Journal of Environmental Biology
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July 2010, 31, 453-460 (2010)
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Effect of defoliation by the pine processionary moth (PPM) on radial, height and volume growth of Crimean pine (*Pinus nigra*) trees in Turkey

Serdar Carus*

Department of Forest Management, Faculty of Forestry, University of Suleyman Demirel, 32260 Cunur, Isparta, Turkey

(Received: December 12, 2008; Revised received: April 15, 2009; Accepted: April 25, 2009)

Abstract: *In this study, we assessed the effects of chronic defoliation on radial, height and volume growth of Crimean pine (Pinus nigra Arnold) trees of the pine processionary moth [Thaumetopoea wilkinsoni Tams (Lepidoptera:Thaumetopoeidae)] in western Turkey. Crimean pine tree ring chronologies were analyzed for evidence of the pine processionary moth (PPM). Tree ring widths from non-defoliated Crimean pine sample trees, which were not defoliated by PPM from 1998 to 2004, were used to estimate potential growth in the defoliated Crimean pine sample trees during the same time interval. In 2004, increment cores collected from 50 defoliated sample trees and 25 non-defoliated sample trees dominant or co-dominant trees. Annual radial growth indices from 1985-2004 calculated for each defoliated Crimean pine and non-defoliated Crimean pine group. We identified regional outbreaks of PPM by synchronous and sustained growth periods of Crimean pine trees. Growth functions of defoliated Crimean pine trees (3) and non-defoliated Crimean pine trees (2) were graphically compared as the cumulative sum of radial, height and volume increment. Two outbreak were identified in 1992 (1992 and 1993) and 1998 (1998-2004) in the study area. PPM caused a significance decrease (average 33%, p<0.05) in the annual radial increment in 1998-2004.*

Key words: *Crimean pine, Thaumetopoea wilkinsoni, Growth loss, Tree ring analysis, Dendrochronology*
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Introduction

Insect outbreaks are one of the major disturbances affecting on the forests (Akkuzu and Guner, 2008). Heavy defoliation by defoliating insects ordinarily results in an abrupt decrease in tree-ring width in the years of insect outbreak, followed by several years of growth suppression. The changes show that dendrochronological methods can be used in the study of insect pest outbreaks (Alfaro and Shepard, 1991; Muzika and Leibhold, 1999). Tree-ring analyses have been used to quantify incremental losses and to reconstruct the frequency and timing of defoliator outbreaks by examining occurrence of tree-ring sequences with specific characteristics in the long-term tree-ring chronologies (Swetnam and Lynch, 1989; Jardon *et al*., 1994; Weber and Schweingruber 1995; Ryerson *et al*., 2003).

The pine processsionary moth (PPM), previously called as *Thaumetopoae pityocompa* Schiff. (Lepidopterea: Thaumetopoeidea) by Turkish foresters. It was identified as a new species named *Thaumetopoea wilkinsoni* Tams in 2002 (Salvato *et al*., 2002). However, widely in Mediterranean region PPM is distributed in Cyprus, Southwestern Turkey and Israel. It is known to feed on needles and build large silk nests on the top of the trees. PPM is usually attack pine and cedar species, although it prefers Crimean pine more than 1300 m in altitude of Turkey. On the other hand, its damage on other species have also been realized including *P. brutia*, *P. sylvestris*, *P. halepensis, P. pinea* and *Cedrus libani* in Turkey. The PPM is widely available in area of about 1.5 million ha in Turkish forests (Canakcioglu, 1983).

The widest natural distribution of Crimean pine, one of the most important forest trees of Turkey, is in the various mountains of Turkey with the total area of about 4202298 ha (Konukcu, 1999). It is one of the most important raw materials for forest products industry in Turkey.

There were no records of PPM outbreaks in the selected region until mid- February 1998 when a partial defoliation of Crimean pine trees of the insect occurred in Gelendost Forests of Isparta. This stand was part of a 20 ha tract in the region. The current severe PPM outbreak that began in the spring of 1998 was absent on the western side (approximately 10 ha). The first outbreak was observed in 1998 (7-8 nests on each defoliated tree), followed by 1999 (4-5 nests), 2000 (5-6 nests), 2001 (6-7 nests), 2002 (7-8 nests), 2003 (4-5 nests) and 2004 (2-3 nests). Generally, two-thirds or more of needles of Crimean pine (from the top to middle of tree) were estimated to have been defoliated by the PPM in these infestation years. Tree crowns recovered to near normal condition by the middle (beginning of July) of each growing season during the outbreak.

