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J. Environ. Biol.
32, 263-270 (2011)
ISSN: 0254-8704
CODEN: JEBIDP

Effect of pine mistletoe on radial growth of crimean pine (*Pinus nigra*) in Turkey

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Publication Data

Paper received:
10 September 2009

Revised received:
17 March 2010

Accepted:
20 April 2010

Abstract

In this study, the influence of infection by pine mistletoe (*Viscum album* L. subsp. *austriacum* (Wiesb.) Volmann) on the radial growth of crimean pine (*Pinus nigra* Arnold) in Turkey was investigated. We built local residual tree-ring-width chronologies using dendrochronogical techniques. Tree ring chronologies of uninfected (control) crimean pine were used to estimate potential radial growth characteristics in the "infected" crimean pine (light, moderate and severe infection groups). In 2005, increment cores were collected from 26 infected and 19 control dominant or co-dominant trees and annual radial growth indices from 1930-2005 were calculated for each infection group in a 14 point sampling. We compared radial growth in the uninfected trees with mean regional chronology. We found a strong decrease in radial growth in during the 1998-2005 period. The periodic average radial growth reduction (in %) from 1998 to 2005, respectively, were 0 for control, 26 for light, 39 for moderate and 63 for severe infection groups. It can be especially concluded that a severe degree of pine mistletoe attack has a negative effect on radial growth of the infected crimean pine trees.

Key words

Pine mistletoe, Infection, Crimean pine, Dendrochronology, Growth loss

Introduction

The mistletoe (*Viscum album* L.) is a parasitic flowering plant with functional chlorophyll and it is considered as semiparasite. It has a wide distribution in Europe and Asia and has also been introduced to North America (Hawksworth and Scharpf, 1986). *V. album* is an important plant parasite infecting a wide variety of hosts. Barney *et al*. (1998) have listed 452 plant species as hosts of *V. album*. Three subspecies of *V. album* are generally recognized: (a) subsp. *abietis* (Wiesb.) Abromeit on *Abies* spp.; (b) subsp. *austriacum* (Wiesb.) Volmann on *Pinus*, *Larix* and *Picea* spp.; and (c) subsp. *album* on hardwoods. *V. album* subsp. *austriacum* has been recorded on Crimean pine (*Pinus nigra* Arnold), Scots pine (*Pinus sylvestris* L.) and Maritime pine (*Pinus pinaster* Ait.) (Barney *et al*., 1998).

Mistletoes cause a great deal of damage in forests, orchards, plantations and ornamentals worldwide. Hawksworth *et al*. (1977) stated that mistletoes impair growth and host vigor, reduce wood quality and quantity, along with fruiting and predispose trees to attack by insects, disease and fungi. It also reduces male and female flowers's production on different host trees. The parasite develops special adaptation for mineral nutrition by using its sucking roots, which leads to reduced growth of the host plant (Canakcioglu, 1985).

Crimean pine shows wide natural distribution in Balkans, Syria, the Crimea, Cyprus and Turkey (Yucel, 1998) and covers an area of about 4.2 million ha in Turkey. However, Crimean pine is the most important timber species in Turkey as it represents approximately 25% of the standing volume (about 297 million m^3) of Turkey forests (Konukcu, 1998). Its growth is seriously affected by parasitic/hemiparasitic flowering plants such as mistletoe a hemiparasitic flowering plant (Ergun and Deliorman, 1995). *V. album* subsp. *austriacum* is known as Pine mistletoe (PM). It was among the biotic factors that reduce tree vigour and predispose trees to beetle attacks (Canakcioglu, 1985). While PM is not a widespread disease in Turkey crimean pine forests, in some localities it is common and severely parasitizes crimean pine. Eroglu (1993) reported that radial growth of Scots pine growing in Turkey was reduced by 56% for 15 yrs due to the infection of PM.

In Turkey particularly in crimean pine forest in Keciborlu Forest of Isparta, local forestry observed the parasite to invade new territories, to reach alarming intensity and consequently to affect growth performance and health of infected trees (Anonymous, 2000). PM is one of the most significant biotic factors that affect crimean pine trees in Keciborlu forest, since two thirds of the overstorey trees were found infected by the PM. Attempting to control the disease, local forestry is removing the infected trees, what is impeding the implementation of silvicultural concepts in heavily infected stands with crimean pine. Furthermore, it seems to be a trend of about 80 yr old trees to be infected and even killed by the parasite.

