

Elongation of Scots Pine Seedlings under Blue Light Depletion

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The effect of blue light (400–500 nm) removal on the elongation of Scots pine (*Pinus sylvestris* L.) seedlings was investigated in a field experiment in Northern Finland during two growing seasons. The seedlings were grown in plexiglass chambers and ambient control plots. The blue wavelengths were removed from the light spectrum by using chambers made of orange plexiglass. The results of nearly daily measurements showed that the elongation of Scots pine seedlings was increased by the removal of blue light only at high latitudes.

Keywords blue light, elongation, high latitude, Scots pine

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1 Introduction

Scots pine (*Pinus sylvestris* L.) follows a fixed growth pattern, i.e. the initiation and elongation of stem units are temporally separate from each other. The number of stem units is determined by the temperature sum during the year of bud initiation. During the following year, the temperature during elongation controls the final extent of shoot elongation. The diurnal variation in Scots pine's shoot elongation also correlates closely with the quantity of solar radiation (Kanninen et

al. 1985), but the effect of light quality has not been studied much.

Fernbach and Mohr (1990) demonstrated with laboratory experiments that Scots pine's hypocotyl growth was reduced in the presence of blue and red light. Blue light alone had no direct effect on hypocotyl growth, but parallel illumination with red light (converts the red-absorbing form of phytochrome to the far-red-absorbing form) reduced hypocotyl growth. The same result was also obtained by illumination with white light. It is similarly well known that the shade avoidance

mechanism, i.e. the response to a low red to far-red ratio, increases pine's height growth rate in a dense stand and vice versa at open sites (de la Rosa et al. 1998, and references therein).

The spectral distribution of light (light quality) depends on the solar angle, which is determined by the diurnal rhythm and depends on latitude. Local factors, such as weather (e.g. clouds) or any particles (water, dust etc.) in the air, also affect light quality. Marked scattering of shorter wavelengths occurs as a consequence of the diminishing solar angle and the increase of air-borne particles. Thus, the relative quantity of blue (400–500 nm) compared to the longer wavelengths decreases in the evening and towards high latitudes. In the northern areas at mid-summer, the sun remains above the horizon continuously. Irrespective of the continuous daylight, the solar angle and hence the light quality pattern show diurnal changes, which differ from those present at lower latitudes. Shifts in climatic envelopes thus affect the light environment experienced by plants.

Some migration of vegetation towards north may occur in the future because the future climate scenarios predict warming by 4–7°C for the boreal zone (Houghton et al. 2001, Rupp et al. 2001). As a consequence of migration, newly colonizing species and ecotypes will undoubtedly experience a changed light climate. The main question is: how will plants respond to the continuous light of the polar region in the summer? Will the relative ratios of shorter wavelengths increase shoot elongation via the kind of mechanisms described by Fernbach and Mohr (1990)? To our knowledge, the present paper is the first report of a study on how the removal of blue light affects the elongation of Scots pine seedlings in the sub-arctic.

2 Materials and Methods

2.1 Experimental Design

The experiment was performed during two growing seasons in the years 2002 and 2003. Three- (2002) and two-year-old (2003) Scots pine (*Pinus sylvestris* L.) seedlings were grown following the standard nursery practice (Forelia Nursery, 64°N)

from seeds of trees originating from Northern Finland (67°N; temperature sum 840 d.d.). The seedlings were potted in plastic Ø120 mm containers containing peat (Kekkilä NPK: N12%-P9%-K18%) prior to cold storage (–5°C) on 2 and 1 of May (2002 and 2003, respectively). The pots were thawed by raising the storage temperature to +5°C on 8 and 7 of May (2002 and 2003, respectively). The experiment was started by placing the seedlings in the experimental field on 15 and 22 of May (in 2002 and 2003, respectively). In 2002, there were two experimental fields: Muhos Research Station of Finnish Forest Research Institute (26°0'E, 64°48'N, 25 m above sea level) and Kilpisjärvi Research Area of Finnish Forest Research Institute (20°47'E, 69°3'N, 473 m above sea level). In both places the chambers were located in an open area. In 2003, the study was focused at Kilpisjärvi, where a larger number of replicates were made. In 2002, the experimental design consisted of three (n=3) replicate chambers and ambient control plots with 50 seedlings in each. In 2003, the experiment at Kilpisjärvi involved four replicates (n=4) with 60 seedlings in each. The experiments were started by placing the seedlings in the chambers and on the ambient control plots. The seedlings were watered 4–5 times a week in both years.

