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Full Length Research Paper

Impact of pine processionary moth (*Thaumetopoea wilkinsoni* Tams) on growth of Turkish red pine (*Pinus brutia* Ten.)

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One of the most important damaging insects on Turkish red pine (*Pinus brutia* Ten.) forests in the coastal Mediterranean Region of Turkey is pine processionary moth (PPM), *Thaumetopoea wilkinsoni* Tams. The larvae of PPM feed on needles of Turkish red pine and on some other Mediterranean conifers such as cedar. This study covers the impact of defoliation caused by PPM on growth of red pine. Three test sites were taken on different plantations in the coastal Mediterranean region of Turkey, near Antalya city. The heights and diameters at breast height (dbh) of individual trees both in the control group and the treatment groups were measured. The trees defoliated over 40% in the test sites were considered as the treatments. The results indicated that, compared to the control, the losses in defoliated trees in terms of dbh increment were 55, 50 and 35% in the three test sites, respectively. The corresponding losses in the three test sites in terms of volume increment were 44, 37 and 17%, respectively. Test results also showed that effects of defoliation and site on both diameter and volume increment were statistically significant at 0.000 probability level.

Key words: Turkish red pine (*Pinus brutia* Ten.), *Thaumetopoea wilkinsoni,* defoliation, growth loss.

INTRODUCTION

Pine processionary moth (PPM) (*Thaumetopoa wilkinsoni* Tams) is the insect feeding on the foliage of conifers, particularly on *Pinus* sp. Most of the studies realized in Mediterranean Region considered the PPM as *Thaumetopoea pityocampa* (Den. & Schiff.). But Semiz et al. (2006) reported - referring to Tams (1925), Wilkinson (1926), Demolin (1988), and Demolin and Frerot (1993) - that pine processionary moth distributed in the region ranging from Turkey to the southern part of Israel is named *T. wilkinsoni*, which is different from *T. pityocampa*. Salvato et al. (2002), who reports on a population genetic study, found out a clear divergence between the *T. pityocampa* and *T. wilkinsoni* at both mitochondrial and nuclear DNA level. They indicated that *T. wilkinsoni* is distributed in the Asiatic Region (Turkey and Middle East) while *T. pityocampa* is distributed in Italy and other southern European countries. Simonato et al. (2007) also had defined the PPM as *T. wilkinsoni* in their study that they have sampled from southern Turkey. Cetin et al. (2006, 2007) called this insect as *T. wilkinsoni* in their study. Based on all these recent studies, I also referred to the *Thaumetopoea* sp. population in our study area (south-west of Turkey) as *T. wilkinsoni*. PPM is considered one of the most important pine pests in the Mediterranean Region in the last century (Cadahja et al., 1975; Salvato et al., 2002). It is commonly observed in pine and cedar forests. Defoliation damage is serious in young forested areas where it may lead to death of young trees, due to attack by bark beetles or other wood-boring insects. Normally, a defoliated tree produces new leaves and thereby restores resources (Lambers et al., 1998), but the new plant tissues may reflect the state of a tree due to damage (Hódar et al., 2004). In mature forests, trees are rarely killed but significant losses occur in volume growth (Battisti et al., 1998; Buxton, 1983). Additionally, it weakens the trees and makes them vulnerable to other pests such as bark beetles. Turkish red pine (*Pinus brutia* Ten.) is the most important tree species for Turkish forestry, with approximately 5.4 million ha natural and planted forest areas (OGM, 2008)

Table 1. Test sites and some associated properties.

Test sites	Stand age (at 2004)	Mean dbh of stand (cm)	Site index (m) (top height at the age of 30)	Mean height of stand (m)	Coordinates of test sites
Asar I	16	14.71	21	9.62	N 37° 04" 44.36';E 30 ° 45" 02.75'
Asar II	17	16.04	22	10.28	N 37° 04" 35.04';E 30 ° 45" 21.34'
Doyran	30	14.74	13	11.11	N 36° 53" 55.83';E 30 ° 30" 41.12'

and 3.4 million m^3 wood production per year (Konukçu, 1999). It accounts for 27% of total national wood production and is valued for industrial wood as paper and lumber production. Turkish Forest service has a protection program, which is based primarily on aerial spraying application of chemical insecticides.

