Interactions between canopy cover density and regeneration cores of older saplings in Scots pine (Pinus sylvestris L.) stands

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Abstract

Aim of the study: This paper provides an analysis of growth and survival of twenty–year–old Scots pine saplings in relation to canopy cover density (CCD) gradients, from dense (D–CCD), sparse (S–CCD), and gap (G–CCD) situations.

Area of study: Aladag (Bolu) in northern Turkey.

Material and methods: Sparse canopy cover density (S–CCD), dense canopy cover density (D–CCD) and gap canopy (G–CCD) were chosen within ten different strip sample plots (10 × 50 m) with sapling regeneration cores. Those regeneration cores were divided into two portions (individuals at the edge and middle of the regeneration cores) and from each portion three individuals were obtained from a sample. The growth relationships of individual saplings were calculated with stem analyses. Honowski Light Factor (HLF) (ratio of Terminal sprout length (T) to Lateral sprout length (L)) was used to present growth potential measure of seedlings.

Main results: The largest sapling regeneration cores were found in the G–CCD followed by S–CCD, and finally D–CCD, all tested for significance with Kruskal–Wallis Test. Compared with saplings in the middle of regeneration cores (crop saplings), those at the edge were always reduced in terms of mean height. Significant difference was only found between the ‘Main Crop’ and the ‘Edge 1’ of the regeneration cores for G–CCD suggesting that sapling regeneration cores are more typical under G–CCD conditions. HLF ratios were greater than 1 with high growth potentials for both CCD gradients (G–CCD and S–CCD) and there were no significant variations between G–CCD and S–CCD for main crop and edges. The thinning after 12–14 years increased sapling growth. However, under D–CCD, growth had virtually ceased.

Research highlights: Naturally occurring Scots pine saplings are suppressed by a dense canopy. However, they are tolerant of shade to the extent that they can survive over relatively long time–periods (10–12 years) and can exploit subsequent opportunities should a canopy gap occur.

Keywords: Gap regeneration; sapling growth; light regime; canopy cover density; irregular silviculture.

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Introduction

In forest understoreys, tree seedling survival and growth are determined mainly by light, water and nutrient availability. Interspecific competition and herbivory may result from variation in canopy cover density (CCD) in the overstorey (Löf et al., 2007), and this may also affect growth and survival. Although forest ecologists and silviculturists have emphasized the importance of creating canopy gaps (G–CCD) to generate spatial variation in order to promote tree regeneration, the effects of G–CCD on seedling recruitment may be offset by the development of dense forest understoreys. Light is a resource that limits tree seedling recruitment in many forest understoreys and G–CCD can raise light levels leading to increased seedling recruitment. However, many forests support dense understoreys that may compete with tree seedlings for resources such as light. This limits seedling recruitment even in gap conditions (G–CCD), and reduces the effectiveness of gaps in promoting seedling recruitment (Beckage et al., 2005; Ruuska et al., 2008). Understanding the behaviour of the seedlings of different tree
species in relation to canopy shade is therefore important.

Studies of gap dynamics have contributed significantly to an understanding of the role of small–scale disturbance in forest ecosystems. Yet these have hardly been used by foresters for predicting tree responses to partial cutting (Coates, 2000). It is clear that interactions between heterogeneity in the forest overstorey (e.g. canopy gap or closed canopy) and understorey micro–environments may affect seedling performance. The presence of gap–understorey interactions may influence both seedling competitive environments and the nature of resource limitation on seedling growth and survival. For example, understorey herbs, ferns, and shrubs may increase in response to high light availability in gaps (G–CCD) and so may compete with tree seedlings. Conversely, micro–environments characterized by high mineral nutrient availability or soil moisture may have disproportionate effects on seedling performance in high light environments (G–CCD), and little effect in light–limited environments (e.g. dense canopy (D–CCD)) (Beckage & Clark, 2003).

Scots pine (Pinus sylvestris L.) is the most widely distributed pine species and one of the most important timber species in Eurasia. It has high commercial and ecological values (Oleksyn et al., 2002; Stanners & Bourdeau, 1995; Fig. 1). Natural Scots pine forests have a wide distribution in Turkey covering nearly 760,000 ha (Fig. 1). There is an abundant literature on the factors affecting natural regeneration in Scots pine forests. Scots pine seed trees have an effect on the structure of pine seedlings (i.e. morphological characteristics), their spatial pattern, and their size distribution. Both height and seedling density decrease close to the parent trees (Siipiletho, 2006). Competition from the mother trees inhibits development of saplings in close proximity (Montes & Canellas, 2007). However, the growth of naturally occurring saplings in response to variations in CCD of Scots pine stands are poorly studied in the southern zone of its distribution area (Beckage et al., 2005; Coates, 2000; Löf et al., 2007; Pukkala et al., 1993; Cameron & Ives, 1997; Andrzejczyk, 2007). Studies on regeneration and advance growth have shown that the effects of the long–term retention of seed trees has a strong negative impact on the development of young Scots pine stands, especially on relatively infertile sites in northern areas of its natural distribution (Ruuksa et al., 2008). The research reported in this paper was designed to address four questions:

1) Are different CCD gradients good predictors of regeneration cores of Scots pine saplings?

2) How do CCD gradients affect the growth of Scots pine saplings?
(3) How was growth affected by the position of the sapling within the regeneration core in Scots pine stands?

(4) Do these responses vary with the shade tolerance rankings of Scots pine saplings?

