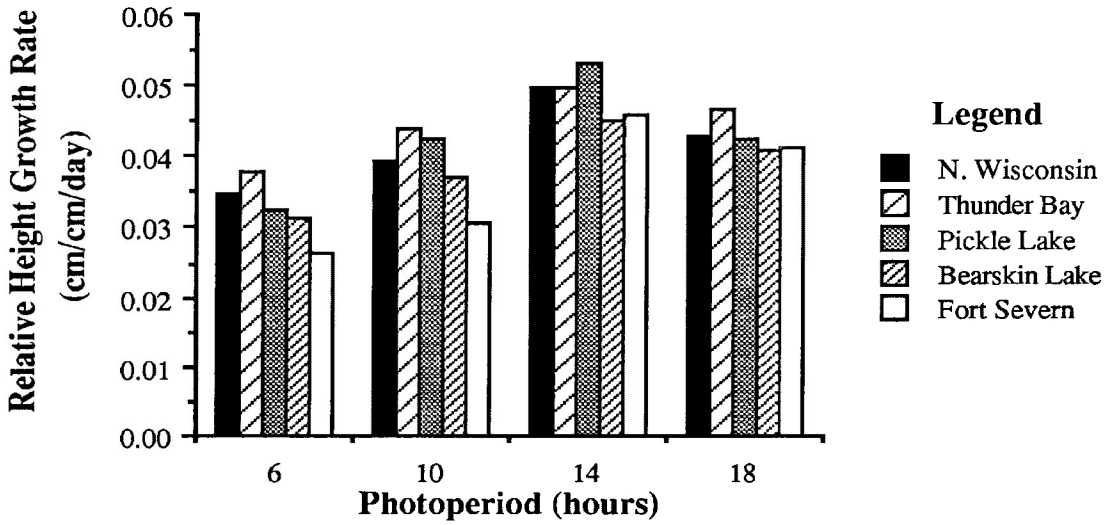

Figure 4.7. The average RHGR for balsam poplar provenances during the peak growing period, by photoperiod based on all clones from three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment in Experiment 2.

Table 4.11. Balsam poplar provenance mean relative height growth rate (cm/cm/day) and range of clone means, by photoperiod, based on three replications for 6, 10, and 18 hour treatments and 2 replications for the 14 hour treatment in Experiment 2.

PROVENANCE		PHOTOPERIOD 6 Hours	10 Hours	14 Hours	18 Hours
Rhinelander	Mean	0.0348	0.0393	0.0498	0.0428
	Range	0.013-0.072	0.019-0.075	0.018-0.097	0.017-0.089
Thunder Bay	Mean	0.0378	0.0440	0.0498	0.0465
	Range	0.014-0.087	0.019-0.087	0.019-0.097	0.017-0.118
Pickle Lake	Mean	0.0324	0.0422	0.0530	0.0423
	Range	0.011-0.086	0.010-0.101	0.018-0.124	0.020-0.108
Bearskin Lake	Mean	0.0315	0.0372	0.0450	0.0410
	Range	0.006-0.064	0.004-0.078	0.011-0.083	0.015-0.072
Fort Severn	Mean	0.0264	0.0306	0.0459	0.0414
	Range	0.008-0.074	0.003-0.088	0.007-0.100	0.010-0.110

The analysis of RHGR values was performed as described above for height. Data from only 5 clones in replications two and three were used. The analysis of variance (Table 4.12) indicates that light treatments had a significant effect on the RHGR. All other factors, including provenance, were non-significant. The RHGR pattern among provenances in the 10 and 6 hour photoperiods may relate to the earlier growth cessation in northern provenances than southern provenances. Although attempts were made to select a time period for calculating RHGR that was before the start of growth cessation, the selected period may have included the initial slowdown in height growth for northern provenances in the short photoperiods (i.e. 6 and 10 hours). Therefore, the RHGR for northern provenances in the short photoperiod treatments may not reflect height growth before the induction of apical growth cessation and bud set.

SNK multiple range test was used to determine significant differences in RHGR among photoperiod treatments. The analysis of RGHR by photoperiod treatment indicated that RGHR in the 18 and 14 hour photoperiods were significantly larger than the RGHR in 10 and 6 hour photoperiod treatments, and the RGHR in the 10 hour treatment was significantly larger than in the 6 hour photoperiod.

Table 4.12. Analysis of variance of balsam poplar relative height growth rate for 5 clones per provenance from replications two and three in Experiment 2.

SOURCE OF VARIATION	S. S.	D.F.	M. S.	F-RATIO	ERROR TERM
Replication	50.5	1	50.50		
First Restriction Error	N.A.	0	N.A.	N.A.	
Light	3.1	3	1.03	14.7 **	Quasi-F ratio
Rep. x Light	0.3	3	0.10		
Second Restriction Error	N.A.	0	N.A.	N.A.	
Provenance	1.0	4	0.25	2.0 ns	Clone within Provenace
Rep. x Provenance	0.4	4	0.10	1.0 ns	Rep x Clone w Prov.
Light x Provenance	0.5	12	0.04	0.9 ns	Light x Clone w Prov.
Rep x Light x Provenance	0.8	12	0.07	1.7 ns	Rep x Light x Clonew P
Clone within Provenance	2.5	20	0.12	1.2 ns	Rep x Clone w Prov.
Rep. x Clone w Provenance	2.1	20	0.10		
Light x Clone w Provenance	2.8	60	0.05	1.2 ns	Rep x Light x Clonew P
Rep x Light x Clone w Prov.	2.4	60	0.04		
Ramet within ($\varepsilon_{(ijkl)m}$)	N.A.	0	N.A.		

** = significant at α=0.01 n.s. = not significant

Days Until Bud Set

The number of days from the start of photoperiod treatments to the ocular detection of bud set was recorded for all ramets. Bud set did not occur under the 18 hour photoperiod in any of the three replications. Therefore, data from only three photoperiods (6, 10 and 14 hours) were examined. However, clones from Rhinelander, Wisconsin did not set bud in the 14 hour light treatment. The number of days until bud set for each clone appear in Appendix VI. The average number of days until bud set for each provenance in each of the three photoperiod treatments, based on replications two and three, is shown in Table 4.12. The average bud set times for provenances within each light treatment appear to correspond with the latitude of each provenance. In all three photoperiod treatments northern provenances set bud earlier than southern provenances. In addition, there appears to be little difference between the bud set times in the two short day treatments (6 hour and 10 hours) for each provenance.

The percentage of clones within a provenance that set bud under each of the three photoperiod treatments is included in Table 4.12. Because Rhinelander, Wisconsin clones did not set bud under the 14 hour light treatment, and due to the limited number of clones from Thunder Bay and Pickle Lake provenances that set bud in the 14 hour photoperiod, an ANOVA of bud set time was not performed. Within the 14 hour light treatment, the percentage of clones which set bud within each provenance follows a latitudinal gradient, with the largest percent bud set occurring in Fort Severn material. Fewer clones set bud with decreasing latitude, with no clones setting bud in the Rhinelander, Wisconsin provenance.

Table 4.11. The average number of days until bud set, and the percentage of clones that set bud for balsam poplar provenances in replications two and three in Experiment 2.

NUMBER OF DAYS UNTIL BUDSET (% of Clones that set bud)

LIGHT	Rhinelander	Thunder Bay	Pickle Lake	Bearskin L.	Fort Severn
6 hr	27 (100)	24 (100)	22 (100)	20 (100)	17 (100)
10 hr	29 (75)	25 (100)	22 (100)	20 (100)	16 (100)
14 hr	no bud set (0)	39 (5)	32 (5)	29 (60)	23 (93)
18 hr	n.b.s. (0)	n.b.s. (0)	n.b.s. (0)	n.b.s. (0)	n.b.s. (0)

EXPERIMENT 3: TAMARACK ROOTED CUTTINGS

Average height growth for each provenance, based on weekly measurements, was plotted by light treatment (Figures 3.8). The growth curves show similar patterns as exhibited in Experiment 1 (Figure 4.1). There appears to be an effect on height growth due to light treatments, although a provenance effect is not apparent. The initial height differences among provenances seen in the growth curves may reflect the rootability of the various provenances. Cuttings taken from North Bay seedlings were generally more difficult to root than other provenances, having high mortality and poor growth during the first season. Height growth for each rooted cutting (i.e.ramet) is given in Appendix VIII.

During light treatments many of the ramets grew slowly and exhibited plagiotrophic growth. Within the short day photoperiod treatments (6 and 10 hours) several ramets contracted *Botrytis* blight (*Botrytis cinerea* Pers.) due to the cool, and dark conditions which prevailed in the short day treatments. Infected ramets were eliminated from the experiment. The 14 hour light treatment was also eliminated from the experiment due to a mechanical failure in the growth chamber. The combination of the generally poor growth, mortality due to botrytus infection, and the elimination of the 14 hour light treatment prevented any statistical analysis of this experiment.

It is of interest to note that what appeared to be plagiotrophic growth exhibited in some of the second year rooted cuttings has not been observed in other cuttings taken from the same ortets used in provenance trials at Lakehead University. Plagiotrophic growth has been reported in tamarack cuttings taken from physiologically mature material (Cook and Frommer, 1969). The branch-like growth pattern (generally horizontal stem with upswung apex) in second year ramets may have been the result of snow and ice loading during outdoor overwintering. The cuttings were initially produced for use in light testing during their first season, but they were not adequately developed by late July/early August, so testing was put off until the following season. Perhaps the ramets were not fully hardened in time for winter, and suffered stem form damage from snow and ice loads.

