

# The Influence of Position and Site on the Height Growth of Young *Populus tremula* L. Ramets in Low Elevation Formations in Northeastern Greece

Elias MILIOS<sup>1\*</sup>, Elias PIPINIS<sup>2</sup>, Petros PETROU<sup>3</sup>, Sofia AKRITIDOU<sup>4</sup>,  
Kyriaki KITIKIDOU<sup>1</sup>, Paulos SMIRIS<sup>2</sup>

<sup>1</sup>Democritus University of Thrace, Department of Forestry and Management of the Environment and Natural Resources, Pantazidou 193, 682 00 Orestiada, Greece; [emilios@fmenr.duth.gr](mailto:emilios@fmenr.duth.gr) (\*corresponding author), [kkitikid@fmenr.duth.gr](mailto:kkitikid@fmenr.duth.gr)

<sup>2</sup>Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Silviculture, 54124 Thessaloniki, Greece; [epipinis@for.auth.gr](mailto:epipinis@for.auth.gr), [psmiris@for.auth.gr](mailto:psmiris@for.auth.gr)

<sup>3</sup>Cyprus Forestry College, Prodromos, 4841 Cyprus; [pepetrou@fd.moa.gov.cy](mailto:pepetrou@fd.moa.gov.cy)

<sup>4</sup>Prefecture of Xanthi, Dioikitirio, 67100 Xanthi, Greece; [sopak@hotmail.com](mailto:sopak@hotmail.com)

## Abstract

This study was carried out in the central part of Nestos Valley in northeastern Greece. The main objective was to examine the effect of different position (dominant, suppressed, side-shaded) and site productivities on the height growth of young *Populus tremula* L. clonal ramets in low elevation formations of the species. Fifty-four ramets growing in different positions and sites were cut and studied. Stem analysis was conducted and the height of each ramet at the age of 10 years was calculated. The main results of this research indicate that the dominant ramets on good productivity sites have greater height at the age of 10 years, when compared with the corresponding ramets on medium productivity sites. On the contrary, in suppressed and side-shaded ramets, there is no statistically significant difference in height at the age of 10 years between the two site types. This pattern indicates that competition is the procedure that characterizes the relationships between ramets in the investigated formations. The heights of dominant *P. tremula* ramets presented in this study are very satisfactory for the species, compared with the height of *P. tremula* trees from other regions of the species expansion reported in other studies.

**Keywords:** competition, dominant ramets, European aspen, side-shaded ramets, suppressed ramets

## Introduction

*Populus tremula* L. is a widely distributed Euro-Siberian tree species (Christensen, 1997). In Greece, it is found as a constituent of damp mixed forests of altitudes between 600 and 1500 m (Christensen, 1997). In a few cases, it has even been observed in lower altitudes.

*Populus tremula* L. is a pioneer, light-demanding species growing in areas varying widely in climatic conditions, soil, and site quality (Athanasiadis, 1986; Johanson, 1996; Suvanto and Latva-Karjanmaa, 2005; Worrell, 1995a). It is a dioecious tree species, which can be reproduced both sexually and asexually (Suvanto and Latva-Karjanmaa, 2005). Even though *P. tremula* flowers and produces enormous numbers of viable seeds almost every year (Latva-Karjanmaa *et al.*, 2003; Worrell *et al.*, 1999), successful sexual reproduction is considered to be rare due to low survival rate of the seedlings (Latva-Karjanmaa *et al.*, 2003). On the other hand, Milios *et al.* (2000) found *P. tremula* seedlings on the slopes of an abandoned road in the central Rhodope Mountains of Greece. Generally, reproduction occurs mainly asexually through root suckers

(Johanson, 1996; Suvanto and Latva-Karjanmaa, 2005; Worrell, 1995a). Regeneration of root suckers leads to clonal structure where one clone usually consists of several interconnected trees (ramets) or single nonconnected trees, which are identical in their genotype (Suvanto and Latva-Karjanmaa, 2005; Svensson *et al.*, 2005). According to Johanson (1996), *P. tremula* grows in small stands (0.1-0.5 ha), most of them consisting of a single clone. However, in nine 1-ha study plots in Finland, Suvanto and Latva-Karjanmaa (2005) found many clones in each plot.