In this study, we assessed the effects of chronic defoliation by ppm on radial, height and volume growth of Crimean pine (*Pinus nigra* Arnold) trees in the western Mediterranean part of Turkey.

* **Corresponding author:** scarus@orman.sdu.edu.tr

Crimean pine tree ring chronologies were analyzed for evidence of the PPM. Tree ring widths from non-defoliated Crimean pine sample trees, which were non-defoliated by PPM from 1998 to 2004, were used to estimate potential growth in the defoliated Crimean pine sample trees during the same time interval. Our assumption is that defoliated and non-defoliated Crimean pine trees within an uncut stand have similar radial growth patterns (growth curves) in the absence of PPM defoliation. Radial growth pattern of Crimean pine trees known to have been previously defoliated by PPM are different from non-defoliated Crimean pine trees that are in the same region.

The purposes of the present study were to: (1) analyze, using dendrochronological methods, the impact of PPM feeding on the tree ring widths of defoliated trees, (2) quantify incremental loss (on radial, height and volume growth of the defoliated Crimean pine trees) during the period of PPM attack and (3) detect possible past outbreaks of PPM at this locality.

Materials and Methods

Biological properties of PPM: PPM has only one generation per year but, a small percentage of its pupae can exhibits extended diapause. Moths may remain in the pupal state for several years until the weather conditions are suitable for its development (Canakcioglu, 1983). In spring, the larvae resume for feeding on the needles, reaching up to 3.5-4.0 cm in length during summer. The heaviest defoliation occurs during February and March. In mid April, fully grown larvae of PPM drop to the forest floor and pupate in the surface litter and soil (exact date depends on several conditions like weather and altitude). Then two months pupal stage, after which the pupae remain in the litter until adult emergence. The oviposition period continue from late July to mid August. The population then increases rapidly during late summer to peak in early to mid-autumn (Kanat, 2002).

Study area: The study area was located in the western Mediterranean in Gelendost Forest, near Isparta of Turkey. The forest has not managed yet. The study area is located at 38°05'N latitude, 31°03'E longitude, average slope 20°, predominately north facing aspect, about 1320 m altitude and approximately 20 ha in size a plantation. The spacings were established as 3.0 x 1.5 m (Table 1).

Climate data: The nearest weather station is at Isparta. Mean monthly and annual temperature and rain fall data for the period 1929-2004 were obtained from Isparta Meteorological station (997 m), 75 km south west of the study site. These climatic values were converted to altitude of study area. At the study area, mean annual precipitation of 730 mm three quarters of the total precipitation falls from October through May. There is great deviation during the investigated period in the distribution and in the amount of precipitation. Mean annual temperature is 10.4°C. In accordance with De Martonne's (1942) dryness coefficient (I=18.51), the study area is identified as being semi-humid.

Study measurements and analysis: This study investigated the relationship between defoliation and growth loss (radial, height and volume) in productivity of trees in the Isparta region of Turkey from 1985 to 2004. The investigation was based on a 25-year-old plantation of Crimean pine where growth and foliage had been monitored since mid-February 1998.

We determined that Crimean pine sample trees in the east section were defoliated sample trees and the west section contained non-defoliated sample trees. Among trees selected as defoliated and non-defoliated Crimean pine in the sample plots, it has been observed that they were not a different subspecies or variety. The sample plots (1 and 2; defoliated and 3; non-defoliated) were selected when this current outbreak (1998-2004) was detected. The two locations (plots), symmetrical to in approximately 3 ha stand, were selected as baseline in order to ensure similar characteristics with respect to stand, edaphic, climatic and physiographic.

All trees within the plots were height and diameter measured, and defoliations were evaluated. Trees in the sample plot provided the growth information and were the basis basal area and radial growth statements for the 0.1 ha-plot. From the data collected, stem volume was calculated for each tree using a double-entry volume table of Crimean pine (Gulen, 1959).

Collection and measurement of increment cores: In the fall of 2004, increment cores were taken from 50 dominant and co-dominant defoliated Crimean pine and from 25 dominant and co-dominant non-defoliated Crimean pine trees. Increment cores were extracted at breast height from opposite sides of each sample tree parallel to the topographic contour. Cores were inserted in labelled plastic straws that were thermally sealed to prevent moisture loss and kept frozen until they were (Table 1). Using a stereomicroscope, annual increment was cross-dated and measured in mm (0.01 mm precision) on each core for the period 1985-2004. The age of the tree (at breast height) was also recorded.

