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The Effects of Pine Processionary Moth (*Thaumetopoea wilkinsoni* Tams.) on Diameter and Volume Increment in Crimean Pine (*Pinus nigra* Arnold) Forests of Bartın

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Araştırma Makalesi

Abstract − The pine processionary moth (PPM) causes damage by eating the needles of trees. It was determined that the normal increment and growth decreased in trees affected by this insect depending on the severity of the epidemic. The aim of this study is to determine the diameter and volume increment losses caused by the PPM in trees in the Crimean pine forests of Bartın province. The research material was obtained from nine temporary trial areas determined in the natural Crimean pine forests of Bartın province. Diameter and height measurements were made on all trees in the trial areas and increment cores were taken from a total of 346 trees. The annual diameter and volume increment values were determined for the period 2010-2021. The period 2015-2017 was determined as loss years. Three classes were created as control, moderate, and high harmful, according to the three-year total diameter increment in the damage years. The differences between the diameter and volume increments of the three classes were checked by the ANOVA and the Duncan test. The effect of climate variables on these differences was examined by the Standardized Precipitation Index and the Erinç Precipitation Efficiency Index. It was understood that increment losses are not affected by the amount of precipitation and temperature. It was determined that there was a 29.89% diameter and 26.72% volume increment loss in the moderate harmful group, and a 40.22% diameter and 35.09% volume increment loss in the high harmful group. Since diameter and volume increment losses have a negative impact on tree wealth and business income, some suggestions were developed to reduce insect damage and ensure sustainable forest management.

Keywords − *Thaumetopoea wilkinsoni*, *Pinus nigra*, insect damage, increment loss, climate-increment relationship

Bartın Karaçam Ormanlarında Çam Kese Böceğinin (*Thaumetopoea wilkinsoni* Tams.) Çap ve Hacim Artımı Üzerine Etkisi

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Öz − Çam kese böceği ağaçların ibrelerini yiyerek zarar yapmaktadır. Bu böceğin arız olduğu ağaçlarda salgının şiddetine bağlı olarak normal artımın ve büyümenin azaldığı saptanmıştır. Bu çalışmanın amacı Bartın ili karaçam ormanlarındaki ağaçlarda çam kese böceğinin neden olduğu çap ve hacim artım kayıplarını tespit etmektir. Araştırma materyali Bartın ili doğal karaçam ormanlarında belirlenen dokuz geçici deneme alanından elde edilmiştir. Deneme alanlarındaki tüm ağaçlarda çap ve boy ölçümleri yapılmış ve toplam 346 adet ağaçtan artım kalemi alınmıştır. 2010-2021 dönem için yıllık çap ve hacim artım miktarları belirlenmiştir. 2015-2017 dönemi zarar yılları olarak tespit edilmiştir. Zarar yıllarındaki üç yıllık çap artım toplamına göre kontrol, orta ve çok zararlı şeklinde üç sınıf oluşturulmuştur. Üç sınıfın çap ve hacim artım değerleri arasında fark olup olmadığı ANOVA ve Duncan testi ile denetlenmiştir. Bu farklara iklim değişkenlerinin etkisi Standardize Yağış İndisi ve Erinç Yağış Etkinlik İndisi ile incelenmiştir. Buna göre 2015-2017 dönemindeki artım kayıplarının yağış ve sıcaklık miktarından etkilenmediği anlaşılmıştır. Böcek zararından dolayı orta zararlı grupta %29,89 oranında çap ve %26,72 oranında hacim artım kaybının, çok zararlı grupta ise %40,28 oranında çap ve %35,09 oranında hacim artım kaybının olduğu saptanmıştır. Çap ve hacim artım kayıpları ağaç serveti ve işletme gelirleri üzerinde olumsuz etki yaptığı için, böcek zararının azaltılmasına ve sürdürülebilir orman yönetiminin sağlanmasına ilişkin bazı öneriler geliştirilmiştir.

Anahtar Kelimeler − *Thaumetopoea wilkinsoni*, *Pinus nigra*, böcek zararı, artım kaybı, iklim-artım ilişkisi

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1. Introduction

There are many factors that damage forest ecosystems. These factors are divided into two basic groups: biotic (harmful insects, etc.) and abiotic (drought, storm, etc.). Abiotic damages affecting forests are followed by biotic epidemics such as bark beetles, and insect damages have increased further in recent years as a result of disruptions due to global climate change. Ecological disruptions caused by harmful insects in forests both harm natural ecosystems and pose a serious threat to human well-being (Seidl and Rammer, 2016; Ivantsova et al., 2019). In fact, it is stated that while forest damage caused by other factors has decreased, the amount of damage caused by insects has increased more than three times (Ivantsova et al., 2019).

Regarding insect damage, the damage caused by the *Dendroctonus frontalis* pest in the pine forests in the south of Texas and Louisiana in the USA was examined in terms of price and welfare changes and it was concluded that it was significantly negatively affected (Holmes, 1991). It is known that harmful insects in forests cause losses in growing stock and growth, and cause economic value losses. Wallner (1998) stated that the economic loss of insect damage in exotic forests in the USA exceeded 30 million US$. Holmes et al. (2006) found a statistically significant negative relationship between the amount of insect damage in exotic forests and housing values in New Jersey. Arnaldo et al. (2010) developed modeling for maritime pines (*Pinus pinaster* Ait.) on the northeastern coastline of Portugal and revealed that the pine processionary moth (PPM) made a loss of 37-73% in biomass increase and the loss was 100 €/ha. It is stated that insects and pathogens that cause damage to forests in the USA are effective in an area exceeding 20.4 million hectares annually and the cost is 2 billion US$ (USDA, 1997; Dale et al., 2001). Aukema et al. (2011) estimated the economic impacts of non-native insect species in the USA and determined the probability of a new species with a devastating effect invading the region to be 32% in a 10-year period. Additionally, it was determined that the *Dendroctonus ponderosae* has caused damage to more than 6.6 million hectares of land since 1996 in a study conducted in the Rocky Mountains National Park region (Rosenberger et al., 2013). It was also stated that there was a loss of 416,000 m^3 in growing stock every year in areas damaged by the *Ips sexdentatus* in the Artvin Çoruh forests in Türkiye (Defne, 1954). Likewise, the economic value loss caused by bark beetles was estimated to be approximately 2 million US$ in a 5-year period (2002-2007) in the Artvin Regional Forestry Directorate (Öztürk et al., 2008).