Materials and methods

Site description

Much of current knowledge of tree species in relation to canopy development is based on studies of trees occurring in naturally regenerated forest communities (Ellenberg, 1996). This research was therefore undertaken in naturally regenerated Scots pine forest in Aladag (Bolu) in northern Turkey (Fig. 1: latitude between 40°30’ and 40°42’ N, longitude between 31°39’ and 31°52’ E) which is characterised by a high degree of naturalness (Colak et al., 2003). The research area is typically covered by 120–140 years–old–stands of Scots pine located at 1.380–1.420 m altitude. Silviculture in the area is based on natural regeneration following a shelterwood system and silvicultural interventions are not frequent at early stages of development (Coban, 2007).

The climate shows Euxinian influences, with mean annual precipitation of 883 mm and mean annual temperature of 5.7 °C, cool winters, and sub–humid summers without significant droughts (Serin, 1998). The Euxinian region covers the whole of the Euro–Siberian phyto–geographical region and is effectively referred to as the Euxinian province. This is an area that covers much of Georgia and the Caucasus, the Istaranca Mountains of European Turkey, and south–east Bulgaria (Davis, 1965–1988). The soils are mainly brown podzols (Tolunay, 1997), and the site quality class of for the research area is I (I–V: “I” shows the high and “V”...
CCD–S) in the stand projection (Klumpp et al., 2002; Globe, 2005; Jennings et al., 1999; Fig. 2):

\[
\text{CCD} \% = \frac{\text{VPTC}}{\text{MA}} \times 100
\]  

(Eq. 1)

VPTC: Vertical projection of the tree crowns (m²)
MA: Forest floor cover (m²) of measured area

G–CCD and S–CCD area calculated as a ration of the measured transect part by gap area (Fig. 2).

Field procedures and calculations/equations

The standard alternative to CCD for the regeneration cores is by means of ‘rectangular sample plots’ (10–50 m) and shows longitudinal (profile) and vertical projection of the stand (Aksoy, 1978). For different CCDs, transects are taken from the strip plots. In this study ten transects from each S–CCD, D–CCD and G–CCD were chosen within ten different strip sample plots with sapling regeneration cores (Fig. 3).

The ages of individual saplings were assessed with stem sections cut in order to estimate the age by ring counting (González–Martínez & Bravo, 2001). The saplings were scored considering the position of individuals in regeneration cores: (1) “Main crop sapling” the highest score in both variables (dominant and healthy) and (2) “Edge sapling” with the lowest score in both variables (dominant and healthy). The main crop saplings which were measured were located in the middle of the typical natural sapling regeneration cores (Fig. 2). The term “main crop sapling”, that is the trees selected to become a component of a future commercial harvest, refers to those saplings with the highest score in both variables (dominant and healthy) (Gonzales–Martinez & Bravo, 2001). Those individuals at the edge of the natural sapling regeneration cores were selected as “Edge saplings” (Fig. 2; G). The individuals were distinguished for stem–analysis as follows: Each core divided into three portions (Edge 1, Edge 2 and Main Crop). From each of the edges three individuals were taken (totalling six for edges) and three individuals were taken from the middle (Fig. 2).

Gradients and measurements of CCD

CCD refers to the proportion of the forest floor covered by the vertical projection of the tree crowns (Fig. 2). This is analogous to the use of the term ‘cover’ by ecologists and silviculturists to refer to the proportion of the plan ground area occupied by the above ground parts of plants. Measures of CCD assess the presence or absence of canopy vertically above a sample of points across an area of forest. Tree height does not affect CCD, since only the vertical projection of the crown is assessed. CCD is a measure reflecting the dominance of a site by trees or by particular species of tree (Jennings et al., 1999). The Scots pine stands in 1997 were allocated into 1 of 3 different CCDs (G–CCD, D–CCD and S–CCD) distinguished by CCD gradients in the shelterwood. These three CCD gradients (Ewald, 2007) are:

- Dense (D–CCD): CCD over 50% (50–80%; Percent canopy cover; Fig. 2).
- Sparse (S–CCD): CCD up to 50% (20–50%; Percent canopy cover; Fig. 2).
- Canopy gap (G–CCD): no cover; the gap size 25–100 m² (All sample plots areas in the canopy gaps were between 25.09 and 95.42 m², Fig. 2).

According to the definition by Jennings et al. (1999), if CCD is to be measured correctly, the measurements should be made in exact vertical direction (Korhonen et al., 2006). The following is the equation (Eq. 1) used to calculate the percentage of tree CCD (CCD–D and CCD–S) in the stand projection (Klumpp et al., 2002; Globe, 2005; Jennings et al., 1999; Fig. 2):

\[
\text{CCD} \% = \frac{\text{VPTC}}{\text{MA}} \times 100
\]  

(Eq. 1)

VPTC: Vertical projection of the tree crowns (m²)
MA: Forest floor cover (m²) of measured area

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Analysis of saplings

Sapling–stem analysis

Sample saplings were cut down to ground level and stem cuts were taken at 1 m intervals for stem analysis (Atici, 2003, 1998; Kalipsiz, 1981, 1999). For the sapling–stem analysis of the increment and growth data of individual trees the “Computer Supported Statistical Analysis Program (GOVAN)” was used (Atici, 2003). GOVAN is computer software, which provides an op-
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Canopy cover density and regeneration cores in Scots pine (*Pinus sylvestris* L.) stands (1974) as the growth potential measure of seedlings and saplings under the canopy cover in coniferous species. The factor is referred to as the HLF ratio (Eq. 2). According to this value, the growth condition can be defined as ‘well’ or ‘weak’ (after Fabjanowski et al. 1974 from Schütz, 2001). The individuals for the HLF ratio were selected from Edge 1, Edge 2 and Main Crop portions and from each part a mean set of data was obtained from a sample of three individuals.

\[
\text{HLF} = \frac{T}{L} \quad \text{(Eq. 2; Schütz, 2001)}
\]

Where: \(T\): Terminal sprout length (cm); \(L\): Lateral sprout length (cm)

HLF ratio: 1.0 > growth well; 1.0–0.5 growth under the good; 0.5–0.25 growth not good; 0.25 < growth very low.

