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CONTENTS

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Light distribution within forest edges in relation to forest regeneration

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ABSTRACT: Light conditions were measured along six transects from 35 m inside of a mixed Norway spruce/Scots pine forest to an adjoining clear-cut in NW-Austria. Photosynthetic photon flux density (PFD) was recorded every minute of the day from 5:00 a.m. to 8:00 p.m. for three weeks in July. PFD decreases exponentially from the clear-cut to the interior of the forest following the gap fraction. Low light intensity classes (< 50 µmol photons m^2/s) decrease from the stand towards the open, whereas the clear-cut receives light of higher intensities (> 200 µmol photons m^2/s) for most of the day. PFD values assessed during the day were compared with photosynthetic light response curves measured on advanced planting of broadleaf species in the same stand. The high light compensation point of *Quercus petraea* enables carbon gain in deep shade for about 60% of the day. The other shade tolerant species *Fagus sylvatica* and *Acer pseudoplatanus* can perform net photosynthesis at 80% and 90% of the time, respectively. This reduces the possibility of advanced planting of light demanding species to the first few meters of the inner part of the forest edge.

Keywords: advanced planting; forest edge; light compensation point; photon flux density

Detailed understanding of light conditions within the forest is important for many forest management decisions. The forest edge is a heterogeneous area that connects two relatively homogeneous ones, the closed stand with low light environment on the forest floor and the clear-cut area with intensive mineralisation and microclimatic stress factors. Difficulties in studying edge effects can arise because not only one but many environmental factors may change along this gradient.

Previous studies of edge dynamics compared plots outside the forest edge with sites located exclusively within the forest (Chen, Klinka 1997). However, gradients from one area to the other crossing the edge zone are rare. In many papers light availability is related to growth parameters or gas exchange, often comparing open and forest understory sites without regarding the edge zone.

Cadenasso et al. (1997) points out that there is a difference between edge effects and edge zones. Edge effects describe the magnitude of the change in some factors, whereas edge zones describe the area within which these changes take place. Different edge effects may be spatially displaced from one another; their location varies with forest exposure.

The goal of this investigation was to get knowledge of changing light conditions within forest edges. This understanding is crucial for forest regeneration in general and for the advanced planting of broadleaf species in the investigation area in NW-Austria in particular.

MATERIALS AND METHODS

The study site is located in NW-Austria near the German border (12°50´E, 48°05´N) at an elevation of 475 m a.s.l. Mean annual temperature is 8°C with mean temperatures during the growing season of about 15°C. Annual precipitation averages to about 1,000 mm. The experimental plot is situated within an extended Norway spruce (*Picea abies* [L.] Karst.) monoculture, where a clear-cut (300 m × 40 m) created a forest edge opened to the east in 1993/1994. The investigation area consists of the 95 years old Norway spruce forest and the adjacent clear-cut. Photosynthetic photon flux density (PFD) was mea-

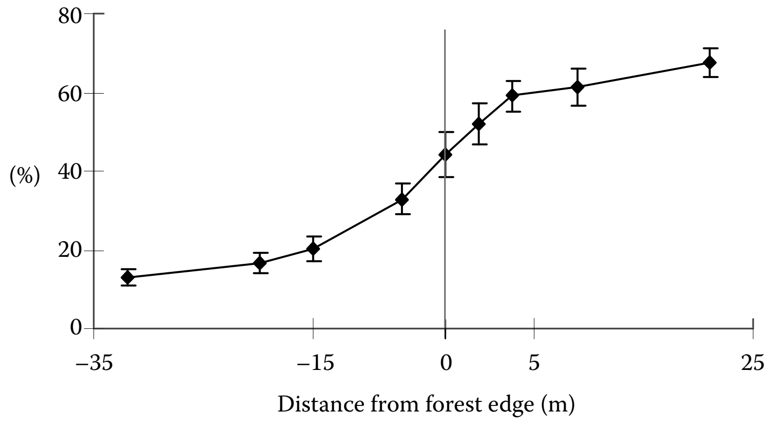

Fig. 1. Transmissivity in % (means and standard deviation of 15 days) along the transects

sured with nine PFD Sensors (LI 190 SZ, LiCor, Inc., Lincoln) connected to a data-logger (DL2, Delta-T, Burwell, Cambridge) monitored at 1 min intervals from 5:00 a.m. to 8:00 p.m.

