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Managing Light to Enable Natural Regeneration in British Conifer Forests

INFORMATION NOTE

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SUMMARY

This Information Note summarises the light requirements for seedling growth of conifer species beneath a forest canopy, and describes how to assess whether light levels beneath a stand are limiting seedling growth. Various methods of assessing light and canopy openness are described. Basal area can be used in conjunction with an assessment of existing regeneration and vegetation growth as an indication of what stand manipulation should be undertaken to encourage or enhance seedling growth.

INTRODUCTION

Continuous cover forestry (CCF) regimes are increasingly favoured in British forestry as a means of delivering a range of benefits. Natural regeneration of seedlings beneath a forest canopy is an important part of these regimes because successful restocking of a stand by natural regeneration will be less expensive than planting.

There are five requirements for successful natural regeneration:

- A suitable seed source nearby.
- A suitable seed bed to enable germination.
- A suitable microclimate, especially light, for seedling growth.
- Freedom from vegetation competition.
- Freedom from browsing.

This Information Note concentrates on the third of these requirements: specifically, the light levels required for seedling growth and how to assess whether light levels in a stand are the limiting factor for seedling growth. Other aspects relevant to natural regeneration and wider issues relating to the transformation of conifer stands to CCF are covered elsewhere (Nixon and Worrell, 1999; Kerr *et al.*, 2002; Mason and Kerr, 2004).

Light levels required

The seedlings of different tree species require different amounts of light to grow successfully. Shade-tolerant species such as western hemlock can survive under relatively dense forest canopies, whereas light-demanding species such as larches require more open conditions.

Below-canopy light levels are commonly expressed as a proportion of the light incident on the canopy of the overstorey trees, rather than absolute light levels, because this allows measurements to be compared between sites even when they have been made in different light conditions. Table 1 shows the approximate minimum amount of light required for seedlings of different species to achieve satisfactory growth, based on a four-year experiment in the Scottish Borders (Mason *et al.*, 2004). The relative ranking of the species is supported by other studies (e.g. Malcolm *et al.*, 2001), but the actual percentage required will depend on latitude, slope and aspect, and also on other limiting factors such as moisture and nutrients. Note also that the minimum light requirement will be higher as the seedlings increase in size.

Table 1

Minimum percentage of incident light (transmittance) required for seedlings to achieve 50% of the growth that would be achieved in full light, and the critical basal area required to achieve these light levels beneath an overstorey of the same species (see 'Stand parameters' below for derivation of the basal area values).

Species	Tolerance ranking	Percentage light	Critical basal area (m^2 ha^{-1})
Larch	Light-demanding	> 40%	~20
Scots pine	Light-demanding	~35%	~25
Sitka spruce	Light-demanding to intermediate	~20%	~30
Douglas fir	Intermediate	~15%	~35
Western hemlock	Shade-tolerant	~10%	~40

BELOW-CANOPY LIGHT REGIME

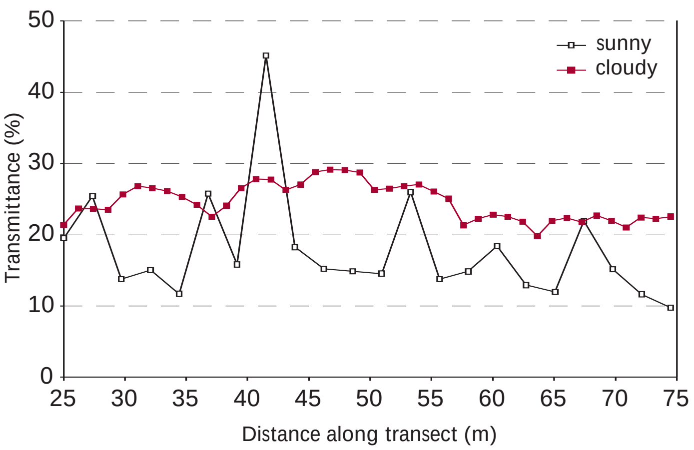
Variability

The light regime beneath a forest canopy varies in space and time. On a sunny day, when most of the light is *direct*, small patches of light (sunflecks) cause large differences in light levels at scales of less than a metre. On overcast days, when most light is *diffuse*, light will vary more gradually from place to place across a stand. Throughout the course of a day, as the sun moves across the sky, differences in the light level received at a single point will vary greatly; again, the differences are most pronounced on sunny days.