Data analysis

The following equation (Eq. 3) was used to calculate 95% confidence intervals of populations of all measured data (Atici et al., 2008; Kalipsiz, 1981; Sachs, 1972):

\[
\mu = \bar{x} \pm t \times SE_{\bar{x}} \quad \text{(Eq. 3)}
\]

Where \(\bar{x}\) is arithmetic mean; \(SE_{\bar{x}}\) is std. error; \(t\) is Student’s t coefficient (\(t_{1-\alpha/2}; n-1\)); for 9 degrees of freedom=2.262, \(n\) is 10 number of samples.

Statistical evaluation including nonparametric test (Kruskal–Wallis H Test), t–tests, one–way variance analyses (ANOVA), and Student–Newman–Keuls (SNK) test were applied to the data collected using SPSS 5.01 software for Windows.

Results

The effect of CCD gradients on formation of regeneration cores

The results show that different CCD gradients result in major differences for sapling regeneration cores. The maximal sapling regeneration cores were found in the G–CCD, followed by S–CCD and finally D–CCD (Table 1). These differences were shown to be statistically significant by the Kruskal–Wallis H test. This test was applied to the difference in the CCD gradients of regeneration cores, and as a result two typical separate groups (1: D–CCD; 2: S–CCD and G–CCD) were determined (P<0.001, Table 1). This situation was consistent in all sample plots with longitudinal (profile) and vertical projection of stands (Fig. 3). Accordingly sapling regeneration cores do not occur in D–CCD.
Table 1. The effect of CCD gradients on formation of sapling regeneration cores. The data and statistical analysis from 30 sapling regeneration cores with different CCD gradients. This was confirmed by Kruskal–Wallis H test (Level: 0: saplings without regeneration cores; 1: saplings with sapling regeneration cores)

| Number of sample plots | Frequency distribution of natural sapling under different CCD gradients |
|------------------------|---------------------------------------------------------------|
|                        | Dense (D–CCD) | Sparse (S–CCD) | Canopy gap (G–CCD) |
|                        | Position in sample plots (Figure 3) | Position in sample plots (Figure 3) | Position in sample plots (Figure 3) |
| 1                      | D1 0          | S1 1           | G1 1           |
| 2                      | D2 0          | S2 1           | G2 1           |
| 3                      | D3 0          | S3 1           | G4 1           |
| 4                      | D4 0          | S4 1           |                |
| 5                      | D5 0          | S5 0           | G5 1           |
| 6                      | S6 1          | S7 1           | G7 1           |
| 7                      | D6 0          | S8 1           |                |
| 8                      | D7 1          | S9 1           |                |
| 9                      | D8 0          |                |                |
| 10                     | D9 0          |                | G8 1           |
|                        | D10 0         | S10 1          | G9 1           |
|                        |                |                | G10 1          |

Homokowski light factor (HLF) in the regeneration cores

Table 4 shows that for both CCD gradients (G–CCD and S–CCD), as Edge 1, Edge 2 and, Main Crop, the HLF ratios were found to exceed 1 but the different groups varied in their values. One–way variance analyses were carried out to test the differences in the G–CCD and S–CCD between Main Crop saplings and both Edge saplings in the regeneration cores. As a result, the assessment established a significant difference for G–CCD (F=4.521; P=0.02) but not for S–CCD (F=1.165; p=0.327). Student–Newman–Keuls (SNK) test was applied to the difference in the G–CCD and two typical separate groups were determined 1) Main Crop saplings and 2) Both Edge samples (Table 4). There were no significant variations between the G–CCD and S–CCD for HLF ratios for each zone in the regeneration core (Main Crop saplings: t=-1.458; P=0.162, Edge 1: t=0.243; P=0.811 and Edge 2: t=-0.092; p=0.928) (Tables 4 and 5).

The growth in the regeneration core after the second cutting (thinning and felling) of upper story

The properties of individuals in regeneration cores

Compared with saplings in the middle of a regeneration core or cluster, those on the edge were always shorter with μ value (Table 2). These μ value differences were found for the S–CCD (Edge 1: 1.86±0.57m; Main Crop: 2.27±0.51m; Edge 2: 1.92±0.37m) and for the G–CCD (Edge 1: 1.79±0.49m; Main Crop: 2.83±0.89m; Edge 2: 2.07±0.43m). Because of height differentiation between edges and main crop the regeneration core form was determined (Table 2; Fig. 3). The distribution of saplings in different height classes in the sapling regeneration cores revealed they were shorter beneath the canopy than beyond the canopy (Fig. 3). These were statistically significant between the Main Crop and Edge 1 of the regeneration core for G–CCD (t=-2.317; α =0.036), but not significant for S–CCD (t=-1.213; P=0.24) (Table 2). This suggests that sapling regeneration cores were more typical under G–CCD conditions than under S–CCD.

