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RESEARCH ARTICLE

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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 was 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 silviculturalists 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 (Ruuska *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?

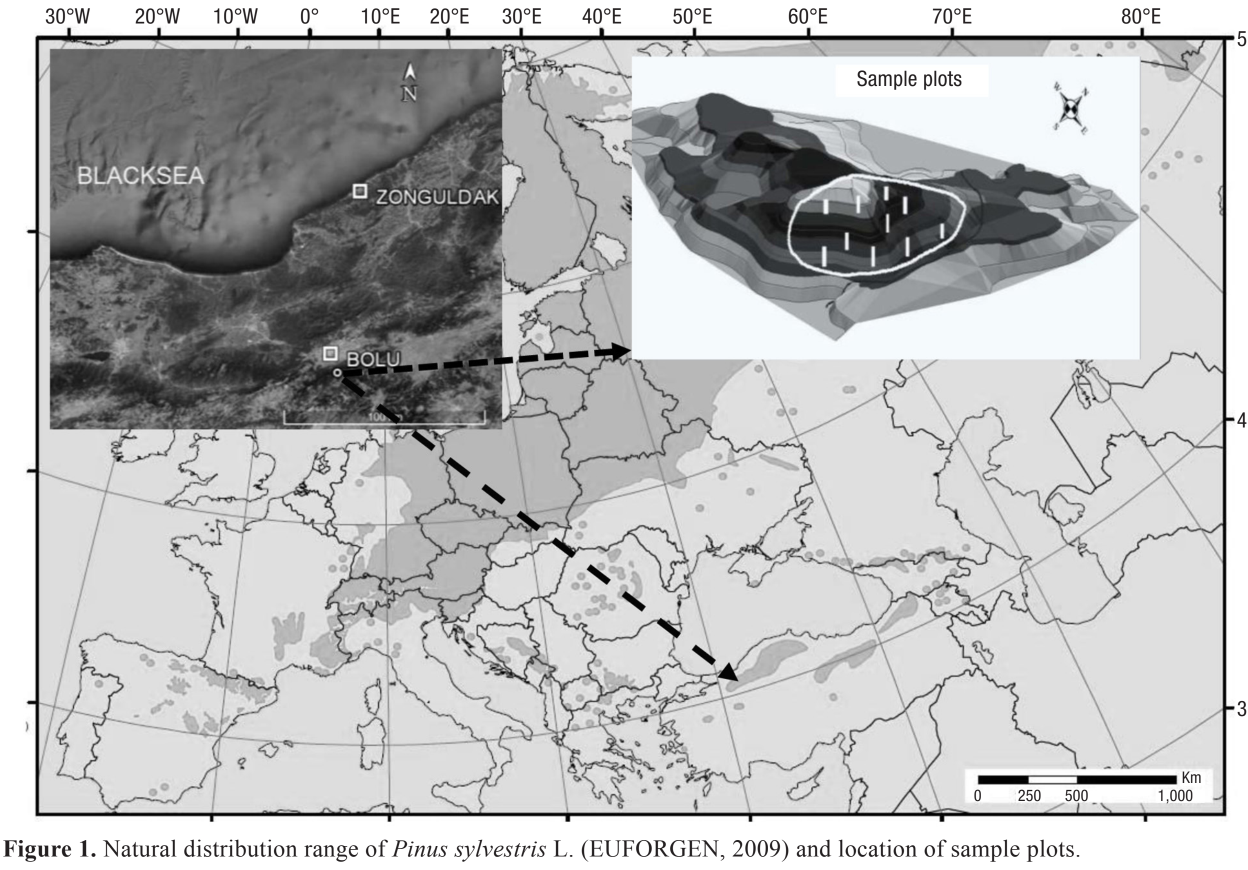

Figure 1. Natural distribution range of *Pinus sylvestris* L. (EUFORGEN, 2009) and location of sample plots.

