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Research Article

Infestation Rates, Seasonal Abundance of Aphids and Relationships with Some Environmental Factors in Different Forest Habitats in Southwestern Türkiye

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Abstract

Aim of study: It was to determine the infestation rate and seasonal abundance of aphids and their relationships with some environmental factors in forests.

Area of study: The study was conducted in *Pinus nigra*, *P. brutia*, *Cedrus libani*, *Abies cilicica*, *Juniperus* spp., *Quercus* spp. and *Robinia pseudoacacia* forests (34 sampling areas) in Isparta.

Materials and methods: Systematic sampling was carried out monthly throughout April-October in 2019-2020. As aphid density and infestation rates were determined, 30 cm shoots were taken from 10 trees. The slope, aspect, elevation, forest characteristics, daily minimum, average, and maximum temperature and total precipitation were recorded.

Main results: Abundance were highest in *P. nigra*, *Quercus* and *Robinia pseudoacacia* forests in both years. There was a significant correlation between abundance and development stages ($p<0.05$). Additionally, abundance showed a negative relationship with minimum temperature in July 2019, maximum temperature in September 2019, and a positive relationship with precipitation in October 2019. In July 2020, abundance showed a negative relationship with both average and maximum temperatures, while in August 2020, there was a positive relationship with average temperature.

Research highlights: It is believed that tree species, development stages and climatic conditions are effective factors on infestation and abundance parameters.

Keywords: Aphid, Forest Ecosystem, Population, Density

Güneybatı Türkiye'de Farklı Orman Habitatlarındaki Yaprak Bitlerinin Bulaşıklık Oranı, Mevsimsel Bolluğu ve Bazı Çevresel Faktörlerle İlişkileri

Öz

Çalışmanın amacı: Ormanlarda yaprak bitlerinin bulaşıklık oranı, mevsimsel bolluğu ve bazı çevresel faktörlerle ilişkileri belirlenmiştir.

Çalışma alanı: Isparta'da *Pinus nigra*, *P. brutia*, *Cedrus libani*, *Abies cilicica*, *Juniperus* spp., *Quercus* spp. ve *Robinia pseudoacacia* ormanlarında (34 örnekleme alanı) gerçekleştirilmiştir.

Materyal ve yöntem: 2019-2020 yıllarında nisan-ekim aylarında ayda bir kez sistematik örnekleme yapılmıştır. Yaprak biti yoğunluğu ve bulaşıklık oranlarını belirlemek için 10 ağaçtan 30 cm'lik sürgünler alınmıştır. Alanların eğim, bakı, yükselti, meşcere karakteristikleri ile günlük minimum, ortalama ve maksimum sıcaklık, toplam yağış değerleri kaydedilmiştir.

Temel sonuçlar: Her iki yılda da bolluk değerleri en fazla karaçam, meşe ve yalancı akasya alanlarında görülmüştür. Bolluk değerleri ile gelişim çağı ($p<\%0.05$) ilişkili bulunmuştur. Ayrıca bolluk değerleri ile 2019 yılı temmuz ayında minimum sıcaklık, eylül ayında maksimum sıcaklıkla negatif, ekim ayında yağış ile pozitif ilişki, 2020 yılı temmuz ayında hem ortalama hem de maksimum sıcaklıkla negatif, ağustos ayında ortalama sıcaklık ile pozitif ilişki saptanmıştır.

Araştırma vurguları: Bulaşıklık ve bolluk parametreleri üzerinde ağaç türü ve iklim koşullarının etkili olduğu düşünülmektedir.

Anahtar kelimeler: Yaprak Biti, Orman Ekosistemi, Popülasyon, Yoğunluk

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Introduction

The forest ecosystem contains many living species with different ecological conditions and habitats. There are many living groups that share various habitats within the ecosystem, and these living creatures continue their lives in a complex structure by adapting to similar ecological conditions both within their own groups and with other living groups with which they share their space. The stronger this structure and the more diverse it is in terms of biotic factors, the more stable the balance within the ecosystem is, it is not easily affected by biotic and abiotic conditions, and even if it is affected, it can tolerate this effect (Perry et al., 2008; Kebede & Mulugeta, 2021).

However, when the complex structure in the ecosystem loses its strength due to various reasons such as rapid population growth, increased construction, climate change and habitat degradation, ecological balance is disrupted. Consequently, while particularly rare species and live in a sensitive habitat may face the danger of extinction, some creatures with a large population may become the dominant species in their habitat (Çolak, 2001; Anderegg et al., 2015; Ülgen et al., 2020; Moos et al., 2021).

The relationships among organisms in an ecosystem, particularly those related to competition and feeding, can determine the course of processes within the ecosystem. Phytophagous species that increase in population or become dominant by invading the ecosystem (such as invasive alien species) are referred to as "harmful species" when they cause economic or ecological damage. When the population of these species does not reach a balance within a certain period, the biological diversity and various ecological relationships within the ecosystem, such as the nutrient cycle, can be adversely affected (Ayres & Lombardero, 2000; Gullan & Cranston, 2012; Kebede & Mulugeta, 2021).

The insect outbreaks associated with the increase in insect populations are known to be related to extreme weather conditions. Insects, which are ectothermal creatures, can respond strongly to changing environmental conditions, especially temperature changes (Kingsolver et al., 2011). In recent years, changes observed in climate patterns have been impacting the distribution, life cycles, phenologies, and population densities of insects (Stange & Ayres, 2010; Anderegg et al., 2015; Pureswaran et al., 2018; Lehmann et al., 2020).

