Stand development and structural analysis of planted *Pinus nigra* stands in northern Greece

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Abstract
The objective of this study was to analyze structure, growth and function of *Pinus nigra* stands artificially established 40 years ago in a large area surrounding Mt. Olympus. The appropriate selection of tree species and the success of the reforestation were evaluated. Ninety sample plots were selected where all trees were measured and their overstorey position and stem-form quality were estimated. The results showed that the studied stands were mostly in a mature thick pole phase. The productivity of stands was satisfactory, but still more appropriate silvicultural treatments need to be applied.
Keywords: artificial stand; growth; selection thinning; species selection; stand structure.

1. INTRODUCTION

Forest plantations are necessary for restoring natural forest ecosystems after intense degradation and when natural regeneration cannot be used [14]. In Greece, degradation activities such as illegal felling, land clearing, overgrazing and forest fires occur repeatedly since ancient times, therefore many forests are degraded and great reforestation projects are strongly needed [6].

Plantation stands are usually managed for sustainable development, public benefit with low monetary costs and they generate ecologically healthy forests for multiple purpose [13]. Structure and growth of planted stands depend on the site quality in terms of the environmental factors that interact, alter, and substitute one another [2]. However sustainable management of forest ecosystems relies on the knowledge of stand conditions [4]. The determination and correlation of specific ecological factors that impact in stands are necessary for the applied silvicultural treatments for goal – oriented plantations. Studies on artificially planted forests analyzing their structure, yield and function are needed to provide answers about site suitability for each tree species used and for the estimation of reforestation success. *Pinus nigra* Arnold var. *austriaca* has been widely used in reforestations in Greece, France and in other parts of the world [8]. In Greece, it has been mainly used in reforestation projects in the phytosociological zone of *Quercetalia pubescentis* and higher in the *Fagetalia* zone.

The objective of this study was to analyze structure, growth and function of planted *P. nigra* stands in a large area surrounding Mt. Olympus. In particular, the current research analyzed the structural characteristics of the stands as well as the differences among the different site qualities, in terms of stand structure, composition and tree growth. The acquisition of knowledge on the stand conditions and their function as artificial ecosystems will contribute to a more appropriate and complete planning of reforestation programs [18]. Planted stands are established within a physical matrix, which is a complex of physical, chemical and biotic factors. So, environmental auditing and a long-term monitoring system are both necessary to describe plantation impacts [14].

2. MATERIALS AND METHODS

The research area is located primarily around Mt. Olympus and to a lesser extent, around Mt. Titaros. It occupies an area of approximately 900 ha and the altitude is 800 m to 1450 m. According to the climatic data, the area is classified as a humid bioclimate with hard winter [11]. Geologically, the research area is dominated by schists, gneisses and in a smaller scale by limestones [12]. The soils are characterized of medium depth, mostly silty-clay and less sandy-clay [16].

For the analysis of the stands structure, 90 sampling plots were taken of 500m^2 (10 m x 50 m). The stratified random sampling was applied for the selection of the sample plots [10]. To determine the strata, the tree species, the site type and the age class of the trees were taken into account. Within each stratum the sample plots were randomly selected. In all sample plots the trees with dbh (diameter at breast height) above 4cm were measured and the measurements included were: Dbh (cm), height (m), crown length (m). Also the overstorey position of the tree was recorded according to IUFRO classification [9].

The stand structure data was analyzed according to the site type classification [16]. Within each site, the data was categorized according to the age class and for each age class according to the tree species composition. The mean and standard deviation of dbh, height, crown length were estimated for each storey position. The vitality, the developmental tendency, the stem quality, the basal area (m ha^{-1}) the stem density (stems ha^{-1}), were estimated for each storey position and totally [17]. The tree vitality is classified in three classes: a. 10, trees of vigorous growth b. 20, trees of normal growth and c. 30, trees of declining growth. The developmental tendency is classified in three classes: a. 1, trees with "upward" tendency b. 2, trees with medium growth tendency and c. 3, and trees with descendant future growth. The stem quality is classified in three categories: a. 40, good quality, b. 50, normal quality and c 60, "worse" quality [9].