As an example, Figure 1 illustrates how transmitted light varies along a transect beneath a mature larch canopy (measurements were made with a ceptometer; see box on pages 5–6). The measurements made on a sunny day illustrate the spatial variability, and a comparison with the measurements made on an overcast day shows how different conditions influence the below-canopy light regime. This variability makes the light regime difficult to characterise. With a light sensor it is simple to make an accurate measurement of light at a given point beneath a canopy, but it is difficult to make a measurement that is representative of the light in all weather conditions, at all times of day and throughout the growing season. The amount of light that is transmitted through a forest canopy is directly related to canopy openness. The box on pages 5–6 describes several methods for assessing below-canopy light levels and canopy openness.

Figure 1

Measurements of transmitted light along a 50 m transect beneath the canopy of a 65-year-old European larch canopy in central Scotland, in sunny and cloudy conditions. Light levels are expressed as a percentage of the light measured simultaneously in an adjacent open area.



Practical issues

Even with the relatively cheap, quick and easy methods described on pages 5–6, it would be impractical to measure the light regime for every stand of interest. The next section describes other indicators that can be used to quickly assess the light regime and its impact on seedling growth.

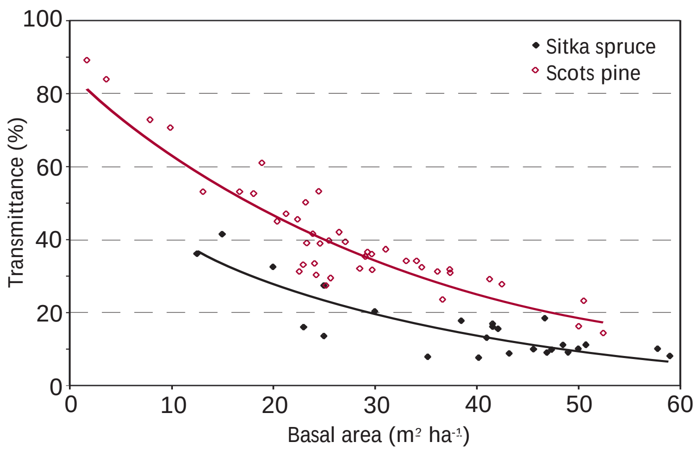
Stand parameters

The amount of canopy cover, and the size and distribution of canopy gaps, determine the amount of light transmitted through the canopy. For a given species, tree leaf area generally increases with stem diameter so, although there is some inter-site variability, there is a loose relationship between stand basal area and average light transmittance through the canopy, with transmitted light decreasing as basal area increases. Figure 2 illustrates the relationship between stand basal area and canopy transmittance (measured using hemispherical photography; see box on pages 5–6) for Sitka spruce and Scots pine stands in Britain. Note that to allow generalisations to be made, all values shown in Figure 2 are from relatively flat sites. The forest floor of a Sitka spruce stand with basal area of ~ 30 m^2 ha^{-1} may receive 25% transmittance on a flat site, but ~ 20% on a north-facing slope and closer to 30% on a south-facing slope.

Table 1 shows the critical maximum basal area for each overstorey species to allow sufficient light transmittance for regeneration of the same species. Values for Sitka

Figure 2

The relationship between average canopy transmittance and stand basal area in Sitka spruce and Scots pine stands. Each point is the average of either seven or nine measurements, made in a plot of approximately 0.1 to 0.25 ha. The spruce stands were in Wales, northern England and central Scotland; the pine stands were in central and northern Scotland.



spruce and Scots pine are based on experimental data; for the other species, assumptions have been made about the relationship between basal area and below-canopy light climate. The data from Table 1 suggest that for most of Britain Sitka spruce seedlings require at least 20% of incident light for growth beneath a canopy. Figure 2 shows that for flat ground only stands with a basal area below 30 m^2 ha^{-1} reach this value. Current management tables recommend retaining stand basal area greater than 30 m^2 ha^{-1}, even immediately after thinning, throughout most of the rotation (Edwards and Christie, 1981). This results in insufficient light for spruce seedling growth, although possibly sufficient for western hemlock. Scots pine supports a less dense canopy for a given basal area than Sitka spruce, and a basal area below about 25–30 m^2 ha^{-1} should produce enough light (~ 35% incident light) for natural regeneration of this species. However, this can also permit growth of ground vegetation such as heather and bilberry, so regeneration may be difficult. A similar problem can occur in larch stands, where the understorey is often colonised by grass, preventing regeneration even if light is not limiting.