Dendrochronological analysis: Ring widths were measured at the Forestry of Faculty of Süleyman Demirel University soon after the cores were extracted. All cores consisted of about 20 annual growth rings; the most reliable chronologies existed for the years from 1985 to 2004. We graphically cross-dated each series and eliminated series that may have had missing rings. The program of COFECHA was used to verify the cross-dating (Holmes, 1983) and corrections were made when necessary. The raw tree ring series were standardized using ARSTAN to correct for age-related growth trend and to produce the final index chronologies (Cook and Holmes, 1986). It was chosen to use a negative exponential or a straight line with a 50% cutoff wavelength to standardize the series. This calculation transforms ring width into dimensionless index values. It was also chosen to be use the standard chronology as a response variable in the analysis of growth in relation to defoliation (Schweingruber, 1979; Carlson and MacCaughey, 1982; MacLean, 1985; Muzika and Leibhold, 1999; Speer *et al*., 2001; Copenheaver and Abrams, 2003). Chronology groups were created for the defoliated group and non-defoliated Crimean pine group. Standardized ring widths were used for analysis of defoliation effects; we used averages at each sample plot.

Comparing defoliated and non-defoliated Crimean pine chronologies A graphical comparison of the defoliated and non-defoliated Crimean pine chronologies should provide some evidence that PPM was caused radial growth reduction in the defoliated Crimean pine trees (Muzika and Leibhold, 1999). Defoliated Crimean pine trees, however, may also have been responding to other environmental factors, such as drought. Equation 1 corrects a defoliated- tree chronology by first scaling residuals from the non-defoliated-site chronology to the same variance as the defoliated-tree chronology. These scaled residuals are called the predicted residual indices (PRI). The PRIs are then simply subtracted from the defoliated- tree indices to produce the corrected indices (CI). The purpose of the CI is to remove environmental effects common to both defoliated and non-defoliated chronologies, so that more precise estimates of growth reduction can be derived. The corrected series (Eqs. 1 and 2) were utilized to identify the timing of outbreaks, the duration of PPM-induced low-growth periods, and the maximum annual and periodic radial growth losses (Swetnam *et al*., 1988). Subtracting the CI during outbreaks from the potential growth value (1.0) and multiplying by 100 derived the latter two measures.

$$PRI = \frac{SD(H)}{SD(NH)} \quad [INDEX(NH) - MEAN(NH)] \qquad (1)$$

$$CI = INDEX(H) - PRI \qquad (2)$$

SD(H) and SD(NH) are the standard deviations for the defoliated and non-defoliated series, INDEX(H) and INDEX(NH) are index values of the defoliated and non-defoliated series, respectively, and MEAN(NH) is the mean of the non-defoliated series (about 1.0).

Tree growth Five sample trees were cut in the study area. The number of trees according defoliation group was determined as follows: defoliated Crimean pine (plot 1; n=2 and plot 2; n=1) and non-defoliated Crimean pine (plot 3; n=2). Cross-sectional discs were then cut from the stem at stump height, 1.3 m and at 0.5 m intervals upward for a total of six to fifteen discs per tree. The discs were air-dried, polished, and the tree ring width was measured to an accuracy of ±0.01 mm along the maximum and minimum radii. Height increment was determined by counting annual rings from discs; volumes were obtained by diameter and height. A complete radial, height and volume increment data-set was established for each sample tree.

Determination of De Martonne dryness coefficients and indices Defoliated Crimean pine trees, may also have been responding to other environmental factors, such as drought. De Martonne (1942) dryness coefficients (Eqs. 3-5) and the corrected indices were utilized to identify the timing of outbreaks.

$$Iy = \frac{P}{T + 10} \qquad (3)$$

$$Ik = \frac{p.12}{t + 10} \qquad (4)$$

$$I = \frac{Iy + Ik}{2} \qquad (5)$$

P= annual precipitation (mm), T= mean annual temperature (°C), p= precipitation of the most drought month (mm), t= mean temperature of the most drought month (°C). I<5 (dry), 5< I < 10 (semi-dry), 10< I < 20 (semi-humid) and I>20 (humid) are De Martonne dryness coefficients (De Martonne, 1942).

Statistical analysis The data was analyzed with repeated measures ANOVA procedure. If it was a significant Year x Defoliated interaction, an independent samples t-test was performed to determine the years when the annual radial increment of host Crimean pine trees differed from the annual radial increment of non-defoliated Crimean pine trees. Data analysis was performed using SPSS v. 11.5.