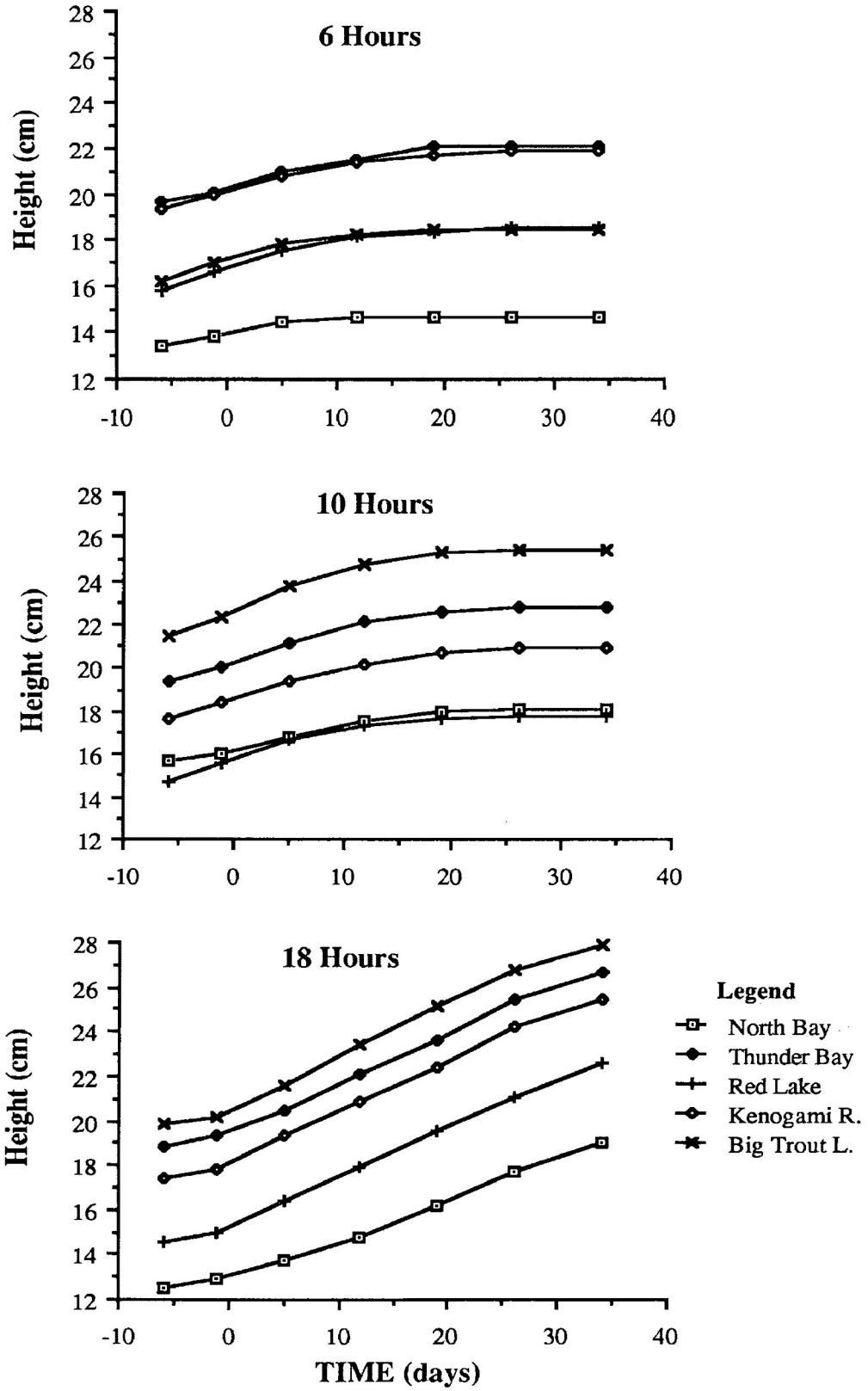

Figure 4.8. Average height growth of two year old rooted-cuttings from tamarack provenances grown under 6, 10, and 18 hour photoperiods in Experiment 3.

5. DISCUSSION

The major findings from Experiments 1 and 2 indicate 1) that balsam poplar provenances have a faster rate of apical growth cessation with increasing latitude, 2) tamarack and balsam poplar differ in their patterns of variation in the rate of apical growth cessation, and 3) apical bud axial primordia production in tamarack seedlings was greater under a 10 hour photoperiod than a six hour photoperiod.

VARIATION IN THE RATE OF APICAL GROWTH CESSATION

Balsam Poplar

The rate at which balsam poplar clones respond to short photoperiods, as well as the critical day length (Pauley and Perry, 1954), differ among northern Ontario provenances. Northern sources stop height growth at longer photoperiods and at a faster rate than southern sources of balsam poplar. Habjørg (1972) tested *Betula pubescens* Ehrh. seedlings from a wide latitudinal range (14°) in Scandinavia in a detailed factorial (light and temperature factors) controlled environment experiment. He reported clinal variation among populations in the critical daylength and presented data indicating faster rates of growth cessation by northern than southern populations. Habjørg (1978) studied photoperiodic variation in 10 different Scandinavian trees and shrubs (*Acer platanoides* L., *Alnus incana* (L) Moench., *Betula verrucosa* Ehrh., *Corylus avellana* L., *Hippophae rhamnoides* L., *Myricaria germanica* (L.) Desv., *Picea abies* L., *Salix caprea* L., *Sorbus aucuparia* L., and *Ulmus glabra* Huds.) ranging in latitude from 56° N to 70° N. Seedlings of each species were grown in greenhouses under six photoperiods (12, 14, 16, 18, 20, 24) and a 18°/13° C day/night temperature regime. Habjørg (1978) found that the critical photoperiod varied from different latitudes, but that it was almost the same for different species from the same latitude. In short photoperiods (e.g. 12 and 14 hours) height growth and dry weight of *Alnus incana* (L) Moench., *Betula verrucosa* Ehrh., *Corylus avellana* L., *Hippophae rhamnoides* L., *Salix caprea* L., and *Ulmus glabra* Huds.were consistently greater in southern than northern sources. The rate of growth cessation increased with increasing latitude, as was found in northern Ontario balsam poplar. Although *Picea abies* L. was among the species tested, the results presented did not indicate variation in the rate of

growth cessation among populations. However, significant variation in the critical photoperiod among populations was detected.

The rate of change in the daily photoperiod during the summer months increases with an increase in latitude (Vince-Prue, 1975) (Figure 5.1 and 5.2). Holmes and Smith (1977), in their work on the function of phytochrome in the natural environment, suggested that the trigger for timing is related to the rate of change in the phytochrome photoequilibrium. Salisbury (1983), in a paper on plant adaptations to the light environment, presented that at northern latitudes the rate of daylength change during spring and fall is rapid, which should facilitate plant responses to photoperiod. This also suggests that plants detect the change in daylength. It appears that for balsam poplar the rate of apical growth cessation is synchronized with the rate of daylength change in the natural environment. The frost-free growing season is generally shorter with increasing latitude, with late summer frosts occurring earlier at northern than southern locations. Therefore, the transition period from warm growing conditions to cold and possibly damaging conditions would be shorter in northern than in southern sites. Bud set may have to occur at a faster rate in northern populations than southern populations in response to their more rapidly changing local environment (i.e. the rate of induction has adapted to the rate of environmental change). Northern conditions would likely select for clones that could maximize the effective growing period by having apical growth cessation synchronized with the more rapidly changing environment. Due to the more rapidly changing photoperiodic condition and the shorter period between growing conditions and damaging conditions with increasing latitude, balsam poplar has apparently developed a clinal response in the critical daylength and the rate of growth cessation.

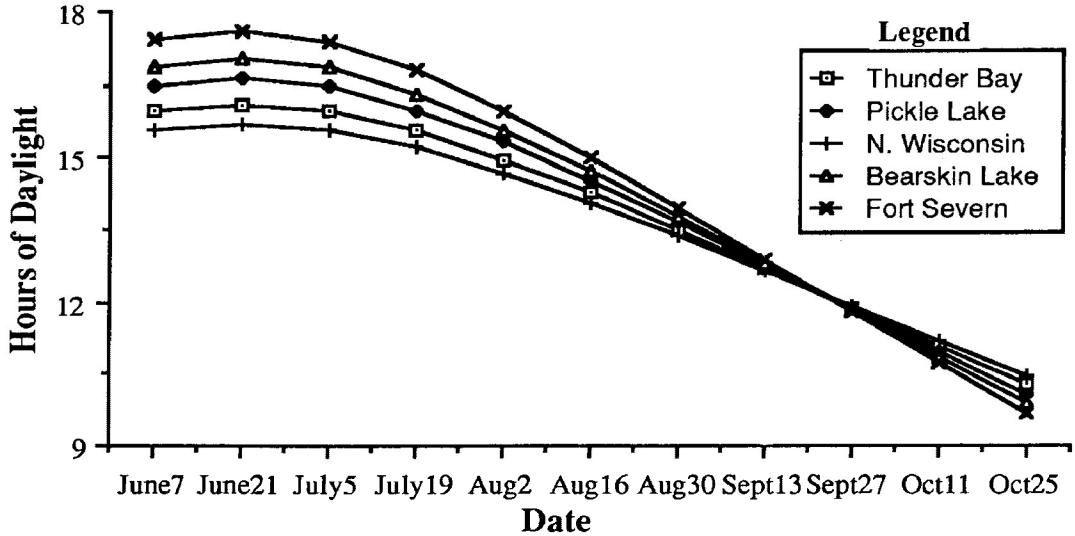

Figure 5.1. Length of daylight (between sunrise and sunset) near balsam poplar collection sites for June 7 to October 25, 1988. Data supplied by Environment Canada.