A ring produced in a particular year is a function of several interrelated biological, physical, stand and climatic factors. Because our main objective was to understand or evaluate the effect of infection on growth, factors that affected the width of an annual ring produced in a given year and that were not related to infection, were removed from the ring width series. Dendroecological methods allow one to account for abiotic and biotic conditions that affect annual radial growth in trees, such as climate and tree age and then isolate the contribution of a single factor, such as PM infection, to radial growth. Several recent North American studies have used dendroecological analysis to investigate the effects of defoliating insects on radial growth (Fritts and Swetnam, 1989; Swetnam *et al.*, 1985; Akkuzu and Guner, 2008). In addition, our study is the first dendrochronological assessment on the effects of the PM infected on the radial growth in a crimean pine stand in the Western Turkey, near the southeastern distribution limit of species. Therefore, the aim of this study was to investigate the influence of damage caused by PM on the radial growth of crimean pine trees grown in the region of Isparta, the western Mediterranean part of Turkey.

Materials and Methods

Study area: The study area was located in the Western Mediterranean region of Turkey, which is approximately 20 km from Isparta (Fig. 1). The 50 ha study area is situated at 37°59'N, 30°21'E, average slope 22°, predominantly east-facing aspect, 1150 m altitude. The study area is found on calcareous formations. The soil is generally shallow or medium-deep, any stony, with a predominantly sandy-clay texture.

Mean monthly and annual temperature and rainfall data for the period 1940-2005 were obtained from the Isparta Meteorological station. In the study area, the 635 mm (mean annual) precipitation falls mainly October through May. There was great deviation in the distribution and amount of precipitation during the investigation period. This region is the transitional zone between the Mediterranean climate and the continental climate with colder winters and hotter summers. Mean annual temperature 11.4°C. In accordance with De Martonne's dryness coefficient (I=15.5), the study area is identified as semi-humid. The last logging activities in stand date from at least 20 yr ago, so no recent radial growth release has been observed in the tree-ring series.