On the other hand, it was determined that climate change affects the distribution of insects and increases the number of insects at different rates by different modeling studies conducted in different countries (Seidl and Rammer, 2016; Thom et al., 2017). It was also determined that insect damage increases with the increase in temperature due to climate change (Gazol et al., 2019). RGB (Red-Green-Blue) images obtained using remote sensing technology integrated into unmanned aerial systems (UAS) with high image quality have also been used to estimate the impact of the PPM and leaf loss (Cardil et al., 2017). Based on all these studies, it is understood that insect damage in forests has increased in recent years around the world, causing significant economic losses, and research on these issues has intensified.

One of the insects that cause damage in forests is the PPM. They cause significant damage to trees by eating conifers, especially Calabrian pine (brutian pine), Crimean pine (black pine), Scots pine, Aleppo pine, maritime pine, stone pine, Taurus cedar, and sometimes junipers. Therefore, it causes the photosynthesis ability of trees to decrease and weaken, affecting increment and growth negatively. The extent of damage caused by the PPM varies depending on the intensity of the epidemic and environmental factors. Repeating the damage every year causes significant losses in growing stock, deformities in trees, and quality losses in the products obtained from forests (Çanakçıoğlu, 1989; Çanakçıoğlu and Mol, 1998). It was determined that Calabrian pine trees damaged by the PPM could only reach normal growth levels after five years (Carus, 2010a). However, even in the same areas, the PPM causes damage to trees periodically during a rotation period.

The life cycle of the PPM (*Thaumetopoea wilkinsoni* Tams.) is one year. During this period, the insect goes through four biological periods: 1) Adult period, 2) Egg period, 3) Larva (caterpillar) period, and 4) Pupa

(Chrysalis) period. The PPM spends the first three of these periods outside the soil and the fourth inside the soil (Çanakçıoğlu, 1989; Çanakçıoğlu and Mol, 1998; İpekdal, 2012). In some cases, the diapause period during the pupa period in the soil lasts up to four years. In different forest ecosystems, its life periods vary depending on factors such as latitude, altitude, and temperature (Köse, 2007; İpekdal, 2012).

The PPM actively causes damage to an area of 2 million hectares in Türkiye (Yüksel, 2019). It has a damage potential in an area of 9,414,915 hectares just for Calabrian pine and Crimean pine. Türkiye's forest area is 23,363,071 ha (30%), and the third most widely (with 4,083,661 ha) distributed tree species is Crimean pine in forest areas after oak and brutian pine (OGM, 2023). Considering the other tree species it affects, it has the potential to cause damage in more than half of Türkiye's forests. Therefore, the PPM is an important insect species that has the potential to cause damage to forests both for Türkiye and for other countries.

Due to its importance, some studies were conducted in various countries on the damage caused by the PPM in forests (Lemoine, 1977; Arnaldo et al., 2010; Cayuela et al., 2011; Dulaurent et al., 2012; USDA, 1997; Dale et al., 2001; Jacquet et al., 2012; Robinet et al., 2014; Cardil et al., 2017; Zaemdzhikova et al., 2018; Camarero et al., 2022; Ferracini et al., 2022). In addition, some research was conducted in Türkiye on the damage of the PPM. In a study conducted by Kanat and Sivrikaya (2004) in Calabrian pine forests of Kahramanmaraş, a 20.15% loss in diameter increment was detected. In another study conducted on Calabrian pine in the same area (Kanat et al., 2005), a 21% loss in annual diameter increment was detected. Likewise, in the same area, Kanat et al. (2010) in another study on Calabrian pine, as a result of the experiments carried out by hanging the PPM pouches on the trees, a loss of 8.60% in height and 11.89% in diameter was detected in the trees whose pouches were hung. In a study on this subject, a triple damage classification (control, moderate, high) was made on Calabrian pine trees in Isparta (Carus, 2004), it was found that the PPM lost 16% in diameter and 38% in volume increment in the moderate harmful group, and 24% in diameter and 52% in volume increment in the high harmful group. It was determined that the PPM caused a loss of 2% and 7% in the moderate harmful group and 11% and 24% in the high harmful group, respectively, in diameter increment and volume increment in the study conducted by Çatal (2011) on the Calabrian pine stands in Isparta. In the study conducted by Erkan (2011) on the damage of the PPM in Calabrian pine afforestation area in Antalya, 55%, 50%, and 35% diameter increment, and 44%, 37%, and 17% volume increment losses were determined for three different trial areas, respectively.

Some studies were also conducted on the damage caused by the PPM in Crimean pine forests in Türkiye. In the study conducted by Carus (2004), the average wood loss between 1997 and 2000 in species affected by the insect was determined to be 221,909 m^3. In a study conducted by Dal (2007) at the Ulus State Forest Enterprise, 22% diameter and 37.5% volume increment loss were determined and a single-entry volume table was prepared. Similarly, in a study conducted in Isparta (Carus, 2009), the diameter increment of the PPM in the control, moderate, and high harmful groups was found to be 49, 33, and 31 mm, and the volume increment was 50, 14 and 10 dm^3, respectively, for a 6-year period. Likewise, in the study conducted by Altunışık (2015) in Isparta, it was determined that annual diameter increment decreased by 34.6% in area 1 and 39.7% in area 2, compared to areas where damage was not observed.