The chambers (Röhm Plexiglass, Gegossennes Acrylglas nach ISO 7823-1, Darmstadt) were made of either orange (GS 303) or transparent (GS 233) plexiglass 3 mm in thickness. The former (–B; minus blue) was meant to remove the blue wavelengths (400–500 nm), while the latter was transparent to all visible wavelengths (CC; chamber control), as demonstrated in Fig. 1. The chambers stood on wooden frames at 0.8 m height above ground, and their bottom area was 1 × 2 m and top height 1.0 m. The chambers were equipped with electric fans, which circulated cooling air taken in through holes in the bottom plate. The ambient control plots (AC) were wooden tables without chambers at 0.8 m height above ground. Light quality in the chambers and on the ambient control plots was controlled with an Ocean Optics spectroradiometer (Model USB2000), and data loggers (StowAway XTI) were used to record the temperature at 1 h intervals. The daily extreme temperatures and the day degrees are shown in Figs. 2–4a and b (respectively).

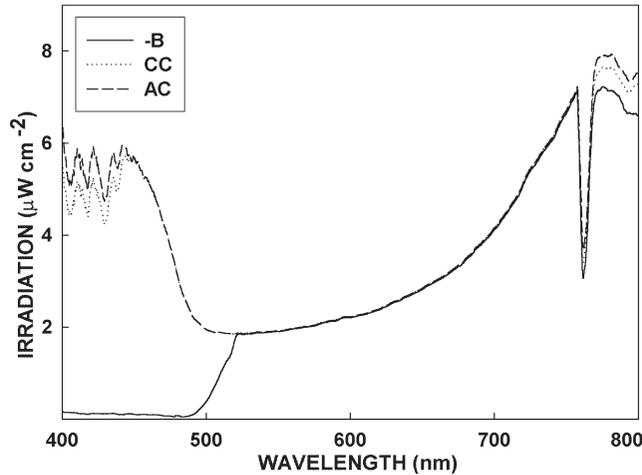


Fig 1. An example of spectral flux densities in orange (–B) and transparent (CC) chambers and on ambient control plots (AC). The spectra were measured at 2.30 pm on 7 June (2002) at Muhos (64°N). Note the blue region (400–500 nm).

2.2 Growth Analysis

Elongation was measured daily (with a few exceptions) until the end of the experiment, i.e. when elongation ceased at the beginning of July. Lots of 10 and 15 seedlings per replicate were measured and averaged in 2002 and in 2003 (respectively) with a mauser device (accuracy ± 0.1 mm).

2.3 Statistical Analyses

In 2002, the difference in shoot elongation at the end of the experiment between the treatments (–B, CC and AC) of Muhos and Kilpisjärvi was tested by two-way ANOVA (i.e. treatment \times site). One-way ANOVA with *post hoc* comparisons (Bonferroni test) was used to test the difference between the treatments. In 2003, the difference between the treatments was tested by one-way ANOVA and subsequent *post hoc* comparison (Bonferroni). The tests were performed with the SPSS software package.

3 Results

3.1 Temperature Conditions

The equality of temperature conditions between the chambers (–B vs. CC) was shown by the daily extremes (Fig. 2–4a) and confirmed by the accumulated temperature sums (Fig. 2–4b). At Kilpisjärvi, the temperature sums that had accumulated by the end of experiment were 640 d.d. in both chambers and 310 d.d. on the ambient plot in 2002 (Fig. 3b), while the respective temperature sums at Muhos were 690 d.d. and 430 d.d. (Fig. 2b). At Kilpisjärvi in 2003, the temperature conditions between the chambers were also equal, although the temperature sum accumulated in –B (705 d.d.) was marginally lower compared to CC (747 d.d.). The temperature sum in AC was again significantly lower (290 d.d.).