The stem distribution in dbh classes of 1 cm and in height classes of 1m. was carried out. Non - parametric goodness of fit test was conducted in stem distributions by using the Kolmogorov – Smirnov criterion [15]. Pearson coefficient was estimated as additional test criterion for stem distributions. Data analysis was carried out using SPSS v. 10.0 statistical programme.

3. RESULTS

3.1 Site types I, II, III

Pure *Pinus nigra* stands appear in the largest part, while mixed stands of *P. nigra* with *Quercus dalechampii* are less frequent in Site type I. *Quercus conferta* and *Ostrya carpinifolia* are commonly found in both pure and mixed stands. Site type II is formed mainly by pure *P. nigra* stands. To a lesser degree, mixed stands with *Q. dalechampii* dominated mainly and less with *Q. conferta* were found. Site type III was found in upper and middle positions of the slopes. Pure *P. nigra* stands were found with sporadic occurrence of *Quercus* sp. trees. According to vegetation data, the site types are found in subzones *Quercion confertae*, *Ostryo carpinion*, and Fagetalia zone [1]. The site types occur in NW, N, NE, S, SE, and SW aspects.

3.1.1 Structure and growth of pure Pinus nigra stands in site types I, II, III

The average age of the *P. nigra* stands was 37-41 years and the dominant height was 12.5-17 m. The stands were classified in the mature phase and mostly in a transition stage from thick poles to thin stems [18]. Most of the stems were in overstorey and accounted for 75-93% of the basal area (Table 1). The middlestorey trees had 12-37% of the stem density and represented 7-25% of the

stand basal area while the understorey consisted of a few trees. The dominant stand comprised mainly individuals with normal to vigorous growth (Table 1). Normal growing trees appeared in middlestorey, and there was a tendency for cachectic growth. The understorey had cachectic growth and descendant trees (Table 1). Stem quality was characterized as good to normal (overstorey), to worse for the middle -understorey. Few dead and forked trees represented 5% of the stem density.

K-S tests showed that the dbh distribution of all trees in the stands didn't follow the normal distribution. The distribution showed a single top curve of bell-shaped form with a slightly right asymmetry (Pearson coefficients: 0.19-0.30) and even aged structure (Fig. 1). Heights distribution did not follow the normal distribution according to the K-S criterion (Fig. 2). The height distribution appeared to have a left asymmetry (Pearson coefficients: 0.47-0.98). This is due to the middlestorey individuals, which had grouped in the height classes of 7 and 9 m. However stands were one-storey even aged.

Table 1. Results of structural analysis of pure *Pinus nigra* stands in site quality I.

	a	**b**	**c**	**d**	**e**	**f**	**g**
	Mean (SD)	**Mean (SD)**	**m^2/ha**	**N/ha**	**Mean**	**Mean**	**Mean**
Overstorey	18.84 (5.12)	12.58 (1.58)	43.79	1419	17.49	1.78	48.80
Middlestorey	10.30 (3.72)	7.41 (1.33)	3.17	202	23.14	2.64	58.18
Understorey	6.45 (2.30)	3.89 (0.83)	0.29	22	27.27	2.88	59.39
Total	17.62 (5.83)	11.83 (2.47)	47.25	1643	18.31	1.90	50.09
SITE QUALITY II							
	a	**b**	**c**	**d**	**e**	**f**	**g**
	Mean (SD)	**Mean (SD)**	**m^2/ha**	**N/ha**	**Mean**	**Mean**	**Mean**
Overstorey	18.53 (5.01)	11.19 (1.66)	39.18	1349	18.89	1.92	49.56
Middlestorey	10.37 (3.97)	6.77 (1.23)	5.71	223	23.88	2.63	57.97
Understorey	7.81 (2.61)	3.62 (0.86)	0.21	11	27.62	2.90	59.52
Total	17.31 (5.68)	10.52 (2.29)	45.09	1583	19.65	2.03	50.81
SITE QUALITY III							
	a	**b**	**c**	**d**	**e**	**f**	**g**
	Mean (SD)	**Mean (SD)**	**m^2/ha**	**N/ha**	**Mean**	**Mean**	**Mean**
Overstorey	18.64 (4.76)	9.52 (1.48)	28.13	836	19.07	1.93	50.13
Middlestorey	10.73 (4.26)	6.29 (0.92)	9.42	509	22.00	2.34	55.50
Understorey	6.78 (2.54)	3.63 (0.47)	0.08	29	25.63	2.69	58.75
Total	15.46 (6.05)	8.19 (2.12)	36.85	1374	20.29	2.09	52.30