Results and Discussion

Stand growth: Sample plot averages indicated that defoliation negatively influenced growth of Crimean pine (Table 2). The mean diameters for defoliated and non-defoliated sample plots were found to be 13.08 and 16.37 cm, respectively. In the fall of 2004, mean radial growth of defoliated sample plot was 0.52 cm for one year, whereas mean diameter in the non-defoliated sample plot grew 0.65 cm. Average growth values of defoliated percentage for basal area, volume and top height were reduced by 45, 59 and 40%, respectively (Table 2).

Individual tree growth: No irregularities in tree-ring formation were identified for defoliated Crimean pine trees. However, defoliated Crimean pine trees exhibited an abrupt growth reduction starting in 13 (1992) and 18 (1998) years old (Fig. 1). As Fig. 1 indicated, Crimean pine sample plots are abbreviated as defoliated Crimean pine sample plot 1 and 2 (Defoliated SP1 and Defoliated SP2), and non-defoliated Crimean pine sample plot 3 (Non-defoliated SP3).

Radial growth of defoliated Crimean pine trees was compared with radial growth of non-defoliated Crimean pine trees in the outbreak. Ratios of annual radial increments for non-defoliated trees to annual increments of defoliated Crimean pine sharply increased after the outbreak. Mean annual radial increments during the periods 1992-1993 and 2000-2002 were found 0.30-1.10 mm and 0.33-0.62 mm for defoliated and non-defoliated Crimean pine defoliation groups sample trees, respectively (Fig. 1). Besides, height increments of defoliated and non-defoliated Crimean pine sample trees during 2000-2002 were 0.37 and 1.22 m. The total volume increments of defoliated and non-defoliated Crimean pine defoliation group sample trees during 2000-2002 were calculated 11 and 20 dm^3, respectively.

Severe defoliation of Crimean pine trees by PPM causes substantial reductions in height growth. The final volume of Crimean pines trees in Gelendost Forest averaged 0.044 m^3 per tree, but this might have reached 0.113 m^3 in the absence of PPM (Table 2). Trees of defoliated Crimean pine sample plot groups had a significant effect on height growth when compared to non-defoliated sample plot trees (Table 2). On average, non-defoliated Crimean pine trees were significantly taller than defoliated trees. However, height growths for dominant or co-dominant defoliated Crimean pine sample trees were reduced by 35% when compared to nonhost Crimean pine sample trees. Moreover, defoliation appeared to have significant effect on volume growth defoliated trees did exhibit the most decreases (61%).

We found that the PPM caused a significant decrease (average 33% for seven years; 1998-2004) in the annual radial increment of the defoliated Crimean pine trees after a severe attack of PPM (age of stand=25). Similar, results had been observed by Carus (2004) and Kanat *et al*. (2005) in the western Mediterranean region of Turkey. Carus (2004), reported that forests of *P. brutia* Ten. periodically subjected to heavy attacks of PPM showed an about radial (24%), height (36%) and volume (52%) growth of the trees decrease within 23 years. Kanat *et al.* (2005), found that the PPM caused a significant decrease (average 21% for four years) in the annual radial increment of *P. brutia* Ten. after a severe attack of PPM (age of stand=30). This partial difference is due, most probably, to the age of stand and species.

Comparing defoliated and non-defoliated Crimean pine chronologies: We developed a single chronology for each group by averaging the chronologies from both defoliated and non-defoliated Crimean pine sample trees. This averaged chronology retained the common signals in the individual chronologies. The corrected chronology of defoliated Crimean pine trees was compared with that of non-defoliated Crimean pine trees and the results presented in Fig. 2. It was realized that the correlation coefficient was 0.436.