There are many studies concerning *P. tremula* in the northern part of Europe since it is a common species, as well as an important component of northern forests, contributing substantially to their biodiversity (Hamberg *et al.*, 2010; Hedenäs and Ericson, 2008; Johanson, 1996; Suvanto and Latva-Karjanmaa, 2005; Van Bogaert *et al.*, 2009; Worrell, 1995a; Worrell, 1995b). Moreover, there is an increased interest in *P. tremula* wood in northern Europe (Johanson, 1996; Rytter, 2006; Yu *et al.*, 2001).

Even though there are many studies on the growth of *P. tremula* in many areas, mainly European (Harrison, 2008; Johansson, 1996; Kitikidou *et al.*, 2012; Misir, 2010; Op-

dahl, 1992), there is not sufficient knowledge regarding growth performance of the species under shaded conditions. Therefore, research on the growth behavior of *P. tremula* under different shaded conditions and sites contributes to a better insight of the species ecology.

The aim of this study is to investigate the effect of different positions (that describe subjection of ramets to different light conditions) and site productivities, as well as the influence of their interaction on the height growth of young *P. tremula* clonal ramets, in low elevation formations of the species, in the central part of the Nestos Valley in northeastern Greece.

## Materials and methods

### Study sites

The study was carried out in the central part of the Nestos river valley. This area is located in the south of the central Rhodope Mountains in northeastern Greece close to the Bulgarian border. The studied stands are located in the southern part (41°12' to 41°13' N, 24°37' to 24°40' E) of the Kalivas-Margaritiou public forest. One of the closest meteorological stations is that of Echinus situated at an elevation of 300 m about 43 km away from our area. On average the annual rainfall is 771 mm, while the mean annual temperature is 12.1°C. It is considered that the climatic conditions of Echinus are close to those of the studied stands.

Small stands (approximately 0.01-0.6 ha) and groups of *P. tremula* are scattered in an area of approximately 1000 ha. The substratum is gneiss (in a small area it is limestone) and soil textures are sandy-clay to loamy-sand (Miliou and Theodoridis, 2006). Some alluvial deposits are also present. Almost all stands are located at (or near) the base of slopes, on upper slope positions, or on flat areas at the top of mainly small hills. The majority of these stands grow on abandoned fields. In these formations, which consist of *P. tremula* clones, most trees are interconnected through their root system. The altitude ranges between 100 and 220 m and the dominant slopes are 0-15%.

Moreover, in the study area there are small stands and groups, which consist mainly of *Quercus* spp., *Carpinus orientalis*, *Corylus avellana*, *Fraxinus ornus*, *Populus* spp., *Cornus mas*, *Acer campestre*, *Ostrya carpinifolia*, etc.

### Methods

On good productivity sites (i.e. site type A), nine sample plots of 25 m<sup>2</sup> (5×5), which consist of young ramets, were established in three *P. tremula* small stands (three in each stand) during the summer of 2005. In each plot, one dominant ramet under full light and one suppressed, i.e. under shade (see Oliver and Larson, 1996) ramet, were cut according to the stratified random sampling method. Moreover, in site type A, in other three *P. tremula* small stands, which mainly consist of older ramets, nine sample plots (three in each stand) of 12 m<sup>2</sup> (6×2) were established

in their periphery, according to the simple random sampling method. In each plot, one side-shaded ramet (i.e. a ramet under side shade of much taller trees) was cut. This ramet was selected randomly from the three tallest side-shaded ramets in the plot. In site type A, 27 ramets were cut. The same procedure was followed in medium productivity sites (i.e. site type B). In each site type, the nine sample plots of young ramets mentioned above were established using the simple random sampling method in areas having approximately the same ramet density. This procedure was followed to approximately secure the same shade conditions for the suppressed ramets. The crowns of suppressed ramets in all cases were under the general level of dominant and codominant ramets. In total, 54 ramets were cut in both site types. Their height ranged from 3.75 to 13.6 m. For each ramet cut, the upper root system was excavated and examined. In the case of suppressed ramets, their upper root system was excavated more extensively, to investigate whether there was a connection with a dominant ramet. The majority of the areas where the plots were established are found in surrounding areas of sparse vegetation cover that alternate with bare vegetation fields.