ASSESSING REGENERATION POTENTIAL

Although Table 1 can be used to give a general indication of the basal area required to provide suitable light levels for seedling growth, regeneration potential is not a function of basal area alone. The structure of the canopy, and therefore the amount of light transmitted, depends on stand management history. A high basal area stand with many small trees (e.g. unthinned 45-year-old Sitka spruce) will have a very dense canopy, and will transmit less light than a stand with the same basal area but fewer, larger trees (e.g. a stand that has been well thinned in the past). For example, in Clocaenog, north Wales, there are 50-year-old Sitka spruce stands with basal areas appreciably higher than 30 m^2 ha^{-1} with prolific regeneration. Therefore, while the critical basal areas proposed in Table 1 are a useful guide for thinning while developing a stand for regeneration, they are no substitute for inspecting a stand once the decision has been made to regenerate it (Mason and Kerr, 2004).

Is light limiting natural regeneration?

The role of light in natural regeneration beneath a forest canopy is complex, because light promotes the growth of both seedlings and competing vegetation. Assuming that there is a suitable seed source nearby, that browsing is controlled, and that the stand is at or near critical basal area, there are a number of questions to ask to determine whether light is limiting natural regeneration in a forest stand.

a) Is there regeneration on the site already?
b) Is regeneration present throughout the stand or only in or near racks or road edges?
c) Does seedling growth appear to be restricted?
d) Is there vegetation on the site?

a) If there is no regeneration on the site and vegetation cover is absent or very sparse, this suggests that there is insufficient light for growth of seedlings or vegetation. Further thinning may be desirable to reduce the basal area of the stand to allow sufficient light to be transmitted through the canopy.

b) If there is regeneration extending several metres into the stand from racks, rides or roadsides, but none further into the stand and vegetation cover is sparse or absent within the stand, this indicates that light is limiting within the stand. Further thinning could create suitable conditions for regeneration throughout the stand. If there is regeneration extending several metres into the stand from racks, rides or roadsides, but none further into the stand, and there is abundant vegetation within the stand, this indicates that there is sufficient light within the stand for seedling growth, but ground disturbance is required to create a suitable seed bed.

c) If there is regeneration greater than about 25 cm tall within the stand, the length of the leader compared to the length of the topmost lateral can give an indication of whether the plant is receiving sufficient light. If there is enough light the leader will be longer than the laterals (Figure 3a). If a seedling is not receiving enough light it will grow outwards at the expense of upwards growth, which increases the horizontal area for light interception; these seedlings will therefore have laterals longer than leaders (Figure 3b). This ability to adapt growth form is found in shade-tolerant and some intermediate species, but not in more light-demanding species such as pines. Figure 3c shows natural regeneration in a Sitka spruce stand in Tarenig forest in mid-Wales. The relatively short leaders suggest that the stand should be opened further to allow these seedlings to thrive.

d) If there is no regeneration on the site and ground vegetation is abundant, then light is not limiting; rather, regeneration cannot become established either because the vegetation is causing a physical barrier preventing the seeds from germinating or because the vegetation is outcompeting small seedlings for water, nutrients and light.

Figure 3

Leader growth relative to lateral growth for (a) a seedling growing with sufficient light, and (b) a seedling growing in limited light. (c) Natural regeneration in a Sitka spruce stand where seedling leader growth is limited.

a

b

c

CONCLUSIONS

The key to achieving successful regeneration beneath a forest stand is to use the canopy to maintain control of the vegetation until regeneration starts to become established. For intermediate and shade-tolerant species, successful regeneration is more probable in stands with basal areas lower than management table recommendations. Successful regeneration of light-demanding species can be more difficult because seedlings require an overstorey with low basal area, yet this risks encouraging colonisation by competing vegetation. This can be a particular problem if the overstorey trees are not mature enough to produce seed. Some points to consider are:

- It will normally be easier to get regeneration on an infertile site than a fertile site because competing weed growth will be less.
- Seedlings are unlikely to be distributed evenly across a site due to localised variations in light regime, soil moisture and nutrients.
- It is important not to open up a stand quickly to try to promote seedling establishment, but to start gradually and open up the stand around seedlings when they appear to be struggling for light, otherwise the regeneration opportunity may be lost to vegetation competition.