(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 40º30' and 40º42' N, longitude between 31º39' and 31º52' 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 Istiranca 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"

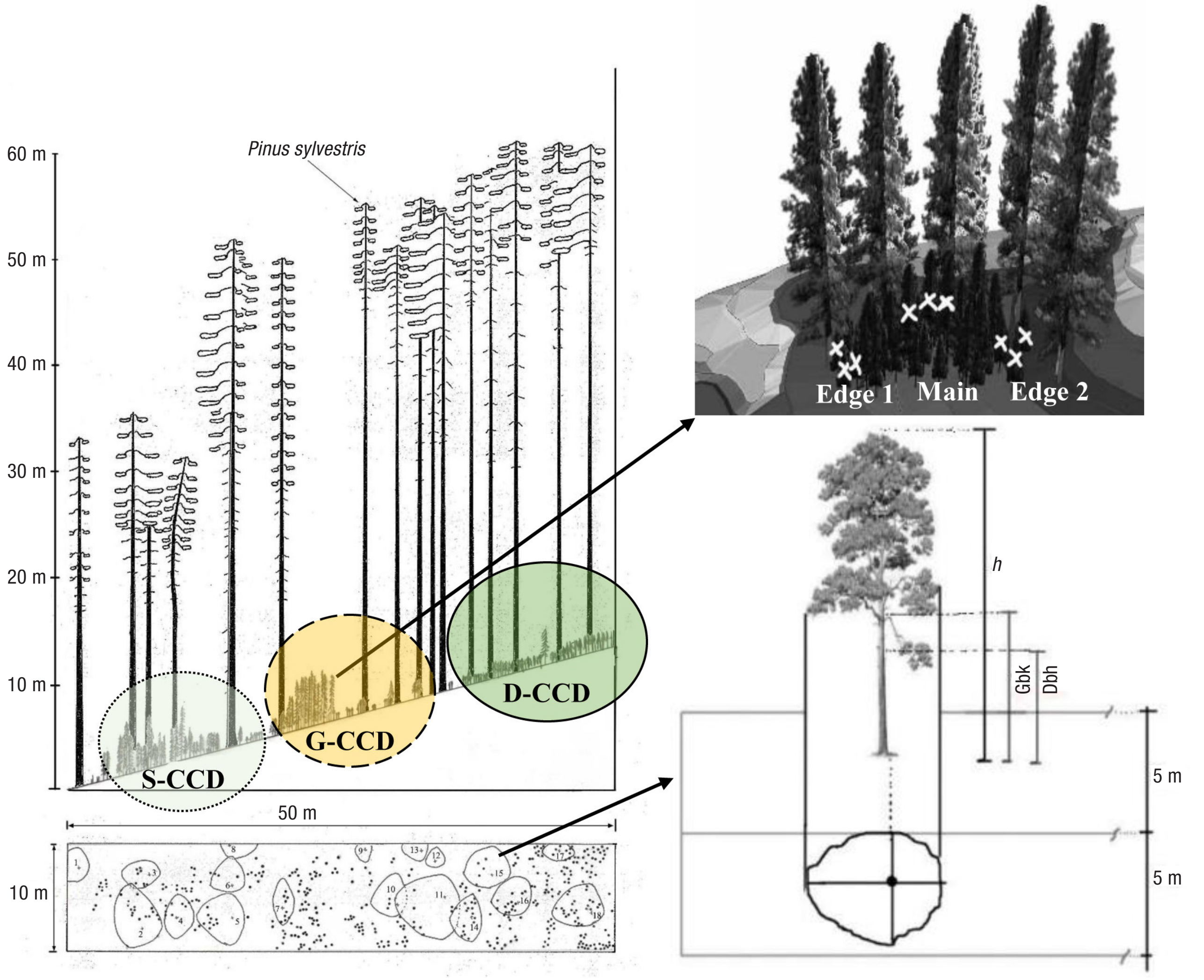

Figure 2. The CCD gradient models of Scots pine stands with three gradients *i.e.* dense (D–CCD: 55%), sparse (S–CCD: 43%) and gap (G–CCD: 87 m^2) (Coban, 2007).

the low site quality) (Forest Management Plan, 2005–2014; Tolunay, 1997).