One–way Variance Analyses (ANOVA) were carried out to test the differences in sapling age under the G–CCD and S–CCD between Main Crop saplings and both Edge saplings in the regeneration cores. There was no significant difference (G–CCD: F= 1.891; p= 0.17, S–CCD; F= 1.122; p= 0.340) for sapling age (Table 3).
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González-Martínez & Bravo, 2001; Valkonen et al., 2002; Montes & Canellas, 2007) and in土耳其 (Pamay, 1962). However, the characteristics of naturally occurring saplings of Scots pine under the different CCD gradients are poorly studied. Estimates of CCD are also becoming increasingly important in forest management (Ganey & Block, 1994; Korhonen et al., 2006) and the demand for natural landscapes, the multi-resource use of forests and the high cost of considered (10–12 years), naturally occurring Scots pine saplings are shade-tolerant in that whilst growth is suppressed they do survive.

### Discussion and Conclusions

There is an abundant literature on population structure and factors affecting natural regeneration in Scots pine in Europe (González-Martínez & Bravo, 2001; Valkonen et al., 2002; Montes & Canellas, 2007) and in Türkiye (Pamay, 1962). However, the characteristics of naturally occurring saplings of Scots pine under the different CCD gradients are poorly studied. Estimates of CCD are also becoming increasingly important in forest management (Ganey & Block, 1994; Korhonen et al., 2006) and the demand for natural landscapes, the multi-resource use of forests and the high cost of...
The practical application of this study requires determination of critical gradients below–CCD (D–CCD, S–CCD and G–CCD) for satisfactory sapling survival and growth of Scots pine. This must then be linked to observations of field light regimes. The studies have revealed a significant relationship between CCD gradients and regeneration core of saplings (P:0.000). Decreased canopy cover had a significant positive effect on sapling growth and this has been found by most plantations all help to focus European foresters’ attention on natural regeneration (González–Martínez & Bravo, 2001). In this context long–term experiments to determine the interactions between different CCD gradients (G–CCD, D–CCD and S–CCD), the regeneration cores of natural Scots pine saplings (Fig. 3), and the effects on sapling growth rates (Table 1–5) and more have been reported by Pamay (1962), Genc (2004) and Odabasi et al. (2004).

| Number of sample plots | Sparse (S–CCD) | Canopy gap (G–CCD) |
|------------------------|----------------|--------------------|
|                        | Place in sample plots (Figure 3) | Edge 1 | Main crop | Edge 2 | Place in sample plots (Figure 3) | Edge 1 | Main crop | Edge 2 |
| 1                      | S1             | 22                | 22       | 18      | G1     | 18                | 21       | 18      |
| 2                      | S2             | 16                | 20       | 13      | G2     | 15                | 21       | 16      |
| 3                      | S3             | 21                | 22       | 19      | G3     | 23                | 32       | 19      |
| 4                      | S4             | 19                | 22       | 19      | G4     | 19                | 22       | 20      |
| 5                      | S5             | 15                | 17       | 18      | G5     | 17                | 17       | 17      |
| 6                      | S6             | 19                | 16       | 18      | G6     | 16                | 19       | 20      |
| 7                      | S7             | 12                | 16       | 16      | G7     | 15                | 19       | 20      |
| 8                      | S8             | 19                | 20       | 19      | G8     | 14                | 16       | 16      |
| 9                      | S9             | 20                | 22       | 22      | G9     | 20                | 19       | 16      |
| 10                     | S10            | 20                | 21       | 20      | G10    | 18                | 16       | 19      |

**Table 3.** The age distributions in the sapling regeneration cores. Data and statistical analysis from twenty regeneration cores (n = 10, v = 9, t= 2.262), μ (Eq.3). This was confirmed by Student’s t–test (α= 0.05): Arithmetic mean of 95% confidence interval of total population

|                        | **Statistical analysis** |
|------------------------|--------------------------|
|                        | **Levene's Test for Equality of Variances** | **t–test for Equality of Means** |
|                        | F            | Sig. | t        | df | Sig. (2-tailed) | Mean Dif. | Std. Error Dif. | 95% Confidence Interval of the Difference |
| **S–CCD**               |              |      |          |    |                |           |                |                                  |
| Edge 1 and main crop   | .194         | .665 | -1.195   | 18 | .247 NS        | -1.500    | 1.2547          | -4.1361 1.1361                           |
| Edge 2 and main crop   | .514         | .483 | -1.453   | 18 | .164 NS        | -1.600    | 2.72            | -1.600 1.101                            |
| **G–CCD**               |              |      |          |    |                |           |                |                                  |
| Edge 1 and main crop   | .643         | .433 | -1.588   | 18 | .130 NS        | -2.700    | 1.700           | -6.271 0.871                           |
| Edge 1 and main crop   | 2.022        | .272 | 1.342    | 18 | .196 NS        | 2.100     | 1.565           | -1.188 5.388                            |
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ents), which is consistent with some previous studies (Kuuluvainen *et al*., 1993). As stated by Tegelmark (1998), regeneration core of naturally–occurring Scots pine saplings is potentially important in future stand development and sapling properties change with the evolving stages of the stand. As with Beckage *et al*., (2005), G–CCD had only a slight positive effect on seedling survival, and the benefit was offset by a large negative effect of understorey shrubs. This study also found, like Pamay (1962) that high overstorey densities