Aphids are among the significant groups of organisms that can easily increase their populations in agricultural, ornamental, and forest plants, causing economic damage (Wieczorek et al., 2019). While some species of the *Phylloxera* genus show symptoms by causing lesions, especially in forest trees and oak species (Laamari, 2016; Lubiarz, 2007), species of the *Adelges* and *Pineus* genera also cause gall formation in coniferous species (McClure, 1991; Havill & Foottit, 2007; Pilichowski et al., 2014). Additionally, aphids quickly develop resistance to chemical control, rapidly expanding their distribution areas and economic damage rates (Dixon, 1998). The detection and monitoring of aphid populations are of great importance due to their small size, rapid reproduction, and their ability to easily adapt to global climate change (Coeur d'acier et al., 2010.

The main idea of this study is to determine whether aphids, which are significant pests in agriculture and landscaping, pose a threat in forest areas, and if so, to assess the intensity of the damage they may cause. In this study, the aims are to (1) determine the abundance values of aphids in forested areas based on sampling sites, host tree species, and seasonal abundance values (on tree and shoot levels), (2) assess the abundance values by months in relation to climatic parameters and climate classifications, (3) identify infestation rates of aphids (on infested trees and infested shoots), and (4) examine the relationship between aphid population density and some environmental factors.

Material and Method

Study Area

The study area is located in Isparta province within the Lakes Region in the western part of the Mediterranean Region. Consequently, the study area and its surroundings are characterized by numerous lakes of various sizes. The most significant among these lakes are Beyşehir Lake, Eğirdir Lake, Burdur Lake, and Kovada Lake. Isparta province has a highly rugged topography. The high mountains within the provincial borders include Dedegöl Mountain (2992 m), Davraz Mountain (2635 m), and Akdağ (2271 m). Located in the Mediterranean transition region, Isparta has a semi-continental climate with both marine and continental characteristics (Yıldız, 2011). This study was conducted in Isparta province, focusing on the primary tree species including *Pinus nigra* subsp. *pallasiana*, *Pinus brutia*, *Cedrus libani*, *Abies cilicica*, *Juniperus* spp., *Quercus* spp., and *Robinia pseudoacacia* forests in 2019 and 2020. Thirty-four sampling sites were identified based on the extent of pure distribution of these tree species (sites: *P. nigra*: 8, *Juniperus* spp.: 8, *C. libani*: 5, *Quercus* spp.: 5, *P. brutia*: 4, *A. cilicica*: 2, *R. pseudoacacia*: 2) and a systematic sampling approach was employed (Figure 1).