The sensors were located at 50 cm above the forest floor: at 0, 3, 9 and 21 m from the edge to the open and at 3, 7, 15, 20 and 32 m from the edge to the understory (sensor distances inside the forest were attributed negative signs). To calculate relative light intensity, the 100% values were recorded by additional equipment on a large clearing nearby. Light conditions were measured on three days in each transect in July 1997. At each sensor position, the fraction of sky, visible to the sensor ("gap fraction") within a zenith angle of 58° was estimated with the LiCor LAI-2000 Plant Canopy Analyser. Its values range between 0 (no sky visible to the sensor) and 100 (no foliage visible to the sensor).

Transmissivity and daily amounts of solar radiation were calculated for four sunny and four overcast days. PFD was subdivided into different light intensity classes (< 50 μmol photons m^2/s, > 200 μmol photons m^2/s and > 500 μmol photons m^2/s) to get information about their distribution along the transect.

In the course of parallel investigations, gas exchange parameters were measured in summer of 1996 and 1997 (LI 6400, LiCor Inc., Lincoln). On the basis of light compensation points in 1996 for the three tree species (*Acer pseudoplatanus*, *Fagus sylvatica* and *Quercus petraea*), the daily percentage of time (from 5:00 a.m. to 8:00 p.m.) when they were not able to achieve a carbon gain on the leaf level (i.e. light intensities below light compensation point) was calculated.

RESULTS AND DISCUSSION

Light environment varies very little among the transects. Mean transmissivity ranges from about 12% in the forest understory (–32 m) to about 70% at 21 m distance in the clear-cut. The greatest variance between the transects occurs in the forest edge, where the transmissivity ranges between 45 and 55% (Fig. 1). Gralla et al. (1997) pointed out that the method of advanced planting can be used even with an average of 5% of diffuse light in the open.

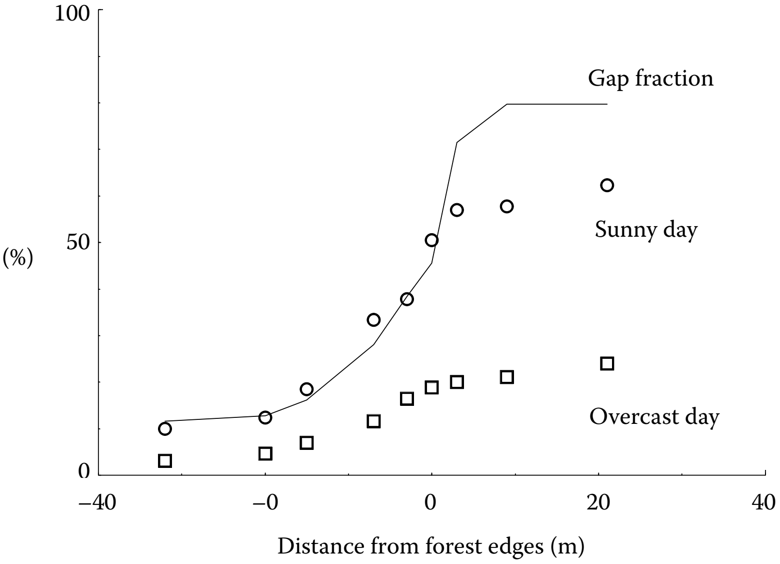

Fig. 2. Fraction of canopy gaps (in %) and relative photon flux density (in %) during a sunny and an overcast day