a: dbh = diameter breast height, b= height, h = total tree height, c: Σg = total basal area, d: n = stems density, e: vit. = vitality, f: dt = developmental tendency, g: sq = stem quality, SD = standard deviation.

3.1.2 Structure and growth of mixed pine-oak stands

The stands were characterized mixed pine-oak, and *Quercus* sp. was the intermixed species with a degree of admixture of ~30%. The mean age was 36-37 years and the dominant height, was 14-15m. *P. nigra* and *Quercus* sp. belong to the thick poles stage. Single medium and larger stems have interspersed, observed in stands of both pine and oak species, which survived a fire and functioned as regeneration centers for *Quercus* sp. and probably for *P. nigra*.

The overstorey had 76-82% of the basal area while the middlestorey had 16-21% and is characterized as Pine – Oak mixedwood. (Table 2). *P. nigra* had 80-84% of its basal area and 48-65% of its stem density in the overstorey. About 66-77% of *Quercus* basal area was in the overstorey. The middlestorey was considered as mixed stand and *Quercus* sp. degree of mixture varies. The understorey had few trees of ~2% of the basal area (Table 2). The overstorey and middlestorey comprised mainly normal growing trees. On the contrary, the understorey trees were descended, with cachectic growth. Stems quality was characterized as normal to worse (Table 2). Forked and dead trees were equated to 3-8% and 4-5% of the stem density respectively.

K-S tests of normality on the dbh distribution showed that it did not follow the normal distribution. The distribution showed a strong right asymmetry (Pearson coefficient: 1.06-3.60) which is due to the mother *Quercus* and *P. nigra* trees in stands. The dbh distribution had a bell, single top shape