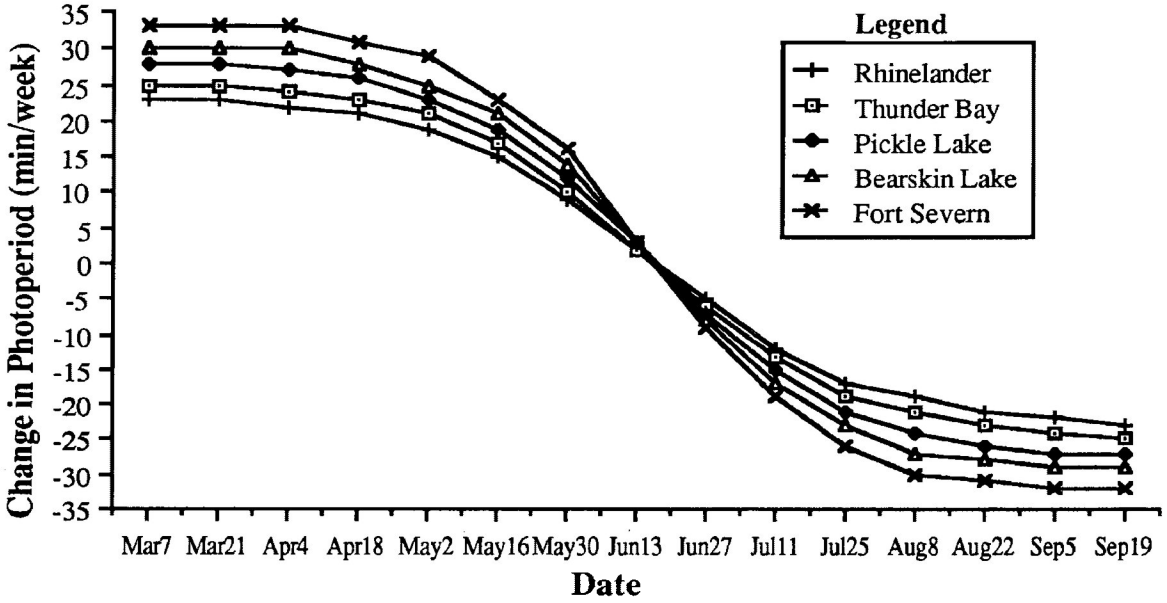

Figure 5.2. The change in photoperiod (between sunrise and sunset) in minutes per week near balsam poplar collection sites from March to September, 1988. Data supplied by Environment Canada.

The clinal pattern of bud set times in balsam poplar may also be the result of a light by temperature interaction. Under constant temperature conditions the critical photoperiod of a population is only slightly, if at all, affected by temperatures within a wide range (Heide, 1974; Junttila, 1980). However, fluctuating day/night temperatures with low night temperatures of approximately 10° C or less have been shown to interact with photoperiod (Perry, 1962; Heide, 1974; Junttila, 1980). Of great interest to this discussion is the apparent increased sensitivity to fluctuating temperatures by northern sources (e.g. *Acer rubrum*, Perry, 1962;*Salix pentandra*, and *Betula pubescens*, Junttila, 1980). The northern source of *Acer rubrum* L. tested by Perry (1962) stopped height growth and set bud under long days with night temperatures at 10° C and day temperatures 23° C while the southern source maintained constant growth. It may be possible that northern sources are adapted to higher critical temperatures than southern populations. Therefore, the observed clinal pattern in balsam poplar may in part be due to the increasing sensitivity of northern populations to fluctuating temperature regimes and its interaction with photoperiod. This hypothesis could be tested by using constant and variable temperature regimes with similar photoperiods. However, since all balsam poplar provenances continued to grow under the same fluctuating temperature regime and an 18 hour photoperiod, it would appear that the fluctuating temperature regime used (i.e. 20°/10° C) was not an over riding factor in causing growth cessation. Although fluctuating temperature regimes have been shown to induce apical growth cessation, they would appear to be of limited ecological importance in

initiating growth cessation when compared to the large role of photoperiod. Low temperatures may act as an additional safety control for inducing growth cessation (Heide, 1974). Although the fluctuating temperature regime used in the present study did not have an overriding effect on the induction of growth cessation, further experiments with fluctuating day/night temperatures and various provenances are suggested in order to obtain a better understanding of their interactions.

Tamarack

Balsam poplar provenances displayed clinal variation in the rate of growth cessation and in the critical daylength for inducing dormancy, whereas tamarack provenances did not vary in the rate of growth cessation, but did display clinal variation in the critical daylength for inducing dormancy. The latitudinal range among tamarack provenances was about half of that among balsam poplar provenances (5° range in latitude among tamarack sources and 10° range in latitude among balsam poplar sources). However, significant differences in height growth and bud set times could be detected among three balsam poplar sources (Rhinelander 45-46° N, Thunder Bay 48-49° N, and Pickle Lake 50-51° N) with similar latitudes as tamarack provenances (North Bay 46° 25' N, Thunder Bay 48° 25' N, and Red Lake 51° 50' N). Therefore, differences in height growth and bud set patterns may be attributed to species differences, and not to the lack of latitudinal sampling.

Tamarack provenances have different critical daylengths for intitating terminal bud formation, as seen in the 14 hour photoperiod, but apical bud development occurs at the same rate among provenances, as seen in the two short photoperiod treatments (i.e. 6 and 10 hours). It appears that adaptive differentiation has occurred in the critical daylength for growth cessation among northern Ontario tamarack provenances (Vaartaja, 1959), but not in the rate of growth cessation.

Hawkins and Draper (1988), used 'dynamic' photoperiods (i.e. photoperiods which parallel the natural ephemeris of the area) on first year seedlings from three white spruce (*Picea glauca* (Moench) Voss) seed sources (ranging from 49° 20' N to 52° 15' N), two Engelmann spruce (*Picea engelmannii* (Bong) Carr.) seed sources (54° 20' N and 55° 45' N) and one *Picea lutzii* Little seed source. They measured numerous seedling attributes, including serial height increment, shoot and root masses, and reported that treatment responses were similar for all seedlots. This suggests that the rate of growth cessation was similar among all sources within the species tested. They also suggested that conifer seedlings may respond to the rate of change in day length to induce growth cessation.

Heide (1974) showed that Norway spruce displays clinal variation among populations based on variation in the critical photoperiod for inducing bud set, but little or no variation in the rate of response to short photoperiods; the same as was found in tamarack. He studied in detail growth as affected by photoperiod and temperature in first year *Pices abies* seedlings from different latitudinal and altitudinal origin. Seedling sources ranged in latitude from 58° 30' N to 64° N. In all sources, apical growth cessation and terminal bud formation occurred within 2 weeks after exposure to a range of short daylengths and temperatures.

Rehfeldt (1970) studied height growth and bud set times among tamarack seedlings grown from seed collected from 30 stands from throughout Wisconsin. He divided Wisconsin into three large geographic areas from which he obtained samples from tamarack stands. Seedlings were grown in a nursery and bud set data was obtained in the second growing season. Bud set times among Wisconsin tamarack sources displayed a clinal pattern in which northern sources set bud significantly earlier than southern sources. The present results from the 14 hour photoperiod, where northern provenances set bud earlier than southern provenances, are consistent with Rehfeldt's (1970) findings on bud set times among Wisconsin tamarack sources.

Joyce (1988) found significant population differentiation in cold hardiness among northern Ontario tamarack populations that was most strongly correlated to latitude. The variation detected in bud set times within the 14 hour photoperiod among provenances in the present study also strongly relates to the latitude of each source. Joyce (1988) suggested that the high level of population differentiation displayed among the 66 populations studied indicates that tamarack may be physiologically specialized to specific environments. The limited provenance sampling and number of photoperiods used in the present study did not allow for as detailed an evaluation of adaptive differentiation as was observed by Joyce (1988).

Variation Between Species

Several northern hardwood tree and shrub species appear to respond to photoperiod changes with faster rates of growth cessation at more northern latitudes. In contrast, the few coniferous tree species studied (e.g. tamarack, Norway spruce (Heide,1974; Habjørg, 1978), white spruce and Engelmann spruce (Hawkins and Draper, 1988)) do not display variation in the rate of growth cessation among provenances. Habjørg (1978) showed that different species from the same latitude (i.e. photoperiod environment) have nearly the same critical photoperiods. Although coniferous and hardwood species from the same areas

are exposed to the same natural light regimes and have simliar critical photoperiods (Habjørg, 1978), hardwood trees and shrubs (e.g. *Populus balsamifera* L., *Alnus incana* (L) Moench., *Betula verrucosa* Ehrh., *Corylus avellana* L., *Hippophae rhamnoides* L., *Salix caprea* L., and *Ulmus glabra* Huds.) have apparently developed a clinal pattern among populations in the rate of response to photoperiod as well as in the critical daylength. It is difficult to account for the differences between hardwood and coniferous tree and shrub species in the rate of response to the same light environment. Hardwood trees and shrubs may simply be more highly evolved than coniferous species. The perception of the photoperiodic response in woody plants relies on phytochrome (Downs, 1962) and resides mainly in the leaves of a plant (Vince-Prue, 1975). Further research into these, and other components of photoperiodic perception is needed to account for the differences between hardwood and coniferous tree and shrub species in their photoperiodic response.

RELATIVE HEIGHT GROWTH RATE

Balsam Poplar

Relative height growth rates (RGHR) were not significantly different among or within balsam poplar provenances. Schnekenburger and Farmer (1989), using the same Northern Ontario balsam poplar provenances, found no significant variation in relative growth among provenances, but significant clonal variation within provenances. In the present study five clones from each provenance were tested, with only one ramet per replication of the experiment. Schnekenburger and Farmer (1989) used six to seven clones, with 22 ramets per clone, from each provenance. The lack of significant clonal variation within sources found in the present study may be due to the limited sample size (i.e. number of clones and ramets per clone) used in the analysis.