The above studies revealed a significant relationship between insect damage and diameter and volume increment losses. The studies on both Calabrian pine and Crimean pine were generally carried out in plantation areas, and insect damage classification was created according to external symptoms on the tree (needle loss, number of sacs, etc.) and the diameter and volume increment losses in these damage classes were calculated. However, the historical diameter and volume increase losses in the following years have not been investigated in natural Crimean pine stands that were damaged in the past years. Likewise, no research has been found that makes a classification according to the increment losses of trees in the damaged area without a prior classification according to external symptoms and reveals the increment losses on an area basis. Therefore, this study was conducted to examine the effect of the PPM on the diameter and volume increment in the sameaged pure natural Crimean pine forests that have been damaged by insects in the past years in the Bartın region, on an area basis, based on the increment cores. The fact that such a study has not been conducted on pure Crimean pine stands in the Bartın-Arıt district before and the evaluation method is different makes this study original. In the study, the trial areas were grouped according to damage classes according to the measurements of increment cores from trees with different damage levels in the same field and the obtained data were analyzed. Therefore, this study has a high potential to contribute to science, practice and sustainable forest management due to its difference in both field and methodology.

2. Materials and Methods

2.1. Study Area

This study was carried out at the Arıt Forest Management Chieftaincy (AFMC) of the Bartın Forestry Enterprise (BFE) affiliated with the Zonguldak Regional Forestry Directorate (ZRFD), in the Western Black Sea Region of Türkiye (Fig. 1). Past and present damage situations of the fields were examined in all forest management chieftaincies of the BFE. Insect damage notification reports were obtained, field surveys were carried out, and it was understood that the most suitable areas for the research purpose are in the AFMC according to the data obtained, the tree type that has been damaged by insects in the past, its pest status, etc. The total area of the AFMC is 18,007.8 ha and consists of pure and mixed forests of mainly fir, beech, hornbeam, oak, and Crimean pine. In the study, Crimean pine trial areas were taken in a total area of 102.9 ha in sections 105 and 107 of the AFMC. Because, from the records of the ZRFD, it was determined that compartments 105 and 107 were exposed to the PPM damage in the 2015-2017 period, and the insect was combated (ZRFD, 2021).

The trial areas are generally located in the southeast aspect, at an altitude of 300 m and a slope of 21%. The soil structure is sandy clay loam and medium depth. The average age of the trees in the trial areas is 28 years and their average diameter is 17 cm.

Fig. 1. Location of the study area

2.2. Yield Data and Evaluation Method

Field studies in the study area were carried out in September-October 2021, paying attention to the slowing down of the increment and the completion of the vegetation period. During the field studies, a total of 9 temporary trial areas were taken in the form of a circle with a radius of approximately 13-15 m, large enough to include an average of 30 trees, in sections 105 and 107. Depending on the number of trees in each trial area, the total number of sample trees was found to be 346. This number is a sufficient sample size as it represents all of the trial areas. All trees with a diameter exceeding 8 cm at breast height (1.30 m) were assigned a row number, their diameters were measured perpendicularly to each other with a caliper with mm precision and the average was recorded. The increment cores were taken from the breast height of each tree whose diameter and height were measured. In addition, the age of several 1.30 m tall saplings in each trial area was determined and averaged to be used in tree age determination. Other characteristics of the trial areas were obtained from the relevant management plans and damage notification reports (Table 1). In addition, external symptoms of insect damage on trees (loss of needles, number of sacs, etc.) were tried to be detected in the trial areas. However, since the field suffered insect damage in 2015-2017, sufficient external symptoms could not be detected in 2021, when the measurement was made.

Table 1
Some characteristics of the trial areas

No	Radius (m)	Number of Trees	Slope (%)	Aspect	Altitude (m)	Site Quality	Age (year)	Diameter (cm)	Height (m)
K1	15	54	20	East	300	IV	28.5	14	7
K2	15	44	15	South	290	IV	28.0	17	8
K3	15	26	20	Southeast	270	IV	28.8	19	11
K4	15	31	25	Southeast	270	IV	25.2	18	11
K5	13	47	18	East	300	IV	27.5	14	8
K6	13	47	35	East	350	IV	27.6	16	7
K7	15	30	10	Southeast	350	IV	27.4	21	9
K8	15	30	22	Southeast	370	IV	27.3	21	11
K9	14	37	25	Northwest	170	IV	30.0	15	9

A total of 346 increment cores were taken from the trial areas and they were transported to the laboratory in a protected manner by special pipettes. In the laboratory, the increment cores were fixed by inserting them into specially made wooden slotted rods, labeled and the upper surface was cleaned. Firstly, the age of each tree was found by adding the age of the saplings after counting the annual rings on the increment cores from the core to the bark by a stereo microscope. Then, the ring widths of the years, from the bark to the core, were measured at 10x magnification by graduated eyepieces and converted to mm and recorded. In addition, an analysis of variance (ANOVA) and Duncan test were performed to check the difference in increment between years (Kalıpsız, 1988; Akalp, 2016; Can, 2020). In evaluating the results obtained, increments in the years when insect damage was observed (2015-2017) were taken as a basis instead of the 12-year measurement period. Volume calculations, diameter, and volume increment losses were made according to barky diameters. The increment values per hectare were calculated by multiplying the increment values calculated on the basis of the trial areas with the conversion coefficient to hectares.

2.3. Calculation of Diameter Increment Losses

Annual diameter increments in each trial area were calculated as the average of single trees. Using the average diameter increments of the 12-year period, the years in which each trial area (K1, K2, ..., K9) was under the influence of the pest were determined by increment graphs. In the graphs, the single tree method was used according to years to eliminate the differences arising from the number of trees in the trial areas and to obtain more reliable results (Mısır, 2003).

When creating harm groups, a triple classification was made as control/low, moderate and high harmful (Carus, 2004; 2009; 2010a; Erkan, 2011; Çatal, 2011; Çoban et al., 2014; Sarıkaya and Çatal, 2014). However, unlike the literature, in this study, a grouping was made on a tree-by-tree basis within the same trial area, based on the three-year total diameter increment in the damage years, rather than the external symptoms on the tree (loss of needles, number of sacs, etc.). Because the study area suffered insect damage in the 2015-2017 period, no relationship was found between the external symptoms on the trees in 2021 when the measurement was made and the increment losses in 2015-2017. Therefore, no harm grouping could be made according to external symptoms. While creating the damage groups, the class range value (2.29 mm) was found by dividing the difference between the maximum (17.88 mm) and minimum (11.02 mm) values of the sum of the annual average diameter increments during the damage period in all trial areas by three. To calculate the diameter increment losses in moderate and high harmful groups, a trend line was passed according to the annual average increment amounts of the trial areas in the control group and the regression equation was obtained by performing regression analysis (Kalıpsız, 1988; Akalp, 2016; Can, 2020). Diameter increment loss percentages were calculated for each harmful group by substituting the diameter increment values obtained by the regression equation of the trend line of the control group and the diameter increment values measured in the moderate and high harmful groups into Formula-2.1:

$$DI_p = \frac{DI_{KG} - DI_{ZG}}{DI_{KG}} \times 100 \tag{2.1}$$

where, DI_p is the percentage of diameter increment loss (%), DI_{KG} is the amount of diameter increment in the control group (mm), and DI_{ZG} is the amount of diameter increment in the moderate or high harmful groups (mm).