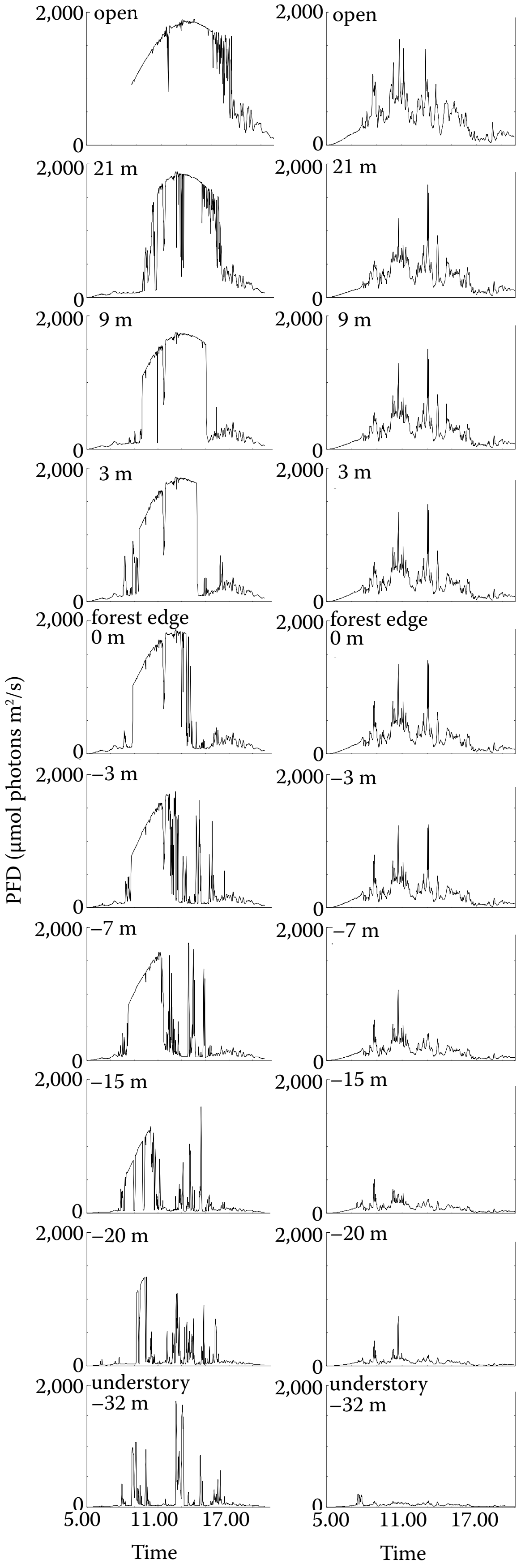

Fig. 3. Light distribution along the transect during a sunny day (a) and during an overcast day (b) in μmol photons m²/s

Approaching the forest edge, canopy PFD transmissivity and gap fraction increase exponentially (Fig. 2). The strip clear-cut receives direct radiation from 10:00 a.m. to 4:00 p.m. during a sunny day (Fig. 3a). From the clear-cut to the forest understory (–15 m) the time when sensors get direct radiation (PFD above 300 μmol photons m²/s) gets shorter and occurs earlier (Vallades et al. 1997). The sensor at –15 m in the forest still receives direct radiation from 8:00 to 11:00 a.m. Further, more inside the forest only scattered light flecks interrupt the base line of indirect radiation.

Uninterrupted direct radiation periods on the ground during the sunny day also occur earlier in the forest than in the clear-cut. Because of the eastwards orientation of the forest edge, the light environment up to –15 m is not substantially reduced until midday.

The direct radiation in the stand will change during the year with the angle of the sun above the horizon (Hutchison, Matt 1977 in Otto 1994). Light distribution along the transects differs between sunny and overcast days (Fig. 3a,b). In Fig. 3b, light intensity shows a more or less regular distribution, apart from the two great peaks occurring in the clear-cut during sunny spells.