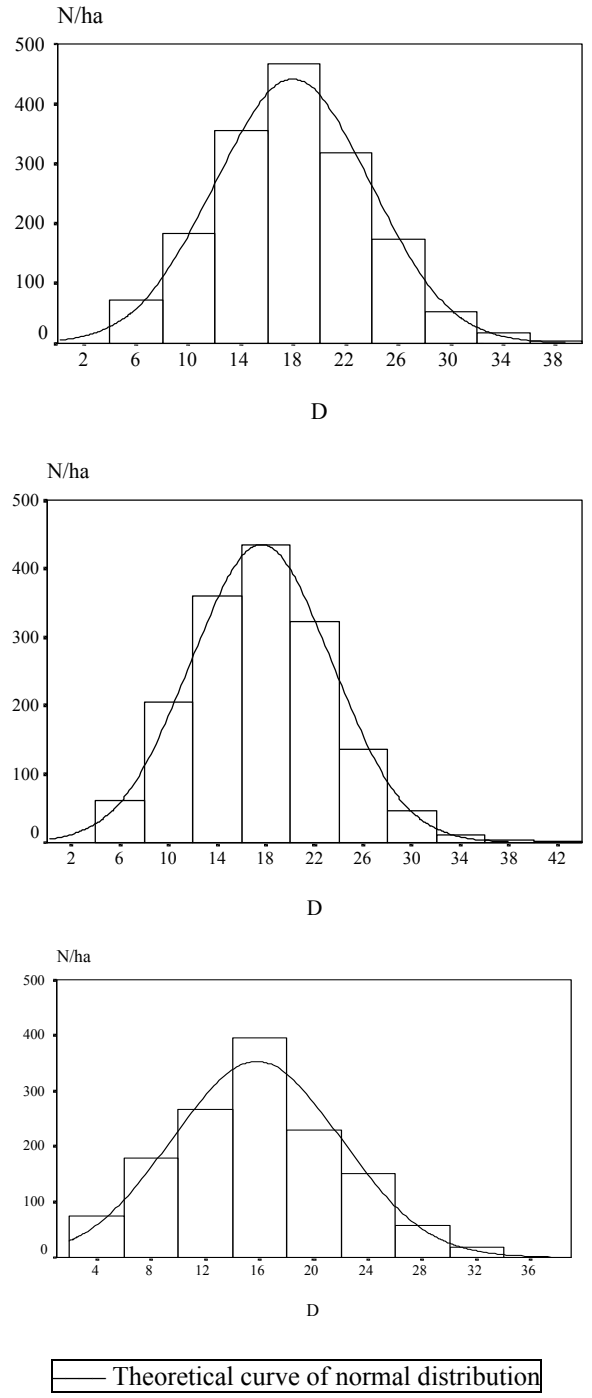

Figure 1. Dbh distribution of pure *Pinus nigra* stands in site I, II, III in dbh midpoint classes.

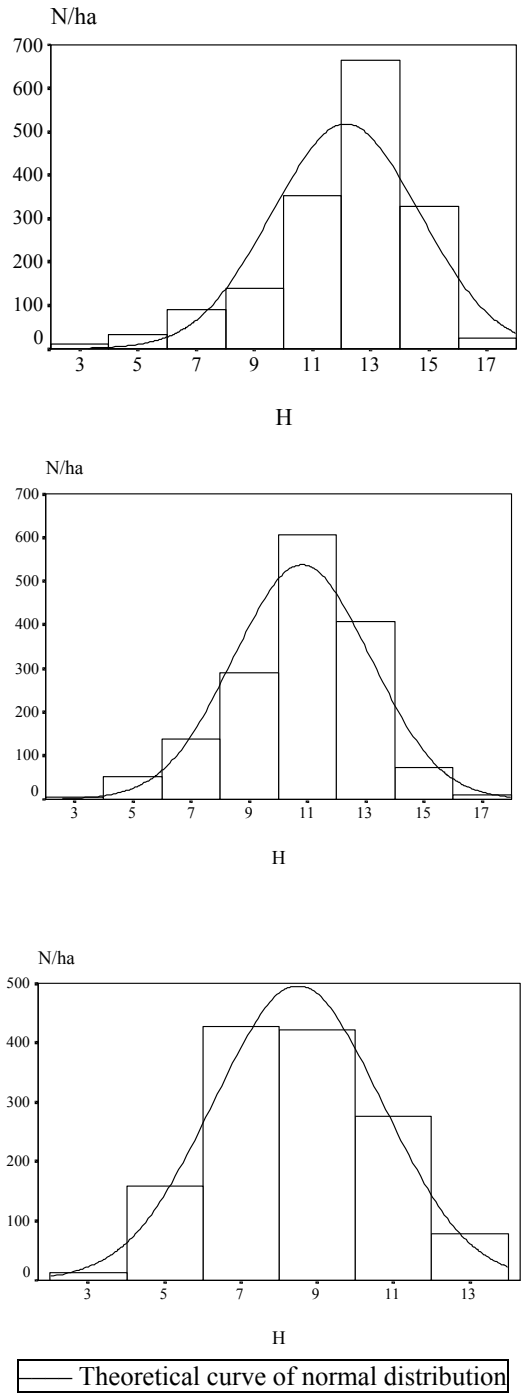

Figure 2. Heights distribution of pure *Pinus nigra* stands in site I, II, III.

with an even aged structure (Fig. 3). The height distribution did not follow the normal distribution and this is due to the middlestorey trees. About 85% of the total trees of the middlestorey was observed in height classes of 5, 7 and 9 m (Fig. 4).

3.1.3 Structure and growth of mixed pine-hophornbeam stands

The average age of the Pine - hophornbeam stands was 35 years and the dominant height was ca 12.5 m. *P. nigra* dominated the stands with sporadic occurence of *Ostrya carpinifolia* and *Quercus*

Table 2. Results of structural analysis of mixed Pine – Oak and Pine – Hophornbeam stands.