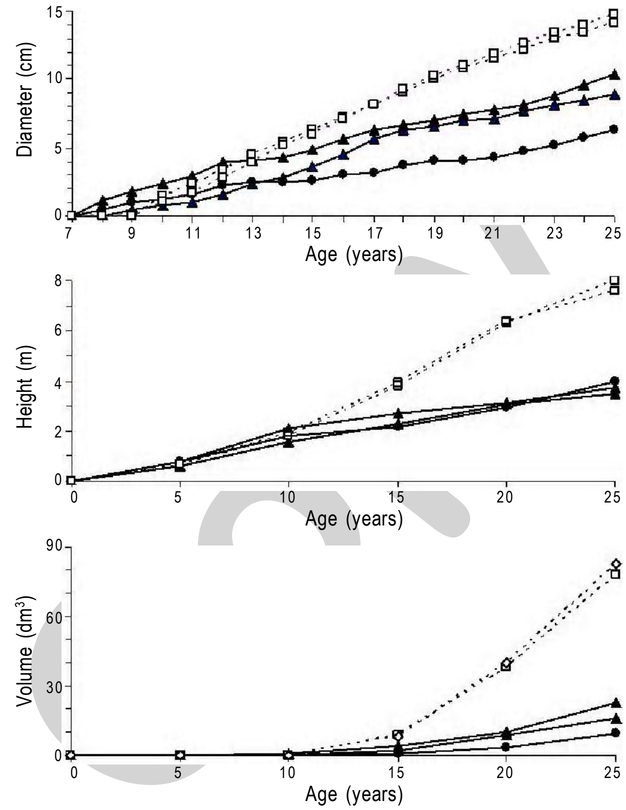

Fig. 1: Developmental trend of diameter, height and volume associated with the age of the defoliated (plot 1;n=2 and plot 2; n=1) and non-defoliated (plot 3; n=2) Crimean pine trees

The tree ring samples used to build chronologies showed significant inter-serial correlation in study area. Mean inter serial

Table - 1: Site description and characteristics of increment cores extracted at breast height

Plot No. and type	Altitude (m)	Aspect	Slope (°)	Number of increment cores	Mean (range) age of rings (years)	Standard deviation (age)
1. Defoliated	1350	N	22	25	17 (14-20)	2.15
2. Defoliated	1320	N	18	25	18 (15-20)	1.49
3. Non-defoliated	1290	N	17	25	18 (16-22)	1.92

Table - 2: Stand characteristics and differences (%) of the defoliated (SP1 and SP2) and non-defoliated Crimean pine sample plots (SP3)

Sample plot No.	Individual tree (mean of dominant or co-dominant trees)			Stand			
	diameter (cm)	height (m)	volume (m^3)	Basal area ($m^2 ha^{-1}$)	Volume ($m^3 ha^{-1}$)	Number (stems ha^{-1})	Top height (m)
SP1	12.62	4.542	0.040	6.949	24.357	525	5.07
SP2	13.53	4.900	0.048	7.863	31.408	640	5.19
SP3	16.37	7.319	0.113	13.394	67.453	847	8.51
Means							
SP1+SP2	13.08	4.721	0.044	7.406	27.883	583	5.13
SP3	16.37	7.319	0.113	13.394	67.453	847	8.51
Differ. (%)	- 20	- 35	- 61	- 45	- 59	- 31	- 40

Table - 3: Results obtained with the ARSTAN and COFECHA programs

Crimean pine groups	Defoliated	Non-defoliated
Chronology type		
Number of trees	50	25
Mean	1.000	1.000
Median	1.030	1.040
Mean sensitivity	0.300	0.261
Standard deviation	0.205	0.090
Skewness	0.396	-0.284
Kurtosis	-0.715	-1.228
Autocorrelation order 1	0.604	0.578
Partial autocorr. order 2	0.215	-0.127
Partial autocorr. order 3	-0.350	-0.169
Series intercorrelation	0.692*	0.744*
Average mean sensitivity	0.142	0.134

*Significance at 99% confidence level

Table - 4: The results of repeated measures ANOVA for annual radial increment of the defoliated and non-defoliated Crimean pine trees in 1998-2004

Source of variance	Sum of squares	df	Mean square	F	p
Between subjects					
Defoliated	5.484	1	5.484	40.690	0.000
Error	9.838	73	0.135		
Within subjects					
Year	1.224	6	0.204	14.889	0.000
Year x Defoliated	0.375	6	0.062	4.559	0.000
Error	6.000	438	0.014		

Table - 5: The results of independent samples t-test for mean annual radial increment (cm) of the defoliated and non-defoliated Crimean pine trees in 1998-2004

Years	Mean annual radial increment (±S.D.)		Difference (%)	t	p
	Defoliated	Non-defoliated			
1998	0.484 ± 0.210	0.803 ± 0.202	40	6.278	0.000
1999	0.488 ± 0.208	0.694 ± 0.167	30	4.307	0.000
2000	0.406 ± 0.182	0.634 ± 0.155	36	5.334	0.000
2001	0.385 ± 0.153	0.608 ± 0.183	37	5.580	0.000
2002	0.415 ± 0.162	0.668 ± 0.191	38	5.992	0.000
2003	0.421 ± 0.166	0.559 ± 0.148	25	3.516	0.001
2004	0.449 ± 0.143	0.600 ± 0.172	25	4.028	0.000

SD = Standard deviation

correlation, which describes the amount of common signal among tree ring series of different samples, ranged from 0.692 to 0.744 for the defoliated and non-defoliated Crimean pine trees (Table 3). This clearly indicated that the increments of individual samples responded simultaneously to environmental influence (including defoliation) within each of Crimean pine tree groups.