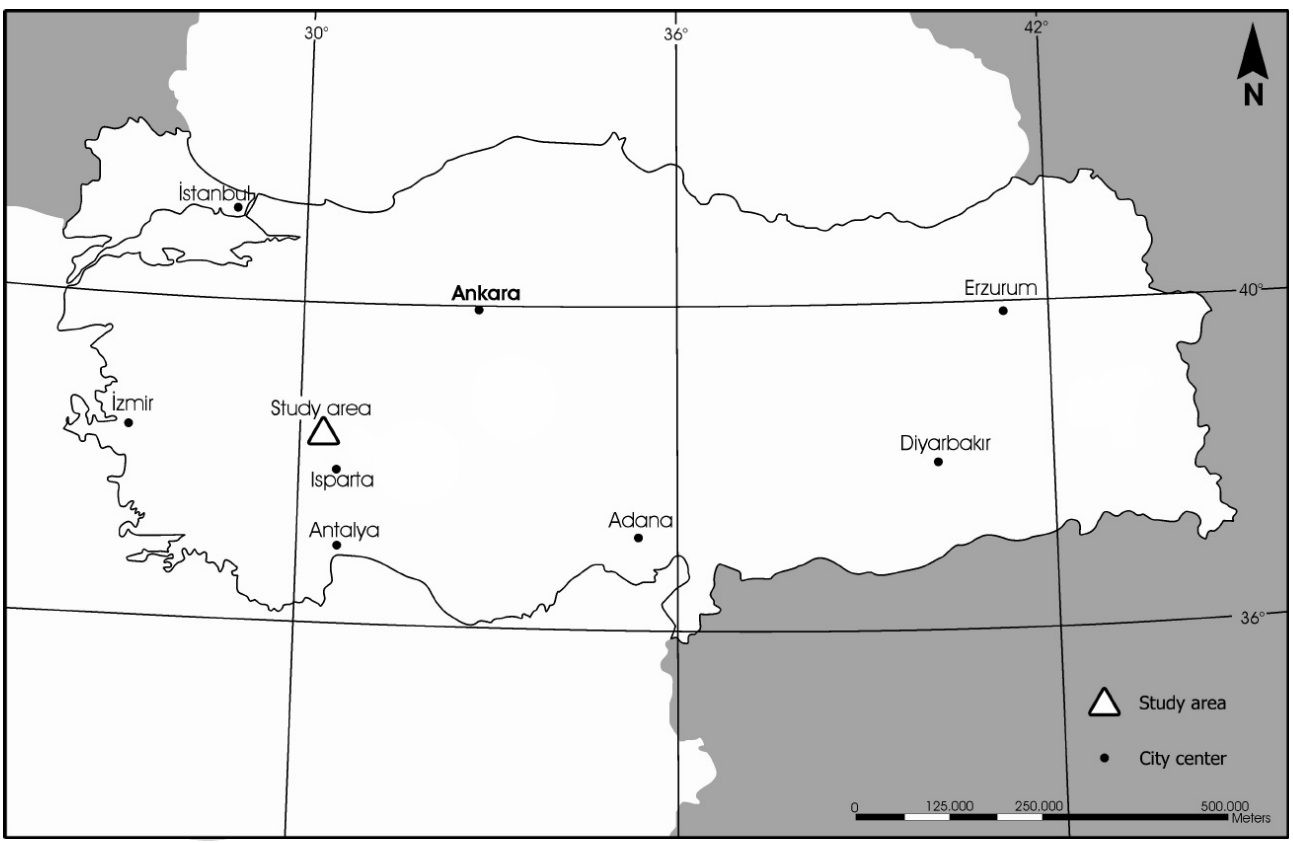

Fig. 1: Map of Turkey showing the Keciborlu study area

The study stand is the result of natural regeneration from 1930-1935. This study investigated the relationship between infection and loss in radial growth of trees in the Isparta region in the Western Mediterranean of Turkey from 1930 to 2005. The investigation was based on a 80 yr old of crimean pine stand where growth and crown had been monitored since 1998.

Biological properties of pine mistletoe: PM is an evergreen epiphytic phanerophyte, respectively an epiphytic hemiparasitic shoot parasite (Dobbertin and Rigling, 2006; Hawksworth *et al*., 1996; Meinzer *et al*., 2004; Zuber, 2004). The maximum age of a shrub is about 27-30 yr. In Turkey, PM grows as a parasite on crimean pine and scots pine (Canakcioglu, 1985).

In 1998, 14 sampling points were selected in the study area. These were systematically located along transects of a 25 m x 25 m grid, over an area of about 2 ha a dense crimean pine forest. For PM assessment, a sample of 10 trees was selected and marked by following a spiral from the plot centre. In total, the sample trees was 140. PMR for each sample tree was estimated visually to the nearest PMR 1 by three persons, and the final assessment was the average of these three estimates. Each sampling point had selected trees with PMR and point sampling number marked at breast height. The crown changes (PMR assessment) of sample trees were observed in the springs of 1998-2005. In 2005, mean PMR of each sample tree was determined in order to analyze the data into control, light, moderate and severe infection classes (groups). It was realized that infection classes of sample trees was not changed (remaining~85%) by PM during the years 1998-2005. In each sampling point, the sample trees (both infected and control trees) were selected from each of four PMR: control (n=19), light (n=9), moderate (n=9), severe (n=8) infection groups and from dominant or co-dominant crimean pine trees in the spring of 2005. In the autumn of 2005, increment cores were extracted at breast height from opposite sides of each sample tree parallel to the topographic contour.

In each sampling point, the height and diameter at breast height of each dendrochronological sampling tree were measured. To estimate stem density and basal area of stand, the number, diameter and height of all neighbors within a circle of 7.62 m radius around each sampled tree were recorded. This sample trees and increment cores characteristics for control, light, moderate and severe infection group were shown in Table 1. In 2005, the average tree density was 781 trees ha^{-1}, mean diameter at breast height (dbh,1.3 m) 20.51 cm, mean height 9.24 m and basal area 25.79 $m^2 ha^{-1}$ and poor site quality.

Mistletoe rating systems (PMR) are typically used for estimating the severity of mistletoe infection on individual trees and within forests. The severity of infection is then used to estimate the amount of growth loss experienced due to mistletoe infection. It is important to understand the relationship between severity of infection as indicated by the rating system and growth reductions experienced by trees or forests so that management priorities can be initiated to reduce the growth effects of mistletoe infection. Sample trees were assessed in 1998, with the "6-class" rating system of Hawksworth (1977), to quantify the degree of infection. This method was originally designed for dwarf mistletoe (*Arceuthobium* spp.). In this system, the live crown of each tree is visually divided into three parts. Each third is rated according to the following scale: 0, no infection; 1, light mistletoe infection (less than half of the branches infected); and 2, heavy mistletoe infections (more than half of the branches infected). Bole infections were rated as 2. The total mistletoe rating of each tree was obtained by adding the rating of each third. In this way, a tree without mistletoe infection was rated as 0 and the maximum PMR of a heavily infected tree was 6. PMR 1 and 2 was characterized as light infection, 3 and 4 as moderate infection and 5 and 6 as severe infection. Besides the mistletoe rating, trees with top killing or trees with tops completely covered by the parasite were recorded in each sampling point.

Dendrochronological analysis: Dendrochronological sampling was carried out following standard methodology (Cook and Kairiukstis, 1990). The cores were dried and polished using sand-paper of progressively finer grain. Ring width was measured, to the nearest 0.01 mm. In this study we were mainly interested in the high-frequency variability of radial growth, such as that related to PM outbreaks. Autoregressive modeling was performed on each detrended ring-width series. They were averaged using a biweight robust mean to obtain residual chronologies. This was done using the ARSTAN program (Cook and Holmes, 1986).