Tamarack

The lack of significant within provenance variation in RGHR in the present study is difficult to explain. The low level of within provenance variation may be due to a small sample size (i.e. five families per provenance) used in the experiment. Joyce (1988) found high levels of variation in fall frost hardiness among northern Ontario tamarack populations. Rehfeldt (1982), using western larch (*Larix occidentalis* Nutt.), showed low levels of variation in growth potential, phenology, and hardiness characters among western

larch populations with high levels of within population varitation. There was significant variation in seedling height growth within tamarack provenances in the present study.

TAMARACK APICAL BUD PRIMORDIA PRODUCTION

The results from the primordia counts illustrate that gains may be made in bud development from determining an optimum short day photoperiod. Remphrey and Powell (1984), using tamarack saplings, reported that there is a close relationship (positive) between the number of preformed leaves per bud and shoot vigour in terms of the length of the resultant shoot that arises from the bud. Therefore, treatments which can be shown to increase preformed growth in tamarack seedlings should also increase resulting shoot growth in the following year. It would appear that the use of short day lengths between 10 and 14 hours would produce greater preformed needle production than photoperiods below 10 hours and result in greater shoot growth in the following season.

The use of increasingly shorter photoperiods did not bring about earlier induction of growth cessation. Although six and 10 hour short day treatments resulted in the cessation of height growth and the intiation of a terminal bud at the same time in all seedlings, axial primordia production was twice as high in the 10 hour treatment as in the six hour treatment. Pollard and Logan (1977), using first year black and white spruce seedlings that had bud scale intiation induced under an eight hour photoperiod, showed that photoperiods within the ranges encountered in natural conditions had little effect on total needle primordia initiation.They concluded that photoperiod does not effect the rate of needle initiation in either white or black spruce seedlings. Remphrey and Powell (1984) suggested that the rate of bud scale differentiation in tamarack buds is correlated with relative vigour of the parent shoot. RHGR and height growth were significantly greater in the 10 hour than six hour photoperiod. This indicates that seedlings were more vigorous under the 10 hour photoperiod than the 6 hour photoperiod. Therefore, differences in the number of primordia between short day treatments may be due to a faster rate of primordia initiation which is correlated to a faster rate of growth in the 10 hour treated seedlings.

MacDonald and Owens (1987a) found that the use of short days with first year Douglas-fir seedlings produced larger preformed shoots, and enhanced cold-hardiness over traditionally drought stress treated seedlings. However, few data are available to indicate that eight hours is the optimum short day treatment in terms of seedling growth and apical bud development. In many previous experiments with other conifer species an eight hour short day treatment has commonly been used to induce growth cessation (van den Driessche, 1970; Christensson, 1978; McCreary *et al.*, 1978; D'Aoust, 1981; Colombo *et*

al., 1982; Rosvall-Ahnebrink, 1982). For the tamarack provenances tested the optimum short day treatment may lie between 10 hours and 14 hours.

CONCLUSIONS

The results from apical growth cessation experiments using first-year tamarack seedlings and balsam poplar rooted cuttings from northern Ontario and northern Wisconsin provenances indicate:

1) Balsam poplar provenances display clinal variation in the rate of apical growth cessation. This pattern appears to be in response to more rapidly changing natural photoperiods with increasing latitude.

2) Balsam poplar provenances displayed clinal variation in the critical daylength for inducing apical growth cessation.

3) Tamarack provenances were significantly different in the critical daylength for inducing apical growth cessation, but did not vary in the rate of response to photoperiod.

4) Tamarack and balsam poplar differ in their patterns of variation in the rate of apical growth cessation.

5) Apical bud needle primordia production in first-year tamarack seedlings was twice as large under a 10 hour photoperiod than a six hour photoperiod despite apical bud initiation occurring at the same time.

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APPENDIX I

MEAN HEIGHT GROWTH (cm) AND COEFFICIENT OF VARIATION PERCENT OF TAMARACK FAMILIES BY PHOTOPERIOD AND REPLICATION IN EXPERIMENT 1.

			Replication One				Replication Two				Replication Three			
			Light (hours)				Light (hours)				Light (hours)			
Provenance	Family		6	10	14	18	6	10	14	18	6	10	14	18
North Bay	105	mean	2.0	3.8	-	9.3	1.0	2.2	9.0	12.2	1.3	3.2	11.6	13.4
		c. var	10.8	25.9	-	20.3	42.4	14.0	16.2	11.7	37.6	17.8	29.2	12.8
	203	mean	2.4	3.6	-	8.3	1.0	3.3	11.7	11.7	1.2	4.0	9.6	13.3
		c. var	23.3	12.7	-	73.4	24.4	17.3	16.0	16.5	39.2	11.2	22.5	7.0
	204	mean	1.7	2.9	-	11.8	0.7	1.0	6.4	10.4	1.2	2.5	13.6	12.4
		c. var	20.8	35.0	-	15.7	32.6	26.5	1.1	25.0	18.1	64.0	17.6	14.9
	205	mean	2.4	4.1	-	11.6	1.4	1.5	11.5	12.1	1.4	2.6	8.9	11.7
		c. var	32.4	10.5	-	17.9	38.7	30.0	9.9	19.6	42.6	45.5	34.4	7.4
	206	mean	2.8	4.9	-	11.5	1.7	1.8	11.0	8.6	1.3	3.9	12.1	11.0
		c. var	8.4	10.5	-	6.9	19.2	31.1	15.2	27.3	14.3	20.8	28.6	11.1
Thunder Bay	101	mean	1.8	2.6	-	9.6	1.1	1.4	7.8	12.7	0.8	3.1	7.2	9.1
		c. var	15.7	10.9	-	38.8	23.6	25.8	37.3	18.0	28.0	29.5	4.2	33.4
	201	mean	1.8	2.6	-	8.8	0.9	1.3	6.7	9.5	0.8	1.7	4.8	8.8
		c. var	28.3	21.8	-	2.4	41.8	27.1	38.5	11.0	6.9	17.3	58.1	50.8
	205	mean	1.7	2.8	-	7.6	1.4	1.9	7.4	9.5	1.2	2.6	8.1	10.6
		c. var	19.2	27.0	-	22.5	14.2	21.5	22.2	16.0	18.0	36.2	41.8	7.4
	207	mean	2.0	2.7	-	10.3	1.4	1.7	9.7	10.8	0.9	3.3	3.3	10.7
		c. var	24.2	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	209	mean	2.1	3.4	-	8.6	1.6	2.3	9.3	13.0	1.6	2.8	11.4	13.7
		c. var	19.4	7.7	-	35.3	7.8	13.8	13	12.4	15.2	36.7	32.5	10.7
Fort Frances	102	mean	1.8	3.7	-	11.9	1.2	1.8	8.6	10.9	1.1	3.0	8.4	11.6
		c. var	41.8	12.9	-	27.3	20.7	38.9	18.0	15.3	48.7	34.8	45.9	11.9
	111	mean	2.3	2.9	-	9.0	1.0	1.4	7.2	12.6	1.0	2.6	9.2	11.4
		c. var	17.3	5.3	-	16.6	16.5	33.5	36.3	23.2	9.5	7.2	17.0	18.7
	113	mean	2.2	2.8	-	10.4	1.2	1.5	7.5	10.3	1.0	2.1	8.4	11.2
		c. var	20.6	33.7	-	5.3	45.9	38.1	36.5	17.5	5.1	20.1	17.1	22.2
	114	mean	2.4	4.5	-	12.5	1.6	2.8	9.9	13.9	1.3	3.2	7.6	13.9
		c. var	27.8	26.0	-	11.3	16.7	15.4	25.8	19.0	30.4	12.8	36.2	11.5
	309	mean	2.3	2.7	-	10.2	1.2	1.9	8.2	10.5	1.0	2.6	9.1	10.8
		c. var	7.5	18.8	-	12.0	13.9	33.3	15.6	26.6	36.8	8.4	37.1	11.5
Red Lake	112	mean	1.7	2.5	-	8.8	1.6	1.6	8.1	12.6	1.4	2.2	6.0	11.1
		c. var	25.4	25.4	-	16.0	21.5	41.6	54.5	26.9	43.4	43.7	62.5	29.5
	305	mean	2.7	3.6	-	9.7	1.2	2.2	8.9	6.9	1.0	2.0	8.4	11.2
		c. var	6.4	24.3	-	3.5	28.1	20.0	20.4	11.9	43.2	70.0	41.4	24.5
	306	mean	1.6	2.7	-	9.1	1.9	2.0	6.6	11.2	1.2	2.4	8.4	13.1
		c. var	20.1	17.4	-	10.9	18.2	22.7	12.4	23.3	39.5	42.5	24.5	13.4
	307	mean	2.5	3.4	-	12.7	1.5	1.7	5.3	10.7	1.3	2.0	5.6	10.5
		c. var	19.6	24.2	-	10.1	20.3	53.4	18.3	20.4	20.8	49.2	3.6	22.5
	308	mean	2.3	3.7	-	11.6	1.2	1.6	6.5	10.1	1.2	1.9	9.7	12.0
		c. var	15.5	21.3	-	29.8	21.5	15.4	23.4	18.0	22.4	22.7	21.2	14.9

APPENDIX II

HEIGHT GROWTH (cm) OF BALSAM POPLAR CLONES BY PHOTOPERIOD AND REPLICATION IN EXPERIMENT 2.