SITE QUALITY I		**a**	**b**	**c**	**d**	**e**	**f**	**g**
		Mean (SD)	**Mean (SD)**	**m^2/ha**	**N/ha**	**Mean**	**Mean**	**Mean**
Overstorey	*Pinus nigra*	17.91 (4.63)	12.48 (1.41)	24.71	864	17.25	1.84	48.81
	Quercus sp.	15.65 (8.02)	10.91 (1.41)	9.19	304	20.13	2.07	55.66
Total		17.32 (5.78)	12.07 (1.58)	33.90	1168	17.98	1.89	50.55
Middlestorey	*Pinus nigra*	8.84 (3.22)	7.11 (1.46)	3.97	376	23.30	2.69	56.38
	Quercus sp.	9.73 (3.28)	7.34 (1.55)	2.58	248	20.65	2.24	58.71
Total		9.19 (3.26)	7.20 (1.49)	6.55	624	22.24	2.51	57.31
Understorey	*Pinus nigra*	8.15 (2.47)	3.79 (0.57)	0.81	92	24.78	2.87	60.00
	Quercus sp.	5.89 (1.36)	4.00 (0.83)	0.16	36	24.44	2.89	60.00
Total		7.52 (2.42)	3.85 (0.65)	0.98	128	24.44	2.89	60.00
Total	*Pinus nigra*	14.68 (6.05)	10.36 (3.29)	29.49	1332	19.46	2.14	51.68
Total	*Quercus* sp.	12.55 (6.98)	8.98 (2.58)	11.93	588	20.61	2.19	57.21
Total		14.00 (4.97)	9.91 (3.17)	41.42	1920	19.81	2.16	53.40
SITE QUALITY I		**a**	**b**	**c**	**d**	**e**	**f**	**g**
		Mean (SD)	**Mean (SD)**	**m^2/ha**	**N/ha**	**Mean**	**Mean**	**Mean**
Overstorey	*Pinus nigra*	12.01 (4.23)	11.50 (1.48)	16.10	1050	17.71	1.85	49.24
	Ostrya carp.	9.86 (2.41)	9.62 (0.95)	4.46	500	19.80	1.98	55.80
Total		11.32 (3.87)	10.89 (1.60)	20.56	1550	18.39	1.89	51.35
Middlestorey	*Pinus nigra*	6.33 (1.65)	5.90 (1.15)	2.70	820	24.39	2.54	55.85
	Ostrya carp.	6.57 (1.58)	7.25 (0.96)	1.00	140	20.71	2.07	58.57
Total		6.36 (1.63)	6.07 (1.23)	3.70	960	23.85	2.47	56.25
Understorey	*Pinus nigra*	5.11 (1.83)	3.57 (0.39)	0.31	140	23.57	2.43	56.43
	Ostrya carp.	0	0	0	0	0	0	0
Total		5.11 (1.83)	3.57 (0.39)	0.31	140	23.57	2.43	56.43
Total	*Pinus nigra*	9.21 (4.40)	8.66 (3.30)	19.11	2010	20.85	2.17	52.44
Total	*Ostrya carp.*	9.14 (2.63)	9.10 (1.36)	5.46	640	20.00	2.00	56.41
Total		9.19 (4.04)	8.77 (2.95)	24.57	2650	20.64	2.13	53.40

a: dbh = diameter breast height, b: height, h = total tree height, c: Σg = total basal area, d: n = stems density, e: vit. = vitality, f: dt = developmental tendency, g: sq = stem quality, SD = standard deviation.