Outbreaks were evident as low growth indices in the defoliated series that were not correspondingly low in the non-defoliated series (Fig. 2). However, the corrected trees ring series were a good measure of the occurrence and radial growth effects of past PPM outbreaks. The study area for development of radial growth and its growth curves indicated that growth of sample trees had been reduced in the past, presumably by PPM. This relationship is illustrated by the increment chronology for Crimean pine in Isparta (Fig. 2). A decline in increment associated with PPM defoliation occurred in the period 1992-1993. In Fig. 2, hatch areas indicate where the outbreaks were most evident. Tree ring records suggested that the severely outbreaks recur periodically every 6 years (1992 and 1998) on average during which rings generally exhibited a pattern of alternating wide and narrow increments (Carus, 2004; Kanat *et al.*, 2005). A peak reduction in Crimean pine growth occurred at intervals 10 year in the following years: 1992 and 2002.

The defoliated Crimean pine tree ring width chronologies showed higher mean sensitivity than the non-defoliated Crimean pine trees. Mean sensitivity of the non-defoliated Crimean pine chronology was found to be 0.134 and indicating a low response to climatic factors. Crimean pine produced complacent rings, and high mean sensitivity revealed relatively low variation in the chronology. Low growth in the previous year (t-1) was a limiting factor for tree ring widths (Table 3). The non-defoliated Crimean pine tree ring width chronologies had a lower first-order autocorrelation than the defoliated Crimean pine trees and non-defoliated Crimean pine trees values first-order autocorrelation were calculated as 0.604 and 0.578, respectively. It is very likely reflecting the effects of PPM (Table 3). There was a sharp decline in increment of defoliated Crimean pine trees during and directly after a PPM outbreak. In contrast, growth of non-defoliated Crimean pine trees declined only slightly during the outbreak but increased greatly directly after the outbreak as shown in Fig. 1, 2.

Two outbreaks (1992 and 1998) were identified in the past 20 years (Fig. 3). Since the PPM outbreaks showed a decrease in radial and height increments of defoliated Crimean pine trees, compared to those of non-defoliated Crimean pine trees (Fig. 1, 3). There was a steady, continuous decrease in height increment of affected trees, during 1998-2004, compared to that of non-defoliated Crimean pine trees. The tree ring width of defoliated trees is lower than non-defoliated trees in PPM outbreak years. However, in this study, the tree ring width of defoliated trees was found larger during out of outbreak years (Fig.3). Similar, result had been observed by Muzika and Liebhold (1999), Ryerson *et al*. (2003) and Carus (2004).

The graphical comparison of the defoliated and non-defoliated Crimean pine chronologies should provide some evidence that PPM have caused radial growth reduction in the defoliated Crimean pine trees. Earlier outbreaks were inferred from corrected tree ring chronologies (Fig. 2).

We estimated that several years would pass before severely defoliated Crimean pine trees would regain their normal growth rate (Fig. 1, 3). If the alternate growth shows up in defoliated Crimean pine trees but not in non-defoliated Crimean pine trees, it is most

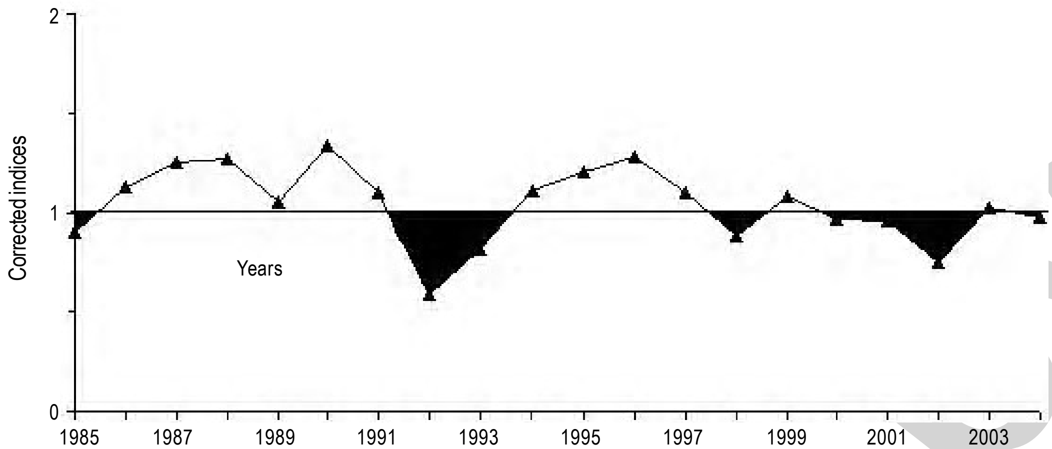

Fig. 2: Comparisons corrected indices with the defoliated and non-defoliated Crimean pine groups