The dendroecological analysis of the effects of infection is usually based on the comparison of radial growth in infected versus uninfected trees (Swetnam *et al*., 1985). We developed a regional mean chronology (control) using 45 trees from same site. The control chronology was compared with light, moderate and severe chronologies to remove other environmental factors from the latter series (climate). The scaled residual ones were substracted from the infected-tree indices to obtain the "CI, corrected indices" (Swetnam *et al*., 1985). Equation 1 corrects an infected-tree chronology by first scaling residuals from the control site chronology to the same variance as the infected-tree chronology to be corrected. These scaled residuals are called the "predicted residual indices" (PRI). The PRIs are then simply subtracted from the infected-tree indices to produce the CIs. The purpose of the CI is to remove environmental effects common to both infected and uninfected chronologies from the infected-tree ring chronologies, so that more precise estimates of growth reduction can be derived. The corrected series (Eq. 1 and Fig. 2) were used to identify the timing of outbreaks, the duration of PM-induced low-growth periods, and the maximum annual and periodic radial growth losses. Subtracting the CIs during outbreaks from the potential growth value (1.0) and multiplying by 100 gave the latter two measures. Thus, the radial growth reduction measures are expressed in relative terms as a percentage of expected growth.

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

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

SD(H) and SD(NH) are the standard deviations of the infected and control series, INDEX(H) and INDEX(NH) are index values of the infected and control series, respectively, and MEAN(NH) is the mean of the control series (about 1.0).

Statistical analysis: Differences in standard chronologies between the control, light, moderate and severe infection groups for all years from 1930-2005 and from 1998-2005 were tested using ANOVA model. Duncan's test was applied to determine whether or not there were significant in chronologies of control, light, moderate and severe infected trees. Data analysis was performed using SPSS ver. 17.0.

Results and Discussion

Increment cores were taken from 26 dominant and co-dominant infected crimean pine trees and from 19 dominant and co-dominant control crimean pine trees. Table 1 presents some growth

Table - 1: Summary of increment cores and sample trees used in radial growth for control, light, moderate and severe infection group

Infection group	Number of increment cores	Mean no. of rings (age)	Age range (years)	Age SD (years)	Average diameter[x] (cm)	Average height (m)	Average volume (m^3)
Control	19	62	41-87	10.9	22.503 [a]	8.974 [a]	0.215 [a]
Light	8	63	53-69	8.1	23.871 [a]	9.063 [a]	0.233 [a]
Moderate	9	69	50-94	17.7	25.680 [a]	9.167 [a]	0.287 [a]
Severe	9	67	49-82	9.5	23.909 [a]	9.278 [a]	0.234 [a]

Means within columns followed by different letters are significantly separated at $p<0.05$, SD = Standard Deviation

Table - 2: Results obtained with the ARSTAN and COFECHA programs

Infection groups	Control	Light	Moderate	Severe
Chronology type	Standard	Standard	Standard	Standard
Mean	1.0000	1.0000	1.0000	1.0000
Median	1.0571	1.0007	1.1655	0.8649
Mean sensitivity	0.0932	0.1525	0.1141	0.0988
Standard deviation	0.2437	0.3667	0.2745	0.4521
Skewness	-0.0770	0.7860	0.0430	0.0509
Kurtosis	-0.8290	0.2060	-1.0770	-1.3120
Autocorrelation order 1	0.8910*	0.8370*	0.8420*	0.9600*
Partial autocorr. order 2	0.7580*	0.6880*	0.7040*	0.9200*
Partial autocorr. order 3	0.6560*	0.5420*	0.6580*	0.8700*
Series intercorrelation	0.4540*	0.5899*	0.5050*	0.6055*

* Significance at 99% confidence level

Table - 3: Mean annual radial growth (mm) of crimean pine trees (light, moderate and severe infected by pine mistletoe) in 1998-2005 (n=45)

Years	Mean annual radial growth[x]			
	Control 1.017 b (0.568)[y]	Light 1.458 a (0.594)	Moderate 0.861 b (0.720)	Severe 0.306 c (0.201)
1998	0.958 [ab]	1.467 [a]	1.022 [a]	0.333 [b]
	(0.560)	(0.757)	(0.751)	(0.141)
1999	0.916 [b]	1.600 [a]	0.844 [b]	0.356 [b]
	(0.571)	(0.400)	(0.773)	(0.194)
2000	0.958 [ab]	1.400 [a]	1.111 [ab]	0.400 [b]
	(0.572)	(0.529)	(1.054)	(0.387)
2001	1.000 [b]	1.733 [a]	0.956 [b]	0.267 [c]
	(0.607)	(0.924)	(0.726)	(0.141)
2002	1.021 [b]	1.667 [a]	0.844 [bc]	0.860 [c]
	(0.577)	(0.643)	(0.684)	(0.647)
2003	1.084 [a]	1.267 [a]	0.822 [ab]	0.244 [b]
	(0.551)	(0.702)	(0.784)	(0.088)
2004	1.147 [a]	1.267 [a]	0.644 [ab]	0.289 [b]
	(0.628)	(0.702)	(0.456)	(0.203)
2005	1.053 [ab]	1.267 [a]	0.644 [bc]	0.289 [c]
	(0.125)	(0.643)	(0.546)	(0.203)

[x] Means within rows followed by different letters are significantly separated at $p<0.05$, [y] Values of standard deviations are given in parenthesis.