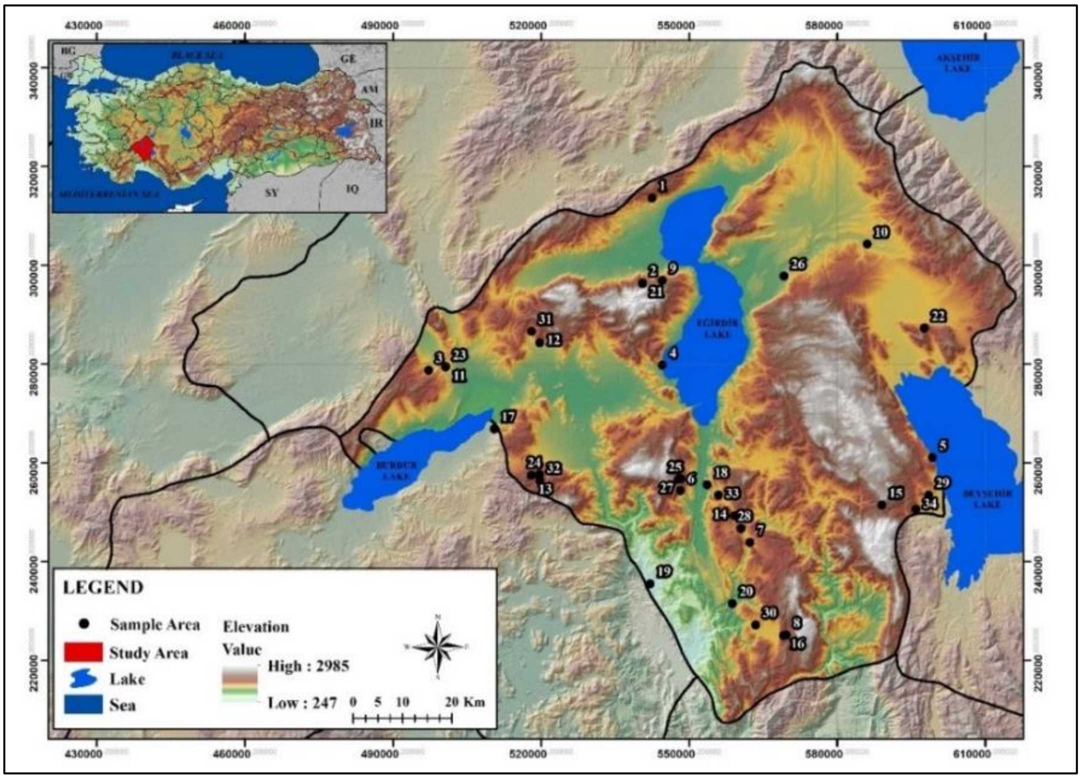

Figure 1. Distribution of sampling areas

Sampling Method

The systematic sampling method was used in the study. Sampling areas were taken in circular shapes with a radius of approximately 25 m (an area of approximately 2,000 m²), and 10 trees closest to the determined central point were sampled. Samples were collected from the parts of the trees up to approximately 2.5 meters above the ground level. The sampled trees were marked, and in the subsequent sampling one month later, samples were collected from the 10 trees near each previously marked tree, ensuring sampling from all trees in the area (modified from Stekolshchikov and Kozlov, 2012). In order to eliminate the edge effect, trees on the roadside or in open spaces within the stand were not preferred as much as possible (Leather, 2005). Since aphids are generally found feeding on young shoots (Bryant, 1976; Fidgen et al., 1994; 2006), and it is challenging to observe them among leaves, especially in species with low populations, 30 cm portions from the shoot tips of trees were collected. Shoots were collected from the four main directions of each tree, resulting in a total of 40 shoots per sampling area for each tree. The collected shoots were placed in plastic bags labelled with tree number and directions, and information such as tree species, number of sample area and date were recorded. Aphids (nymphs and adults) were dislodged using a fine brush (size 0), collected with the same brush, and transferred to Eppendorf tubes containing 96% ethanol. The study focused on the overall population density of aphids and did not involve a species-level assessment. Sampling was conducted 14 times in each sampling area between April and October of 2019 and 2020. Aphid abundance values and infestation rates obtained during each sampling period were recorded.

Environmental Factors

Coordinates (Datum: WGS 84), altitude (m), slope (%), aspect (°), dominant tree species, development stages (1 (stage a): 0-7.9 cm, 2 (stage b): 8.0-19.9 cm, 3 (stage c): 20.0-35.9 cm, 4 (stage d): 36.0-51.9 cm), and canopy cover (B: ≤%10, 1: %11-40, 2: %41-70, 3: %71-100) values of the sampling areas were recorded. Additionally, daily and monthly minimum, average, and maximum temperatures, as well as total precipitation values for the nearest weather stations, and the climate classification of the sampling areas according to the Thornthwaite method (Thornthwaite, 1948), were obtained from the General Directorate of Meteorology (MİGM, 2021) (Table 1). Both monthly values for the period of 1980-2020 and daily values on the dates when samples were collected in 2019 and 2020 were used in the study. The variables of slope (1: 0-9, 2: 10-19, 3: 20-29, 4: 30-40), aspect [1(N): 316-45, 2(E): 46-135, 3(S): 135-225, 4(W): 226-315], and elevation (1: 0-500 m, 2: 501-1000 m, 3: 1001-1500 m, 4: 1501-2000 m) have been transformed into categorical data.

Table 1. Properties of sampling areas

Areas	Coordinates	Slope (%)	Aspect (°)	Altitude (m)	Canopy*	Development stages**	Dominant tree species	Climate classification
A1	38°15'04"N-30°43'30"E	25	110	1364	1	1	*Juniperus excelsa, J. oxycedrus*	Semi-humid
A2	38°05'54"N-30°42'49"E	15	115	1458	B	1	*Juniperus excelsa, J. oxycedrus, J. foetidissima*	Semi-humid
A3	37°54'27"N-30°13'33"E	25	90	1235	B	1	*Juniperus excelsa, J. oxycedrus, J. foetidissima*	Semi-humid
A4	37°58'24"N-30°46'30"E	30	135	971	B	1	*Juniperus excelsa, J. oxycedrus*	Humid
A5	37°48'29"N-31°24'17"E	30	55	1140	2	1	*Juniperus excelsa, J. oxycedrus, J. foetidissima*	Humid
A6	37°43'13"N-30°49'44"E	25	105	1330	B	1	*Juniperus excelsa, J. oxycedrus*	Humid
A7	37°37'59"N-30°59'43"E	25	195	1207	2	3	*Juniperus excelsa, J. oxycedrus*	Humid
A8	37°28'05"N-31°05'25"E	5	210	1324	1	3	*Juniperus excelsa, J. oxycedrus*	Humid
A9	38°11'16"N-31°13'38"E	30	80	1128	2	2	*Pinus nigra*	Semi-humid
A10	38°06'08"N-30°45'36"E	35	315	1320	1	3	*Pinus nigra*	Semi-arid
A11	37°55'15"N-30°16'21"E	5	235	1184	3	2	*Pinus nigra*	Semi-arid
A12	37°58'32"N-30°29'07"E	15	170	1202	2	1	*Pinus nigra*	Semi-arid
A13	37°43'50"N-30°29'08"E	5	100	1415	2	2	*Pinus nigra*	Semi-arid
A14	37°41'37"N-30°56'51"E	5	215	1247	2	1	*Pinus nigra*	Humid
A15	37°42'45"N-31°17'40"E	25	10	1808	2	2	*Pinus nigra*	Humid
A16	37°28'00"N-31°05'05"E	40	15	1314	2	1	*Pinus nigra*	Humid
A17	37°49'00"N-30°23'37"E	10	320	928	2	4	*Pinus brutia*	Semi-arid
A18	37°44'05"N-30°53'17"E	25	180	1113	1	3	*Pinus brutia*	Humid
A19	37°32'49"N-30°46'16"E	20	90	356	2	3	*Pinus brutia*	Semi-humid
A20	37°31'13"N-30°57'47"E	5	95	966	2	1	*Pinus brutia*	Humid
A21	38°05'52"N-30°42'50"E	5	30	1458	2	1	*Cedrus libani*	Semi-humid
A22	38°02'16"N-31°22'13"E	15	35	1471	2	2	*Cedrus libani*	Semi-arid
A23	37°55'11"N-30°16'19"E	5	275	1171	3	2	*Cedrus libani*	Semi-arid
A24	37°44'07"N-30°30'20"E	40	90	1491	B	1	*Cedrus libani*	Semi-arid
A25	37°44'29"N-30°49'37"E	40	175	1558	2	3	*Cedrus libani*	Humid
A26	38°07'18"N-31°02'28"E	8	315	1034	2	1	*Quercus ithaburensis, Q. infectoria, Q. cerris, Q. trojana*	Semi-arid
A27	37°44'34"N-30°49'43"E	8	120	1555	3	2	*Quercus vulcanica, Q. trojana*	Humid
A28	37°39'31"N-30°58'23"E	5	70	1218	2	2	*Quercus cerris*	Humid
A29	37°44'15"N-31°23'55"E	5	70	1181	2	1	*Quercus cerris*	Humid
A30	37°28'57"N-31°01'09"E	20	305	1191	2	2	*Quercus cerris, Q. infectoria*	Humid
A31	37°59'41"N-30°27'55"E	25	160	1230	3	1	*Robinia pseudoacacia*	Semi-arid
A32	37°43'17"N-30°30'05"E	10	275	1418	3	1	*Robinia pseudoacacia*	Semi-arid
A33	37°42'58"N-30°54'58"E	15	340	1167	1	3	*Abies cilicica*	Humid
A34	37°42'38"N-31°22'16"E	15	90	1431	2	3	*Abies cilicica*	Humid