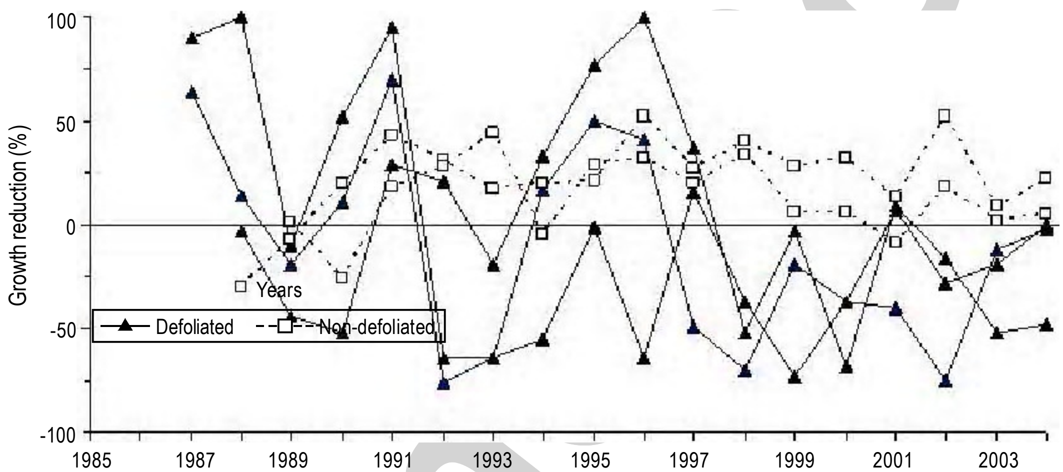

Fig. 3: Reduction (%) in mean radial increment for the defoliated and non-defoliated Crimean pine trees

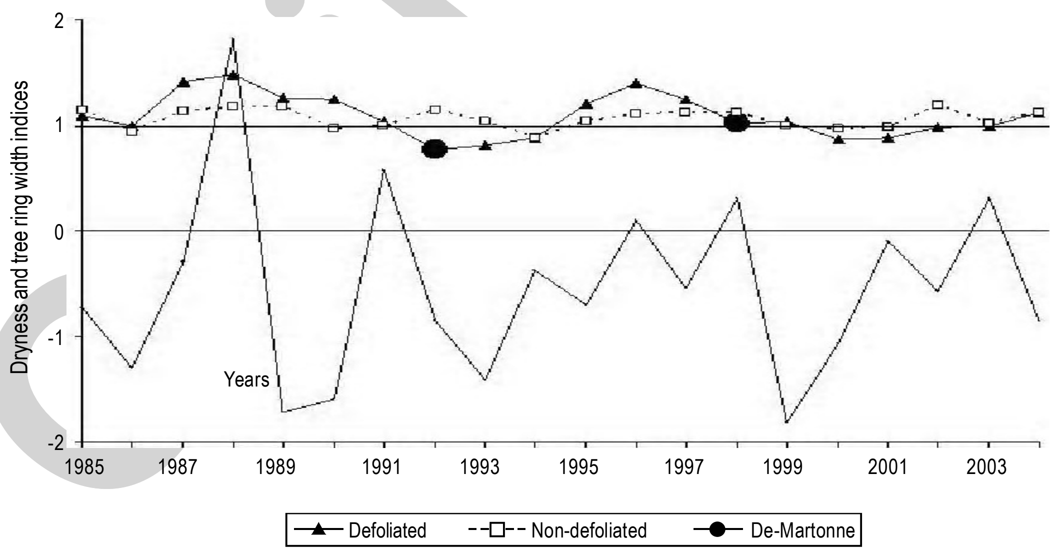

Fig. 4: Comparisons of De Martonne's dryness indices (*solid line*) and tree ring width indices in the defoliated and non-defoliated Crimean pine sample plot groups. *Large filled circles* indicate outbreaks years

likely that such growth is caused by defoliation of PPM. However, cold winter temperatures can kill PPM larvae or cool spring temperatures can result in poor synchrony between larval populations and host plant development (Blais, 1985; Mattson and Haack, 1987).