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MEASURING LIGHT AND CANOPY OPENNESS

This section describes several methods of measuring light below a forest canopy, and of estimating canopy openness. The first two methods are primarily research methods; equipment for these costs several thousand pounds which, along with the need for particular weather conditions and analysis time, means that they are impractical as everyday tools for assessing below-canopy light conditions. The last three methods are cheap, robust and practical ways to obtain rough estimates of canopy openness or canopy transmittance.

Ceptometer

The ceptometer is a 1 m long 'wand' with 80 light sensors along its length. It directly records the light beneath a canopy, while the incident light is recorded separately in a nearby open area, so the proportion of incident light transmitted through the canopy (the 'transmittance') can be calculated. This method allows accurate point measurements of transmittance to be made, but values will vary with time of day, time of year and weather conditions, so a large number of repeat measurements are required to obtain representative values.

Hemispherical photography

Hemispherical photography is a common research technique for assessing both the canopy transmittance and the canopy openness of forests. A photograph is taken looking up into the canopy using a fisheye lens, which gives a 180º view of the canopy. The user analyses the resulting image (Figure 4) using specialised software to determine which pixels are sky and which are canopy, and canopy openness and transmittance are calculated. One limitation of hemispherical photography is that it does not work well beneath very dense canopies (below approximately 10% transmittance).

Canopy-scope

The canopy-scope assesses the relative size of the largest canopy gap within the field of view, which has been found to correlate well with either canopy openness or canopy transmittance measured using hemispherical photography in a range of forest types (Brown *et al.*, 2000; Hale and Brown, 2004). The canopy-scope is a perspex square with 25 dots etched at 3 cm intervals in a 5 x 5 grid, which can be easily made for a few pounds. At a number of locations in the stand the user holds the canopy-scope 20 cm from the eye, points it at the largest canopy gap (which may not necessarily be directly overhead), and counts the dots unobstructed by canopy. Eight to ten measurements in a 0.25 ha plot were found to be sufficient to represent the average canopy openness or canopy transmittance (Figure 5). Canopy transmittance at each point can be calculated using the following equation:

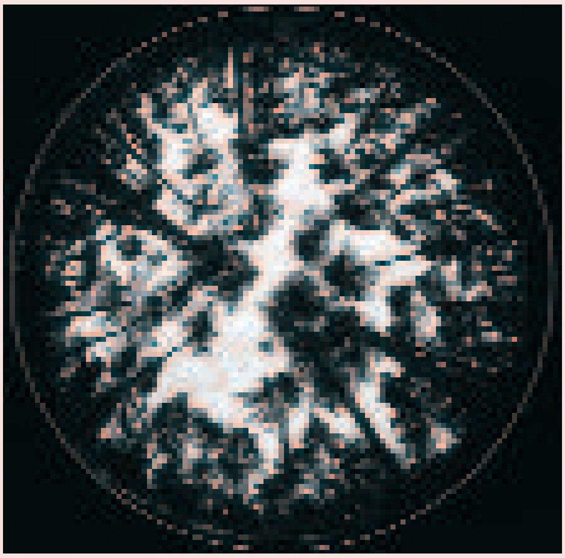
Transmittance =
1.2 **x** (Average no. of unobstructed dots) + 8.6

The canopy-scope is not recommended for canopies with more than about 30% openness.

Figure 4

Hemispherical photographs taken in (a) a Scots pine stand with a transmittance of 35%, and (b) a Sitka spruce stand with a transmittance of 20%. Both stands had a basal area of 30 m^2 ha^{-1}.