During a sunny day, high light intensity classes dominate in the clear-cut (Fig. 4). Intensities higher than 500 μmol photons m²/s occur in about one third of the day. The percentage of high intensity classes (> 200 and > 500 μmol photons m²/s) decreases along the transect from the open to the understory. On the contrary, intensities < 50 μmol are more frequent under the closed canopy. They increase from < 10% in the clear-cut to > 55% in the interior of the forest.

During the overcast day the situation is quite similar, but light intensity classes < 50 μmol take up a greater part of time. Plants under the closed canopy receive very low light levels up to 90% of time. Differences in light compensation points between the species influence substantially their carbon gain potential (Table 1). The percentage of time with light supply below the light compensation point increases exponentially from the open to the forest (Fig. 5). Differences between sunny and overcast days are surprisingly small, whereas differences between the species are considerable in the year of planting. Percentage of time with carbon losses (negative net photosynthesis) is the highest in *Quercus petraea* with about 40% of the day, followed by *Fagus sylvatica* (20%) and *Acer pseudoplatanus* (10%). However, these calculations do not consider post-illuminative carbon gain after

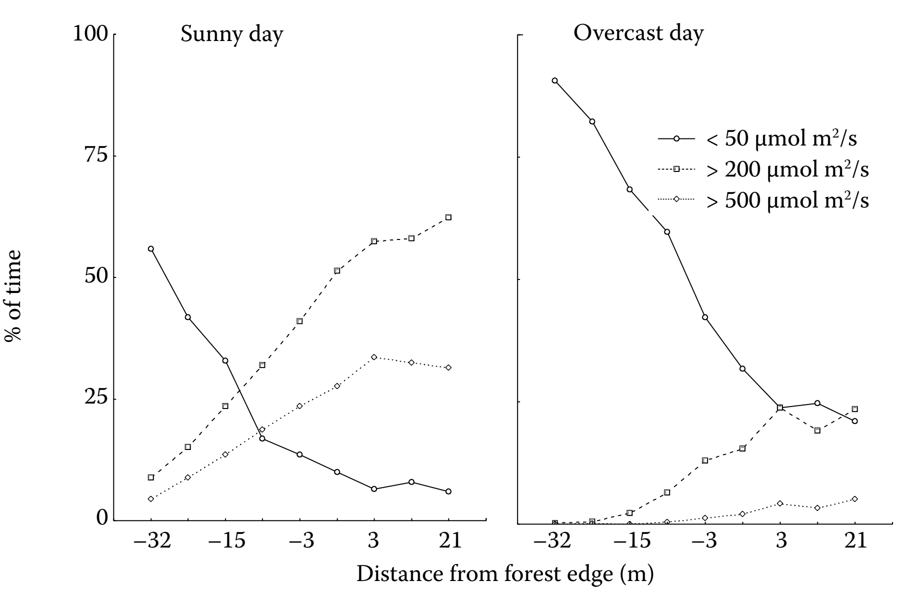

Fig. 4. PFD (in percentage of time) subdivided into different light intensity classes