However, the program is relatively costly to be applied on large areas and may have undesired harmful effects on other plant and animal species inhabiting the forest ecosystems. For example, Forest Service spent 1.4 million USD in spraying 404 000 ha area in 2003, and 1.8 million USD in 418 000 ha area in 2004 (Forest Service, 2005). Although chemical protection program appears to be effective to combat with PPM, it is clear that such a program requires a relatively large budget, besides its significant negative effects on the environment through killing many other useful organisms along with PPM. Therefore, accurate scientific information about annual growth reduction caused by PPM is needed before any fighting strategy can be decided against the PPM attack on *P. brutia* forests.

The aim of this study is to quantitatively describe the diameter and volume growth loss for Turkish red pine due to PPM damage. Kanat et al. (2005) studied it in the East Mediterranean Region of Turkey using stand level data, while we aimed to figure it out for the West Mediterranean Region of Turkey using individual level.

MATERIALS AND METHODS

The study was conducted on three different sampling sites in Turkish red pine plantation areas, some of its properties are given in Table 1 and each of them was sized 2 500 m2 (50 × 50 m), in the Antalya region. The region has a typical Mediterranean climate with relatively hot and dry summers, and mild and rainy winters. The mean minimum temperature in the coldest month (January) is 5°C, and the mean maximum temperature of the hottest month (July) is 34°C. Annual rainfall, which is about 1091 mm, is concentrated mainly in winter months, the contribution of summer months (June to September) being only 22 mm in the total annual precipitation. The means represent for the years from 1975 to 2010. P. *brutia* is light depending on the tree species and forms even aged stands. Trees selected for measurement were co-dominant trees, in order to see more clearly the defoliation effect on growth rate.

The study was carried out between the years 2000 to 2004 on three test sites. In the year 2000, we selected and identified originally 120 trees, exhibiting diverse levels of attacks by PPM (as measured by the number of silk nests) at each test site. Among these, 32 trees, which were defoliated over 40%, were chosen as the "subject trees (treatments)". Additional 32 trees from the original 120 trees were also selected as the "control trees" at each test site. The control trees had no or very little (less than 5%) defoliation. The control trees at each test site were chosen in such a way that each control tree has to match to a treatment-tree in the same test site. The matching was performed in pairs of trees within each test site, provided that the only apparent difference between the paired trees was the level of PPM damage. The other site variables (such as spacing, stand density, canopy closure, crown structure, tree age, tree diameter) that have primary effects on the growth (Erkan, 1996, 1998) were more or less similar between any paired trees at each test site.

Dbh increment of all the four years (2000 to 2004) were measured for all the subject trees, but only the measurements for the year 2000 were analysed. Because defoliation rate of subject trees were not stable during the four years as some examples can be seen on Figure 1. This instability in defoliation, together with the carry-over effect of it on the dbh growth, did not allow analysing all four years' measurements. Test sides were checked from the Forest Service records, not to be defoliated at least in two years before 2000 to eliminate this misleading effect on research. Two increment cores were taken in the winter of the year 2005 (after the end of the vegetation period of the year 2004) from two sides (north and south direction) of each sampled tree. Annual dbh increment for related year (annual tree ring width as a sum of the two ring widths on two cores taken from opposite side of subject tree) was measured from fine sanded core samples to the nearest 0.01 mm using PREISSER DIGI-MET measurement machine. PRESSLER increment borers were used to get the core samples. Heights of the trees were measured at end of the vegetation period of each years (2000 to 2004) using Haglöf Vertex III Hipsometer. Annual diameter and volume increment were determined on defoliated trees as follows:

$$AID_i = RW_{i1} + RW_{i2} \quad (1)$$

$$AIV_i = AV_i - BV_i \quad (2)$$

where, for related year, AID_i is the annual diameter increment inside bark of i^{th} tree, RW_{i1}, RW_{i2} are the ring width measured from opposite side ($_1$ and $_2$) of i^{th} tree, AIV_i is the annual volume increment of i^{th} tree, AV_i is the volume inside bark of the i^{th} tree after defoliation and BV_i is the volume inside bark of i^{th} tree before defoliation. Loss of diameter and volume increments were determined using the increment values of paired defoliated and control trees as follows:

$$LAID_i = AID_{i,ct} - AID_i \quad (3)$$

$$LAIV_i = AIV_{i,ct} - AIV_i \quad (4)$$

where, for related year, $LAID_i$ is the loss of annual diameter

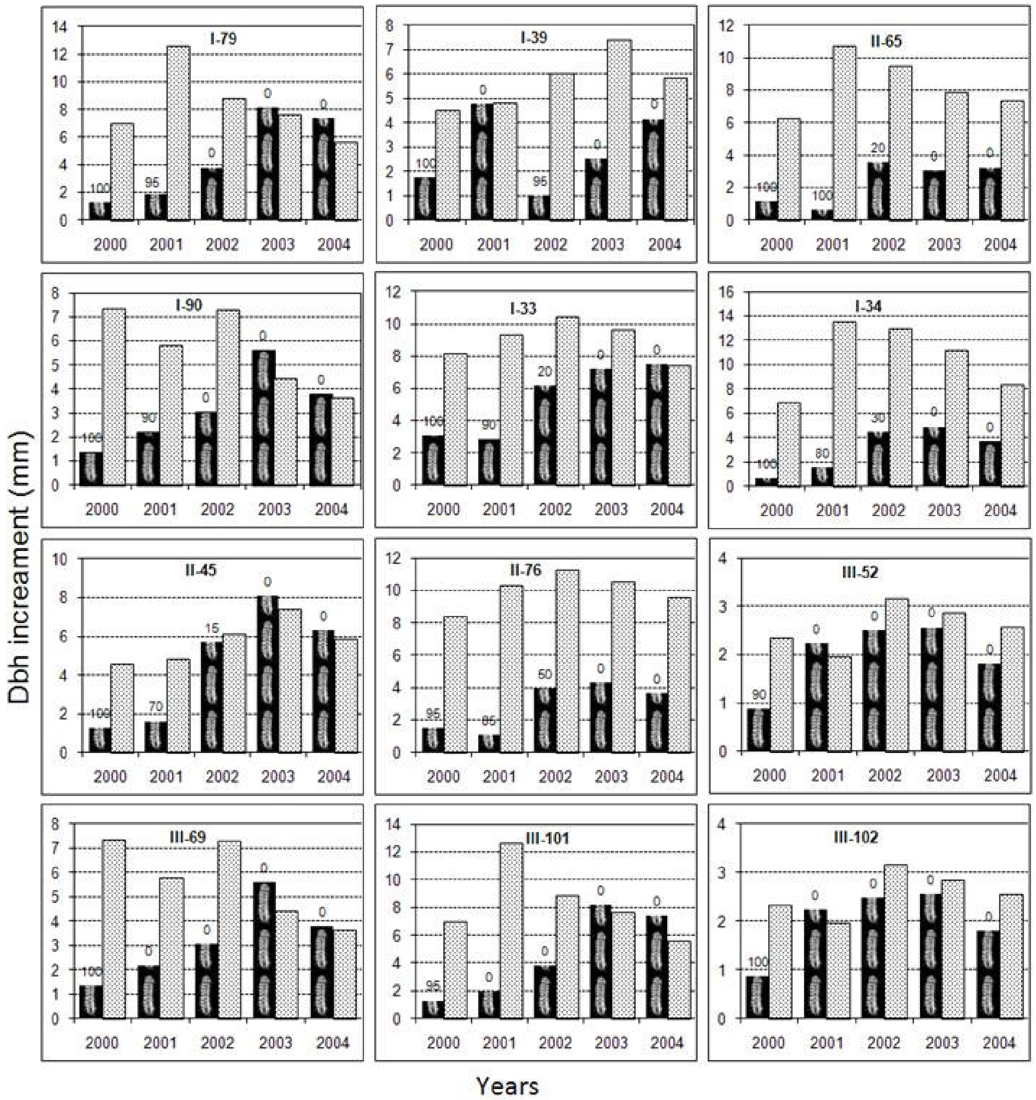

Figure 1. Effect of defoliation on the tree dbh growth. Paired trees are chosen from three test sites. Light and dark columns show the control and the defoliated trees, respectively. The signs at top sides of each graphic show the combination of sites (I: Asar I, II: Asar II, III: Doyran) and related tree number (For instance, I-79 means tree number 79 in the site "Asar I", II-45 means tree number 45 in the site "Asar II" and III-69 means tree number 69 in the site "Doyran"). The numbers just on the top of the dark columns show the defoliation percentage in the corresponding year..