From each ramet, cross-sectional discs were cut and removed at stump height (0.3 m), at breast height (1.3 m), and at 2-m intervals, up to the bole (3.3 m, etc.). The last disc was collected from the 5-cm bole diameter. When a ramet had small dimensions, the discs at stump height (0.3 m) and at breast height (1.3 m) were cut. These discs were taken to the laboratory to count the number of rings using a stereoscope with a ring width measurement device. The height of each ramet at the age of 10 years was calculated using the stem analysis technique of the modified Carmean's method (Carmean, 1972; Newberry, 1991). The age of 10 years was used since it was the age of the youngest ramet that was cut.

The site characterization of an area in terms of productivity was made using a two-stage procedure (see Adamopoulos et al., 2009). In stage 1, the distinction was based on the shape of the terrain and the location of the area, as regards the inclined plots (see Barnes et al., 1998; Dafis, 1986). The plots situated at (or near) the base of the slopes in concave or approximately flat areas were considered to belong to site type A (good productivity sites). On the other hand, those located a) in gentle slope or convex or approximately flat surfaces in more or less upper slope positions and b) in approximately flat areas at the top of mainly small hills were considered to belong to site type B (medium productivity sites). Lower slopes with concave surfaces have deeper soils, are moister, and more fertile than upper convex slope areas (see Barnes et al., 1998; Dafis, 1986). Moreover, soil depth and water-storing capacity determine, to a large extent, the soil and site productivity in most Greek forests (Dafis, 1986; Hatzistathis and Dafis, 1989). In stage 2, the site productivity distinction of stage 1 was evaluated and verified using height growth data of dominant ramets. Specifically, all the dominant ramets

that were cut in the nine plots of site type A had a higher height than the corresponding dominant ramets that were cut in the nine plots of site type B (for the same ages). The height of dominant trees is closely related to site quality and in even aged stands, it is usually used as an index of a site's growth potential (Oliver and Larson, 1996; Smith *et al.*, 1997).

Even though each ramet that was cut was connected with other ramets, genetic analysis of the ramets in each plot was not done. Moreover, the root system of all ramets in the plots was not excavated to make sure whether all ramets are interconnected with each other. As a result, it is not certain that all ramets in the plots of each one of the small stands (in each site type) belong to the same clone; so each small stand is considered to consist of at least one clone (or more). On the other hand, in each site type, the distances (hundreds of meters) between the stands where the plots were established, in combination with the existence of roads, areas of sparse vegetation, and abandoned fields between them (in almost all cases) ensure that the ramets that were cut belong to different clones.

#### Experimental Design and Statistical Analysis

The data collection scheme of the height of ramets (at the age of 10 years) applies to the following experimental design: The ramet is considered to be the experimental unit. The design includes two factors <<between>> the experimental units. The factors are: a) the "ramet position" (FP) with three levels, dominant (FP<sub>D</sub>), suppressed (FP<sub>S</sub>), and side-shaded (FP<sub>SS</sub>) ramets, and b) the "site" (FS) with two levels, site type A (FS<sub>TA</sub>) and site type B (FS<sub>TB</sub>).

The height data were analyzed using the ANOVA method (Gomez and Gomez, 1984; Sit, 1995) in the frame of the General Linear Models (GLM), while the comparisons were made using the Bonferroni test (Klockars and Sax, 1986; Toothaker, 1993).

The GLM that corresponds to our experimental design includes the main effects of the "site" and "ramet position", as well as the interaction of these two factors. All statistical

analyses were carried out using the SPSS software (SPSS, Inc., USA).

At this point, should be noted that even though ramets' independence was not verified, the independence assumption for ANOVA is strongly related to the assumption for sampling units random selection (Algina and Olejnik, 2003; Turner and Thayer, 2001). The independence of observations within and between samples can be determined from the design of the study, i.e., it is based on the way data are collected; the sample plots were established by applying simple random sampling, and, in each plot, the ramets (or ramet) that were cut were selected randomly.

#### Results

In both site types, in most plots, the suppressed ramet was younger than the dominant ramet (usually by 1 year). However, in two plots of site type B and in one in site type A, the suppressed ramets (that were under shade) had the same age as the dominant ramets. Moreover, the majority of the ramets that were cut (dominant, suppressed, and side-shaded) were between 10 and 12 years old.

All ramets that were cut were connected through their roots to at least one other ramet. These ramets were not necessarily adjacent. All suppressed ramets were connected with dominant ramets. This connection in many cases was in the frame of a complex root system.