		Replication 1				Replication 2				Replication 3			
		Light (hours)				Light (hours)				Light (hours)			
Provenance	Clone	6	10	14	18	6	10	14	18	6	10	14	18
N. Wisconsin	203	11.7	13.7	-	15.9	18.5	21.2	23.0	28.0	10.2	10.5	25.0	16.8
	207		11.8	-	15.0	15.3	24.8	25.8	30.0	9.8	13.8	25.4	17.1
	213	8.3	14.5	-	15.9	17.0	20.3	24.6	25.6	9.3	16.5	27.3	17.6
	216	8.0	10.8	-	18.6	9.8	21.5	24.1	27.2	11.3	14.0	20.7	16.3
	217	7.5	11.1	-	16.9	13.6	15.7	25.2	26.2	3.8	6.7	17.9	16.8
	220	10.9	9.7	-	18.4	12.3	20.7	27.5	29.9	9.4	10.1	23.5	21.0
	223	8.3	14.2	-	14.8	8.2	19.9	12.8	19.2	8.4	13.5	23.1	15.1
	227	10.6	11.6	-	19.3	14.4	26.0	21.0	30.0	5.9	11.5	21.6	19.0
	233	11.3	12.6	-	17.8	17.1	29.0	15.1	33.1	3.9	13.2	24.0	26.2
	238	7.7	15.0	-	18.9	19.5	26.3	34.9	33.8	13.2	13.5	29.8	22.9
Thunder Bay	3	7.1	12.7	-	13.1	10.5	15.2	24.7	29.2	3.6	11.2	19.7	21.7
	10	3.3	8.3	-	17.4	12.2	21.8	25.3	29.7	4.2	4.9	18.7	12.7
	16	9.2	8.9	-	13.6	17.0	21.1	29.2	21.5	11.6	6.0	21.1	21.7
	20	9.8	11.4	-	13.9	14.6	18.6	23.6	27.0	10.1	11.8	21.3	18.5
	28	11.2	13.5	-	18.5	12.9	11.9	28.1	28.5	11.4	12.0	12.8	16.0
	30	8.8	10.8	-	17.7		19.3	18.4	20.3	4.2	8.1	16.6	16.8
	32	10.1	11.4	-	17.7	13.5	21.4	31.0	29.5	10.1	10.6	16.5	
	41	6.0	11.1	-	16.5	7.5	11.5	17.2	21.1	7.8	11.4	19.1	16.5
	45	8.7	9.3	-	15.5	12.0	15.1	23.5	28.9	5.5	5.1	19.0	22.0
	48	6.1	11.1	-	17.8	10.6	19.8	24.3	26.5	2.4	4.4	25.0	21.7
Pickle Lake	102	4.6	9.2	-	12.5	8.7	11.3	14.7	21.2	5.0	9.5	17.7	20.3
	107	6.3	9.1	-	14.4	14.4	17.8	26.4	29.0	6.8	2.3	26.1	
	108	8.4	9.8	-	18.7	13.6	16.4	23.3	27.7	5.3	10.8	15.9	16.9
	114	4.4	12.8	-	14.5	7.0	16.3	24.0	18.0	4.6	9.0	25.5	22.8
	119	6.8	7.9	-	21.3	13.5	18.5	9.7	33.7	1.9	7.8	31.2	26.8
	127	4.7	9.1	-	17.7	7.5	10.2	13.4	28.6				
	136	5.2	4.3	-	14.8	11.0	14.9	23.9	25.9	2.4	3.3	21.4	20.0
	138	7.9	9.3	-	18.8	12.1	18.4	21.5	26.4	6.3	9.4	23.6	20.9
	144	6.1	7.6	-	14.0	13.5	15.3	25.7	25.0	7.6	5.9	23.0	17.8
	152	8.0	9.1	-	19.0	15.0	14.6	27.0	25.0	5.0	8.6	25.0	18.3
Bearskin Lake	303	2.5	5.8	-		6.4	8.8	16.7	27.4	7.1	0.7		
	306	6.0	6.7	-	16.6	8.0	9.8	17.2	24.5	4.3	9.5	15.6	16.4
	307	2.3	4.9	-	15.2	10.1	10.6	14.0	26.0	6.6	5.8	3.3	12.7
	311	6.1	8.4	-	20.8	10.6	17.1	20.5	34.1	4.9	12.0	16.4	23.7
	314	3.6	5.7	-	11.1	10.9	15.7	18.1	33.3	5.9	1.7	14.9	24.3
	315	6.4	8.7	-	8.5	12.1	17.8	22.8	27.9	2.1	4.7	15.7	12.8
	318	2.4	7.0	-	10.6	13.1	19.0	24.4	32.2	6.8	4.9		26.4
	319	7.6	7.1	-	19.1	13.9	22.1	26.8	31.9		10.0	25.0	32.1
	323	6.8	6.7	-	24.0	7.9	12.3	17.9	31.7	3.7	4.9		21.4
	346	6.2	6.7	-	16.2	5.3	11.6	13.4	27.4	8.1	10.3	7.3	
Fort Severn	402	2.8	1.6	-	15.4	9.4	14.9	13.2	27.8	3.5	2.1	3.3	16.0
	409	0.6	0.8	-	8.6	8.8	4.8	16.3	32.5	6.3	1.3		
	410	2.3	2.9	-		7.2	7.5	6.7	26.9				
	423	3.5	3.9	-	6.4	6.6	10.1	12.0	24.7	5.7	5.2	5.9	24.4
	428	2.4	2.0	-	6.3	6.4	9.3	16.4	30.5	1.9	5.4	10.4	
	437	2.3	6.0	-	16.0	9.7	11.2	18.3	16.8	3.4	6.0	19.4	25.6
	444	2.4	1.9	-	16.7	8.8	11.0	15.3	18.1	1.2	1.0	7.0	16.2
	445	4.9	2.0	-	16.1	9.9			19.4				
	446	1.1	1.9	-	12.0	3.6	11.2		17.5				
	448	2.4	2.4	-	4.7	8.0	9.5						

APPENDIX III

MEAN RELATIVE HEIGHT GROWTH RATE (cm/cm/day) OF TAMARACK FAMILIES BY PHOTOPERIOD AND REPLICATION IN EXPERIMENT 1

Provenance	Family	Replication 1 Photoperiod (hours) 6	10	14	18	Replication 2 Photoperiod (hours) 6	10	14	18	Replication 3 Photoperiod (hours) 6	10	14	18
North Bay	105	0.009	0.016	-	0.014	0.006	0.016	0.016	0.023	0.008	0.015	0.017	0.018
	203	0.009	0.015	-	0.013	0.007	0.016	0.019	0.016	0.007	0.016	0.017	0.022
	204	0.012	0.018	-	0.022	0.007	0.013	0.017	0.022	0.005	0.013	0.020	0.020
	205	0.009	0.017	-	0.016	0.008	0.011	0.019	0.022	0.008	0.013	0.018	0.019
	206	0.012	0.016	-	0.018	0.011	0.014	0.023	0.017	0.008	0.014	0.023	0.019
Thunder Bay	101	0.008	0.013	-	0.021	0.009	0.012	0.017	0.020	0.009	0.016	0.017	0.023
	201	0.016	0.022	-	0.022	0.008	0.011	0.021	0.024	0.007	0.013	0.015	0.017
	205	0.010	0.021	-	0.022	0.010	0.017	0.018	0.026	0.008	0.013	0.020	0.021
	207	0.012	0.025	-	0.032	0.008	0.013	0.022	0.022	0.005	0.014	0.010	0.015
	209	0.013	0.023	-	0.020	0.009	0.015	0.017	0.022	0.009	0.013	0.020	0.021
Fort Frances	102	0.011	0.015	-	0.018	0.007	0.014	0.024	0.022	0.011	0.015	0.018	0.023
	111	0.010	0.012	-	0.018	0.007	0.014	0.019	0.018	0.007	0.015	0.018	0.022
	113	0.009	0.016	-	0.017	0.010	0.011	0.020	0.019	0.007	0.013	0.019	0.021
	114	0.012	0.015	-	0.015	0.010	0.014	0.019	0.019	0.008	0.016	0.018	0.021
	309	0.012	0.014	-	0.017	0.011	0.019	0.023	0.021	0.008	0.016	0.022	0.021
Red Lake	112	0.016	0.024	-	0.031	0.012	0.017	0.023	0.025	0.008	0.011	0.020	0.025
	305	0.010	0.014	-	0.014	0.010	0.017	0.020	0.025	0.007	0.009	0.019	0.020
	306	0.011	0.018	-	0.028	0.013	0.015	0.015	0.024	0.007	0.012	0.018	0.019
	307	0.011	0.017	-	0.018	0.010	0.014	0.022	0.015	0.010	0.014	0.017	0.021
	308	0.012	0.016	-	0.019	0.009	0.014	0.021	0.021	0.011	0.010	0.019	0.023

APPENDIX IV

RELATIVE HEIGHT GROWTH RATE (cm/cm/day) OF BALSAM POPLAR CLONES BY PHOTOPERIOD AND REPLICATION IN EXPERIMENT 2.