Table 4. Statistical analysis of difference for HLF ratios between Main Crop saplings and both Edge saplings in the regeneration core with different CCD gradients. This was confirmed by one–way variance analyses (ANOVA) and Student–Newman–Keuls (SNK)

| Number of sample plots | Sparse (S–CCD) | Canopy gap (G–CCD) |
|------------------------|----------------|---------------------|
|                        | Place in sample plots (Figure 3) | Edge 1 | Main crop | Edge 2 | Place in sample plots (Figure 3) | Edge 1 | Main crop | Edge 2 |
| 1                      | S1             | 1.4 | 1.5 | 1.3 | G1             | 1.4 | 1.5 | 1.5 |
| 2                      | S2             | 1.3 | 1.5 | 1.3 | G2             | 1.1 | 1.4 | 1.3 |
| 3                      | S3             | 1.2 | 1.3 | 1.4 | G3             | 1.6 | 2.3 | 2.0 |
| 4                      | S4             | 1.1 | 1.1 | 1.2 | G4             | 1.3 | 1.4 | 1.2 |
| 5                      | S5             | 1.1 | 1.5 | 1.5 | G5             | 1.3 | 2.0 | 1.5 |
| 6                      | S6             | 2.2 | 1.6 | 1.4 | G6             | 1.5 | 1.8 | 1.0 |
| 7                      | S7             | 0.9 | 1.9 | 1.8 | G7             | 1.1 | 1.5 | 1.5 |
| 8                      | S8             | 1.3 | 1.6 | 1.3 | G8             | 1.0 | 1.7 | 1.7 |
| 9                      | S9             | 1.4 | 1.3 | 1.4 | G9             | 1.5 | 1.6 | 1.1 |
| 10                     | S10            | 1.3 | 1.4 | 1.3 | G10            | 1.3 | 1.4 | 1.2 |

| Statistical analysis | |
|----------------------|------------------|
| $\bar{x}$           | 1.34             |
| $s^2$                | 0.11             |
| $s$                  | 0.34             |
| $n$                  | 10               |
| $\mu$                | $1.34 \pm 0.11$  |

ANOVA

| Sum of Squares | df | Mean Square | F    | Sig. |
|----------------|----|-------------|------|------|
| Between Groups | .134 | 2 | .067 | 1.165 | .327 NS |
| Within Groups  | 1.553 | 27 | .058 |        |
| Total          | 1.687 | 29 |      |        |
| Between Groups | .661 | 2 | .330 | 4.521 | .020' |
| Within Groups  | 1.973 | 27 | .073 |        |
| Total          | .661 | 29 | .330 | 4.521 | .020' |

Student–Newman–Keuls Test (SNK)

| Subsets for alpha = 0.05 | |
|--------------------------|------------------|
| Edge 1                   | 1.3100 |
| Edge 2                   | 1.4000 |
| Main crop                | 1.6600 |

Table 4. Statistical analysis of difference for HLF ratios between Main Crop saplings and both Edge saplings in the regeneration core with different CCD gradients. This was confirmed by one–way variance analyses (ANOVA) and Student–Newman–Keuls (SNK)
(D–CCD) slightly increased sapling growth (Figs. 4 and 5). Lower overstorey densities (G–CCD and S–CCD) substantially increased sapling growth (Figs. 4 and 5). Other key factors were intraspecific competition (González-Martínez & Bravo, 2001; Kuuluvainen & Juntunen, 1998) between saplings placed differently in the regeneration cores (Pamay, 1962), and root competition with mature trees (Valkonen, 2000; Siipilehto, 2006; Montes & Canellas, 2007). Compared with saplings in the middle of regeneration cores (crop sapling), those on the edge were shorter with μ value (α: 0.05; Eq. 3). This also highlights root competition effects and CDD gradients (Valkonen, 2000; Siipilehto, 2006). Examination of the positions of previously removed trees indicated that root system shape and extent resulted from past competition prior to regeneration works (Valkonen, 2000).

The ideas of shade tolerance suggest that there are species–specific physiological and growth adaptations which influence the ability to survive and grow at different levels of light. For example, in low light, shade–tolerant Abies species exhibit reduced height and diameter growth without mortality, but this is not true for pine species (Kobe & Coates, 1997; Mason et al., 2004). Scots pine is a typical shade–intolerant pioneer (Coates & Burton, 1999; Chantal et al., 2003; Ewald, 2007) for which regeneration is practically restricted to open, non–forest vegetation (Ewald, 2007). Its behaviour in native pinewoods in Scotland certainly reflects this. While the broad classification of species as ‘shade tolerant’, ‘intermediate’, or ‘light demanding’ appear to be consistent between regions (Mason et al., 2004). However, the behaviour is not totally fixed and shade tolerance within species may be affected by site quality (Carter & Klinka, 1992). Consequently, the magnitude of the competition effect may vary between geographical areas along with differences in site productivity. However, there is little published research available to evaluate or quantify this hypothesis (Valkonen, 2000). Sapling establishment and development continues out of the dense groups of the younger cohort, under the protection of the low density groups of remaining mother trees. This semi–shade tolerant behaviour found in the southern distribution of Scots pine, i.e. the Sistema Central range, the Iberian Mountain Range and other enclaves in Spain, is quite different from the poor shade tolerance shown by the species in the rest of its distributional area (Montes & Canellas, 2007). Although Scots pine is generally considered a shade intolerant species (Chantal et al., 2003), with increasing site quality it can survive for long periods under a dense forest canopy (Odabasi et al., 2004). Species–specific growth responses show little difference under high available light conditions, but performance at low light levels is generally consistent with shade tolerance rankings in the literature. The exception was that Scots pine shade intolerance was higher than expected (Claveau et al., 2002). The results of stem sampling and correlation and regression analyses, age–height graph and age–periodical height growth graph evaluations showed naturally–occurring sapling of Scots pine in the study area were shade tolerant (Figs. 4 and 5). Some previous studies suggest that Scots pine saplings cannot survive long under a dense forest canopy (Ata, 1995; Genc, 2004). However, as found in this study and earlier investigations (e.g. Pamay, 1962), Scots pine saplings can survive 20–25 years under dense forest canopy (Fig. 3). According to Pamay (1962), this period may be up to 45–60 years in the case of less dense clustering. Pamay described this situation as the “semi–shade type” of Scots pine. This is important since a more detailed understanding of species response to different light levels can help develop appropriate silvicultural prescriptions to promote varied forest structures with improved species diversity. Linked to other decision–making tools this can help inform the potential impacts of different stand management regimes (Mason et al., 2004).