The ANOVA analysis indicated that the factors "ramet position" and "site" as well as their interaction have a statistically significant influence on the height of ramets at the age of 10 years ("ramet position":  $F(2,48) = 86.344$ ,  $p = 0.000$ , "site":  $F(1,48) = 26.656$ ,  $p = 0.000$ , "site"  $\times$  "ramet position":  $F(2,48) = 8.255$ ,  $p = 0.001$ ).

The dominant ramets from site type A have greater height at the age of 10 years on average, compared with the corresponding ramets in site type B ( $p < 0.05$ ) (Tab. 1). On the contrary, in suppressed and side-shaded ramets, there is no statistically significant difference in height at the age of 10 years between the two site types (Tab. 1).

Tab. 1. Mean height of *P. tremula* ramets at the age of 10 years for the two levels of the factor "site", in each of the levels of the factor "ramet position" (interaction between the factors "ramet position" and "site")

Ramet position	Site	Height of ramets at the age of 10 years (m)		n
		Mean	S.D.	
<sup>1</sup> FP <sub>D</sub>	<sup>4</sup> FS <sub>TA</sub>	10.95 <sup>a</sup>	0.835	9
	<sup>5</sup> FS <sub>TB</sub>	7.81 <sup>b</sup>	1.255	9
<sup>2</sup> FP <sub>S</sub>	FS <sub>TA</sub>	5.34 <sup>a</sup>	0.765	9
	FS <sub>TB</sub>	4.92 <sup>a</sup>	1.080	9
<sup>3</sup> FP <sub>SS</sub>	FS <sub>TA</sub>	6.04 <sup>a</sup>	1.252	9
	FS <sub>TB</sub>	5.10 <sup>a</sup>	1.113	9

In each level of the factor "ramet position", the height means of the two "site" levels are significantly different at  $p < 0.05$  when they share no common letter. The comparisons were made using the Bonferroni test

1. FP<sub>D</sub>: dominant ramets, 2. FP<sub>S</sub>: suppressed ramets, 3. FP<sub>SS</sub>: side-shaded ramets, 4. FS<sub>TA</sub>: site type A, 5. FS<sub>TB</sub>: site type B, 6. S.D.: Standard Deviation

Tab. 2. Mean height of *P. tremula* ramets at the age of 10 years for the three levels of the factor “ramet position”, in each of the levels of the factor “site” (interaction between the factors “site” and “ramet position”)

Site	Ramet position	Height of ramets at the age of 10 years (m)		n
		Mean	<sup>6</sup> S.D.	
<sup>1</sup> FS <sub>TA</sub>	<sup>3</sup> FP <sub>D</sub>	10.95 <sup>a</sup>	0.835	9
	<sup>4</sup> FP <sub>S</sub>	5.34 <sup>b</sup>	0.765	9
	<sup>5</sup> FP <sub>SS</sub>	6.04 <sup>b</sup>	1.252	9
<sup>2</sup> FS <sub>TB</sub>	FP <sub>D</sub>	7.81 <sup>a</sup>	1.255	9
	FP <sub>S</sub>	4.92 <sup>b</sup>	1.080	9
	FP <sub>SS</sub>	5.10 <sup>b</sup>	1.113	9

In each level of the factor “site”, the height means of the three levels of “ramet position” are significantly different at  $p < 0.05$  when they share no common letter. The comparisons were made using the Bonferroni test.

1. FS<sub>TA</sub>: Site type A, 2. FS<sub>TB</sub>: Site type B, 3. FP<sub>D</sub>: dominant ramets, 4. FP<sub>S</sub>: suppressed ramets, 5. FP<sub>SS</sub>: side-shaded ramets, 6. S.D.: Standard Deviation

In both site types, on average, the dominant ramets exhibited greater height at the age of 10 years than the suppressed and side-shaded ramets ( $p < 0.05$ ), while there is no statistically significant difference between the suppressed and side-shaded ramets (Tab. 2).

## Discussion

In nonclonal tree species, the result of the tree differentiation process of even aged stands is the development of a dominance hierarchy (Perry, 1994). In this process, where the rich get richer and the poor get poorer (Perry, 1994), the dominant trees became larger than the average trees in the stands (Smith *et al.*, 1997). The same pattern is observed in the young small clonal *P. tremula* stands and groups of the present research. The dominant ramets under full light were taller than the suppressed and side-shaded ramets ( $p < 0.05$ ), at the age of 10 years in both site types.