*Canopy (B: ≤%10, 1: %11-40, 2: %41-70, 3: %71-100)
**Development stages [1 (stage a): 0-7.9 cm, 2 (stage b): 8.0-19.9 cm, 3 (stage c): 20.0-35.9 cm, 4 (stage d): 36.0-51.9 cm]

Assessment of Data

The abundance values obtained during the sampling months were considered for the seasonal assessment of aphid abundance and interpreted as spring (April and May), summer (June, July, and August), and autumn (September and October). Concerning the damage status of aphids, infestation rate and population density (abundance) values were taken into account. For this purpose, parameters such as the number of infested trees, the number of infested shoots, the number of individuals per infested tree, and the number of individuals per infested shoot were used in the dataset (Kebede & Mulugeta, 2021). To determine whether there was a significant difference in these parameters between areas and months, the normal distribution of the data was first tested using the Kolmogorov-Smirnov test, which indicated non-normal distribution. Therefore, it was used two-way analysis of variance with Friedman rank from non-parametric tests (Friedman, 1937; Zimmerman & Zumbo, 1993; Pereira et al., 2015). Additionally, to explore the relationships between aphid abundance values and constant variables such as daily maximum, average, and minimum temperatures, and precipitation were used to Pearson correlation analysis. The relationships between abundance values and categorical environmental factors, which are elevation, slope, aspect, canopy cover, development stages, and climate classification according to the Thornthwaite method, were assessed with Kruskal-Wallis analysis (Hauke & Kossowski, 2011; Tabachnick & Fidell, 2013). All analyses were conducted using the SPSS 26.0 statistical software package.

Results

At the end of the study, 16981 individuals were collected from a total of 4760 trees and 19040 shoots in 34 areas in 2019 and 2020 (April-October). Seasonal abundance and infestation rate, population density by year and by host tree species, population density in trees and shoots of aphids in the sampling areas were determined. Evaluation of infestation and density data with tree species and time factors, and the relationship of abundance data with climate and other environmental factors were also determined.

Population Density in Sampling Areas by Years

There were differences in the number of aphids in almost all areas in 2019 and 2020. Generally, a higher aphid population was found in 2019. However, in 2020, aphid density was higher in 11 sampling areas [7, 8 (*Juniperus* spp.), 9, 15, 16 (*Pinus nigra*), 19 (*Pinus brutia*), 23 (*Cedrus libani*), 26 (*Quercus* spp.), 31, 32 (*Robinia pseudoacacia*), and 33 (*Abies cilicica*)]. Specifically, in 2019, area 24 (882 individuals, *Cedrus libani*), 29 and 30 (793 and 1197 individuals, *Quercus* spp.), and in 2020, area 15 (786 individuals, *Pinus nigra*), and 31 and 32 (869 and 559 individuals, *Robinia pseudoacacia*) were identified as having the highest populations. When both years are considered together, a significant decrease is observed in 2020 in area 24 (*Cedrus libani*) and 28, 29, and 30 (*Quercus* spp.) (Figure 2).