Recent studies of shade tolerance have examined the relationships between mortality and growth in varying

### Table 5. Statistical analysis of HLF ratios between G–CCD and S–CCD for each cluster zone

| HLF ratios | Levene’s Test for Equality of Variances | t–test for Equality of Means | 95% Confidence Interval of the Difference |
|------------|----------------------------------------|-----------------------------|----------------------------------------|
|            | F  | Sig. | t  | df | Sig. (2–tailed) | Mean Diff. | Std. Error Diff. | Lower  | Upper       |
| Between G–CCD and S–CCD |      |      |    |    |               |            |                |       |             |
| Edge 1     | .230 | 637  | .243 | 18 | .811 NS | .03000 | .12351 | -.22949 | .28949 |
| Edge 2     | 4.089 | .058  | -.092 | 18 | .928 NS | .01000 | .10899 | -.23897 | .21897 |
| Main crop  | 2.810 | .111  | -.1.458 | 18 | .162 NS | -.16000 | .10975 | -.39057 | .07057 |

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Canopy cover density and regeneration cores in Scots pine (*Pinus sylvestris* L.) stands

The opportunity arises. Vaat & Vildo (2005) concluded that for Scots pine such management intervention with thinning and opening up the canopy needed to be within the first six years and stand densities radically reduced (recommended to be to the minimum values allowed by forest legislation or guidance). High-density stands will be unsuitable for shelterwood cutting due to shorter crowns and a higher risk of windfall after repeated overstorey removals. This research found sapling survival for 10–14 years under a dense overstorey (D–CCD) without mortality and with growth at a standstill (Figs. 4 and 5). But after the second cutting, lower overstorey densities (G–CCD and S–CCD) released saplings (10–14 years) to growth well and without mortality (Figs. 4 and 5).

It is suggested that key elements to the interpretation of this situation are the local differences and distinctiveness of landscapes, together with variations in forest product extraction and management. This finding relates to the idea that application of “close-to-nature” silviculture in Turkey could significantly reduce the problems facing Turkish forests today. However, it will take time and requires a change from current practices. The application of similar management regimes for all forest zones regardless of stand properties is not sustainable.

![Figure 4](image-url). The examples of the age–height graph of sapling–stems (stem analyses) (Coban, 2007).
to–nature silviculture is the protection and generation of irregular stand structures (multi–layer stand, uneven–aged stands etc.). According to the findings of this study, the stands of parent Scots pine and of young–growth stands (old saplings) may occur together under S–CCD and G–CCD gradients. This is particularly the case where site quality is high. This study concluded that stands of young Scots pine can persist under the shelter of the parental canopy. With this information the practice of suitable forest management can be directed to the protection and maintenance of necessary conditions for sustainability. When developing silvicultural systems for Scots pine forests that would produce structural and compositional features as found in natural forests, there must be a better understanding of the role of microhabitats in regeneration dynamics (Kuuluvainen & Juntunen, 1998).

There is a wealth of good practice and evidence from case studies in Europe that can help inform the future management of this unique resource. In the United Kingdom and Germany, and in mountain regions of Italy and Austria, for example, there are many situations where sustainable forest management is increasingly moving towards ‘close–to–nature’ silviculture. This is generally incorporated into development plans that help sustain local communities through jobs and economic regeneration; the forest seen as a key to success. In particular, the concept of multi–functional forest management, including timber and wood production, sustainable tourism and leisure, wildlife, heritage and forest culture (with local food and drink), begins to provide a potential framework for long–term remediation (Çolak & Rotherham, 2006). To conclude, this study supports the point of view that one of the most important rules of close–

Figure 5. Height growth of saplings within regeneration cores under G–CCD and S–CCD (a) and D–CCD (b) (only 20 saplings from G–CCD and S–CCD, 8 from D–CCD were shown in the graph).
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References

Aksoy H, 1978. Untersuchungen über Waldgesellschaften und Ihre waldbauliche Eigenschaften im Versuchswald Büyükdüz bei Karabük. Istanbul Üniversitesi Orman Fakültesi Yayınları 2332 (237), İstanbul. [In Turkish].

Andrzejczyk T, 2007. Response of Scots pine (Pinus sylvestris L.) young-growth stands to an overstorey canopy in the postoutbreak stands in Pila Forests. Sylvan 151(1): 20-29.