Svensson *et al.* (2005) observed that the resources available to a ramet in a clone are altered by physiological integration. Moreover, they mention that clonal plants can be efficient competitors, since a ramet can receive nutrients from other ramets or young ramets can be supported by the clone. Moreover, according to Barnes (1966), a ramet arising from the root system of a clone, containing many adult ramets, may receive carbohydrates through root connection. On the other hand, Peltzer (2002), in an experiment regarding *Populus tremuloides* (which is a clonal species as well) invasion into native prairie, reports that clonal integration tended to improve ramet survival and growth, but this trend was not always significant. In addition, according to Pennings and Callaway (2000), the importance of clonal integration can differ between species.

Even though, in the present study, the connection of ramets was not investigated from a physiological point of view, it seems that the connection of the suppressed ramets with dominant ramets does not result in an equal partition of resources. It is quite likely that the greatest amount of water and nutrients is taken by the dominant ramets through an intense competition process with the suppressed (shaded) ramets.

This is the reason why, even though this is not observed in suppressed ramets, dominant ramets from site type A have greater height at the age of 10 years, when compared with the dominant ramets in site type B ( $p < 0.05$ ). The height of suppressed ramets in site type A has no statistically significant difference when compared with that of suppressed ramets in site type B. This pattern indicates that competition is the procedure that characterizes the relationship between ramets in the investigated clonal formations. Better site conditions do not lead to taller heights of suppressed ramets in site type A, compared with those of site type B. On the contrary, only the dominant ramets profit, since the extra resources that the clone assimilates as a result of better site are incorporated mainly by them.

According to Krasny and Johnson (1992), the pattern of stand development in *P. tremuloides* clones was similar to that of even aged monospecific stands of nonclonal woody species. Moreover, they mention that the self-thinning process in *P. tremuloides* clones may occur initially through competition between stems for the carbohydrates and nutrients supplied by the parent root system.

The heights of dominant *P. tremula* ramets at the age of 10 years presented in this study are very satisfactory for the species. According to the site index curves created by Johanson (1996), the mean height for dominant trees at the total age of 10 years is 8.43 m, at best sites, in Sweden. On the other hand, the mean height for dominant trees at the breast age of 10 years was calculated to be 9.98 m at the most productive sites in the site index curves created for Norway (Opdahl, 1992 as referred in Johansson 1996). According to a growth model for young *P. tremula* ramets in Sweden (Johanson, 1996), the height of dominant ramets at the age of 10 years is lower than 6 m. This value is lower than the height of dominant ramets at the age of 10 years on both site types in the present study. For east and northeast Anatolia in Turkey, Misir (2010) presents for *P. tremula* site indexes at an index age of 30 years 4.1 to 14.8 m. In Scotland, the mean heights of 40 *P. tremula* clones, 13 years since planting were 4.85 and 6.06 m in two trial sites (Harrison, 2008). These values are more or less the same with the mean heights of suppressed and side-shaded ramets at the age of 10 years in the two site types of Nestos

valley. However, in the first trial site in Scotland, the mean heights of the 10 tallest clones ranged from 5.7 to 13.3 m, while in the second site the height range of the 10 tallest clones were from 6.4 to 11.6 m (Harrison, 2008). According to Kitikidou *et al.* (2012), the estimated heights of dominant trees at the age of 10 years, for the three site qualities in *P. tremula* stands of Athos Peninsula (northern Greece), are 13.5, 9.9, and 6.5 m, respectively. These stands are found at elevations between 460 and 893 m.

The early height growth of ramets in the present study is high. The time needed for the dominant ramets to reach the breast height (1.3 m) in both site types ranges from 1 to 3 years. Most dominant ramets in site type A reached breast height in their first growing season. On the other hand, the corresponding time to reach the breast height ranges from 1 to 4 years in suppressed ramets on both site types, from 2 to 6 years in side-shaded ramets on site type A and from 1 to 6 years in side-shaded ramets on site type B. In the study of Johanson (1996), in Sweden, the dominant trees needed 2.5 years to reach breast height. According to Kitikidou *et al.* (2012), *P. tremula* dominant trees need 1-3 years to reach a height of 1.5 m in *P. tremula* stands of Athos Peninsula.