increment of the i^{th} defoliated tree, $AID_{i,c}$ is the annual diameter increment of paired control tree of i^{th} defoliated tree, AID_i is diameter increment of i^{th} defoliated tree, $LAIV_i$ is the loss of annual volume increment of i^{th} defoliated tree and $AIV_{i,c}$ is the annual volume increment of paired control tree of i^{th} defoliated tree and AIV_i is the volume increment of i^{th} defoliated tree. Volume was calculated from the volume table function derived for Turkish red pine plantations by Usta (1991), based on dbh and height and given with Formula (5).

$$\ln(V_i) = [\ln(-2.07746621) + 1{,}67681754 * \ln(d_i) + 0.845096118 * \ln(h_i)] * 1.007987 \quad (5)$$

where, V_i is the volume (dm^3) of i^{th} tree, d_i is diameter at breast height (dbh) (cm) of i^{th} tree, and h_i is the height (m) of i^{th} tree. Annual dbh and volume increments of defoliated and control trees were compared by paired t-tests. Statistical analyses were conducted using the SPSS 10.0 (1999) package.

RESULTS AND DISCUSSION

In this study, trees defoliated over 40% in the growing season of the year 2000 and were monitored during the next five years. Only some of them were defoliated again in the following years after the year 2000. For instance, on average, in the three test sites, of those defoliated in

Table 2. ANOVA results of dbh increment for sites and defoliation status (mm/year).

Test site	Mean annual increment (MAI)					
	Diameter at breast height (mm)			Volume (dm^3)		
	Defoliated	Control	Loss (%)	Defoliated	Control	Loss (%)
Asar I	4.35	9.69	55.1	6.289	11.209	43.9
Asar II	3.26	6.52	50.0	5.822	9.188	36.6
Doyran	1.44	2.23	35.4	4.092	4.934	17.0

Table 3. ANOVA results of volume increment for sites and defoliation status (dm^3/year).

Source of variance	Sum of squares	df	Mean squares	F	Sig.
Foliage	4.444	1	4.444	50.73	0.000
Site	6.068	2	3.034	34.64	0.000
Error	16.468	188	0.088[a]		

Table 4. Average losses and results of t-Tests for dbh increment per tree (mm/year).

Pairs and test sites	Paired differences					t	df	P≤Sig. (2-tailled)
	Mean	Std. dev.	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
Pair 1 – Asar 1	4.919	3.278	0.579	3.737	6.101	8.488	31	0.000
Pair 2 – Asar 2	3.366	2.610	0.461	2.425	4.307	7.295	31	0.000
Pair 3–Doyran	0.842	0.993	0.175	0.484	1.204	4.799	31	0.000

the first year only 21% were re-defoliated in the second year. Furthermore, of those defoliated in the first year, only 10% were re-defoliated both in the second and the third year. So, our analyses to estimate growth loss were based on trees defoliated only in year 2000 and the available data was not able to detect the additional losses that might arise due to repeated attacks on the same trees following the year 2000. Similarly, earlier studies on the biology of PPM as well indicate that population dynamics of the species change, depending on various factors such as altitude, exposure and structure of the forest. The distribution of nests is not uniform even within a given part of forest; that is some trees may be attacked more frequently than others, due to variety of factors like genetic differences among trees, soil depth, soil fertility and drainage, shading and history of exposure to wind and other organisms (Buxton, 1983; Ozkazanc, 2002; Avci, 2000). My observations in the field also showed that PPM prefers trees at the edges of woodlands and bordering clearings more than those in closed forest. But defoliation rate may also change from year to year in each tree, even in the same area. It can be seen from Figure 1 that trees have received different number of insects and defoliated at different levels of intensity.

Average values for dbh and volume growth per tree for defoliated and control trees and percentage loss are shown in Tables 4 and 5. On average, defoliation caused a reduction of 55.1, 50.0, and 35.4% in dbh increment in Asar I, Asar II and Doyran test sites, respectively. The corresponding reductions in volume increment were 43.9, 36.6, and 17.0% in the respective test sites. We have performed ANOVA to see whether there was a statistically significant effect of treatment (defoliation) on dbh and volume growth or not. Results showed that there were significant difference at P≤0.000 level between test sites and treatment levels (defoliated and control trees) in terms of dbh and volume growth (Tables 2 and 3).