2.4. Calculation of Volume and Volume Increment Losses

In order to make volume calculations, the barky diameter values of the trees in the damage years must be known. For this, double bark thickness was found for each tree by taking double the bark thickness measured on the increment cores. The actual bark-free diameters of the trees were calculated by subtracting the double bark thickness from the actual barky diameters of the trees in 2021. The bark factor was found by dividing the barky diameter value in 2021 by the bark-free diameter (Formula-2.2).

$$BF = \frac{d_{kbl}}{d_{kbz}} \tag{2.2}$$

In Formula-2.2, BF shows the bark factor, d_{kbl} shows the barky diameter (mm) and d_{kbz} shows the bark-free diameter (mm). The bark factor, calculated separately for each tree, was used in barky diameter calculations in previous years. The sum of the diameter increment to the previous years was subtracted from the current bark-free diameter and the value found was multiplied by the bark factor to reach the barky diameter values in the past years (Formula-2.3).

$$d_{kblG} = \left[(d_{kbl} - B_K) - DI_G\right] \times BF \tag{2.3}$$

Where d_{kblG} indicates the barky diameter value in the past years (mm), B_K indicates the double bark thickness (mm) and DI_G indicates the total bark-free diameter increment in the previous year (mm).

Since the height of the trees at the time of damage is unknown, a single-entry volume table must be used in volume calculations. In this regard, volumetrication was attempted with the single-entry volume table equation prepared by Dal (2007) for Crimean pine forests in the Ulus Forestry Enterprise, which is close to the study area. However, Dal’s (2007) volume table could not be used because negative results were obtained for small diameter trees when making historical volume calculations. Instead, the volume values in the double-entry volume table calculated by Gülen (1959) with Formula-2.4 (Fırat, 1973) for Crimean pine forests were used.

$$V=\frac{\pi}{4}(d_{1.30})^2\times h\times f \quad (2.4)$$

In Formula-2.4, V is the volume (m^3), $d_{1.30}$ is the diameter at breast height (cm), h is the height (m) and f is the figure coefficient. In this study, since historical tree height values were not available, Gülen's (1959) double-entry volume table values were converted into single-entry volume values based on the graphical method developed by Mısır (2003) in order to make volume calculations based on diameter only. While making this transformation, the double-entry volume values taken from Gülen (1959) according to the diameter and height values in 2021 were transferred to the diameter-volume graph and the regression curve most suitable for the distribution was obtained by the BERKHOUT exponential function (Formula-2.5) (Kalıpsız, 1984).

$$V= a.d^b \quad (2.5)$$

Where, a is regression coefficient, d is diameter (cm) and b is exponent value of the equation. The volumes in the previous years (2010-2021) were calculated using this single-entry volume equation obtained, and the volume increments were found by taking the volume differences of consecutive years. Volume increment loss percentages were determined for each loss group based on Formula-2.6.

$$VI_P=\frac{VI_{KG}-VI_{ZG}}{VI_{KG}}\times 100 \quad (2.6)$$

In Formula-2.6, VI_P shows the percentage of volume increment loss (%), VI_{KG} shows the amount of volume increment in the control group (m^3), and VI_{ZG} shows the amount of volume increment in the moderate or high harmful groups (m^3).

2.5. Climate Data and Evaluation Method

In order to understand whether the increment losses in the 2015-2017 period were due to the climate factor (lack of precipitation and temperature), monthly and annual average precipitation and temperature data for the last 50 years (1961-2021) were obtained from the Bartın Meteorology Directorate, the closest meteorological station to the study area. According to the average of the last 50 years, the annual precipitation is 1039.94 mm and the temperature is 12.8°C. Standardized Precipitation Index (SPI) values were calculated using precipitation data. SPI is calculated by dividing the average difference of actual precipitation within a certain time period by the standard deviation (McKee, 1993; Bong and Richard, 2020). However, in order to measure the effect of temperature along with precipitation, Precipitation Efficiency Index (PEI) values prepared by Erinç (1965) were also calculated (Çepel, 1978). Calculated SPI values were interpreted according to the McKee (1993) and Bong and Richard (2020) SPI classification table, and PEI values were interpreted according to the Erinç (1965, 1996) classification table. On the other hand, whether the amounts of precipitation and temperature were different between years was also checked by the ANOVA. Thus, it was determined whether there was a loss of increment due to lack of precipitation and temperature (drought) in the 2015-2017 period.

3. Results and Discussion

3.1. Relationship between Climate-Related Increment and Insect Damage

In the study, the annual precipitation average of the last 50 years and the annual precipitation amounts for the research years (2010-2021) are shown graphically in Fig. 2. Accordingly, except for 2011, 2019, and 2020, the annual precipitation in all other years is above the precipitation average of the last 50 years. Annual precipitation amounts, especially in the years identified as damage periods (2015-2016-2017), are above the

50-year precipitation average. In addition, the amount of precipitation falling during the growing season (spring and summer months) during the 2015-2017 period is above the average of precipitation in the last 50 years of the growing season. Therefore, based on these results, it was understood that the increment losses in the 2015-2017 period were not due to a lack of precipitation.