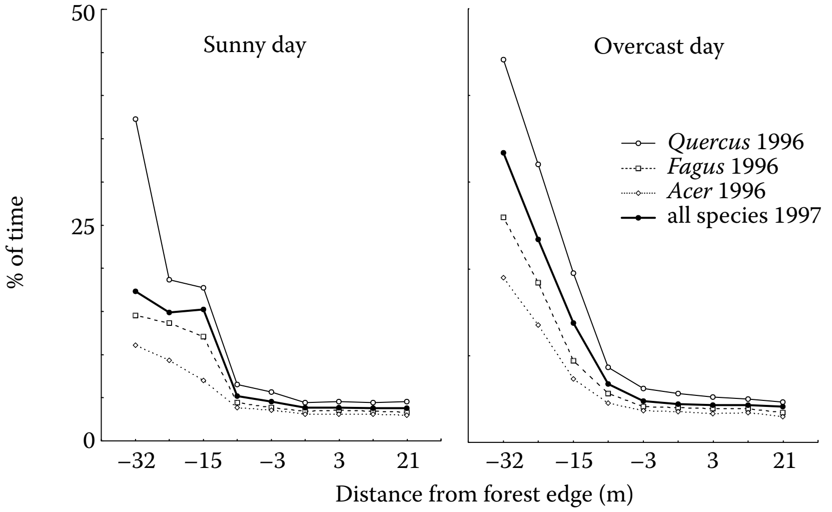

Fig. 5. Percentage of time without carbon gain in three tree species in 1996. Only the average for 1997 is given because of no differences in light compensation points between the species

short time sun flecks (Pearcy et al. 1985; Schneider et al. 1991).

As a consequence of the different light compensation points, *Acer pseudoplatanus* could be planted much further into the forest understory than *Fagus sylvatica* and *Quercus petraea*. The presented results show the great importance of understanding the light distribution along the forest edges and the necessity to bring it together with species specific light requirements. Light compensation points in 1997 (one year after planting) do not show any significant differences between the species any more. Therefore, the time without carbon gain is shown on the basis of the average light compensation point of the three species (18.3 µmol m^2/s, Fig. 5). Regarding this evaluation, the shade tolerant species *Fagus sylvatica* and *Acer pseudoplatanus* lost their ability to utilise low light intensities in the second year after planting, which is rather contrasting to their attributes as "shade tolerant".

Table 1. Light compensation points of the investigated plants in 1996 (Letters behind the means indicate significant differences between the plants at the 5% significance level in the Tukey HSD Test, Standard deviation in parenthesis, see Kazda et al. 1998 for details)

Tree species	Light compensation point (µmol m^2/s)
Quercus petraea	23.9 b (6.7)
Fagus sylvatica	14.9 a (3.0)
Acer pseudoplatanus	11.9 a (3.6)

CONCLUSIONS

Light compensation points of photosynthesis differed significantly between *Quercus petraea*, *Fagus sylvatica* and *Acer pseudoplatanus* in the first year after planting. Regarding the light conditions along the forest edge, this may be an important factor for the survival of broadleaved species. Not only light conditions but also the nutrient status may play an important role in plant survival as *Acer pseudoplatanus* lost its optimal adaptation to low light intensities in the second year after planting.

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Světelné podmínky na okrajích lesních porostů ve vztahu k jejich obnově

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ABSTRAKT: Světelné podmínky byly měřeny v šesti 35 m dlouhých transektech ve smíšeném porostu smrku a borovice zevnitř porostu na mýtinu. Světelné podmínky (tok fotonů PFD µmol m^2/s) byly zaznamenávány v minutových intervalech denně od 5 do 20 hodin po dobu tří týdnů. PFD se exponenciálně zmenšoval od okraje směrem do porostu, přičemž tato změna odpovídala zvyšujícímu se zápoji korun vyjádřených jako „gap fraction“. Nízký světelný požitek pod 50 µmol m^2/s byl méně častý na stanovištích v porostu, zatímco na holině byly po většinu dne měřeny hodnoty nad 200 µmol m^2/s. Hodnoty PFD byly porovnány se světelnými křivkami fotosyntézy u podsadeb listnatých dřevin ve stejném porostu. Vysoký kompenzační bod fotosyntézy u dubu zimního (*Quercus petraea*) umožňuje absorpci CO_2 v hlubokém zástinu po cca 60 % délky dne. Dřeviny snášející stín – buk lesní (*Fagus sylvatica*) a javor klen (*Acer pseudoplatanus*) – jsou schopné udržet kladnou bilanci fotosyntézy po 80–90 % dne. Rychlý pokles fotosynteticky využitelného záření proto omezuje možnost provádění podsadby světlomilných dřevin na pouze několik metrů od okraje porostu.

Klíčová slova: podsadba; okraj porostu; bod světelné kompenzace, tok fotonů

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