Selection of Sample Plots

By the end of 1987, shelterwood cutting areas in the 120–year–old Scots pine stands were at a uniform level of shade (dense: D–CCD) resulting from regular thinning and felling. There were 2– to 5–year–old Scots pine seedlings here. After 10 years, in the second half of 1997, the CCD in these stands was assessed and placed into three broad gradients: (1) Dense (D–CCD), (2) Sparse (S–CCD), and (3) Gap (G–CCD) overstorey conditions (Fig. 2). In autumn 2007, samples were separated depending on typical sapling regeneration cores under different CCD within these stands. Sampling in the stands was conducted with a simple random sampling method. Measurements were taken for 10 rectangular (10 × 50 m) sample plots with different CCD gradients and chosen from natural regeneration cores of Scots pine saplings (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 silviculturalists 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 m^2 (All sample plots areas in the canopy gaps were between 25.09 and 95.42 m^2, 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):

$$\text{CCD (\%)} = \frac{\text{VPTC}}{\text{MA}} 100 \qquad \text{(Eq. 1)}$$

VPTC: Vertical projection of the tree crowns (m^2)

MA: Forest floor cover (m^2) 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).

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-

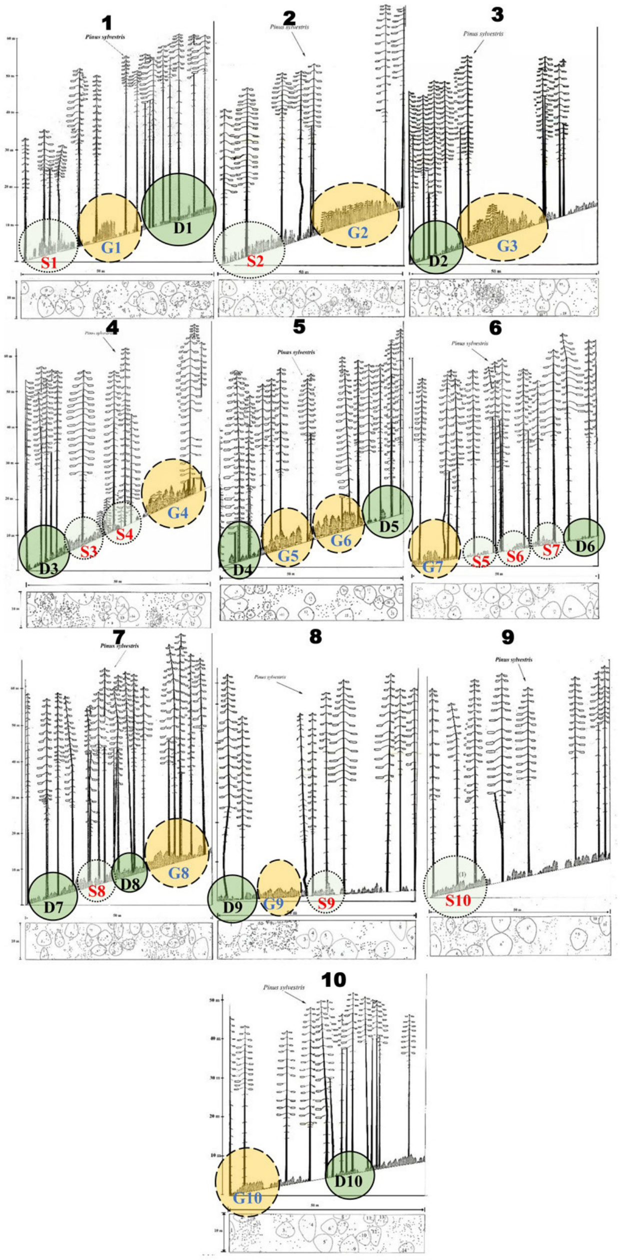

Figure 3. Longitudinal (profile) and vertical stand projection of all sample plots with different CCD gradients (D–CCD: Dense; S–CCD: Sparse; G–CCD: Gap) (Stand profiles from Coban, 2007).

portunity to make computer–based stem analyses to determine the growth relationships of individual trees. Two different forms of graphs of absolute and relative age–height and stem models were drawn with this program. Correlation and regression analyses of the statistical model used for drawing the age–height graph were carried out (Atici, 2003).