One possible reason for the significant height growth of *P. tremula* ramets in our study, except from the possible genetic background differences, is probably the greater duration of the growing season of southern Europe and the different availability of growing space (water, heat, etc.) (see also Kitikidou *et al.*, 2012).

Shade affects the height growth of *P. tremula* ramets negatively. The ramets of *P. tremula*, after a selective copice in central Sweden, tended to be shorter when compared with those arising in the traditional coppice regime where all trees were felled (Rydberg, 2000). Moreover, high availability of light leads to vigorous growth of *P. tremuloides* ramets (Frey *et al.*, 2003).

The question is to what extent suppressed ramets do survive as a result of the common root system of the clone. Even though competition between the interconnected ramets seems to be the dominant process, an adequate amount of water and nutrients (and maybe photosynthates) for survival are allocated to the suppressed ramets. What will the future of the suppressed ramets be after the development of their own root system and separation from the other ramets? More research is required to determine the growth of *P. tremula* under various environmental and competition conditions in southern Europe. Moreover, when the studied *P. tremula* stands in southern Europe are in low altitudes, the subsequent knowledge will not only contribute to a better-quality forest management of *P. tremula* stands but will be a useful tool in the development of new silvicultural manipulations to conserve *P. tremula*, in northern regions of the species expansion that will be warmer, if the predicted climate change takes place (see Perry, 1994).

#### Acknowledgment

Special thanks to the forest service of Stavroupolis for their cooperation.

#### References

- Adamopoulos S, Milios E, Doganos D, Bistinas I (2009). Ring width, latewood proportion and dry density in stems of *Pinus brutia* Ten. *Eu J Wood Products* 67:471-477.
- Algina J, Olejnik S (2003). Conducting power analyses for ANOVA and ANCOVA in between-subjects designs. *Evaluat Health Professions* 26(3):288-314.
- Athanasiadis N (1986). Forest botany, Part II. Giahoudis-Giapoulis, Thessaloniki, 309 p.
- Barnes BV (1966). The clonal growth habit of American aspens. *Ecology* 47:439-447.
- Barnes BV, Zak DR, Denton SR, Spurr SH (1998). *Forest Ecology*, 4th John Wiley & Sons (Eds.). Inc. New York, 774 p.
- Carmean W (1972). Site index curves for upland oaks in the central states. *Forest Sci* 18:109-120.
- Christensen KI (1997). Salicaceae, 27-35 p. In: Strid A, Tan K (Eds.). *Flora Hellenica*, Koeltz Scientific Books, Germany.
- Dafis S (1986). Forest ecology (in Greek). Giahoudi-Giapouli, Thessaloniki, 443 p.
- Frey BR, Lieffers VJ, Landhauer SM, Comeau PG, Greenway KJ (2003). An analysis of sucker regeneration of trembling aspen. *Canad J Forest Res* 33:1169-1179.
- Gomez KA, Gomez AA (1984). *Statistical Procedures for Agricultural Research*. 2nd (ed.) John Wiley & Sons, Inc. New York, 680 p.
- Hamberg L, Malmivaara - Lämsä M, Löfström I, Vartiamaäki H, Valkonen S, Hantula J (2010). Sprouting of *Populus tremula* L. in spruce regeneration areas following alternative treatments. *Eu J Forest Res* 130:99-106.
- Harrison A (2008). Aspen growth trials: showing the species' potential in Scotland 49-51 p. In: Parrott J, MacKenzie N (Eds.). *Aspen in Scotland: biodiversity and management*, Highland Aspen Group.
- Hatzistathis A, Dafis S (1989). Reforestations - Forest nurseries. Giahoudi-Giapouli, Thessaloniki, 265 p. (in Greek)
- Hedenäs H, Ericson L (2008). Species occurrences at stand level cannot be understood without considering the landscape context: Cyanolichens on aspen in boreal Sweden. *Biol Conservation* 141:710-718.
- Johansson T (1996). Site index curves for European aspen (*Populus tremula* L.) growing on forest land of different soils in Sweden. *Silva Fennica* 30:437-458.
- Kitikidou K, Kaymakis M, Milios E (2012). Site index curves for young *Populus tremula* stands on Athos Peninsula (northern Greece). *Turkish J Agric Forestry* 36:55-63.
- Klockars A, Sax G (1986). *Multiple Comparisons*. Sage Publications, Newbury Park California, 97 p.