sp. as intermixed species. *Q. carpinifolia* was in the overstorey and the middlestorey with admixture 22% and 27% respectively. About 35% of the stems belongs to the thick poles stage and 63% of the stems belongs to the thin poles stage. The overstorey was characterized as a mixed stand of Pine-hophornbeam. It had 59% of the stem density and 84% of the basal area. The middlestorey was considered as a mixed species group and it had 36% of stem density and 15% of the basal area. The understorey comprised few *P. nigra* trees with ca. 1% of the basal area. Many *P. nigra* trees were found in the overstorey (52%) followed by the middlestorey (41%). *P. nigra* had 84% of the basal area. *O. carpinifolia* had 78% of stem density and 82% of basal area in the overstorey (Table 2). The overstorey development was characterized as vivid with few normal growing trees. Normally growing individuals were in the middlestorey and there was a tendency of cachectic growth for *P. nigra* trees. The understorey trees were remnants thus had cachectic growth. Stems quality was characterized as medium in the overstorey and worse in the middlestorey. In the stands, 120/ha of dead *P. nigra* trees were found. The total stem distribution doesn't follow the normal distribution (figure 5). The analyses of the overstorey dbh distribution showed a single top curve of bell- shaped form and even-aged structure. Also the height distribution doesn't follow the normal distribution. *P. nigra* trees were gathered in height classes of 5-7 m and 11-13 m (Fig. 6).

4. DISCUSSION

The studied *P. nigra* stands were classified in three site types. All the stands were even aged and