Honowski light factor (HLF ratio)

The ratio of Terminal sprout length (T) to Lateral sprout length (L) was presented by Fabjanowski *et al.* (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.

$$\mathrm{HLF} = \frac{\mathrm{T}}{\mathrm{L}} \qquad \text{(Eq. 2; Schütz, 2001)}$$

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):

$$\mu = \overline{x} \pm tSE_{\overline{x}} \qquad \text{(Eq. 3)}$$

Where $\overline{x}$ is arithmetic mean; $SE_{\overline{x}}$ 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)	**Level**	**Position in sample plots (Figure 3)**	**Level**	**Position in sample plots (Figure 3)**	**Level**
1	D1	0	S1	1	G1	1
2			S2	1	G2	1
3	D2	0			G3	1
4	D3	0	S3	1	G4	1
			S4	1		
5	D4	0			G5	1
					G6	1
6	D5	0	S5	0	G7	1
			S6	1		
			S7	1		
7	D6	0	S8	1		
	D7	1	S9	1		
	D8	0				
8	D9	0			G8	1
9	D10	0	S10	1	G9	1
10					G10	1

Frequency distribution

	D–CCD		S–CCD		G–CCD	
Level	0	1	0	1	0	1
Total	9	1	1	9	0	10

Statistical analysis (Kruskal–Wallis H Test)

Descriptive Statistics

N	Mean	Std. Deviation
30	.6667	.47946

Test Statistics

Ch–Square	21.170
df	2
Asymp. Sig.	p<0.001

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).

Honowski 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 results from examination of the age–height graph of sixty sapling–stems (stem analyses) and derived from correlation and regression analyses (*e.g.* Fig. 4) show major differences for growth in height after the first and second cutting stages in the stand. It was found that high overstorey densities (D–CCD) slightly increased sapling growth (Figs. 4 and 5), and lower overstorey densities (G–CCD and S–CCD) substantially increased sapling growth (Figs. 4 and 5). D–CCD gradient exhibited reduced growth in height without mortality, but after the second cutting it was found that the saplings (10–14 years in age) grew very well without any obvious slowing or mortality. This indicates that for the time–periods

Table 2. The effect of CCD gradients on height of saplings in the sapling regeneration core. 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

Number of sample plots	Height (m)							
	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**	3.1	2.8	1.9	**G1**	2.0	3.8	2.1
2	**S2**	2.4	3.0	1,8	**G2**	2.0	4.6	1.8
3	**S3**	2.2	2.8	2.1	**G3**	3.6	5.2	3.7
4	**S4**	1.6	2.5	1.7	**G4**	1.6	2.5	1.7
5	**S5**	1.4	2.4	2.0	**G5**	1.5	2.1	1.8
6	**S6**	0.9	0.9	2.2	**G6**	1.7	1.9	2.0
7	**S7**	0.8	1.4	0.7	**G7**	1.4	2.4	2.2
8	**S8**	2.2	2.1	1.9	**G8**	1.1	2.1	1.6
9	**S9**	2.8	3.0	2.7	**G9**	1.5	1.9	1.9
10	**S10**	1.2	1.8	2.2	**G10**	1.5	1.8	1.9
Statistical analysis $\bar{x}$	-	1.86	2.27	1.92	-	1.79	2.83	2.07
s^2	-	0.63	0.51	0.26	-	0.48	1.54	0.36
s	-	0.80	0.71	0.51	-	0.69	1.24	0.60
$SE_{\bar{x}}$	-	0.25	0.23	0.16	-	0.22	0.39	0.19
n	-	10	10	10	-	10	10	10
μ	-	1.86 ± 0.57	2.27 ± 0.51	1.92 ± 0.37	-	1.79 ± 0.49	2.83 ± 0.89	2.07 ± 0.43

Independent Samples Test

		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	
									Lower	Upper
S–CCD	Edge 1 and main crop	.415	.527	-1.213	18	.241 NS	-.41000	.33805	-1.12022	.30022
	Edge 2 and main crop	2.273	.149	-1.261	18	.224 NS	-.35000	.27763	-.93328	.23328
G–CCD	Edge 1 and main crop	5.242	.034	-2.317	14.089	.036*	-1.04000	.44883	-2.00206	-.07794
	Edge 1 and main crop	7.409	.014	-1.744	12.996	.105 NS	-.76000	.43566	-1.70122	.18122