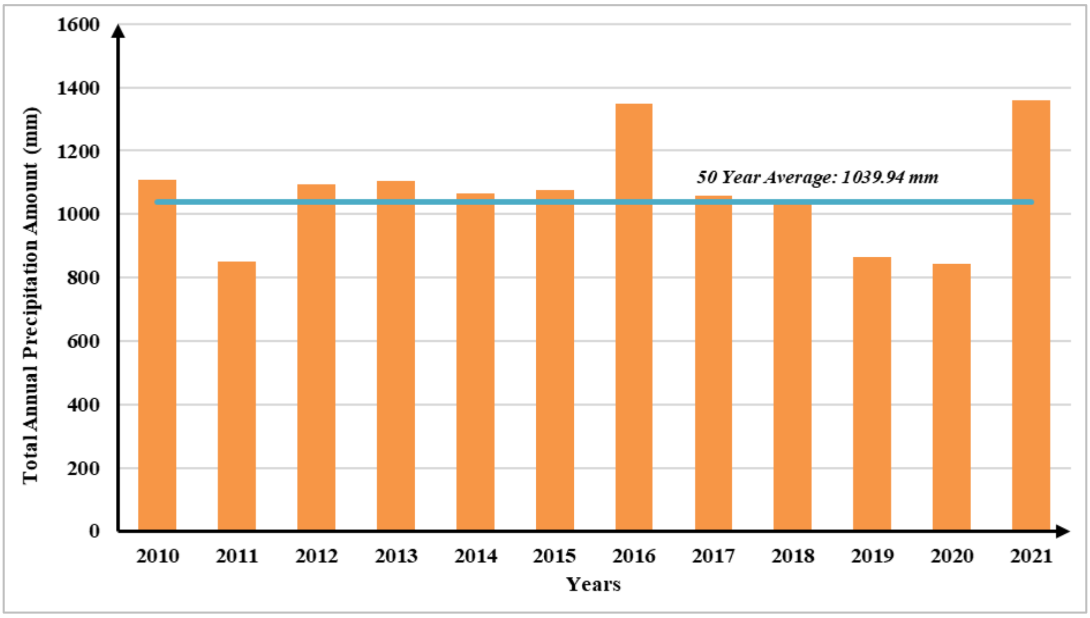

Fig. 2. Precipitation amounts by years and 50-year average (1039.94 mm)

Likewise, the SPI values calculated (0.01 for 2015, 1.62 for 2016, -0.10 for 2017) based on precipitation data were interpreted according to the table of McKee (1993) and Bong and Richard (2020). Accordingly, it was determined that 2015 and 2017 were in the normal class ($0<SPI\leq1.0$), and 2016 was in the very rainy class ($1.5<SPI\leq2.0$). These results show that the increment losses in the 2015-2017 period were not due to insufficient precipitation.

In addition, according to the PEI values (I_m) calculated in the study, 2015 (I_m=38.41) and 2017 (I_m=37.28) are in the semi-humid class ($23<I_m<40$), while 2016 (I_m=45.82) is in the humid class ($40<I_m<55$) was included. Thus, according to these results, which take both precipitation and temperature into account, it was determined that the increment losses in the 2015-2017 period were not caused by insufficient precipitation and temperature (drought).

On the other hand, in the ANOVA conducted to understand whether there was a difference in the amount of precipitation between years, F=0.665 and p=0.770 were found, and since p(0.770)>0.05, no significant difference was found. Likewise, in the ANOVA for temperature values, F=0.155 and p=0.999 were found, and since p(0.999)>0.05, there is no significant difference between the temperature amounts between years. Hence, it was determined that there was no drought in the years when insect damage was observed and there was no loss of increment due to climatic factors (precipitation, temperature). Therefore, it was concluded that the increment losses were caused by insect damage. Similar results were found in the study conducted by Altunışık (2015) on Crimean pine and Calabrian pine, and it was determined that the increment losses in 2014-2015 were not caused by climate factors and were due to insect damage.

3.2. Findings Regarding Diameter Increment

Annual bark-free diameter increments in each trial area were calculated as the average of a single tree, and graphs for a 12-year period were created to determine the years in which the trial areas were affected by insect damage. At the end of the measurements made on trees in all trial areas, it was observed that there were generally diameter increment losses in 2015, 2016, and 2017 (Fig. 3). The lowest diameter increment occurred in 2016. Since there was no increment loss due to climate data in the 2015-2017 period according to the calculated SPI and PEI values, it was understood that the increment losses were due to insect impact. According to Fig. 3, it can be seen that the amount of increment decreased in 2016 when the PPM was effective in all trial areas, and approximately three years must pass for the increment to reach its normal level. Similarly, this period was determined as three years by Lemoine (1977). However, Carus (2010a) stated that this period is five years. In fact, this period varies depending on the severity and degree of impact of insect damage. In addition, insect damage continues cyclically in certain periods during a rotation period, especially in young stands, in accordance with its biological life stage.