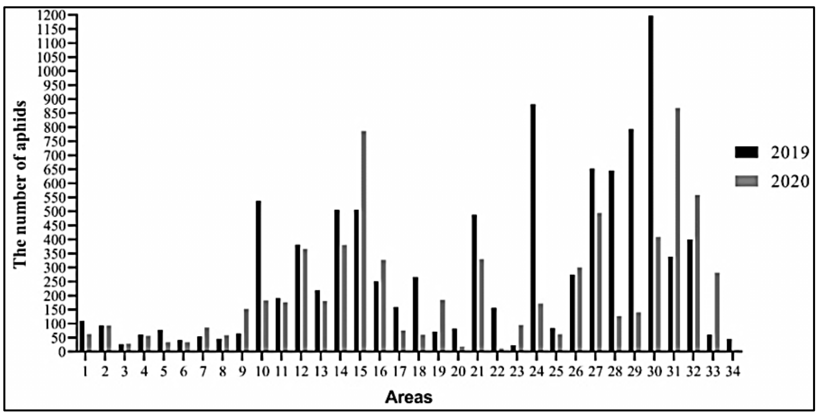

Figure 2. Number of aphid individuals in sampling areas by years

The Rate of Aphids in Host Tree Species

In 2019, the highest aphid population was observed in *Quercus* spp. (%36), followed by *Pinus nigra* (%27) and *Cedrus libani* (%27). In 2020, the population density was highest in *P. nigra* (%35), followed by *Quercus* spp. (%21) and *Robinia pseudoacacia* (%20). A decrease in aphid population density was identified in *C. libani* areas in 2020 while an increase (%150) was observed in *R. pseudoacacia* areas compared to 2019. In both years, the lowest population density was observed in *Abies cilicica* (%1 in 2019 and %4 in 2020). Similar population densities (5-6%) were found in *Pinus brutia* and *Juniperus* spp. areas in both years (Figure 3).

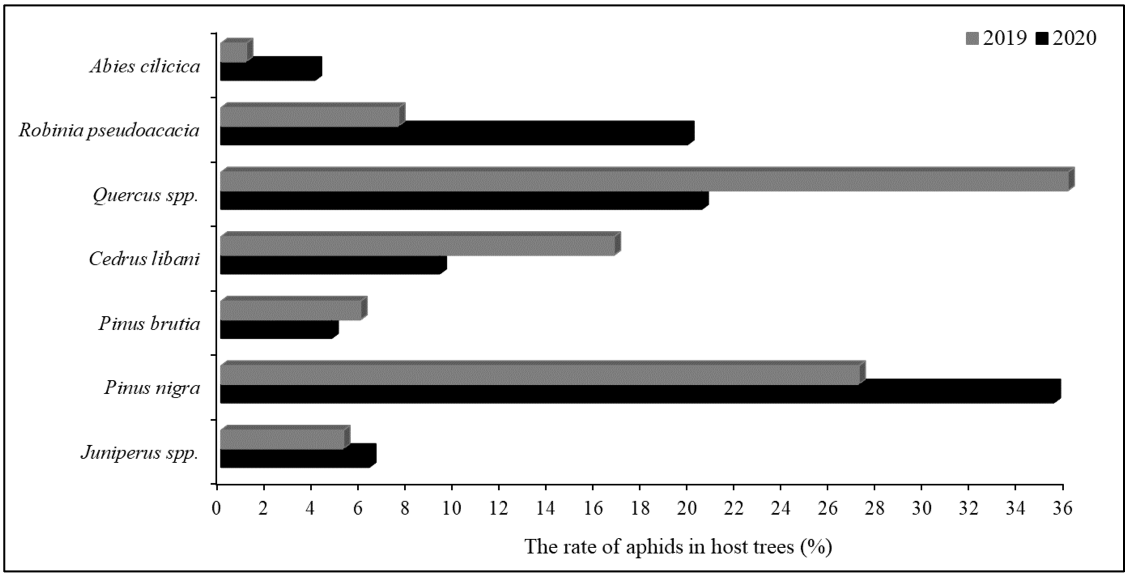

Figure 3. Occurrence percentages of aphids in host tree species

Seasonal Abundance Values in Sampling Areas

The aphid abundance value was highest in the summer season (June, July, August) in 2019, observed in 29 areas, followed by spring (April and May) and then autumn (September and October). In the assessment by areas, the highest abundance value was found in spring months in 4 areas (5, 10, 26, and 29) and in one area (13) in autumn. When examined by tree species, it was generally determined that aphid density in sampling areas of *Juniperus* spp. (areas 1-8) and *Abies cilicica* (areas 33 and 34) was lower than other tree species in all three seasons. The highest aphid abundance values (20 areas) were detected in the summer season in 2020, but unlike 2019, they were followed by autumn and spring seasons, respectively. The highest aphid density was observed in 8 areas in the autumn season and in 5 areas in the spring season. By tree species, in both years, *Juniperus* spp. (areas 1-8), *Pinus nigra* (areas 8-16), *Pinus brutia* (areas 16-20), *Cedrus libani* (areas 21-25), and Robinia pseudoacacia (areas 31-32) sampling areas had higher abundance values in the summer months. While *Quercus* spp. (areas 26-30) areas had high abundance values in spring in 2019 and in autumn in 2020, *Abies cilicica* (areas 33-34) areas had high abundance values in summer in 2019 and in spring in 2020 (Figure 4).