- Krasny ME, Johnson EA (1992). Stand development in aspen clones. *Canad J Forest Res* 22:1424-1429.
- Latva-Karjanmaa T, Suvanto L, Leinonen K, Rita H (2003). Emergence and survival of *Populus tremula* seedling under varying moisture conditions. *Canad J Forest Res* 33:2081-2088.
- Milius C, Theodoridis P (2006). Management plan of Kalivas Margaritiou Public Forest for the period 2006-2015. Forest Service of Stavroupolis. (in Greek)
- Milius E, Aslanidou M, Pipinis E, Ranis G, Berberidis TH (2000). Dynamics of *Populus tremula* L. stands in central Rhodope in the region of Xanthi. *Sci Ann Depart Forestry and Natural Environ* 40(2):648-663. (in Greek)
- Misir N (2010). Generalized height-diameter models for *Populus tremula* L. stands. *Afr J Biotechnol* 9:4348-4355.
- Newberry J (1991). A note on Carmean's estimate of height from stem analysis data. *Forest Sci* 37:368-369.
- Oliver CD, Larson BC (1996). *Forest Stand Dynamics*. John Wiley & Sons, Inc. New York, 520 p.
- Opdahl H (1992). Site-index, growth and yield in aspen (*Populus tremula* L.) stands in south Norway. *Commun of Skogforsk* 44(11):1-44.
- Peltzer DA (2002). Does clonal integration improve competitive ability? A test using aspen (*Populus tremuloides* [Salicaceae]) invasion into prairie. *Am J Bot* 89:494-499.
- Pennings SC, Callaway RM (2000). The advantages of clonal integration under different ecological conditions: a community-wide test. *Ecology* 81:709-716.
- Perry DA (1994). *Forest ecosystems*. The Johns Hopkins University Press, Baltimore, 649 p.
- Rydberg D (2000). Initial sprouting, growth and mortality of European aspen and birch after selective coppicing in central Sweden. *Forest Ecol Manag* 130:27-35.
- Rytter L (2006). A management regime for hybrid aspen stands combining conventional forestry techniques with early biomass harvests to exploit their rapid early growth. *Forest Ecol Manag* 236:422-426.
- Sit V (1995). *Analyzing ANOVA Designs*. Biometric Information Handbook Series No. 5. Work. Working paper 07/1995. Province of British Columbia, Ministry of Forests Research Program, Victoria, British Columbia, 61 p.
- Smith DM, Larson BC, Kelty MJ, Ashton P, Mark S (1997). *The practice of silviculture*. Applied Forest Ecology. John Wiley & Sons, Inc. New York, 537 p.
- Suvanto L, Latva-Karjanmaa T (2005). Clone identification and clonal structure of the European aspen (*Populus tremula*). *Molec Ecol* 14:2851-2860.
- Svensson BS, Rydin H, Carlsson B Å (2005). Clonal plants in the community 129-146 p. In: Eddy van der Maarel (Ed.). *Vegetation Ecology*, Blackwell Publishing, UK.
- Toothaker L (1993). *Multiple Comparison Procedures*. Sage Publications, Newbury Park California, 96 p.
- Turner JR, Thayer JF (2001). *Introduction to analysis of variance: Design, analysis, & interpretation*. Sage Publications, Thousand Oaks, CA. 187 p.
- Van Bogaert R, Jonasson C, De Dapper M, Callaghan TV (2009). Competitive interaction between aspen and birch moderated by invertebrate and vertebrate herbivores and climate warming. *Plant Ecol Diversity* 2(3):221-232.
- Worrell R, Gordon AG, Lee RS, McInroy A (1999). Flowering and seed production of Aspen in Scotland during a heavy seed year. *Forestry* 72:27-34.
- Worrell R (1995a). European aspen (*Populus tremula*): a review with particular reference to Scotland 1: Distribution, ecology and genetic variation. *Forestry* 68(2):93-105.
- Worrell R (1995b). European aspen (*Populus tremula* L.): a review with particular reference to Scotland 2: Values, silviculture and utilization. *Forestry* 68(3):231-244.
- Yu Q, Tigerstedt PMA, Haapanen M (2001). Growth and phenology of hybrid aspen clones (*Populus tremula* L. x *Populus tremuloides* Michx.). *Silva Fennica* 35:15-25.