

## Effect of photon flux density on bud dormancy release in Norway spruce seedlings

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The effect of photon flux density on bud dormancy release in two-year-old seedlings of Norway spruce (*Picea abies* (L.) Karst.) was examined. The seedlings were first chilled for 0–21 weeks under natural conditions and then forced in a warm greenhouse either in low ( $15 \mu\text{Em}^{-2}\text{s}^{-1}$ ) or in high ( $300 \mu\text{Em}^{-2}\text{s}^{-1}$ ) photon flux density. Occurrence of bud burst was observed in the forcing conditions, and the observations were used for estimating the cumulative frequency distribution of the chilling requirement for growth competence. The estimated distribution had greater variance in the low photon flux density than in the high photon flux density forcing. This finding suggests that unnaturally low photon flux densities during forcing may yield overestimates of the genetic within-population variation in the chilling requirement for growth competence.

Työssä tutkittiin fotonivuon tiheyden vaikutusta kaksivuotiaiden kuusentaimien (*Picea abies* (L.) Karst.) silmudormanssin purkautumiseen. Taimia kylmäkäsiteltiin ensin 0–21 viikkoa ulkona, minkä jälkeen niitä hyödettiin lämpimässä kasvihuoneessa joko matalassa ( $15 \mu\text{Em}^{-2}\text{s}^{-1}$ ) tai korkeassa ( $300 \mu\text{Em}^{-2}\text{s}^{-1}$ ) fotonivuon tiheydessä. Silmunpuhkeamista seurattiin hyödon aikana, ja silmunpuhkeamishavaintojen perusteella estimoitiin kasvukompetenssin kylmävaatimuksen kumulatiivinen frekvenssijakauma. Estimoidun frekvenssijakauman hajonta oli suurempi matalan fotonivuon kuin korkean fotonivuon hyödoässä. Tulos viittaa siihen, että käytettäessä hyötövaiheen aikana luontaista matalempia fotonivuon tiheyksiä saatetaan päätyä yliarvioon populaation sisäisestä kasvukompetenssin kylmävaatimuksen perinnöllisestä vaihtelusta.

Keywords: annual habit, development, buds, chilling requirement, dormancy, light intensity, *Picea abies*, seedlings.  
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## 1 Introduction

Air temperature is, for most tree species from the cool and temperate regions, the main environmental factor regulating the processes of bud dormancy release. After growth cessation, exposure to chilling temperatures (e.g.  $0\text{ }^{\circ}\text{C} < T < 10\text{ }^{\circ}\text{C}$ ) is first required for a rest break, i.e. for attaining the growth competence of the buds. After rest completion, ontogenetic development towards bud burst takes place at temperatures above a given threshold (e.g.  $5\text{ }^{\circ}\text{C}$ ) (Romberger 1963, Perry 1971, Sarvas 1974, Fuchigami et al. 1982, Cannell and Smith 1983, Hänninen 1990).

The night length is another environmental factor that regulates bud dormancy release in trees. Under experimental conditions, short night lengths compensate for lack of chilling in rest break in several tree species (Olmsted 1951, Nienstaedt 1966, Worrall and Mergen 1967, Farmer 1968, Garber 1983). This phenomenon may have ecological importance at mild locations, where the wintertime chilling may be insufficient to meet the chilling requirement of rest completion. Furthermore, in *Pseudotsuga menziesii* (Mirb.) Franco, short night lengths

hasten bud burst also after prolonged chilling (Campbell and Sugano 1975).

Compared with air temperature and night length, photon flux density has received rather minor attention in studies of bud dormancy release. High photon flux density during chilling has been shown to delay bud burst, obviously indirectly by slowing rest break by increasing tissue temperatures (Chandler et al. 1937). As far as the present authors are aware, no other aspects of the effects of photon flux density on bud dormancy release have been previously studied. The purpose of the present study is to examine the effects of post-chilling photon flux density on bud dormancy release in *Picea abies* (L.) Karst. seedlings.

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## 2 Materials and methods

### 2.1 Experimental design and analysis of the results

The treatment of the seedlings consisted of a chilling period outdoors and a subsequent forcing period in a warm greenhouse. The seedlings were divided into 24 treatment groups ( $n = 30$ ), according to the duration of chilling (0–21 weeks, 12 levels) and photon flux density prevailing during forcing (two levels). The growth status of the terminal bud of the seedlings was visually checked twice a week under the forcing conditions. If the new needles were visible, then the seedling was determined to have burst bud.

The value of *dormancy release ratio* DRR was calculated for each treatment group as the proportion of bud bursting seedlings amongst the total number of seedlings in the group. An estimate for the cumulative frequency distribution of chilling requirement for growth competence was obtained by plotting the values of

DRR against duration of chilling. The variances of the distributions (i.e. slopes of the DRR-curves) obtained for the low and high photon flux density forcing were compared using the Probit analysis (SAS 1990, p. 1325–1350).

### 2.2 Seedling material

The seedlings were raised at the nursery of Suonenjoki Research Station ( $62^{\circ}40'\text{N}$ ,  $27^{\circ}00'\text{E}$ , 130 m asl) according to normal nursery routines, including irrigation, fertilization and weed control. Seeds of naturally growing local trees were sown in a greenhouse on May 6, 1987 in paper pots in fertilized peat. The seedlings were transferred outdoors between September 4 and 8 1987. At the end of their second growing season during August 1988, the seedlings were transferred to the Botanical Garden of the University of Joensuu ( $62^{\circ}36'\text{N}$ ,  $29^{\circ}43'\text{E}$ , 81 m

asl), where they were transplanted into a peat-sand mixture (50/50 by volume) in containers of  $10\text{ cm} \times 40\text{ cm} \times 30\text{ cm}$ . Fifteen seedlings were sampled at random in one container, and two containers were subsequently sampled in one treatment group. The roots of the seedlings were separated by heavy cardboard. The experimental treatments were started at the Botanical Garden on September 15, 1988 and terminated on May 10, 1989.