Defoliation estimates were comparable between defoliated and non-defoliated Crimean pine sample trees and reflected PPM populations in outbreak years followed by a steep decline in populations within a few years following the defoliation (Table 4 and Fig. 3). In contrast, growth of non-defoliated Crimean pine trees declined slightly during the outbreak and increased significantly in post outbreak years. A period of recovering of tree ring widths to pre-outbreak levels should last 2 to 3 years.

The final size of the sample trees at felling was reduced significantly by PPM outbreaks, the effect was calculated with Eq. 2. Final diameter was reduced 59%, height by 48% and total stem volume by 80% for defoliated Crimean pine sample trees of potential. But, the magnitude of the damage varied from tree to tree (Fig. 3).

Annual radial increments of defoliated and non-defoliated Crimean pine trees were measured for seven years different growing years, namely, 1998, 1999, 2000, 2001, 2002, 2003 and 2004. The result or repeated measures ANOVA test for the annual radial increment of both defoliated and non-defoliated Crimean pine trees are presented in Table 4. The interaction of outbreak and growing years studied and a strong significant difference is determined for defoliation, thus revealing that annual radial increments in the Crimean pine trees are considerably affected by the defoliation of the PPM at $p<0.05$ level.

From 1998 to 2004, the results of independent samples t-test for mean annual radial increment of the defoliated and non-defoliated Crimean pine trees are given in Table 5. As indicated in this table, the mean annual radial increment of defoliated Crimean pine trees were significantly lower in 1998-2004 (t-tests, $p<0.05$).

Average decrease in annual radial increment for seven growing years (1998-2004) is about 33%. The greatest percent decrease (40%) in the annual radial increment of the defoliated Crimean pine trees defoliated by the PPM was for the year of 1998, followed by 38% in 2002, 37% in 2001, 36% in 2000, 30% in 1999 and 25% in 2003 and 2004, respectively (Table 5).

Response to drought: Trees on defoliated and non-defoliated sample plots responded to a severe drought, which occurred over the period 1998-2004, with a substantial decrease in annual radial increment. The observed decrease in growth began in 1998. A similar decrease in radial increment was as great as in 1992 (Fig. 3 and 4). The highest De Martonne dryness the corrected indices occurred in 1989 which however, was not followed by PPM outbreak. It was probably related to dryness period that was very short in terms of PPM outbreak.

The coefficients of correlation (r) between De Martonne's dryness coefficient and tree ring width index for non-defoliated and defoliated Crimean pine group were found 0.20 and 0.31, respectively. The very low r calculated for the PPM outbreak stands suggest that PPM altered of Crimean pine trees radial growth. Independently derived tree-ring reconstruction of De Martonne's dryness index from non-defoliated Crimean pine trees show that, over the past 20 years, PPM outbreaks generally coincided with dry periods, whereas low PPM population levels corresponded to wet periods (Fig. 4). Since 1985, 2 of 2 outbreaks coincided with dry episodes. The probability of obtaining such a coincidence of events by chance was very low (Carus, 2004). It is reasonably to conclude that the ecological role of PPM is an important disturbance agent in the western Mediterranean Crimean pine forests.

Speer *et al*. (2001), also demonstrated that defoliation reduced latewood formation. Increases in the proportion of earlywood correspond with the defoliation periods and the loss in total increment. With having this in information, it is reasonable to conclude that a narrow latewood band is significant indicator of defoliation by PPM. In addition to the parameters based on total ring-width variations, we visually confirmed the timing of identified outbreaks by scrutinizing the dated tree-ring specimens (Fig. 4). The total ring width was typically reduced during the first year of heavy defoliation and continued to be for a few years.

In the study indicated that the PPM caused a significant impact on radial (20%), height (35%) and volume (61%) growth of Crimean pine trees in the young plantation (age of stand=25). Furthermore, this research provided insight into the evaluation of historical frequency of PPM outbreaks and factors controlling the activity of PPM in Gelendost Forest.

This type of research will greatly improve our ability to sample and interpret both short-term changes in the abundance of needle-feeding insects and decipher basic biological limitations on insects. This information may prove useful in refining simulations and models, as well as providing data for ecological and economical studies (Gatto *et al*., 2009) of the relations between PPM outbreaks, stand density, species diversity, site history (fire control and logging), and climatic events.

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