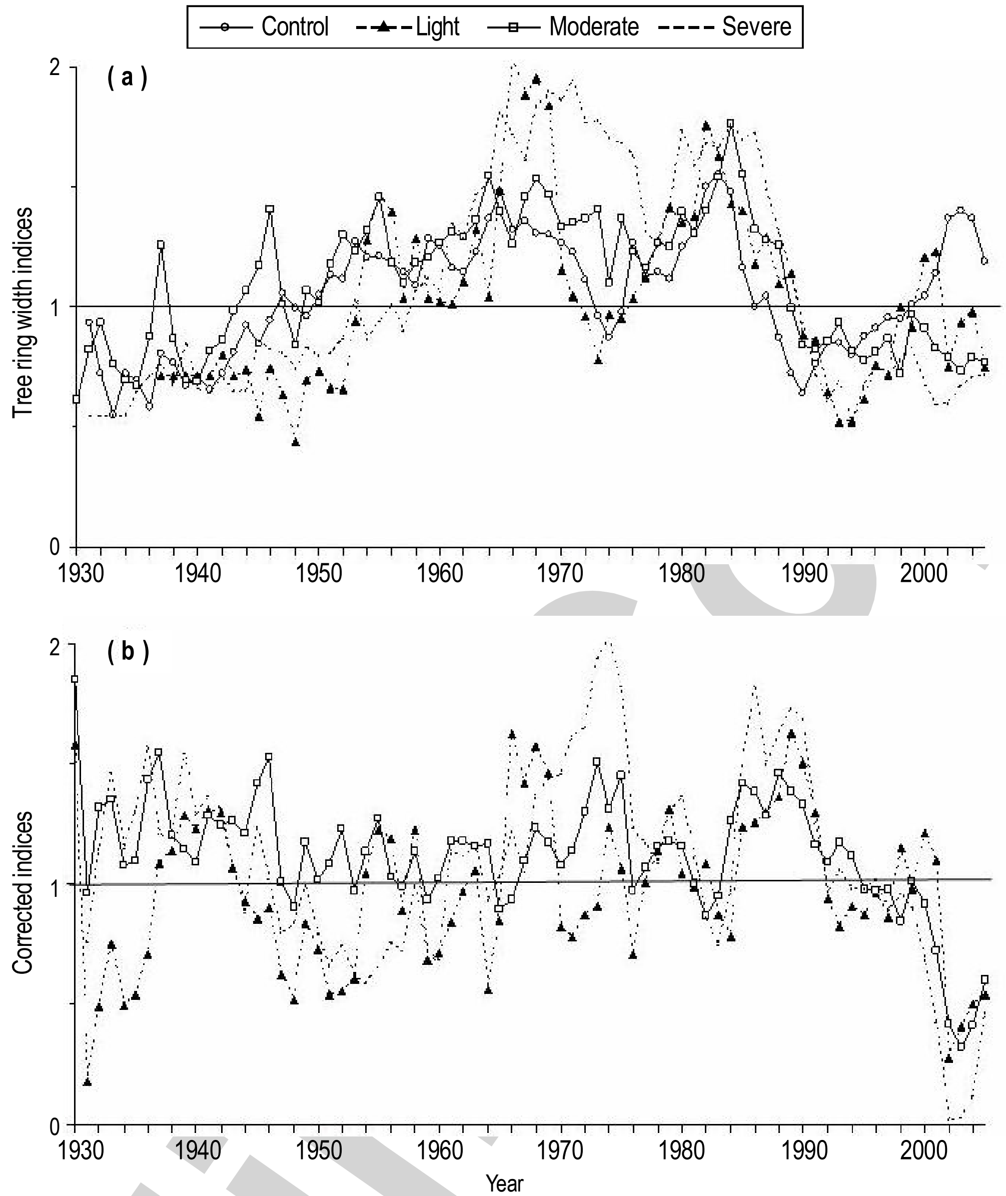

Fig. 2: Comparisons of tree-ring-width indices (a) and corrected indices for different infection groups (b)

statistics of sample trees in four infection groups. The F values of ANOVA for diameter, height and volume were found to be 0.581, 0.178 and 0.744, respectively. However, there was no statistically significant differences for diameter, height and volume (from 1930-2005). The cumulative effect of PM on final tree size was small in relation to some of the reductions in annual increment, but rose because annual growth was reduced only partially, and in only 8 years out of the total 80-year life of the stand. Viewed in this context, the effect on final tree size could not be much greater (Table 1).