Ata C, 1995. Silvikültür Tekniği. Zonguldak Karaelmas Üniversitesi Yayınları 4(3), Bartın. [In Turkish].

Atici E, 1998. Volume Table of Oriental Beech (Fagus orientalis Lipsky) and the Comparison of Present Situation. J Poplar Fast Growing Forest Trees Res Inst 1(25): 23-48.

Atici E, 2003. Computer supported statistical analysis (GOVAN) of the increment and growth data of individual trees. Review Faculty Forestry, Istanbul University 53(2): 37-55. [In Turkish].

Atici E, Colak AH, Rotherham D, 2008. Coarse Dead Wood Volume of Managed Oriental Beech (Fagus orientalis Lipsky) Stands in Turkey. Invest Agraria: Sist Recursos Forestales 2008 17(3): 216-227.

Beckage B, Clark JS, 2003. Seedling Survival and Growth of Three Forest Tree Species: The Role of Spatial Heterogeneity. Ecology 84(7): 1849-1861. http://dx.doi.org/10.1890/0012-9658(2003)084[1849:SSAGOT]2.0.CO;2.

Beckage B, Lavine M, Clark JS, 2005. Survival of tree seedlings across space and time: estimates from long-term count data. J Ecol 93: 1177-1184. http://dx.doi.org/10.1111/j.1365-2745.2005.01053.x.

Cameron AD, Ives JD, 1997. Use of hemispherical photography techniques to determine the association between canopy openness and regeneration of Scots pine (Pinus sylvestris L.) and downy birch (Betula pubescens Ehrh.) in Ballochbuie native pinewood, north-east Scotland. Scottish Forestry. 51(3): 144-149.

Carter RE, Klinka K, 1992. Variation in shade tolerance of Douglas fir, western hemlock and western red cedar in coastal British Columbia. Forest Ecology and Management 55: 87-105. http://dx.doi.org/10.1016/0378-1127(92)90094-P.

Chantal M, Leinonen K, Kuuluvainen T, Cescatti A, 2003. Early response of Pinus sylvestris and Picea abies seedlings to an experimental canopy gap in a boreal spruce forest. Forest Ecol Manage 176(1-3): 321-336. http://dx.doi.org/10.1016/S0378-1127(02)00273-6.

Claveau Y, Messier C, Comeau PG, Coates KD, 2002. Growth and crown morphological responses of boreal conifer seedlings and saplings with contrasting shade tolerance to a gradient of light and height. Can J Forest Res 32: 458-468. http://dx.doi.org/10.1139/x01-220.

Coates KD, 2000. Conifer seedling response to northern temperate forest gaps. Forest Ecol Manage 127: 249-269. http://dx.doi.org/10.1016/S0378-1127(99)00135-8.

Coates KD, Burton PJ, 1999. Growth of planted tree seedlings in response to ambient light levels in northwestern interior cedar-hemlock forests of British Columbia. Can J Forest Res 29(9): 1374-1382. http://dx.doi.org/10.1139/x99-091.

Coban S, 2007. Research on the natural generation samples of Scots pine (Pinus sylvestris L.) stands in Bolu-Aladag. Master Thesis, Istanbul University, Graduate School of Natural and Applied Sciences, Istanbul, Turkey. [In Turkish].

Colak AH, Calikoglu M, Rotherham ID, 2003. Combining Naturalness Concepts with Close-to-Nature Silviculture. Forstwissenschaftliches Centralblatt, 122: 421-431. http://dx.doi.org/10.1007/s10342-003-0007-1.

Colak AH, Rotherham ID, 2006. A review of the Forest Vegetation of Turkey: its status past and present and its future conservation. Royal Irish Academy, J Biol Environ 106(3): 343-355.

Davis PH, 1965-1988. Flora of Turkey and the East Aegean Islands. Edinburgh University Press. Edinburgh, UK.

Ellenberg H, 1996. Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht, 5. Auflage, Stuttgart, Ulmer.

EUFORGEN 2009. Distribution map of Scots pine (Pinus sylvestris). www.euforgen.org.

Ewald J, 2007. Ein pflanzensoziologisches Modell der Schattentoleranz von Baumarten in den Bayerischen Alpen A Phytosociological Model of Shade Tolerance of Tree Species in the Bavarian Alps. Forum geobotanicum 3:11-19.

Fabjanowski J, Jaworski A, Musiel W, 1974. The use of certain morphological features of the fir (Abies alba Mill.) and spruce (Picea abies Link.) in the evaluation of the light requirements and quality of their up-growth. Orig. Poln. Acta agraria et silvestris, Series silvestris (Warschau & Krakau). 14: 3-29.

Ganey JL, Block WM, 1994. A Comparison of Two Techniques for Measuring Canopy Cover. Western Journal of Applied Forestry 9(1): 21-23.

Genc M, 2004. Silvikültür Temel Esaslari. Süleyman Demirel Üniversitesi Yayınları No: 44, SDÜ Basmevi, Isparta, Turkey. [In Turkish].

Globe, 2005. Canopy Cover and Ground Cover. Field Guide. Land Cover/Biology. Biometry Protocol 9(11): 1-3.

González-Martínez SC, Bravo F, 2001. Density and population structure of the natural regeneration of Scots pine (Pinus sylvestris L.) in the High Ebro Basin (Northern Spain). Ann For Sci 58: 277-288. http://dx.doi.org/10.1051/forest:2001126.