3.2 Shoot Elongation

A significant ($P < 0.05$) treatment \times site interaction was found in 2002. At Muhos, there were no significant differences in elongation between the chambers and the control plots in 2002, although

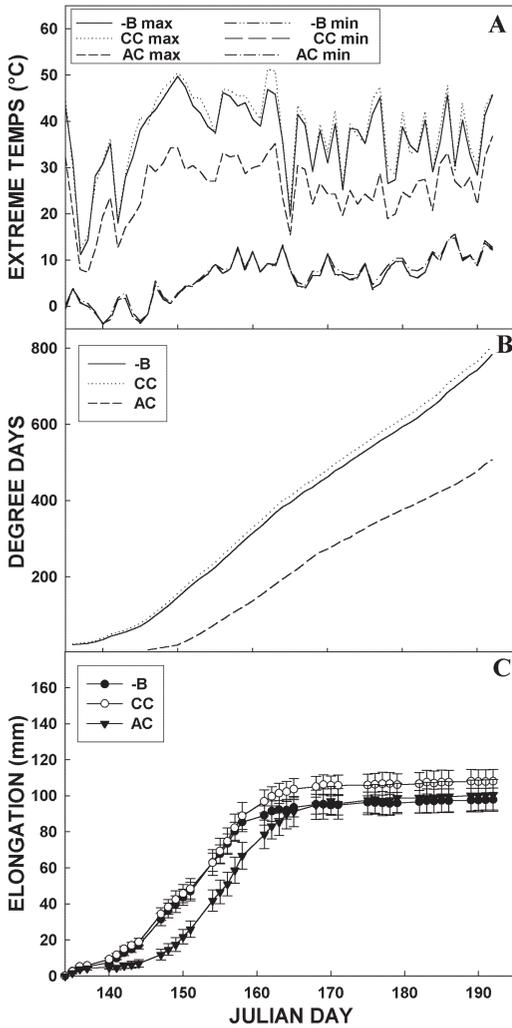


Fig 2. (A) Daily extreme temperatures, (B) accumulation of day degrees and (C) mean elongation of Scots pine seedlings ($n = 3$ chambers/plots) in orange (-B) and transparent (CC) chambers and on ambient control plots (AC) at Muhos (64°N) during the experiment in 2002. The error bars represent the SE (standard error). Julian day 152 is 1 June.

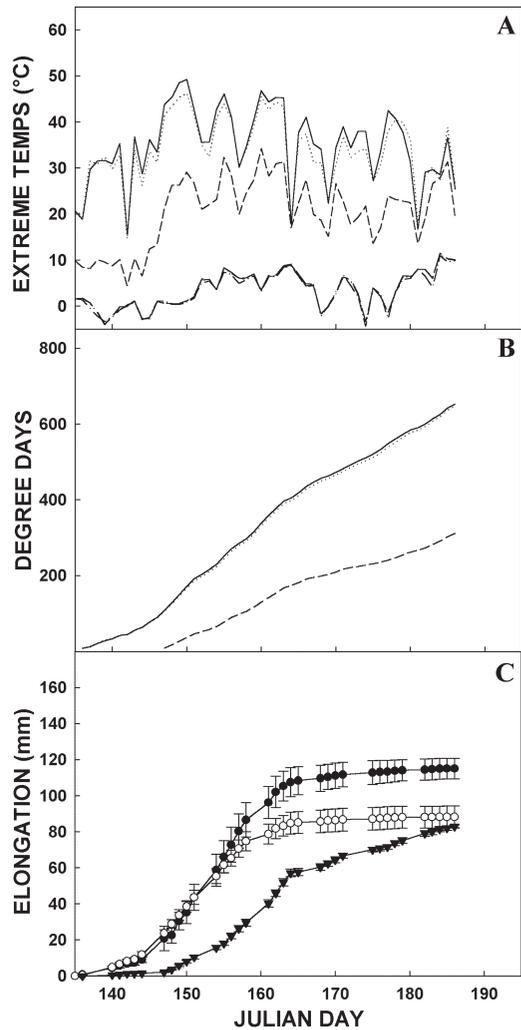


Fig 3. See the explanation for Fig. 2 except for the study site: Kilpisjärvi (69°N).

the maximum elongation of 107 mm occurred in CC, while the elongations for -B and AC were 97 and 100 mm, respectively (Fig. 2c). At Kilpisjärvi, however, the removal of blue light (i.e. -B) increased elongation significantly ($P < 0.05$), as the growth records for the treatments were 115,

88 and 83 mm in -B, CC and AC (respectively) (Fig. 3c). In 2003, the results obtained at Kilpisjärvi were consistent but even more significant ($P < 0.01$), as the seedlings elongated 153 (-B), 118 (CC) and 94 (AC) mm (Fig. 4c).