		Replication 1				Replication 2				Replication 3			
		Light (hours)				Light (hours)				Light (hours)			
Provenance	Clone	6	10	14	18	6	10	14	18	6	10	14	18
N. Wisconsin	203	0.027	0.037	-	0.025	0.058	0.074	0.071	0.068	0.023	0.039	0.024	0.032
	207		0.023	-	0.026	0.048	0.066	0.067	0.061	0.025	0.024	0.030	0.025
	213	0.030	0.031	-	0.031	0.048	0.056	0.082	0.076	0.023	0.024	0.022	0.025
	216	0.024	0.019	-	0.035	0.046	0.058	0.073	0.069	0.026	0.023	0.027	0.027
	217	0.019	0.026	-	0.030	0.051	0.060	0.082	0.069	0.013	0.031	0.018	0.017
	220	0.029	0.025	-	0.036	0.072	0.058	0.065	0.063	0.022	0.025	0.029	0.033
	223	0.026	0.037	-	0.021	0.061	0.060	0.071	0.057	0.027	0.025	0.026	0.023
	227	0.037	0.027	-	0.043	0.051	0.075	0.097	0.089	0.017	0.021	0.026	0.024
	233	0.025	0.026	-	0.027	0.055	0.063	0.057	0.088	0.018	0.026	0.024	0.033
	238	0.029	0.027	-	0.025	0.066	0.069	0.070	0.084	0.022	0.026	0.037	0.024
Thunder Bay	3	0.024	0.027	-	0.072	0.047	0.059	0.056	0.067	0.015	0.035	0.027	0.034
	10	0.016	0.024	-	0.026	0.065	0.072	0.078	0.080	0.021	0.019	0.019	0.017
	16	0.036	0.029	-	0.021	0.080	0.058	0.076	0.091	0.024	0.027	0.025	0.026
	20	0.023	0.029	-	0.022	0.073	0.073	0.068	0.080	0.025	0.028	0.024	0.023
	28	0.031	0.052	-	0.031	0.087	0.087	0.097	0.118	0.023	0.040	0.023	0.021
	30	0.031	0.037	-	0.035		0.071	0.068	0.064	0.014	0.044	0.021	0.034
	32	0.022	0.028	-	0.036	0.055	0.067	0.081	0.066	0.021	0.028	0.022	
	41	0.026	0.058	-	0.033	0.073	0.085	0.083	0.090	0.022	0.032	0.027	0.033
	45	0.032	0.030	-	0.026	0.060	0.064	0.077	0.076	0.022	0.020	0.027	0.029
	48	0.020	0.027	-	0.023	0.063	0.051	0.067	0.068	0.016	0.021	0.029	0.025
Pickle Lake	102	0.022	0.038	-	0.021	0.048	0.080	0.084	0.071	0.022	0.031	0.022	0.021
	107	0.017	0.033	-	0.009	0.043	0.056	0.050	0.051	0.018	0.010	0.027	
	108	0.024	0.029	-	0.028	0.040	0.068	0.058	0.065	0.019	0.031	0.018	0.026
	114	0.025	0.042	-	0.044	0.044	0.101	0.088	0.108	0.017	0.035	0.031	0.033
	119	0.023	0.025	-	0.030	0.058	0.065	0.052	0.081	0.011	0.025	0.033	0.036
	127	0.021	0.041	-	0.029	0.086	0.055	0.124	0.081				
	136	0.021	0.022	-	0.023	0.048	0.070	0.090	0.078	0.016	0.021	0.025	0.027
	138	0.023	0.035	-	0.029	0.084	0.076	0.082	0.059	0.024	0.027	0.029	0.030
	144	0.028	0.024	-	0.017	0.062	0.068	0.086	0.084	0.015	0.027	0.029	0.027
	152	0.023	0.032	-	0.026	0.055	0.046	0.067	0.059	0.015	0.029	0.038	0.020
Bearskin Lake	303	0.018	0.024	-		0.049	0.057	0.072	0.057	0.048	0.004		
	306	0.026	0.038	-	0.023	0.047	0.054	0.074	0.062	0.015	0.027	0.021	0.029
	307	0.011	0.020	-	0.015	0.050	0.050	0.055	0.045	0.051	0.040	0.011	0.047
	311	0.026	0.030	-	0.027	0.045	0.062	0.055	0.072	0.018	0.029	0.029	0.037
	314	0.015	0.019	-	0.015	0.043	0.071	0.051	0.053	0.027	0.010	0.018	0.024
	315	0.016	0.025	-	0.011	0.047	0.054	0.068	0.052	0.006	0.021	0.029	0.015
	318	0.012	0.023	-	0.022	0.046	0.064	0.071	0.053	0.024	0.022		0.033
	319	0.023	0.018	-	0.020	0.057	0.062	0.062	0.059		0.025	0.024	0.034
	323	0.034	0.028	-	0.119	0.064	0.078	0.083	0.069	0.018	0.022		0.044
	346	0.018	0.034	-	0.024	0.038	0.067	0.077	0.071	0.024	0.036	0.029	
Fort Severn	402	0.029	0.006	-	0.051	0.054	0.069	0.062	0.071	0.018	0.007	0.007	0.010
	409	0.002	0.003	-	0.002	0.041	0.020	0.087	0.080	0.020	0.003		
	410	0.009	0.028	-		0.068	0.061	0.022	0.079				
	423	0.012	0.024	-	0.004	0.052	0.080	0.100	0.110	0.018	0.029	0.022	0.041
	428	0.013	0.008	-	0.008	0.046	0.067	0.086	0.077	0.008	0.017	0.017	
	437	0.011	0.025	-	0.014	0.026	0.062	0.093	0.030	0.021	0.027	0.031	0.044
	444	0.015	0.011	-	0.008	0.036	0.060	0.062	0.073			0.018	0.033
	445	0.020	0.002	-	0.003	0.037			0.095				
	446	0.003	0.006	-	0.006	0.074	0.057		0.052				
	448	0.007	0.013	-	0.068	0.066	0.088						

APPENDIX V

DAYS UNTIL BUD SET FOR TAMARACK SEEDLINGS BY PHOTOPERIOD IN EACH REPLICATION OF EXPERIMENT 1

			PHOTOPERIOD											
			6 Hours				10 Hours				14 Hours			
			Seedling				Seedling				Seedling			
Replication	Provenance	Family	a	b	c	d	a	b	c	d	a	b	c	d
1	North Bay	105	20	20	20	20	20	20	20	20	-	-	-	-
		203	20	20	20	20	20	20	20	n.s.	-	-	-	-
		204	20	20	20	20	20	20	20	20	-	-	-	-
		205	20	20	20	20	20	20	20	20	-	-	-	-
		206	20	n.s.	20	20	20	n.s.	20	n.s.	-	-	-	-
	Thunder Bay	101	20	n.s.	20	n.s.	20	n.s.	20	n.s.	-	-	-	-
		201	20	n.s.	20	n.s.	20	n.s.	20	n.s.	-	-	-	-
		205	20	20	20	20	20	20	20	20	-	-	-	-
		207	20	n.s.	20	n.s.	20	n.s.	n.s.	n.s.	-	-	-	-
		209	20	20	20	20	20	20	20	20	-	-	-	-
	Fort Frances	102	20	20	20	20	20	n.s.	20	20	-	-	-	-
		111	20	20	20	20	20	n.s.	20	20	-	-	-	-
		113	20	20	20	20	20	20	20	20	-	-	-	-
		114	20	20	20	20	20	20	20	20	-	-	-	-
		309	20	20	20	n.s.	20	20	n.s.	20	-	-	-	-
	Red Lake	112	20	20	20	20	20	20	20	20	-	-	-	-
		305	20	20	20	20	20	20	20	20	-	-	-	-
		306	20	20	20	20	20	20	20	20	-	-	-	-
		307	20	20	20	20	20	20	20	20	-	-	-	-
		308	20	20	20	20	20	20	20	20	-	-	-	-
2	North Bay	105	17	17	17	17	17	17	17	17	41	41	26	29
		203	17	17	17	17	17	17	17	17	32	32	41	41
		204	17	17	n.s.	n.s.	17	n.s.	17	17	35	32	n.s.	n.s.
		205	17	17	17	17	17	17	17	17	41	32	35	35
		206	17	17	17	17	17	17	17	17	23	32	26	32
	Thunder Bay	101	17	17	17	n.s.	17	17	17	n.s.	35	38	38	32
		201	17	17	17	17	17	17	17	17	23	29	26	23
		205	17	17	17	17	17	17	17	17	29	26	26	26
		207	17	n.s.	n.s.	n.s.	17	n.s.	n.s.	n.s.	38	n.s.	n.s.	n.s.
		209	17	17	17	17	17	17	17	17	32	29	26	32
	Fort Frances	102	20	20	20	20	17	17	17	17	23	38	35	35
		111	17	17	17	17	17	17	17	17	23	26	26	23
		113	17	17	17	17	17	17	17	17	29	35	32	41
		114	17	17	17	17	17	17	17	17	29	29	32	23
		309	17	17	17	17	17	17	17	17	29	32	35	29
	Red Lake	112	17	17	20	17	17	17	17	17	23	32	23	35
		305	17	17	17	17	17	17	17	17	29	32	41	32
		306	17	17	17	17	17	17	17	17	23	23	23	23
		307	17	17	17	17	17	17	17	17	23	26	29	29
		308	17	17	17	17	17	17	17	17	23	23	23	29