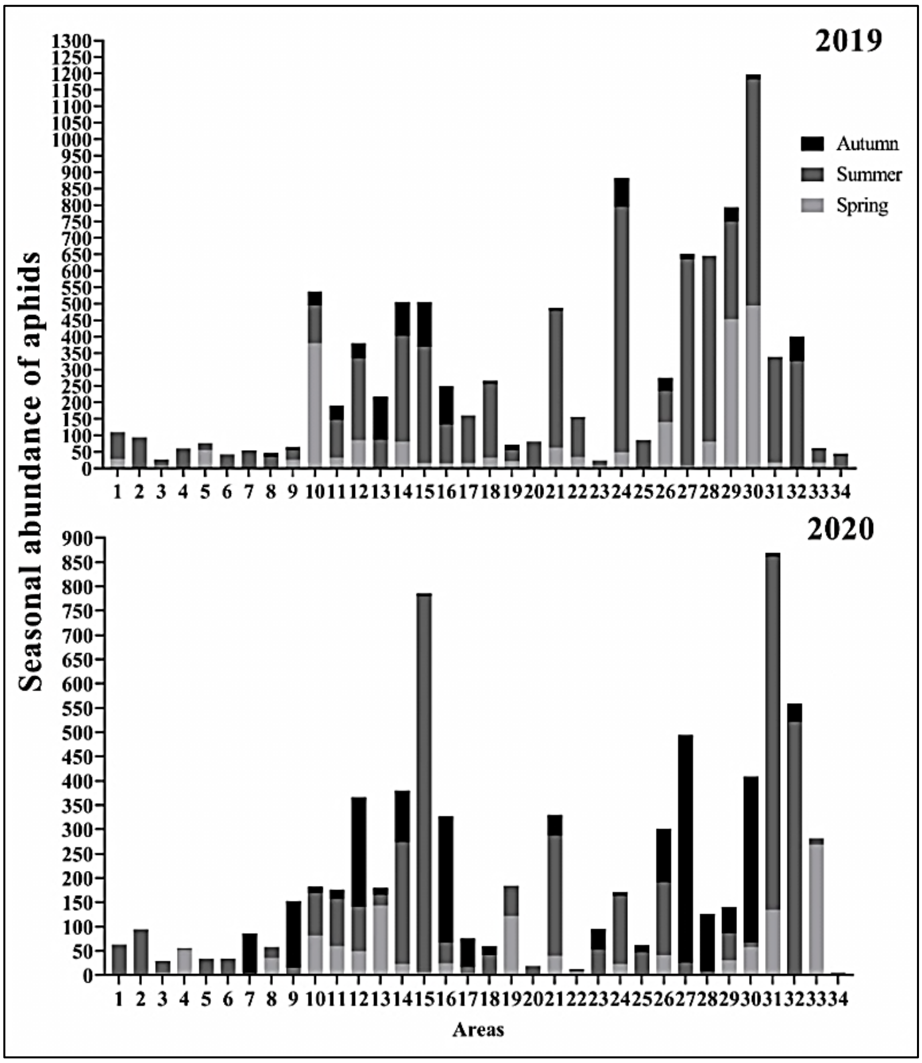

Figure 4. Seasonal abundance of aphids in sampling areas in 2019-2020

Aphid Population Density by Month in Host Tree Species

The distribution of aphid density varied among tree species by month. It was generally found to be high in June 2019 (especially *Juniperus* spp., *Quercus* spp., *R. pseudoacacia* and *A. cilicica*). The population trend increased between June and July and started to decrease in August. The highest population density was reached in May in *Pinus nigra* sampling areas, in July for *P. brutia* and *C. libani* sampling areas. In 2020, differences were observed in the months with the highest population compared to 2019. *Juniperus* spp. and *R. pseudoacacia* areas, population density was found to be high in June in both years. *Quercus* spp. areas reached the highest population in October. Population density was high in *P. nigra* areas in July, *P. brutia* and *A. cilicica* in May, and *C. libani* areas in June (Figure 5).