Comparing infected and control chronologies; after measuring and matching of individual chronologies, a master chronology of crimean pine was developed for each infection group (Fig. 2). The chronologies patterns of all infection groups were analysed from 1930 to 2005. When infected trees and those in control are taken from the same stand, differences between increment or growth rate are not affected by climatic and ecological factors (Shaw *et al.*, 2008). Therefore sample trees were taken from the same stand in this study. The signal of climatic influence on the growth of infected trees had been minimized by the control chronology, the growth reductions were most likely caused by PM outbreaks.

The tree ring samples used to build chronologies showed significant inter-serial correlation in the study area. Mean inter-serial correlation, which describes the amount of common signal among tree ring series of different samples, ranged from 0.4540 to 0.6055 for the infection groups (Table 2). This indicated that the increment of individual samples responded simultaneously to environmental influence (including infection) within each infection group.

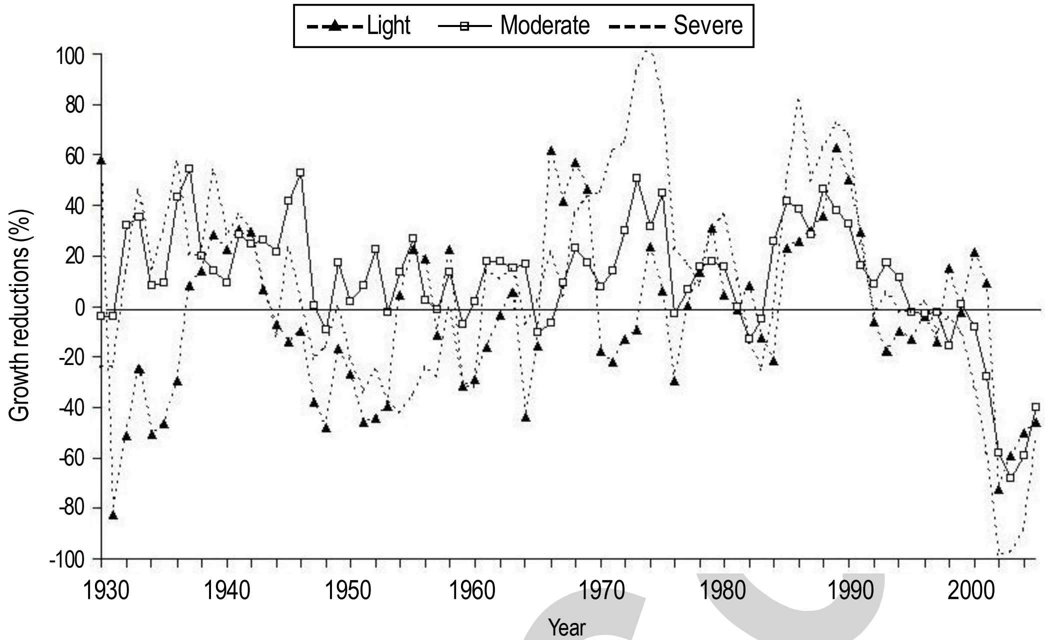

Fig. 3: Reductions (%) in mean radial growth for different infection groups (light, moderate and severe)

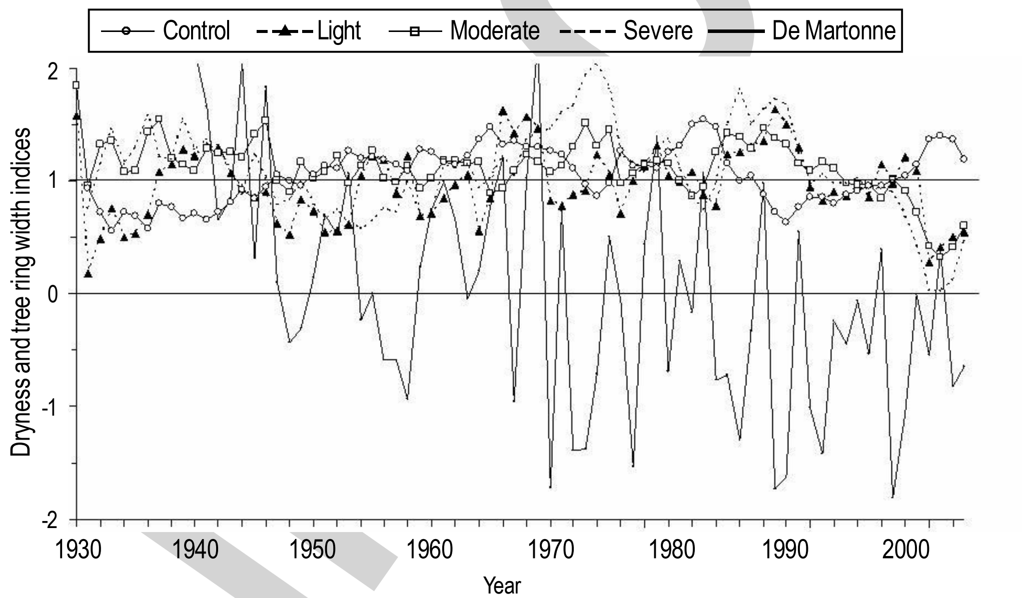

Fig. 4: Comparisons of De Martonne dryness index (solid line) and tree-ring-width indices in the different infection and control sample trees groups