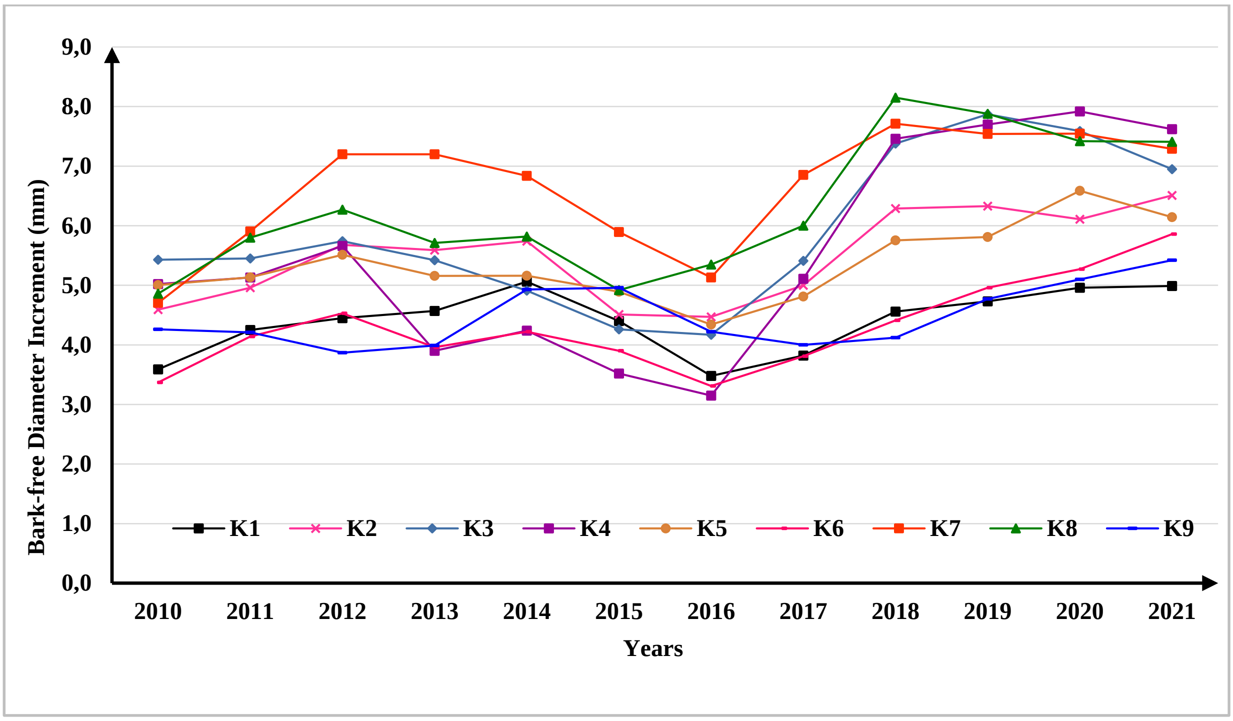

Fig. 3. Bark-free diameter increments in the trial areas by years

On the other hand, whether the diameter increments were different by year was checked by variance analysis and the Duncan test, and it was determined that the increments in 2015, 2016, and 2017 were different in other years (Table 2). Accordingly, there is a significant difference between annual diameter increments at the 1% confidence level because of p(0.00)<0.01. As a result of the Duncan test performed to identify different years, it was determined that there was the least increment in 2016, 2010, 2015, 2011, and 2017, a moderate increment in 2013, 2014, and 2012, and the highest increment in 2018, 2021, 2019, and 2020.

Table 2

Variance analysis results according to annual diameter increments

Source of Variation	Sum of Squares	Degrees of Freedom	Mean of Squares	F	p
Between groups	2,183.821	11	198.529	38.544	0.00**
Within groups (Error)	21,324.077	4,140	5.151		
Total	23,507.898	4,151			

In addition, whether the diameter increment during the damage period differed according to age was checked by the ANOVA. Since the p values found were greater than 0.05, it was understood that there was no significant difference to age.

While creating damage groups according to the three-year diameter increment amounts, the class range value was calculated as 2.29 mm. According to this range value, K8 and K7 trial areas with an increment of more than 15.59 mm located in the control/low group, K5, K2, and K3 trial areas with an increment of 15.58–13.31 mm in the moderate group, and K9, K4, K1, and K6 trial areas with an increment 13.30–11.02 mm in the high harmful group. The bark-free diameter increment graph drawn according to the group average of control, moderate, and high harmful trial areas is given in Fig. 4. According to the Y=a+bx model, the regression equation for the control group was found to be Y=5.1739 + 0.2002x and R^2=0.5007.

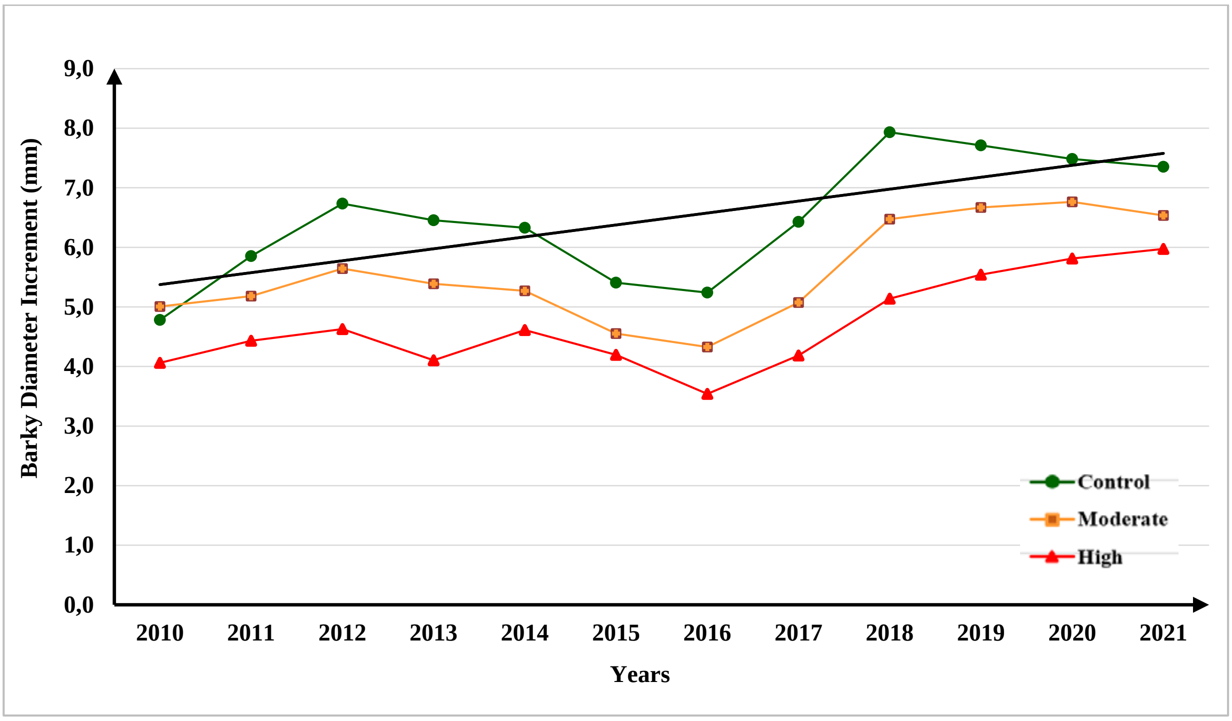

Fig. 4. Bark-free diameter increment in control, moderate and high harmful groups by years

The diameter increment values for the 2015-2017 period found by the control group regression equation and the measured diameter increment values of the moderate and high harmful groups were used in Formula-2.1, and the percentages of average diameter increment losses were calculated (Table 3).