Additionally, combining three test sites, treatment trees and control trees were matched in pairs by considering the variables like diameter, canopy closure and crown structure and paired t-test was performed. According to t-test results (Tables 4 and 5), defoliation (40% and over) had statistically significant (P≤0.000) effects on both dbh and volume growth. Difference in dbh and volume growth, between sites was because of the site quality which was different for the sites and is one of the main effective factors on the growth of dbh and volume. Therefore, Doyran has higher site quality than the others. Results from earlier studies also support the results of this study. For example, Lemoine (1977) conducted a study on maritime pine and determined that the effect of defoliation caused by *T. pityocampa* lasts up to four years

Table 5. Average losses and results of t-Tests for volume increment per tree (dm^3/year).

Pairs and test sites	Mean annual volume increment of pairs			Paired differences				t	df	P≤Sig. (2-tailled)
	Defoliated	Control	Loss (%)	Mean	Std. error mean	95% confidence interval of the difference				
						Lower	Upper			
Pair 1 – Asar I	6.29	11.21	43.9	4.919	0.579	3.737	6.101	8.488	31	0.000
Pair 2 – Asar II	5.82	9.19	36.6	3.366	0.461	2.425	4.307	7.295	31	0.000
Pair 3 – Doyran	4.09	4.93	17.0	0.842	0.175	0.484	1.204	4.799	31	0.000

and estimated the loss of circumference increment as 31% during the four-year period of defoliation. Laurent-Hervouet (1986) also investigated the effect of *T. pityocampa* on the radial diameter growth for some *Pinus* sp. and found out that the average loss in diameter increment was 35%. Markalas' (1998) study on young (5-year-old) *Pinus pinaster* Ait. trees showed that one year after defoliation, losses in total shoot biomass were 41 to 45% in moderately defoliated trees and 54 to 64% in completely defoliated trees. Kanat et al. (2005) determined a significant difference for annual diameter increment between defoliated and non-defoliated pine trees by *T. pityocampa*. Houri et al. (2006) indicated that PPM has a significant economic impact in the loss of forest wood growth. Kanat et al. (2002) studied the effect of tending activities on the amount of defoliation damage in East Mediterranean Region of Turkey, using stand level data and found out that these activities decrease the loss in diameter increment from 38 to 22%. Buxton (1983) reported that all pine species in the Mediterranean Region suffer from PPM damage.

The most regular, extensive and damaging outbreaks occur in large plantations which are located outside of their natural distribution ranges. In Turkey, however, according to our preliminary observations in the field most Turkish pine forests, both natural and plantations, regardless of their natural distribution areas, are suffering from PPM damage. In this study, it was observed that defoliation rate in all test sites varied from tree to tree and the effect of defoliation lasted more than one year. It makes the analysis of this effect more difficult when considered, this over year effect together with the current year's effect. Therefore, Turkish red pine has mostly one and two year old leaves and defoliation is expected to affect the growth rate during more than one year, even if there is not defoliation in the following years after current year. In this study, the test sites were checked at the site selection stage, as much as possible, not to be defoliated in the last two years. For this reason, only data taken in the year 2000 were evaluated to see clearly the defoliation effect and to avoid the complexity of post defoliation effects.

The carry-over effect of defoliation on the dbh growth is seen clearly on Figure 1. For tree II-65, it is shown that heavy defoliation (100%) in the year 2000 and 2001, affected the annual dbh growth till the end of 2004. On the other hand, the carry-over effect of PPM appears to depend on the conditions of the subject tree. For instance, tree I-33 also has defoliated 100 and 90% in the years of 2000 and 2001, but the carry-over effect was not as heavy as tree II-65. Because tree I-33 has 16.0 cm of dbh while tree II-65 has 12.1 cm of dbh, site index is approximately the same. The dbh shows the growth capability of trees depending on conditions like spacing (canopy area or growth area), competition status (dominant or co-dominant) and individual genetic ability, in a given site quality. Tree I-33 was able to refoliate faster and could tolerate the defoliation easier, in comparison to the tree II-65. As a conclusion, the defoliation on Turkish red pine by PPM causes dbh and volume increment loss, with significance at 0.000 level (Tables 2 and 3). Furthermore, these loses may increase up to 55.1 and 43.9% in annual dbh and volume increment, respectively (Tables 4 and 5). The results showed that the worse the site quality is, the more severe the damage is. All these information will be based on the determination of the program for fighting against PPM damage for Forest Service and decision makers and will help them when deciding the allocation of budget and other sources.

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