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 Turkey (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

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

Number of sample plots		**Age (year)**							
		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
Statistical analysis	$\bar{x}$	-	18.30	19.80	18.20	-	17.50	20.20	18.10
	s^2	-	9.34	6.40	5.73	-	7.39	21.51	2.99
	s	-	3.06	2.53	2.39	-	2.72	4.64	1.73
	$SE_{\bar{x}}$	-	0.97	0.80	0.76	-	0.86	1.47	0.55
	$\boldsymbol{n}$	-	10	10	10	-	10	10	10
	μ	-	18.30 ± 2.19	19.80 ± 1.81	18.20 ± 1.71	-	17.50 ± 1.94	20.20 ± 3.32	18.10 ± 1.24

Independent Samples Test

		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**	
									Lower	**Upper**
S–CCD	Edge 1 and main crop	.194	.665	-1.195	18	.247$^{\text{NS}}$	-1.500	1.2547	-4.1361	1.1361
	Edge 2 and main crop	.514	.483	-1.453	18	.164$^{\text{NS}}$	-1.600	1.101	-3.914	.71420
G–CCD	Edge 1 and main crop	.643	.433	-1.588	18	.130$^{\text{NS}}$	-2.700	1.700	-6.271	0.871
	Edge 1 and main crop	2.022	.272	1.342	18	.196$^{\text{NS}}$	2.100	1.565	-1.188	5.388

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).

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

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		**HLF ratios**							
		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**	1.3	1.4	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	1.50	1.39	-	1.31	1.66	1.40
	s^2	-	0.11	0.03	0.03	-	0.04	0.09	0.09
	s	-	0.34	0.18	0.17	-	0.20	0.30	0.30
	$s_{\bar{x}}$	-	0.11	0.06	0.05	-	0.06	0.09	0.10
	n	-	10	11	12	-	13	14	15
	μ	-	1.34 ± 0.57	1.50 ± **0**.58	1.39 ± **0**.59	-	1.31 ± 0.60	1.66 ± 0.61	1.40 ± 0.62

ANOVA

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
S–CCD	Between Groups	.134	2	.067	1.165	.327 ^{NS}
	Within Groups	1.553	27	.058		
	Total	1.687	29			
G–CCD	Between Groups	.661	2	.330	4.521	.020*
	Within Groups	1.973	27	.073		
	Total	.661	2	.330	4.521	.020*

Student–Newman–Keuls Test (SNK)

			Subset for alpha = 0.05	
		N	1	2
G–CCD	Edge 1	10	1.3100	
	Edge 2	10	1.4000	
	Main crop	10		1.6600
	Sig.		.463	1.000

studies in the past (Pamay, 1962; Genc, 2004; Odabasi *et al*., 2004; Valkonen, 2000).

The maximal regeneration core of sapling was found in the G–CCD, followed by S–CCD and finally D–CCD (Table 1). Similar responses were found by Pukkala *et al*. (1993) with the correlation between the radiation parameters and Scots pine sapling growth significantly positive. The variation in height growth of Scots pine seedlings seems to be caused mostly by the spatial heterogeneity of the stand (i.e. different CCD gradients), 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 5. Statistical analysis of HLF ratios between G–CCD and S–CCD for each cluster zone

Independent Samples Test										
	HLF ratios	Levene's Test for Equality of Variances		t–test for Equality of Means						
Between G–CCD and S–CCD		F	Sig.	t	df	Sig. (2–tailed)	Mean Dif.	Std. Error Dif.	95% Confidence Interval of the Difference	
									Lower	Upper
	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