Table 3
Diameter increment losses of moderate and high harmful groups compared to the control group

Groups	Diameter Increment Amount (mm)				Diameter Increment Loss (%)			
	2015	2016	2017	Mean	2015	2016	2017	Mean
Control	6.375	6.575	6.776	6.575	-	-	-	-
Moderate Harmful	4.574	4.290	4.968	4.611	28.25	34.75	26.68	29.89
High Harmful	4.197	3.511	4.073	3.927	34.16	46.60	39.89	40.22

According to these results, although there were some differences in diameter increments over the years in the 2015-2017 period, there was a 29.89% loss in diameter increment in the moderate harmful group and 40.22% in the high harmful group as a three-year average. In a study conducted by Dal (2007) on Crimean pine without any damage classification, the diameter increment loss was found to be 22%, and it was understood that this figure approximately matches the moderate harmful group. Carus (2009) calculated the total diameter increment in Crimean pine in a 6-year period (1998-2004) as 49 mm in control, 33 mm in moderate, and 31 mm in high harmful groups. Likewise, Carus (2010b) stated that there was an average of 33% ($p<0.05$) diameter increment loss in Crimean pine in the 1998-2004 period in Isparta. In another study conducted by Altunışık (2015) on black pine in Isparta, it was determined that the annual diameter increment decreased by 34.6% in area I and 39.7% in area II compared to the general average, and the following year by 58.3% and 43.1%, respectively. These results show that the effect of the PPM on diameter increment is greater in warmer regions with a Mediterranean climate than in the Bartın region.

On the other hand, in some studies conducted on Calabrian pine in the Kahramanmaraş region of Türkiye, it was determined that there was a loss of diameter increment at the rate of 20.15% (Kanat and Sivrikaya, 2004), 21% (Kanat et al., 2005) and 11.89% (Kanat et al., 2010). Similarly, in a study conducted on Calabrian pine trees in Isparta (Carus, 2004), a 16% diameter increment loss was detected in the moderate harmful group and 24% in the high harmful group, while Çatal (2011) found a 2% diameter increment loss in the moderate harmful group and 11% in the high harmful group. These results in Calabrian pine show that the increment losses are lower than both those in this research and those in previous studies on Crimean pine. However, in a study conducted by Erkan (2011) in Antalya, diameter increment losses of 55%, 50%, and 35% were calculated for three different trial areas, respectively. These values in Calabrian pine show that the diameter increment losses are higher than both those in this study and those in previous studies on Crimean pine.

3.3. Findings Regarding Volume Increment

While calculating volume and volume increment, firstly, barky diameters for the 2010-2021 period were calculated (Formula-2.3). In diameter-volume graphs, the following regression equation giving volume calculations was obtained based on the exponential function in Formula-2.5.

$$V=0.0003(d_{1.30})^{2.1644} \qquad (R^2= 0.9348;\ Se=0.163) \qquad (3.1)$$

Using Formula-3.1, the volumes of all trees for the last 12 years were calculated and the annual volume increments were found by taking the volume differences of consecutive years. The volume increment graphs of control, moderate, and high harmful groups over the years are shown in Fig. 5. The regression equation ($Y=2.602+0.3384x$ and $R^2=0.8047$) values of the control group for the 2015-2017 period using volume increments and the volume increment values of moderate and high harmful groups were substituted into Formula-2.6. Volume increment losses were calculated first on a trial area basis and then on a hectare basis by multiplying them by the hectare conversion coefficient (15.43) (Table 4).

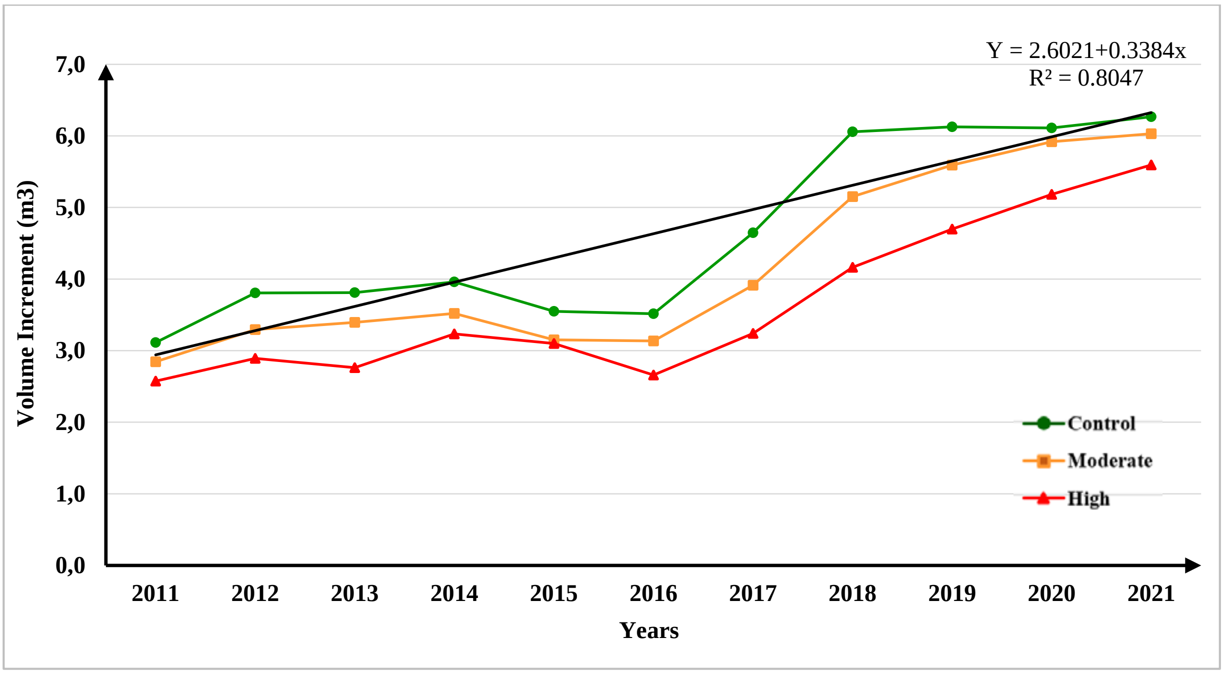

Fig. 5. Volume increments in control, moderate and high harmful groups by years

Table 4
Volume increment losses of moderate and high harmful groups compared to the control group