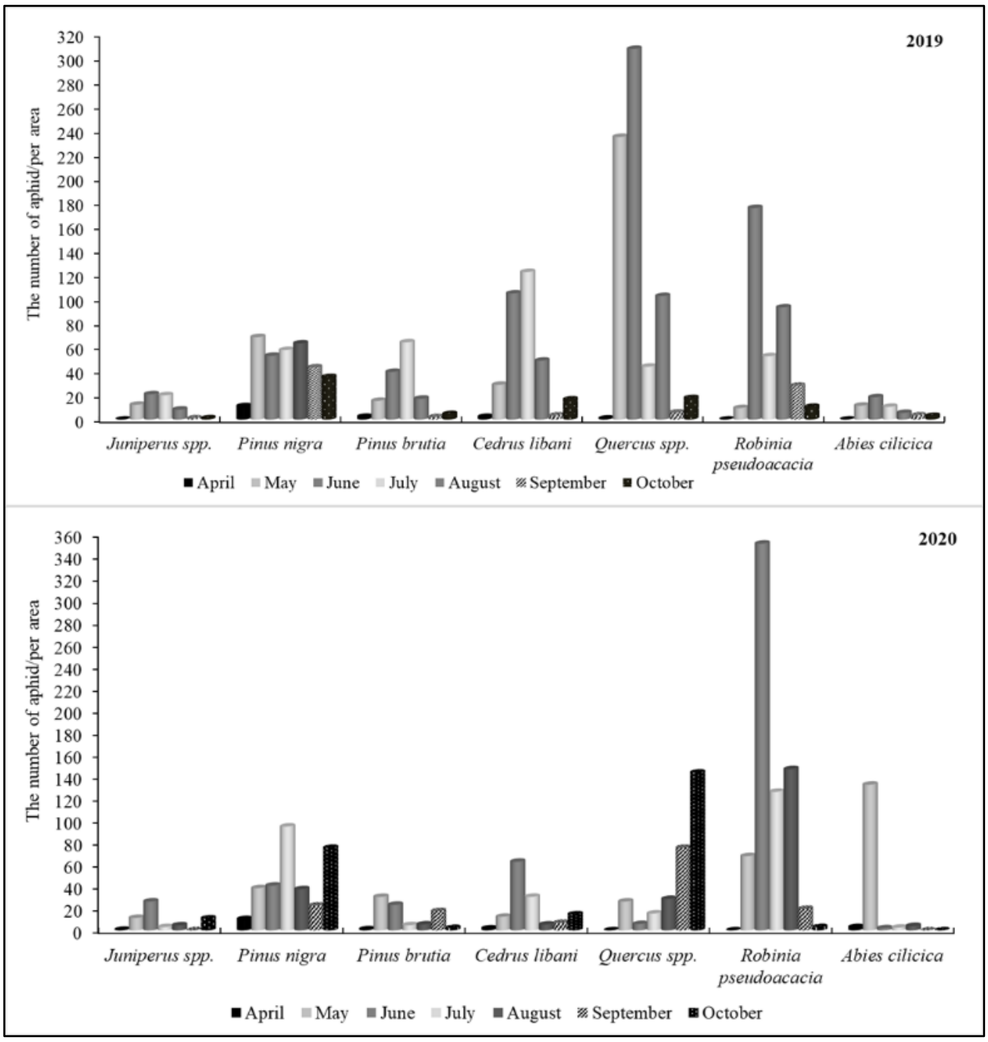

Figure 5. Aphid abundance values according to months in host tree species

Infestation Rate in Sampling Areas

According to years, the rates of infected trees and infected shoots are parallel in 2019 and 2020. The infestation tree rate was the same in 2019 for sampling areas 28 and 29 (*Quercus* spp.), while the infestation shoot rate was higher in area 29. Infestation rate of over 50% was determined in areas 10, 12, 16 (*Pinus nigra*), 24 (*Cedrus libani*), 27, 30 (*Quercus* spp.) and 32 (*Robinia pseudoacacia*) in 2019. The lowest infestation tree rate was observed in Juniperus spp. (areas 1-8), *P. brutia* (areas 17-20), and *Abies cilicica* (areas 33 and 34) sampling areas. Infected shoot rate was highest in the same year in *P. nigra*, *C. libani*, *Quercus* spp., and R. pseudoacacia sampling areas. The rate of infected tree was detected in sampling areas 14 (*Pinus nigra*) and 26 (*Quercus* spp.) with a rate of approximately 70% in 2020 (Figure 6).

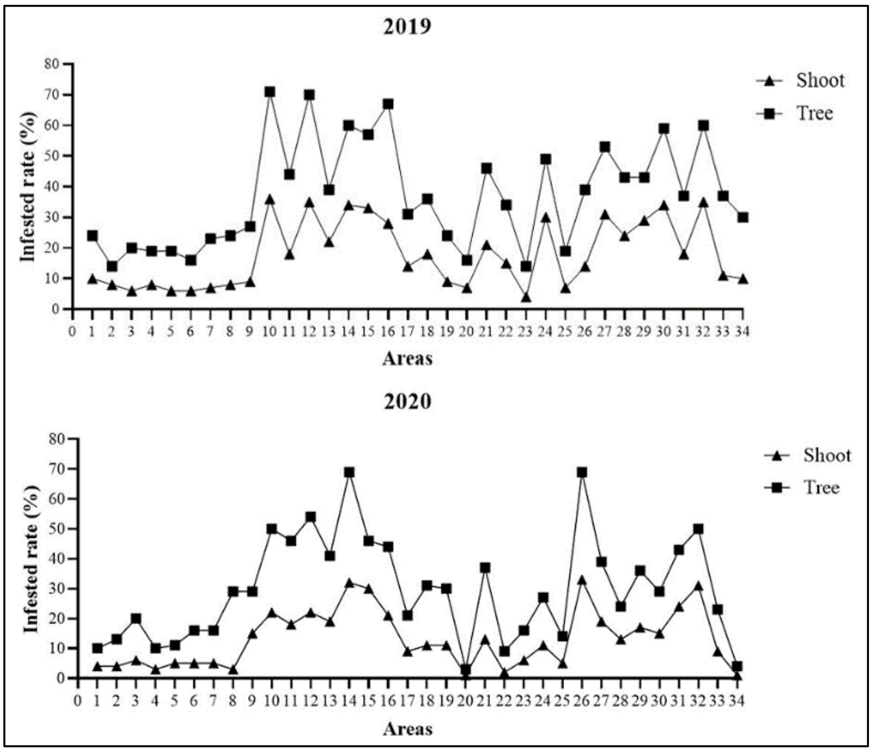

Figure 6. Ratio of infested trees and shoots in sampling areas

Population Density of Aphids in Trees and Shoots According to Sampling Areas

In the sampling areas, a general decrease in the number of aphids per tree (per tree/70 trees) and per shoot (per shoot/280 shoots) is observed in 2020 compared to both 2019. However, in 2020, there is an increase in the number of aphids per tree in areas 15 (*Pinus nigra*), 27 (*Quercus* spp.), and 31 and 32 (*Robinia pseudoacacia*) compared to 2019. The number of aphids per shoot remained the same in areas 15, 31, and 33 in both 2019 and 2020. The number of aphids per shoot was higher in 2019 than in 2020, except for these areas (Figure 7).