Jennings SB, Brown ND, Sheil D, 1999. Assessing forest canopies and understorey illumination: canopy cover, canopy cover. Forestry 72: 59-74. http://dx.doi.org/10.1093/forestry/72.1.59.

Kalipsiz A, 1981. Statistical Methods. Istanbul University, publication number: 2837/294, Istanbul, Turkey. [In Turkish].
Korhonen L, Korhonen KT, Rautiainen M, Stenberg P, 2006. Estimation of forest canopy cover: a comparison of field measurement techniques. Silva Fennica 40(4): 577-588. http://dx.doi.org/10.14214/sf.315.

Kuuluvainen T, Hokkanen TJ, Järvinen E, Pukkala T, 1993. Factors related to seedling growth in a boreal Scots pine stand: a spatial analysis of a vegetation-soil system, Can J For Res 23: 2101-2109. http://dx.doi.org/10.1139/x93-262.

Kunstler G, Curt T, Bouchaud M, Lepart J, 2005. Growth, mortality, and morphological response of European beech and downy oak along a light gradient in sub-Mediterranean forest. Can J Forest Res 35: 1657-1668. http://dx.doi.org/10.1139/x05-097.

Löf M, Karlsson M, Sonesson K, Welander TN, Collet C, 2005. Competition. Silva Fennica 40(3): 473-486.

Montes F, Canellas I, 2007. The spatial relationships between post-crop remaining trees and the establishment of saplings in Pinus sylvestris stands in Spain. Appl Vegetation Sci 10: 151-160. http://dx.doi.org/10.1685/1402-2001(2007)10[151:TSRBPR2.0.CO;2.

Odabasi T, Caliskan A, Bozkus HF, 2004. Silvikültür Tekniği. Istanbul Üniversitesi Orman Fakültesi, I.Ü. Yayın no: 4459, İstanbul, Turkey. [In Turkish].

Olekyn J, Reich PB, Zytkowski R, Karolewski P, Tjoelker MG, 2002. Needle nutrients in geographically diverse Pinus sylvestris L. populations. Ann For Sci 59: 1-18. http://dx.doi.org/10.1051/forest:2001001.

Pamay B, 1962. Türkiye’de Sarıçam (Pinus sylvestris L.) in tabi Gençlenmesi İmkanları Üzerine Araştırmalar, Orman Genel Müdürlüğünü Yayınları No: 337/31, İstanbul, Turkey. [In Turkish].

Pukkala T, Kuuluvainen T, Stenberg P, 1993. Below-Canopy Distribution Of Photosynthetically Active Radiation and its Relation to Seedling Growth In A Boreal Pinus sylvestris Stand - A Simulation Approach. Scand J Forest Res 8(3): 313-325. http://dx.doi.org/10.1080/02827589309382780.

Ruuska J, Siipilehto J, Valkonen, S. 2008. Effect of edge stands on the development of young Pinus sylvestris stands in southern Finland. Scand J Forest Res 23(3): 214-226. http://dx.doi.org/10.1080/02827580802098127.

Sachs L, 1972. Statistical Methods (Statistique Auswertungsmethoden). Springer-Verlag, Berlin, Heidelberg, New York. http://dx.doi.org/10.1007/978-3-662-10037-4.

Schütz J-PH, 2001. Die Technik der Waldverjüngung von Wäldern mit Ablösung der Generationen. Skript zur Vorlesung Waldbau. ETH-Zentrum, Zürich, Switzerland.

Serin M, 1998. Climatic data for 21 years of Bolu-Serif Yuksel Research Forest Meteorological station. Bati Karadeniz Ormancılık Araştırmaları Enstitüsü Dergisi. Seri no 1.

Siipiletho J, 2006. Height Distributions of Scots Pine Sapling Stands Affected by Retained Tree and Edge Stand Competition. Silva Fennica 40(3): 473-486.

Stanners D, Bourdeau P, 1995. Europe’s Environment-The Dobris Assessment Report. European Environment Agency, Copenhagen, Denmark.

Tegelmark DO, 1998. Site factors as multivariate predictors of the success of natural regeneration in Scots pine forests. Forest Ecol Manage 109: 231-239. http://dx.doi.org/10.1016/S0378-1127(98)00255-2.

Tolunay D, 1997. Aladağ’da (Bolu) Sıklık Cağındaki Sarıçam (Pinus sylvestris L.) Mescelerelinde Bakımların Madde Dolasımına Etkileri. Doktora Tezi, İstanbul, Turkey. [In Turkish].

Vaal T, Vildo M, 2005. Shelterwood cutting in Scots pine (P. sylvestris L.) stands. Transactions of the Faculty of Forestry, Estonian Agricultural University Issue, 38: 53-64.

Valkonen S, 2000. Effects of retained Scots pine trees on regeneration, growth, form and yield of forest stands. Invest. Agraria fora serie 1:121-146.

Valkonen S, Ruuska J, Siipilehto J, 2002. Effect of retained trees on the development of young Scots pine stands in Southern Finland. Forest Ecol Manage 166: 227-243. http://dx.doi.org/10.1016/S0378-1127(01)00668-5.

Wyckoff PH, Clark JS, 2002. The relationship between growth and mortality for seven co-occurring tree species in the southern Appalachian Mountains. J Ecol 90: 604-615. http://dx.doi.org/10.1046/j.1365-2745.2002.00691.x.