Groups	Volume Increment Amount (m^3/ha)				Volume Increment Loss (%)			
	2015	2016	2017	Mean	2015	2016	2017	Mean
Control	4.294	4.633	4.971	4.633	-	-	-	-
Moderate Harmful	3.152	3.136	3.914	3.401	26.60	32.31	21.26	26.72
High Harmful	3.099	2.659	3.240	2.999	27.83	42.61	34.82	35.09

Due to the PPM, a volume increase loss of 26.72% per hectare in the moderate harmful group and 35.09% in the high harmful group was found. In this regard, while Carus (2009) detected a volume increment of 50 dm^3 in the control group in Crimean pine between 1998 and 2004, he detected a volume increment of 14 dm^3 in the moderate harmful group and 10 dm^3 in the high harmful group. When the volume increment values in the moderate and very harmful groups are compared to the control group, it is understood that there is more damage due to insects in the high harmful group and the percentage of volume increment loss is higher due to the low increment. Therefore, Carus's (2009) findings are parallel to the findings in this research. On the other hand, Durkaya et al. (2009) calculated volume increment loss as 37.5% without any damage classification on Crimean pine. This result is higher than the increment loss (35.09%) found in the study for the high harmful group.

In a study conducted in Calabrian pine, a volume increment loss of 38% in the moderate harmful group and 52% in the high harmful group was detected (Carus, 2004). Although these figures are higher than the figures regarding volume increment losses detected in Crimean pine, in a study conducted by Çatal (2011) in Calabrian pine, less volume increment loss was detected (7% in the moderate harmful group, 24% in the high harmful group). Since different results were obtained in different studies, it was not possible to draw a conclusion that the PPM causes more damage to Calabrian pine or Crimean pine.

Additionally, Jacquet et al. (2012) who compiled 45 studies reported that the PPM is 50% more effective on young trees. In this study, as a result of the variance analysis regarding whether volume increment was different according to tree age, a statistically significant difference was found at the 1% confidence level ($F=7.306$, $p(0.00)<0.01$). As a result of the Duncan test, the 1st age group (16-20 years) with a low volume increment (2.5783 dm^3) constitutes the first group, while the 2nd, 3rd, and 4th age classes (21-40 years) with a higher volume increment (6.5385 dm^3) constituted the second group. However, the reason why the volume increment in the first group was lower than the second group may be due to the low diameter of the trees in this group rather than insect damage. Therefore, a complete result regarding the level of damage of the insect depending on tree age could not be obtained in this study.

4. Conclusions

This study was carried out to determine the increment loss caused by the PPM on trees in previous years by classifying the increment on an area basis rather than external symptoms on the trees. The years 2015, 2016, and 2017 were determined as the loss period and the loss calculations were made based on the average increment of these three years. The amount of diameter increment was calculated as 5.405 mm, 5.240 mm, and 6.427 mm in the control group for the years 2015, 2016, and 2017 respectively; as 4.574 mm, 4.290 mm, 4.968 mm in the moderate harmful group and 4.197 mm, 3.511 mm, and 4.073 mm in the high harmful group. As a result of the analyses made with climate data, it was understood that the precipitation and temperature did not change in the damage years (2015-2017), therefore, based on both the ZRFD records and SPI and PEI values, the increment losses in 2015-2017 were caused by insect damage. As a result of the calculations made according to the control group regression equation regarding diameter increment losses, 29.89% diameter increment loss was found in the moderate harmful group and 40.22% in the high harmful group. In the calculation of volume increment losses, it was determined that there was a 26.72% volume increment loss in the moderate harmful group and 35.09% in the high harmful group.

The results regarding diameter and volume increment losses obtained in this study are in parallel with the results of similar research conducted previously. However, it can be stated that the harmful effect of the PPM is greater in warmer regions such as the Mediterranean region. This result means that the harmful effect of the insect increases as the temperature increases, which is a normal situation and compatible with the biology of the insect. Nevertheless, no definitive conclusion was reached that the PPM caused more damage to which of the Crimean pine and Calabrian pine tree species. In addition, it could not be determined that insect damage had a different effect on diameter and volume increase depending on age. On the other hand, similar to the findings in the literature, it has been understood that the diameter increase slows down after insect damage and approximately 3-5 years must pass for it to reach its normal course. In fact, this period varies depending on the severity or degree of impact of insect damage, and insect damage continues cyclically throughout a rotation period, especially in young stands. However, in order to reach generalizing and comprehensive conclusions on these issues, long-term research is needed in different regions, different tree species, and stands of different ages.

Similar studies to this study need to be carried out in other forests where the PPM is seen and insect combat measures should be taken accordingly. Deciding to combat the PPM based only on biophysical diameter and volume loss may not be the right approach. In order to decide on the fight against the PPM, the economic loss of the damage caused by the insect must be calculated and compared with the costs of the fight. Assuming that other conditions are constant, a decision should be made to combat if the amount of economic damage exceeds the costs of combat in terms of sustainable forest management. However, since this issue is beyond the scope of the study, the calculation of economic value losses was not included in this study. Nevertheless, the results of this study constitute a basis for calculating the loss of economic value. Therefore, similar studies should be carried out in different areas where insect damage is seen and thus provide a basis for calculations regarding economic value losses. In conclusion, the results of this study have a high potential to contribute to science, practice, and sustainable management of forest resources.

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Author Contributions

İsmet Daşdemir planned and directed the research, designed methodology, collected the data, provided guidance in evaluating the data and wrote the article.

Yağmur Yeşilbaş collected the data and made the evaluation of the data and writing the article.

Conflict of Interest

There is no conflict of interest.

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