			PHOTOPERIOD											
			6 Hours				10 Hours				14 Hours			
			Seedling				Seedling				Seedling			
Replication	Provenance	Family	a	b	c	d	a	b	c	d	a	b	c	d
3	North Bay	105	15	15	15	15	15	15	15	15	33	33	36	30
		203	15	15	18	15	15	15	15	15	30	36	30	36
		204	15	15	15	15	15	15	15	15	33	36	24	36
		205	15	18	21	18	15	15	15	15	33	33	21	21
		206	15	18	15	15	15	15	15	15	30	39	33	36
	Thunder Bay	101	15	15	15	12	15	15	15	15	n.s.	21	24	21
		201	21	18	n.s.	15	15	15	15	15	21	n.s.	n.s.	18
		205	15	18	18	15	15	15	15	15	18	18	21	24
		207	n.s.	n.s.	15	n.s.	15	n.s.	n.s.	n.s.	18	n.s.	n.s.	n.s.
		209	15	15	15	15	15	15	15	15	27	21	18	30
	Fort Frances	102	18	18	18	15	15	15	15	15	33	21	21	21
		111	15	15	15	15	15	15	15	15	24	21	21	21
		113	15	15	15	15	15	15	15	15	27	21	21	27
		114	15	15	15	18	15	15	15	15	18	21	18	21
		309	18	15	18	18	15	15	15	15	21	30	21	27
	Red Lake	112	15	15	15	n.s.	15	15	15	15	18	18	18	18
		305	15	15	15	15	15	15	15	15	21	30	21	24
		306	18	15	18	21	15	15	15	15	18	18	18	21
		307	15	18	15	15	15	15	15	15	18	21	18	n.s.
		308	15	18	18	15	15	15	15	15	18	21	33	21

n.s.= no seedling

APPENDIX VI

DAYS UNTIL BUD SET FOR BALSAM POPLAR CLONES BY PHOTOPERIOD AND REPLICATION IN EXPERIMENT 2

		Replication 1			Replication 2			Replication 3		
		Light (hours)			Light (hours)			Light (hours)		
Provenance	Clone	6	10	14	6	10	14	6	10	14
N. Wisconsin	203	n.b.s.	n.b.s.	-	32	n.b.s.	n.b.s.	27	24	n.b.s.
	207	n.b.s.	n.b.s.	-	32	32	n.b.s.	27	27	n.b.s.
	213	n.b.s.	n.b.s.	-	32	n.b.s.	n.b.s.	24	33	n.b.s.
	216	n.b.s.	n.b.s.	-	32	n.b.s.	n.b.s.	27	27	n.b.s.
	217	n.b.s.	28	-	24	32	n.b.s.	27	21	n.b.s.
	220	n.b.s.	28	-	27	27	n.b.s.	24	24	n.b.s.
	223	n.b.s.	n.b.s.	-	32	n.b.s.	n.b.s.	24	27	n.b.s.
	227	n.b.s.	28	-	32	n.b.s.	n.b.s.	24	30	n.b.s.
	233	n.b.s.	28	-	32	32	n.b.s.	24	27	n.b.s.
	238	n.b.s.	n.b.s.	-	32	32	n.b.s.	24	24	n.b.s.
Thunder Bay	3	n.b.s.	25	-	27	27	n.b.s.	21	24	n.b.s.
	10	28	25	-	27	32	n.b.s.	21	21	39
	16	28	25	-	27	24	n.b.s.	23	21	n.b.s.
	20	28	28	-	27	32	n.b.s.	23	21	n.b.s.
	28	n.b.s.	28	-	27	32	n.b.s.	23	24	n.b.s.
	30	n.b.s.	28	-	n.r.	27	n.b.s.	18	21	n.b.s.
	32	n.b.s.	28	-	32	27	n.b.s.	24	24	n.b.s.
	41	25	25	-	24	24	n.b.s.	18	21	n.b.s.
	45	n.b.s.	28	-	24	27	n.b.s.	21	15	n.b.s.
	48	n.b.s.	28	-	27	32	n.b.s.	15	21	n.b.s.
Pickle Lake	102	n.b.s.	28	-	24	24	n.b.s.	18	21	n.b.s.
	107	25	22	-	21	21	32	12	12	n.b.s.
	108	28	28	-	24	24	n.b.s.	21	21	n.b.s.
	114	n.b.s.	28	-	27	32	n.b.s.	18	21	n.b.s.
	119	n.b.s.	22	-	24	24	n.b.s.	21	21	n.b.s.
	127	25	28	-	32	27	n.b.s.	n.r.	n.r.	n.r.
	136	n.b.s.	22	-	24	24	n.b.s.	15	18	n.b.s.
	138	n.b.s.	25	-	32	32	n.b.s.	21	21	n.b.s.
	144	n.b.s.	25	-	27	24	n.b.s.	18	18	n.b.s.
	152	25	22	-	24	24	n.b.s.	18	21	n.b.s.
Bearskin Lake	303	25	22	-	27	24	n.b.s.	21	12	n.r.
	306	n.b.s.	25	-	24	24	32	18	21	n.b.s.
	307	19	19	-	24	21	24	15	15	24
	311	25	25	-	24	24	32	15	18	39
	314	28	25	-	24	24	27	15	15	n.b.s.
	315	25	22	-	24	24	n.b.s.	12	18	n.b.s.
	318	28	22	-	24	24	32	15	15	n.r.
	319	28	25	-	24	24	32	21	18	n.b.s.
	323	19	19	-	27	21	n.b.s.	12	15	21
	346	22	22	-	24	24	27	18	18	30
Fort Severn	402	25	22	-	18	21	24	12	6	21
	409	28	25	-	18	15	21	12	6	n.r.
	410	25	19	-	21	15	18	n.r.	n.r.	n.r.
	423	19	19	-	21	21	21	15	15	18
	428	25	25	-	18	18	21	9	15	30
	437	28	22	-	21	21	n.b.s.	15	18	42
	444	28	22	-	21	21	24	18	n.r.	15
	445	19	19	-	21	n.r.	n.r.	n .r.	n.r.	n.r.
	446	19	25	-	15	21	n.r.	n.r.	n.r.	n.r.
	448	28	22	-	24	24	n.r.	n.r.	n.r.	n.r.

n.b.s. = no bud set n.r. = no ramet

APPENDIX VII

AXIAL AND BASAL PRIMORDIA COUNTS FROM APICAL BUDS OF TAMARACK SEEDLINGS AT THE END OF REPLICATION 3 IN EXPERIMENT 1

			PHOTOPERIOD					
			6 Hours		10 Hours		14 Hours	
			PRIMORDIA		PRIMORDIA		PRIMORDIA	
Provenance	Family	Seedling	Axial	Basal	Axial	Basal	Axial	Basal
North Bay	10105	a	32	25	78	32	24	15
		b	40	25	65	32		
		c	32	30	52	32	24	15
		d	24	32	65	32	24	15
	10203	a			65	32	24	24
		b	24	24			24	15
		c	24	24	78	32	39	24
		d	40	24	65	32		
	10204	a	40	24	91	32		
		b	40	24	52	32		
		c	40	24	24	24		15
		d	24	24	52	24		24
	10205	a			40	32	32	24
		b	24	24	78	32		
		c	16	16	56	32	32	24
		d	24	16	65	32	32	24
	10206	a	40	24	78	32		
		b	24	16	78	32		
		c	24	16	78	32		
		d	40	24	78	32		
Thunder Bay	50101	a	40	32	78	32	78	32
		b	32	24				
		c	16	16	78	32	40	32
		d	24	24	78	32	78	32
	50201	a	20	15	52	32	40	16
		b			56	32		
		c	16	16	52	30		
		d	16	16	39	32	65	32
	50205	a	40	24	78	32	40	32
		b	16	16	52	32	40	32
		c	16	16	56	32	65	32
		d	16	24	56	32	65	24
	50208	a	40	24	65	32	24	24
		b						
		c	16	16			32	24
		d			65	32		
	50209	a	24	25	56	32	52	24
		b	32	24	65	32	52	24
		c	40	24	48	24	65	24
		d	16	16	65	24	39	24

			PHOTOPERIOD					
			6 Hours		10 Hours		14 Hours	
			PRIMORDIA		PRIMORDIA		PRIMORDIA	
Provenance	Family	Seedling	Axial	Basal	Axial	Basal	Axial	Basal
Fort Francis	60102	a	15	15	65	24		
		b	16	16	65	32	52	32
		c	16	16	78	32	52	32
		d	24	16	104	32	39	24
	60111	a	32	32	65	32	39	24
		b	16	16	65	32	52	24
		c	40	24	65	32		
		d	40	24	78	32	65	32
	60113	a	24	16	65	32	52	32
		b	24	16	64	32	39	24
		c	24	24	65	32	65	32
		d	40	24	65	32	39	24
	60114	a	32	24	72	32	24	24
		b	32	32	65	32	65	32
		c	32	32	65	32	52	24
		d	24	24	65	32	65	32
	60309	a	40	24	65	32	39	26
		b	32	32	65	32	39	24
		c	15	15	65	32	65	24
		d	24	24	78	32	65	24
Red Lake	70112	a	24	24	65	32	65	32
		b	40	32	39	32	65	32
		c	16	16	39	24	65	32
		d			52	32	39	32
	70305	a	24	24	65	32	78	32
		b	24	24	65	40		
		c	24	24	65	32	52	32
		d	32	16	104	32	39	24
	70306	a	16	16	52	32	65	32
		b	32	32	65	40	52	32
		c	16	16	52	24	65	32
		d	24	24	52	32	65	32
	70307	a	24	16	52	32	65	40
		b	24	16	52	32	40	24
		c	32	24	52	32	64	32
		d	24	24	24	24	32	32
	70308	a	32	32	52	32	65	32
		b	16	24	78	40	39	24
		c	32	32	65	32	24	16
		d	24	24	65	32	65	24