(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

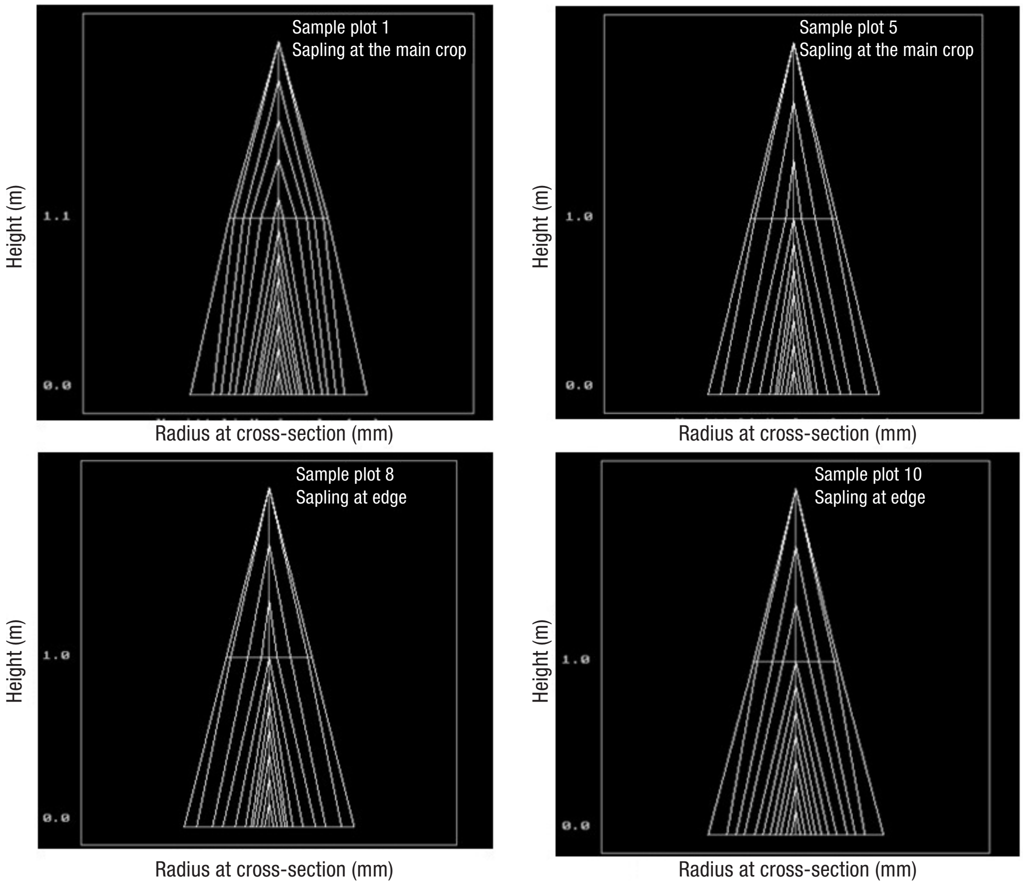

Figure 4. The examples of the age–height graph of sapling–stems (stem analyses) (Coban, 2007).

light conditions (Kobe *et al*., 1995; Kobe & Coates, 1997; Wyckoff & Clark, 2002; Kunstler *et al*., 2005; Löf *et al*., 2007). In these studies, the interactions between CCD gradients and Scots pine sapling regeneration cores was on the basis of trade–offs between the ability to survive at D–CCD gradients and to achieve a high growth rate at G–CCD and then S–CCD. Edge 1, Edge 2 and, Main Crop HLF ratios (α:0.05) were found to be more than 1 for both CCD gradients (G–CCD and S–CCD). According to this value, the growth potential can be defined as high (Eq. 2; After Fabjanowski *et al*., 1974 from Schütz, 2001). The results of HLF ratio assessments and stem analyses drawn by correlation and regression analyses, age–height graphs and age–periodical height increment graphs show the growth of sapling regeneration cores to be affected by CCD gradients. It was found that growth continued rapidly in CCD gradients at G–CCD and S–CCD; a response to thinning after 12–14 years suppression by parent trees. In published research it has been suggested that older suppressed saplings were degenerated individuals which under a dense forest canopy lost their vigour (Ata, 1995). However, as this study indicates, these older saplings retain their growth potential during the time of suppression and can recover when 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 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 survive 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.