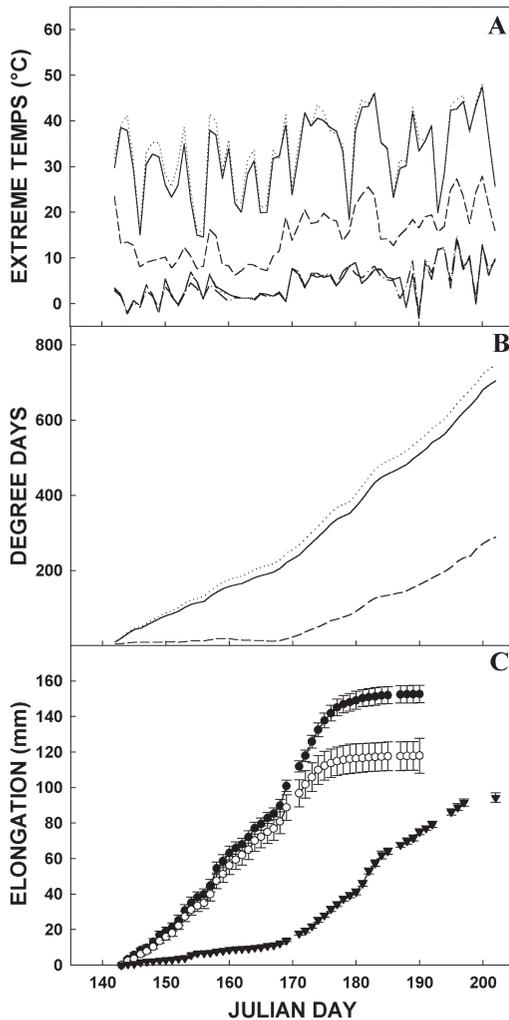


Fig 4. See the explanation for Fig. 2 except for the study site and year: Kilpisjärvi (69°N) in 2003.

4 Discussion

The present findings are in accordance with the results of Fernbach and Mohr (1990), who showed that blue light controls hypocotyl growth in Scots pine. They (Fernbach and Mohr 1990) concluded that the inhibition of hypocotyl growth by blue light also requires interaction with the red wavelengths (600–700 nm). It has been suggested

that this inhibition effect of blue and red light on hypocotyl growth is coaction of cryptochrome and phytochrome, and even phototropin receptors (i.e. cry1, cry2, phyA, phot1) (Mohr 1994, Parks et al. 2001, Ahmad et al. 2002). Simulated shade, i.e. a low red to far-red (R/FR; 660 nm/730 nm) ratio also elongates pine trees (Warrington et al. 1988). Consistently, pine trees produce tall and straight trunks in dense stands, as pine is a shade-avoiding species.

Interestingly, this result was obtained at a sub-arctic latitude (Kilpisjärvi, 69°N) but not at a lower (64°N) latitude. The response cannot be attributed to simple etiolation, since similar light manipulation did not improve elongation at a lower latitude (64°N) of the experiment. The 69°N latitude exhibits a relatively long “end of day” situation at mid-summer (period of elongation), which lasts for up to 4–6 hours (approx. 20% of the daily hours) (Nilsen 1985). The observed response may be also an interaction between light manipulation (removal of blue) and photoperiod. It is thus suggested that 1) the longer the period with light, the greater is the effect of artificial removal of blue light. 2) On the other hand, the 4–6 h “end of day” period itself favours elongation without any other light manipulation, since the red to far-red ratio is reduced (Nilsen 1985). 3) Therefore, shifts in the climatic envelopes may provide a light environment favourable for shoot elongation in species with a marked shade avoidance response.

As for the future prospects, the above results raise questions concerning the responses to plant age, ecotype, species, etc. In addition, the exact physiological mechanism behind the response remains open.

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