APPENDIX VIII

HEIGHT GROWTH (cm) OF TAMARACK ROOTED CUTTINGS BY PHOTOPERIOD IN EXPERIMENT 3

		PHOTOPERIOD								
		6 Hours			10 Hours			18 Hours		
		Ramet			Ramet			Ramet		
Provenance	Clone	a	b	c	a	b	c	a	b	c
North Bay	1010104	0.3	0.5	0.6	3.1	0.8	4.4	5.9	3.5	11.4
	1010205	0.6	0.6	0.6	3.4	1.2	0.5	8.4	5.0	8.4
	1010206	1.3	1.2	2.0	1.9	0.6	0.9	8.0	6.1	5.4
	1011103	1.1	0.9	0.7	0.7	3.0				
	1011104	0.6	1.1	1.3	4.8	3.4	1.3	2.1	4.0	5.1
Thunder Bay	5020806	1.2	0.9	1.7	1.2	3.1	0.6	3.7	18.4	6.5
	5020905	1.1	0.9	2.2	2.9		2.0	4.7	2.9	10.8
	5021106	3.2	4.3	2.4	4.3	2.3	4.6		5.2	5.3
	5021206	2.9	1.1	1.1	1.5	1.6	3.4	4.7	7.9	6.4
	5021306	1.5		4.2	1.2	2.0	1.0	11.8	15.3	6.7
	5030103	2.7	2.3	1.3	6.4	4.1	4.7	6.4	7.3	11.2
	5030201	1.6		1.3	1.5		0.4	9.8	5.6	5.8
	5030208	1.3	1.8	1.7	2.3	1.8	2.3	5.9	12.6	8.7
	5030303	0.9	3.5	1.3	3.1	1.2	1.0	4.9	6.1	7.1
	5030404	0.8	3.8	5.3	3.1	7.4	5.3	3.5	4.5	4.2
Red Lake	7011401	1.8		2.2	3.5	1.6	2.2	7.4	11.0	9.6
	7030101	3.4	1.8	2.5	5.2	2.5	3.5	7.0	15.3	8.0
	7030103	1.4	1.4	3.4	2.0	3.0	1.2	10.6	8.7	3.0
	7030105	1.9	1.3	1.1	1.3	3.8	0.3	3.4	8.0	5.7
	7030502	1.0	1.8	2.2	1.6	3.9	3.0	7.3	5.6	4.9
	7030505	3.6	3.6	1.2	2.4	2.7	0.7	7.4	9.9	
	7030506	3.5	0.6	1.7	3.1	1.2	2.8	16.4	5.1	10.8
	7030701	1.3	2.1	1.9	1.1	2.4	1.4	4.8	5.9	10.7
	7030704	2.7	1.2	1.9	1.5	2.3	2.2	1.9	6.0	2.2
	7030905	1.0	1.8	1.3	1.0	2.0	3.0	6.8		8.7
Kenogami R	9011001	2.7	2.3	1.6	2.4	2.4	2.8	4.1	3.3	
	9011204	1.0		1.8	1.3	2.7	1.9	6.2	10.9	2.4
	9011312	0.8	3.0	2.9	3.8	3.4	2.6	9.2	9.0	10.1
	9011404	1.3	1.8	1.4	6.1	1.8	4.6	10.8	8.3	6.3
	9020215	1.1	1.7	2.3	1.3	2.1	0.7	10.2	12.6	8.0
	9020302	1.1	3.2	1.8	2.1	6.0	2.1	5.0	8.9	10.6
	9020602	1.9	2.5	2.8	1.5	1.9	3.9	1.7	4.6	8.8
	9020603	1.3	1.3	1.2	1.8	2.4	1.6	7.8	5.6	5.7
	9020706	2.0	4.6	2.9	1.0	2.1	3.6	11.0	8.0	
	9021303	1.3	2.5	1.1	2.4	3.3	0.4	12.0	5.8	8.7
Big Trout L.	12010102	0.9	3.4	2.1	3.4	3.1	2.4	8.0	13.5	8.2
	12010104	2.9	2.8	2.3	4.9	4.9	7.6	8.5	15.2	10.0
	12010502	1.5	1.3	0.8	3.3	1.4	2.2	2.1	7.4	4.8
	12010807	1.3	1.5	1.7	1.8	0.6	3.3	4.9	7.2	3.8
	12010903	2.2	1.3	0.8	1.3	1.5	4.1	8.6	6.5	5.1
	12020601	1.4	1.3	0.7	3.4	0.0	4.1	8.1	6.8	4.2
	12020604	1.0	1.3	0.7	2.1	3.7	2.6	4.9	4.6	5.7
	12020606	1.6	2.2	1.0	3.7	1.5	1.1	11.3	10.0	9.3
	12020607	1.7	0.8	0.4	6.0	4.9	4.1	9.0	13.0	10.9
	12020903	1.3	0.9	0.7	2.9	1.7	3.7	7.0	6.6	5.0

APPENDIX IX

DESCRIPTION OF TAMARACK COLLECTION SITES

North Bay, 01 01:

Stand Composition:	L	Sb	Bf	Pw
	45%	45%	7.5%	2.5%

Stand Density: 625 stems/ha

Average DBH: 20.0 cm

Average Height: 15.1 m

Average Age: 53.7 years

Site Classification: Undulating bedrock - soil depth varies - generally shallow with wet pockets containing larch and sphagnum moss.

Associated Vegetation: *Picea mariana, Alnus rugosa, Vaccinium myrtilloides, Coptis groenlandicum, Kalmia polifolia, Sphagnum* spp.

North Bay, 01 02:

Stand Composition:	L	Sb
	42%	58%

Stand Density: 1445 stems/ha

Average DBH: 24.9 cm

Average Height: 17.8 m

Average Age: 58.9 years

Site Classification: Sb - Ledum on wet moderately decomposed organic soil.

Associated Vegetation: *Ledum groenlandicum, Kalmia angustifolia, Coptis groenlandicum, Linnea borealis, Sphagnum* spp.

Thunder Bay, 05 02:

Stand Composition:	L	Sb	Bf	Ce
	72%	8%	18%	2%

Stand Density: 1189 stem/ha

Average DBH: 20.3 cm

Average Height: 15.5 m

Average Age: 59.5 years

Site Classification: not available (n.a.)

Associated Vegetation: n.a.

Thunder Bay, 05 03:

Stand Composition:	L	Sb	Bf	Bw
	10%	38%	47%	5%

Stand Density: 2688 stems/ha

Average DBH: 22.2 cm

Average Height: 16.7 m

Average Age: 55.4 years

Site Classification: Lycopodium - herb poor on moist to wet loamy soil.

Associated Vegetation: *Clintonia borealis, Rubus* spp., *Aralia nudicalis, Cornus canadensis, Coptis groenlandicum, Sorbus americana, Lycopodium lucidulum, Sphagnum* spp., *Pleurozium schreberi, Mnium punctatum*

Fort Frances, 06 01:

Stand Composition:	L	Sb	Ce	Bw	Po
	65%	15%	12%	3%	5%

Stand Density: 453 stems/ha

Average DBH: 18.4 cm

Average Height: 14.5 m

Average Age: 40.1 years

Site Classification: Alnus - herb poor on wet moderately decomposed organic soil.

Associated Vegetation: *Alnus rugosa, Cornus canadensis, Rubus pubescens, Ledum groenlandicum, Coptis groenlandicum, Vaccinum myrtilloides, Sphagnum* spp.

Fort Frances, 06 03:

Stand Composition:	L	Sb	Bf	Pj
	52%	35%	10%	3%

Stand Density: 726 stems/ha

Average DBH: 15.8 cm

Average Height: 10.5 m

Average Age: 43.0 years

Site Classification: Alnus - herb poor on wet moderately well decomposed organic soil.

Associated Vegetation: *Alnus rugosa, Chamaedaphne calyculata, Vaccinium oxycoccos, Sphagnum* spp., *Polytrichum* spp.

Red Lake, 07 01:

Stand Composition:	L	Sb	Bf
	32%	65%	3%

Stand Density: 865 stems/ha

Average DBH: 16.9 cm

Average Height: 18.3 m

Average Age: 65.2 years

Site Classification: Feathermoss - sphagnum on moist fine loamy - clayey soil with 20 to 39 cm of organic matter.

Associated Vegetation: *Ledum groenlandicum, Cornus canadensis, Aster* spp., *Petasites palmatus, Vaccinium myrtilloides, Pleurzium schreberi, Dicranum* spp., *Sphagnum* spp.

Red Lake, 07 03:

Stand Composition:	L	Sb	Bf	Bw
	20%	25%	50%	5%

Stand Density: 5030 stems/ha

Average DBH: 13.7 cm

Average Height: 11.2 m

Average Age: 32.2 years

Site Classification: Feathermoss on fresh - moist fine loamy - clayey soil.

Associated Vegetation: *Ledum groenlandicum, Vaccinium myrtilloides, Abies balsamea, Equisetum* spp., *Linnea borealis, Gaultheria hispidula, Pleurozium schreberi, Hylocolium splendens*

Kenogami River, 09 01:

Stand Composition:	L	Sb	Ce
	34%	50%	16%

Stand Density: 935 stems/ha

Average DBH: 17.7 cm

Average Height: 14.7 m

Average Age: 102 years

Site Classification: Conifer - herb/moss rich on moist, fine loamy - clayey soil.

Associated Vegetation: *Thuja occidentalis, Mitella nuda, Cornus canadensis, Equisetum* spp., *Fragaria* spp., *Linnea borealis, Pyrola rotundifolia, Hylocomium splendens*

Kenogami River, 09 02:

Stand Composition:	L	Sb
	70%	30%

Stand Density: n.a.

Average DBH: 17.3 cm

Average Height: 11.4 m

Average Age: 107 years

Site Classification: n.a.

Associated Vegetation: *Betula glandulosum, Salix* spp., *Equisetum* spp., *Menyanthes trifoliata, Kalmia polifolia, Sphagnum* spp., *Dicranum* spp.

Big Trout Lake, 12 01:

Stand Composition:	L	Sb
	40%	60%

Stand Density: n.a.

Average DBH: 9.8 cm

Average Height: 8.3 m

Average Age: 62.3 years

Site Classification: Alnus - herb poor on wet, moderately decomposed organic soil.

Associated Vegetation: *Alnus rugosa, Ledum groenlandicum, Potentilla palustris, Caltha palustris, Smilacina trifolia, Pyrola secunda, Sphagnum* spp., *Dicranum* spp.

Big Trout Lake, 12 02:

Stand Composition:	L	Sb
	40%	60%

Stand Density: n.a.

Average DBH: 9.8 cm

Average Height: 6.8 m

Average Age: n.a.

Site Classification: Ledum on wet, moderately decomposed organic soil.

Associated Vegetation: *Salix* spp., *Ledum groenlandicum, Chaemaedaphne calyculata, Equisetum arvens, Vaccinium vitis - idaea, Vaccinium oxycoccus, Smilicina trifolia, Pyrola virens, Sphagnum* spp., *Dicranum* spp.