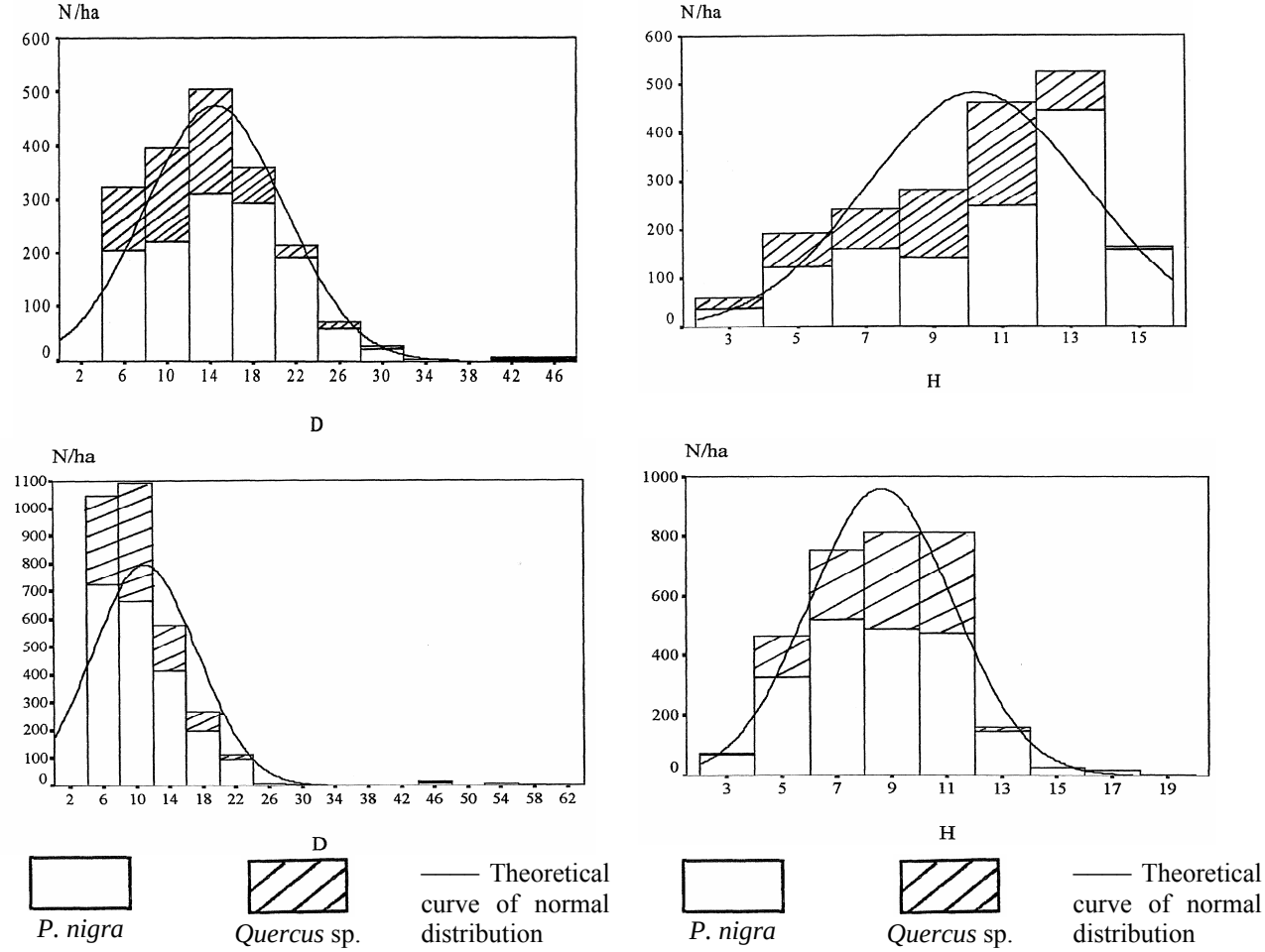

Figure 3. Dbh distribution of Pine - Oak mixed stands in site I, II, unfilled is pine and stuffed block is oak.

Figure 4. Heights distribution of Pine - Oak mixed stands in site I, II, unfilled is pine and stuffed block is oak.

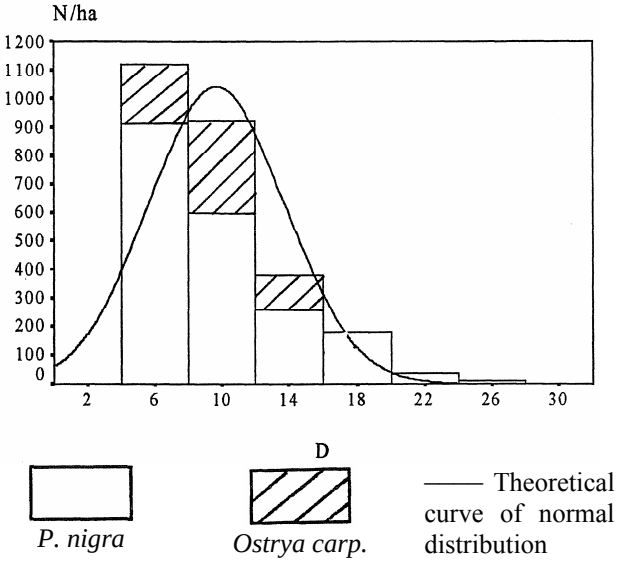

Figure 5. Dbh distribution of Pine – hophornbeam mixed stands in site I.

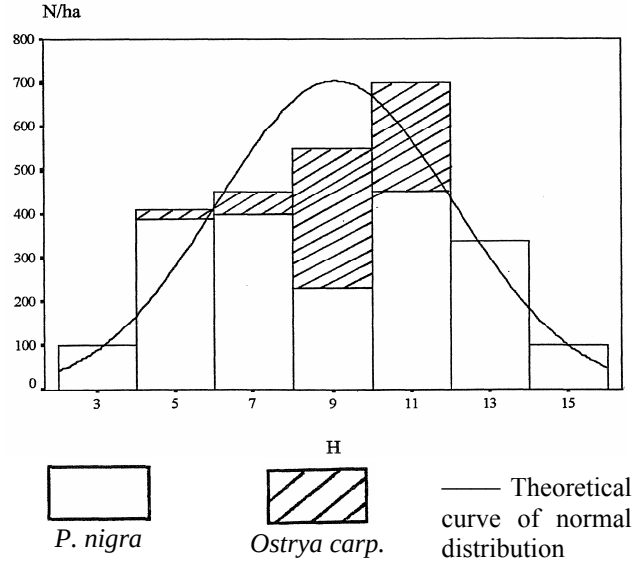

Figure 6. Heights distribution of Pine – hophornbeam mixed stands in site I.