### 2.3 Growing conditions

The air temperature was monitored by thermographs (model 'Lambrect 257' in the chilling conditions and model 'Lambrect 252' in the forcing conditions). The temperature of the buds was measured a few times with a thermocouple.

The *chilling treatments* were given outdoors. Before snowfall, which occurred during the eleventh week of the experiment, the weekly mean air temperature dropped from  $+9\text{ }^{\circ}\text{C}$  to  $-5\text{ }^{\circ}\text{C}$ . The weekly minimums dropped during the same period from  $+2\text{ }^{\circ}\text{C}$  to  $-18\text{ }^{\circ}\text{C}$ , and the maximums from  $+20\text{ }^{\circ}\text{C}$  to  $0\text{ }^{\circ}\text{C}$ . After snowfall, the weekly mean air temperature fluctuated between

$-4\text{ }^{\circ}\text{C}$  and  $0\text{ }^{\circ}\text{C}$ , the minimums fluctuating between  $-10\text{ }^{\circ}\text{C}$  and  $-2\text{ }^{\circ}\text{C}$ , and the maximums constant at  $0\text{ }^{\circ}\text{C}$ .

Under the *forcing conditions*, the photon flux density was either  $15\text{ }\mu\text{Em}^{-2}\text{s}^{-1}$  (low photon flux density conditions, fluorescent tubes model 'Airam L65/80W-1XC Daylight Deluxe'), or  $300\text{ }\mu\text{Em}^{-2}\text{s}^{-1}$  (high photon flux density conditions, mercury lamps model 'Airam H9LX 400W'). The night length was 12h. The intended air temperature was  $17\text{ }^{\circ}\text{C}$ . Under the low photon flux density conditions, the air temperature was  $17.2 \pm 1.3\text{ }^{\circ}\text{C}$  ( $\bar{x} \pm \text{S.D.}$ ). Under the high photon flux density conditions, the warming effect of the mercury lamps was reduced by placing a plastic plate between the lamps and the seedlings. Despite this, bud temperatures rose to  $20\text{ }^{\circ}\text{C}$  under the high photon flux density conditions.

If the seedlings were frozen during the scheduled transfer time to the forcing conditions, they were first melted at  $5\text{ }^{\circ}\text{C}$  before the transfer. The time required for melting was added to the chilling duration in the analysis of the results. During the chilling no watering took place. Under the forcing conditions the seedlings were watered once a week.

## 3 Results and discussion

Under both low and high photon flux density conditions, the DRR-values started to increase from zero after five weeks of chilling (Fig. 1). The slope of the DRR-curve was, however, smaller for the low than for the high photon flux density forcing ( $\chi^2 = 21.2$ ,  $p < 0.001$ ). This difference between the DRR-curves was presumably generated by differences in the photon flux density conditions *per se*. Another possible rea-

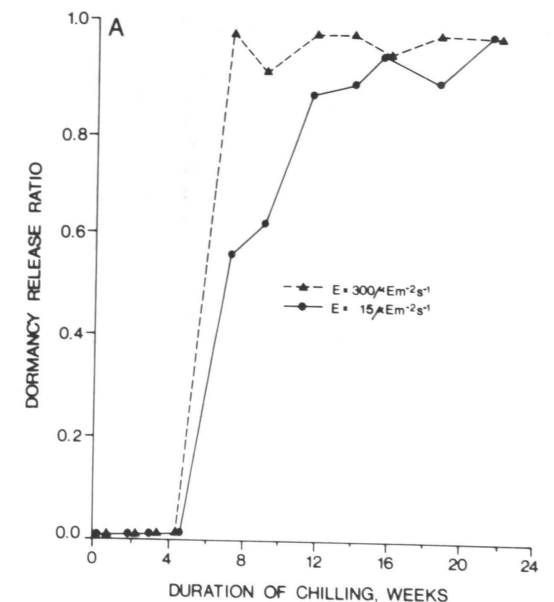


Fig. 1. Dormancy release ratio (DRR) in Norway spruce seedlings, as a function of the duration of the previous chilling, and photon flux density prevailing during forcing. Each point is based on observations with 30 seedlings. In the low photon flux density data, bud burst observations at 0–3 weeks of chilling were neglected as resulting from the rest breaking effect of the forcing temperature (Höyhty 1990).

son for the different results could be the increased tissue temperature ( $T = 20\text{ }^{\circ}\text{C}$ ) in the high photon flux density forcing. This is, however, presumably not the case, since in earlier studies no differences were found in the DRR-curves obtained in the forcing temperatures of  $17\text{ }^{\circ}\text{C}$  and  $22\text{ }^{\circ}\text{C}$  (Hänninen and Pelkonen 1988, Hänninen 1990).

For a given experiment, the DRR-curve provides an estimate of the cumulative frequency distribution of the chilling requirement for growth competence in the examined population. The results of the present study suggest that this estimate may be affected by the forcing conditions used in the experiment. Much greater variance of the estimated chilling require-

ment distribution (greater slope of the DRR-curve) was obtained with forcing in an unnaturally low photon flux density than with forcing in a more natural photon flux density (Fig. 1). This finding suggests that the high within-population variation in the chilling requirement for growth competence that has been found with low photon flux density forcing both in the present and in some previous studies (Hänninen and Pelkonen 1988, Hänninen 1990) is an artefact. In this case, photon flux densities similar to those prevailing under natural conditions during the spring should be used in forcing experiments in order to reveal the real genetic within-population variation in the chilling requirement for growth competence.

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