The control tree ring width chronologies had a lower first-order autocorrelation than the infected trees; the severe, moderate, light and control values first-order autocorrelation were calculated as r=0.9600, r=0.8420, r=0.8370 and r= 0.8910, respectively, very likely reflecting the effects of PM. The graphical comparison of the infected and control chronologies should provide some evidence that PMs have caused radial growth reduction in the infected trees.

There was a considerable difference in variability of the infection data in stand rated severe, moderate, light and control, as was expected from the original classification scheme. Growth loss was calculated using Eq. 1, as the proportional reduction in observed growth relative to expected growth. There was also a clear pattern in average infection (Figs. 2 and 3), with trees rated severe having the highest average infection, followed by trees rated moderate, light and control.

Radial growth; Sample trees exhibited an abrupt growth reduction starting at 1998 and lasted 8 years (Fig. 2). Average annual ring widths of crimean pine were smaller during an outbreak, indicating a temporary decline in growth due to feeding by PM (Fig. 2). To confirm this visual comparison of chronologies, one-way analysis of variance was performed to detect any statistical significance. The analysis was conducted using outbreak years and ratings as infection groups and control chronology as the response variable. F value of ANOVA was 1.632 (df=3, 259; p=0.182), indicating that for control-infected groups, there were no statistically significant difference between the standard chronologies (from 1930-1998). However, F value for the outbreak (from 1998-2005) was 18.570 (df=3,28; p<0.0001). This result indicated that for the control-infected group, there was a statistically significant difference between the standard chronologies during 1998-2005 (Fig. 3). While radial growth of trees with either light infection rates (PMR=1 or 2) was not detectably different from growth of uninfected trees; radial growth of moderate or severely infected trees (PMR= 3 or 4 and PMR= 5 or 6) was found to be quite different (Table 3).

As a percentage annual radial growth reductions during the period 1998-2005 were found as light (+15, 3, +21, +9, 72, 59, 50, 46), moderate (16, +1, 8, 28, 58, 68, 59, 40) and severe (4, 10, 32, 58, 98, 97, 88, 54) infection group of control, respectively. The greatest percentage decrease in the annual radial increment was realized in 2002 and 2003 for light, moderate and severe defoliation groups, respectively (Table 3). Average decrease on annual radial increment for eight growing years was 26, 39 and 63 for light, moderate and severe infection group, respectively. Trees infected exhibited the most decreases in radial growth (Fig. 3). During the period of 1998-2005, the average radial growth of trees for control, light, moderate and severe infection groups was 8.137, 11.666, 6.889 and 3.038 mm, respectively.

Response to drought; Trees in control and infection groups responded to a drought, which occurred during the period 1998-2005, with a substantial decrease in annual radial increment (Fig. 4). In 1998, De Martonne's dryness coefficient and total monthly precipitation was 16.78 (semi-humid) and 683 mm, respectively. The observed decrease in growth began in 1999 and reached a minimum in 2002. However, this pattern was not observed in the control trees for the same interval (Fig. 4). The coefficients of correlation (r) between De Martonne's dryness coefficient and ring width index for control and infected crimean pine infection groups (light, moderate and severe) were found to be 0.21, 0.11, -0.84 and -0.78, respectively. The very high r (as absolute) calculated for the PM outbreak stands suggests that PM altered crimean pine radial growth. In the absence of PM, the near unity slopes and higher r show that infected and control crimean pine of similar dominance and size are also similar in radial growth pattern.

The sample trees (n=140) that died, during the period of observation (1998-2005), were (n=23) infected by the PM. The levels of mortality were higher in trees with intensive PM infection. Mortality of the sample trees was low in 1998 (n=1) and in 1999 (n=2), but it was significantly increased in the years 2000-2005, with mortality sample tree 2, 4, 3, 3, 6, 2 respectively. Extensive tree mortality was observed during the years 2002-2004. Low precipitation in two consecutive years (1999-2000) was an important parameter that affected tree mortality. Crimean pine trees were attacked by the bark beetles *Tomicus minor* (Hartig), *Orthomicus erosus* (Wollaston), *Ips sexdentatus* (Borner) and *I. acuminatus* (Gyllenhal). PM is an important factor that reduces tree vigour and predisposes trees to beetle attacks during periods of low precipitation. Tree mortality was correlated with the degree of PM infection. During a 8-year-period (1998-2005), mortality of trees with severe and moderate infection was 32.08%, while mortality of trees with light infection was 10.53% and that of the uninfected trees 4.08%. Tsopelas *et al*. (2004) and Idzojtic *et al*. (2008) determined that similar mortality results for infection groups on Greek fir (*Abies cephalonica* Loud.) and Silver fir (*Abies alba* Mill.) respectively.