Table 3. Results of structural analysis of mixed Pine – Oak stands in site quality II.

		a	b	c	d	e	f
		Mean (SD)	**Mean (SD)**	**m^2/ha**	**N/ha**	**Mean**	**Mean**
Overstorey	*Pinus nigra*	14.80 (7.36)	10.53 (1.79)	24.31	1010	18.96	1.98
	Quercus sp.	13.79 (5.83)	10.04 (1.03)	9.00	495	19.60	1.98
Total		14.47 (6.90)	10.37 (1.60)	33.30	1505	19.17	1.98
Middlestorey	*Pinus nigra*	7.20 (2.21)	6.64 (1.32)	5.14	915	21.86	2.35
	Quercus sp.	7.59 (1.99)	7.05 (1.42)	4.14	505	20.50	2.19
Total		7.34 (2.14)	6.79 (1.37)	9.27	1420	21.37	2.29
Understorey	*Pinus nigra*	5.83 (2.14)	3.83 (0.62)	0.66	165	24.55	2.64
	Quercus sp.	5.83 (2.19)	4.44 (0.68)	0.54	45	23.33	2.56
Total		5.83 (2.13)	3.96 (0.68)	1.20	210	24.29	2.62
Total	*Pinus nigra*	10.76 (6.63)	8.30 (2.75)	30.11	2090	20.67	2.19
Total	*Quercus* sp.	10.45 (5.32)	8.36 (2.08)	13.67	1045	20.19	2.11
Total		10.66 (6.22)	8.32 (2.54)	43.78	3135	20.51	2.16

a: dbh = diameter breast height, b: height, h = total tree height, c: Σg = total basal area, d: n = stems density, e: vit. = vitality, f: dt = developmental tendency, g: sq = stem quality, SD = standard deviation.

according to the dominant trees, they were classified as either pure pine stands or as mixed pine-oak or pine- hophornbeam stands. The presence of broadleaved species in the mixed stands was a result of the resprouting of the existed species before planting. However the pure stands occupied a larger part of the study area compared to the mixed stands. The site III occupied the smallest area.

Stem density was high in all cases, a fact attributed to the dense planting spacing and lack of thinning. Also, a high stem density was found in planted pine stands in Chalkidiki (Northern Greece), at class age 30-40 years, with 1460 stems per hectare in site type I, 2100 stems per hectare in site type II and 1860 trees per hectare in site type III [5].

The dominant height was 16.5 m, 14 m, 12.5 m for sites I, II, III respectively. In [3], *P. nigra* stands in southern Britain had dominant heights 15m and 22.4m at ages of 33 and 43 years respectively. The diameter growth and the stem density were affected by the site. This explains why almost the same mean dbh were found in site types I and II. The basal area fluctuated at the same levels in site types I and II while it was smaller in site type III.

The vitality and developmental tendency concluded that growth was better in site I than in site II and III. In general, stands were characterized as normal growing, with trees of medium growth tendency. The stem quality was at medium levels for site I and II and worse in III. The results in this case would have been better if the appropriate silvicultural measures had been taken according to the stands developmental stage. Stem – form of forked trees was found in site I (9% of the trees) while in site II and III the percentage of such stems were 5% and 3%, respectively. Dead stems were 5%, 3.3% and 2% of the total stem density for site I, II and III respectively. Stems dbh distribution followed the normal distribution with small standard deviations. Most individuals belong to the phase of thick poles in almost all the stand categories. In some stands, mostly pure, a certain percentage of trees (15%-30%) is placed in the phase of thin stems. In mixed stands of *P. nigra – Q. carpinifolia*, the biggest percentage of trees is found in the phase of thin poles. This is attributed to the strong competition among forest species and the existence of the secondary stand.

5. CONCLUSION

Based on the findings, the use of *P. nigra* to restore the degraded ecosystems around Mt. Olympus was deemed as successful. The productivity of stands is good and it probably would have been even better if the necessary silvicultural treatments had been taken. For site I and site II, a high good

quality timber production is feasible. However, the protective and water management purposes are also important, because many stands were established near and around mountain villages. The recreational and aesthetical impact of these stands is important and the mixed stands contributed to multiple-use and enhanced biodiversity [7]. In site III areas, more attention should be paid to the investigation related to the potential of protecting the soil from erosion. The silvicultural treatments proposed, are the positive selection thinnings [9].

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