a



b

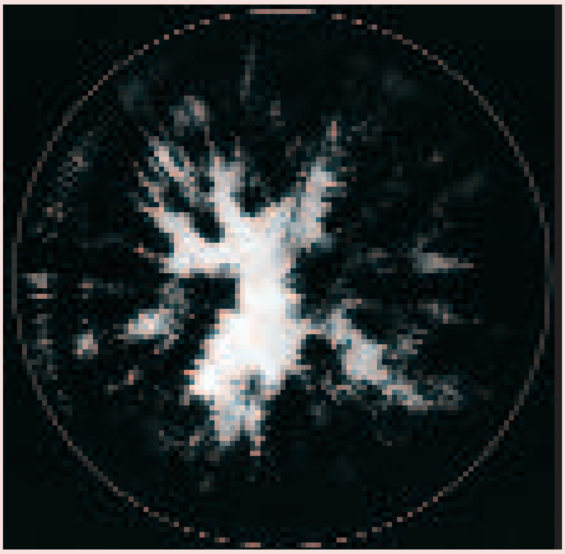
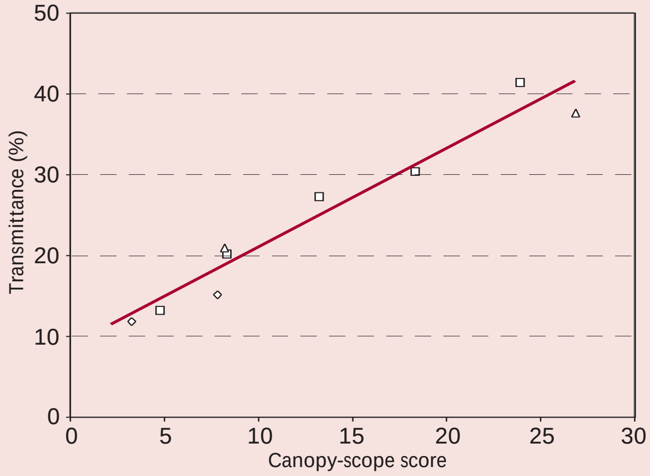


Figure 5

The relationship between average canopy transmittance and average canopy-scope score in Sitka spruce (□), larch (△) and mixed conifer/broadleaf stands (◇). Transmittance (y) can be calculated from canopy-scope score (x) using the equation: $y = 1.2x + 8.6$.



There are two other similar techniques which readers may see advertised (briefly described below). These give a direct estimate of canopy openness, which is closely related to light transmittance. While we have not evaluated these directly, they should prove reliable in British forests if appropriate guidelines are followed.

Densitometer or vertical sighting tube

This allows the user to look directly up at the canopy using a mirror in a tube with either single cross-hairs or a grid at the end, and note whether the cross-hairs (or how many grid intersections) are seen to be in ‘sky’ or ‘canopy’. Readings taken at different locations can be used to give an average canopy openness for a stand.

Spherical densiometer

This is a convex or concave mirrored hemispherical dome with 96 dots etched within a grid on the surface. It is held horizontally in the palm of the hand, and the user counts the dots unobstructed by the canopy. Again, readings in a number of locations are taken to produce an average value of canopy openness.

Note that the vertical sighting tube and the spherical densiometer measure slightly different characteristics of the forest canopy. The sighting tube looks only at the canopy directly overhead, whereas the densiometer, because of the shape of the mirror, integrates the canopy over a larger area. Both pieces of equipment cost under £100.

REFERENCES

BROWN, N., JENNINGS, S., WHEELER, P. AND NABE-NIELSON, J. (2000).
An improved method for the rapid assessment of forest understorey light environments. *Journal of Applied Ecology* 37, 1044–1053.

EDWARDS, P. N. AND CHRISTIE, J. M. (1981).
Yield models for forest management.
Forestry Commission Booklet 48.
HMSO, London.

HALE, S. E. AND BROWN, N. (2004).
Use of the canopy-scope as a means of assessing canopy openness in plantation forests in Britain. *Forestry* in review.

KERR, G., MASON, W. L., BOSWELL, R. AND POMMERENING, A. (2002).
Monitoring the transformation of even-aged stands to continuous cover management.
Forestry Commission Information Note 45.
Forestry Commission, Edinburgh.

MALCOLM, D. C., MASON, W. L. AND CLARKE, G. C. (2001).
The transformation of conifer forests in Britain – regeneration, gap size and silvicultural systems. *Forest Ecology Management* 151, 7–23.

MASON, W. L., EDWARDS, C. E. AND HALE, S. E. (2004).
Survival and early seedling growth of conifers with different shade tolerance in a Sitka spruce trial and relationship to understorey light climate. *Silva Fennica* in review.

MASON, W. L. AND KERR, G. (2004).
Transforming even-aged conifer stands to continuous cover management.
Forestry Commission Information Note 40 (Revised). Forestry Commission, Edinburgh.

NIXON, C. J. AND WORRELL, R. (1999).
The potential for the natural regeneration of conifers in Britain.
Forestry Commision Bulletin 120.
Forestry Commission, Edinburgh.

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