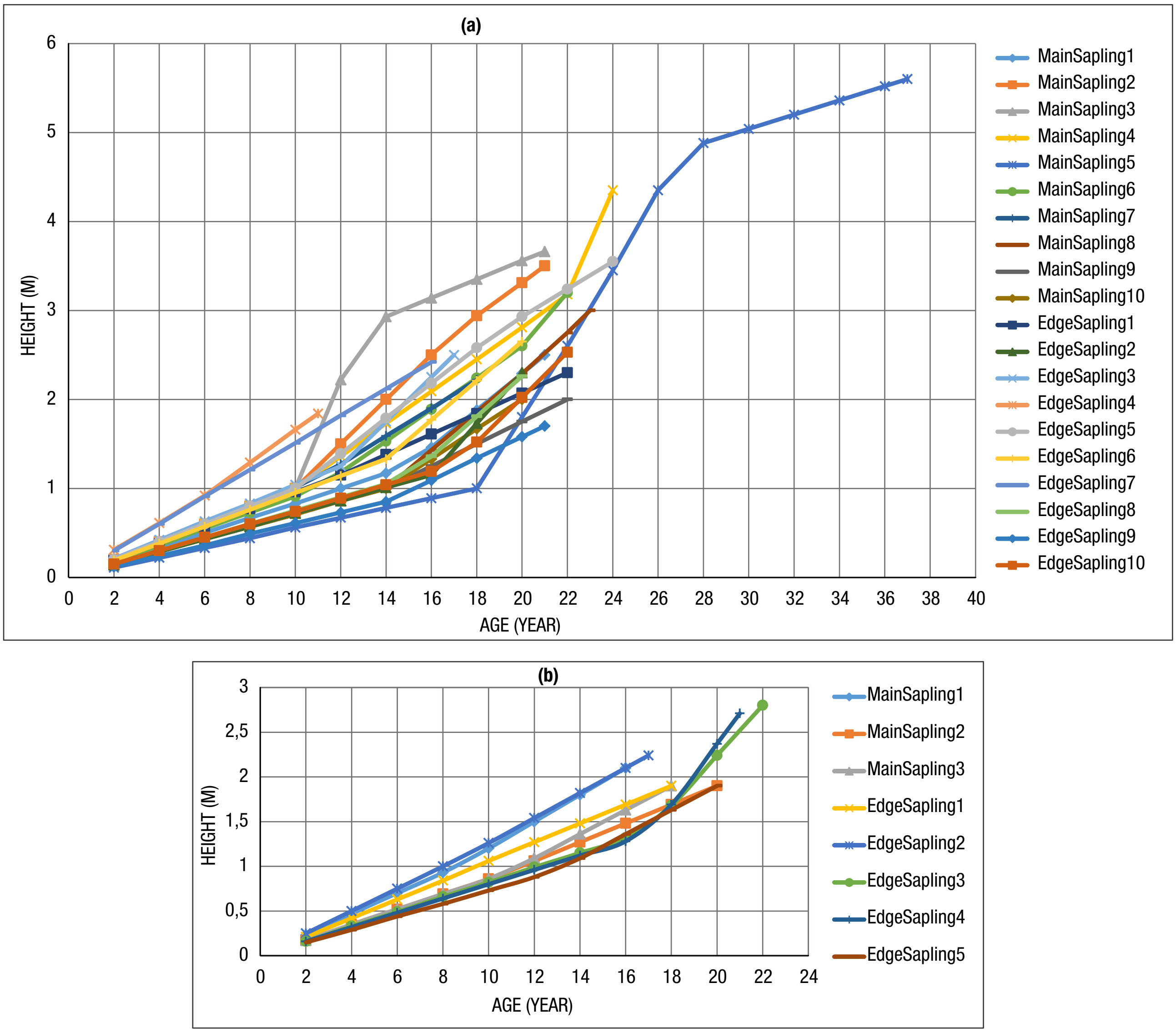

Figure 5. Height growth of saplings within regeneration cores under G–CCD and S–CCD (a) and D–CCD (b) (only 20 saplings from G–CCD and S–CCD, 8 from D–CCD were shown in the graph).

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–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).

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