In certain heavily infected trees we observed more PM foliage than host tree foliage. Bole infections were very frequent, especially on the upper part of the crown. In 15.16% of the sample trees, the whole part of the top was covered by the PM, which had infected the trunk and the branches causing deformation of the crown. Very often, branch dieback was observed beyond the point of bole infection. In 5.51% of the sample trees the top was recently (2004 and 2005) dead, as a result of the PM infection. Additionally, the cones of the infected trees were smaller than those of control trees. The more the number of mistletoe was available, the more the growth reduction was observed.

The radial increment of affected trees decreased from 1998-2005, especially in lightly, moderately and severely infected trees (Fig. 3). In addition, our results in Keciborlu Forest indicate clearly that PM was the most important biotic factor that affected tree mortality. A strong linear correlation was found between infection levels (PMR) and the mortality rate.

The impacts in radial growth were no detectable on infected trees until the individual tree was moderately to severely infected (Table 3). This has also been observed in most other studies (Hawksworth *et al*., 1996; Geils *et al*., 2002). Hawksworth *et al*. (1996) estimated that forests of Ponderosa pine (*Pinus ponderosa* Laws.) severely infected with southwestern dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Hawksw. and Wiens) showed the general reduction in 10 yr radial growth, compared with uninfected trees, was 30 and 50% or more for moderate and severe infection group, respectively. Similar results had been observed by Eroglu (1993) in the Eastern Black sea region of Turkey. The relationship between percentage of trees infected was similar to that reported for Scots pine stands severely infected with PM (Eroglu, 1993). Reported that annual radial growth of Scots pine was reduced by 56% for 15 yrs due to infection of PM. In the our study, average decrease on annual radial growth for eight growing years (1998-2005) was 26, 39 and 63 for light, moderate and severe infection group, respectively. This result corresponds with the findings of Eroglu for PM. Fig. 3 shows the percent decrease in mean radial increment of crimean pine trees infected by the crimean pine trees due to the PM infection groups for the eight growing years, from 1998 to 2005.

The growth declines caused by severe dwarf mistletoe infection are likely a result of the multiple interacting factors that influence hydraulic architecture, water, and carbon relations of trees infected with western hemlock dwarf mistletoe (Meinzer *et al*., 2004). One major effect reported by Meinzer *et al*. (2004) was that maximum photosynthetic rates of severely infected trees (PMR 6) were approximately half those of uninfected trees largely because of reduced leaf nitrogen, which was 35% lower in infected trees. In addition, they estimated the whole tree reduction in carbon accumulation was about 60% because of combination of reduced photosynthesis and loss of leaf area from branch mortality. Infected trees also had fewer live branches than uninfected trees of equivalent size. Shaw *et al*. (2008), reported as dwarf mistletoe infection intensifies in Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) trees, it is likely that the tree goes through a transformation in leaf area from an initial increase followed by a decline as branches die and the top dies back. Stanton (2006) and Shaw *et al*. (2008) determined that a minor radial growth increase in light DMR trees in Ponderosa pine and Western hemlock, respectively. In this study, similar results were observed on crimean pine trees in the Western Mediterranean region of Turkey (Table 3). They hypothesized might be related to increased leaf area associated with broom formation.

To avoid economical losses due to PM on crimean pine, it was suggested to reduce the ratio of this tree species in favour of Lebanon cedar (*Cedrus libani* A. Rich.) (Anonymous, 2000). In mixed stands of crimean pine with other species, silvicultural measures can be applied to favor the non-host species, in order to reduce PM infection. Lebanon cedar is a non-host of PM and it grows well in the areas of Keciborlu Forest that has been planted. Reforestations with this species have been proposed in certain sites where crimean pine is declining. Futhermore, pruning is a useful measure in controlling PM in Keciborlu Forest stands, since it improves the vigour of the trees and prolongs their life (Hawksworth *et al*., 1996).

If the growth reductions for crimean pine reported from the sites we sampled are representative of other locations in Turkey, infection by PM is responsible for a substantial loss of potential growth of this commercially important species in trees infected for several years. Therefore, management of this PM should be considered wherever it occurs in stands managed for timber production. Management could include removal of severely infected trees and/or pruning of branches infected with PM to reduce the level of infection in stands and on trees.

Acknowledgments

We would like to thank my colleagues (all foresters) for their hospitality and help to trips for the study area.

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