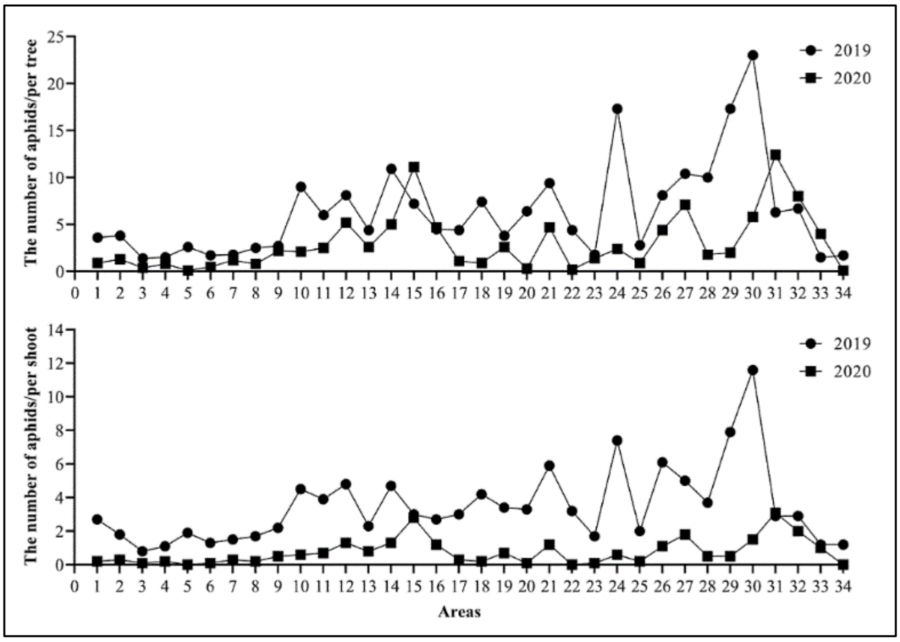

Figure 7. Number of individuals per tree and shoot in sampling areas

Evaluation of Infestation and Abundance Parameters

Friedman ranked two-way analysis of variance test was applied the parameters: the number of infested trees, infested shoots, individuals per tree, and individuals per shoot in the sampling areas in 2019-2020. According to the analysis, there was a significant difference in the relevant parameters for both 2019 (χ^2: 575305, $p<0.05$) and 2020 (χ^2: 567968, $p<0.05$). There was a decrease in the average values of all parameters for both years in 2020, especially a significant decrease of approximately 50% in the number of individuals per tree and approximately 76% in the number of individuals per shoot (Figure 8).

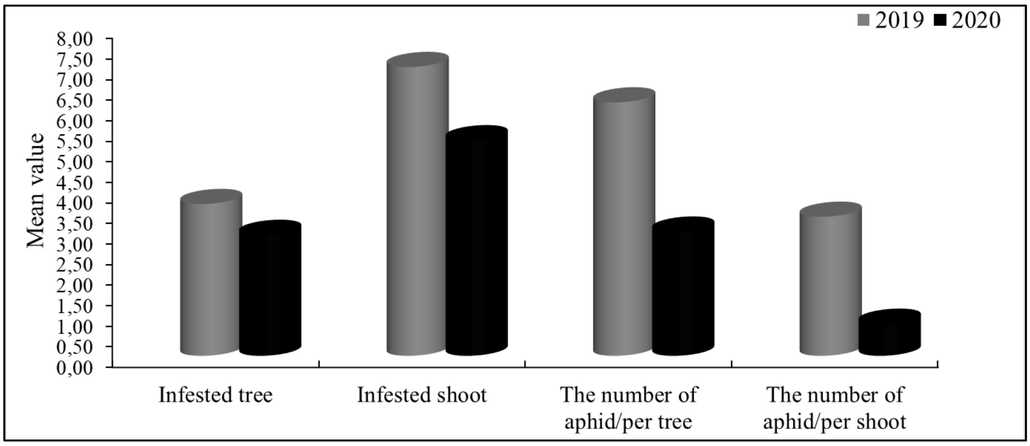

Figure 8. Average infestation and abundance values in trees and shoots by years

The infested tree and shoot rate reached the highest values in both years for *P. nigra*, *Quercus* spp., and *R. pseudoacacia*. The highest number of individuals per tree was found respectively in *Quercus* spp., *C. libani*, and *P. nigra*, in 2019, and in *R. pseudoacacia*, *P. nigra*, and *Quercus* spp. in 2020, respectively. The number of individuals per shoot decreased in all tree species in 2020 compared to 2019. The highest number of individuals in this parameter was seen in *Quercus* spp. in 2019 and *R. pseudoacacia* in 2020 (Figure 9).

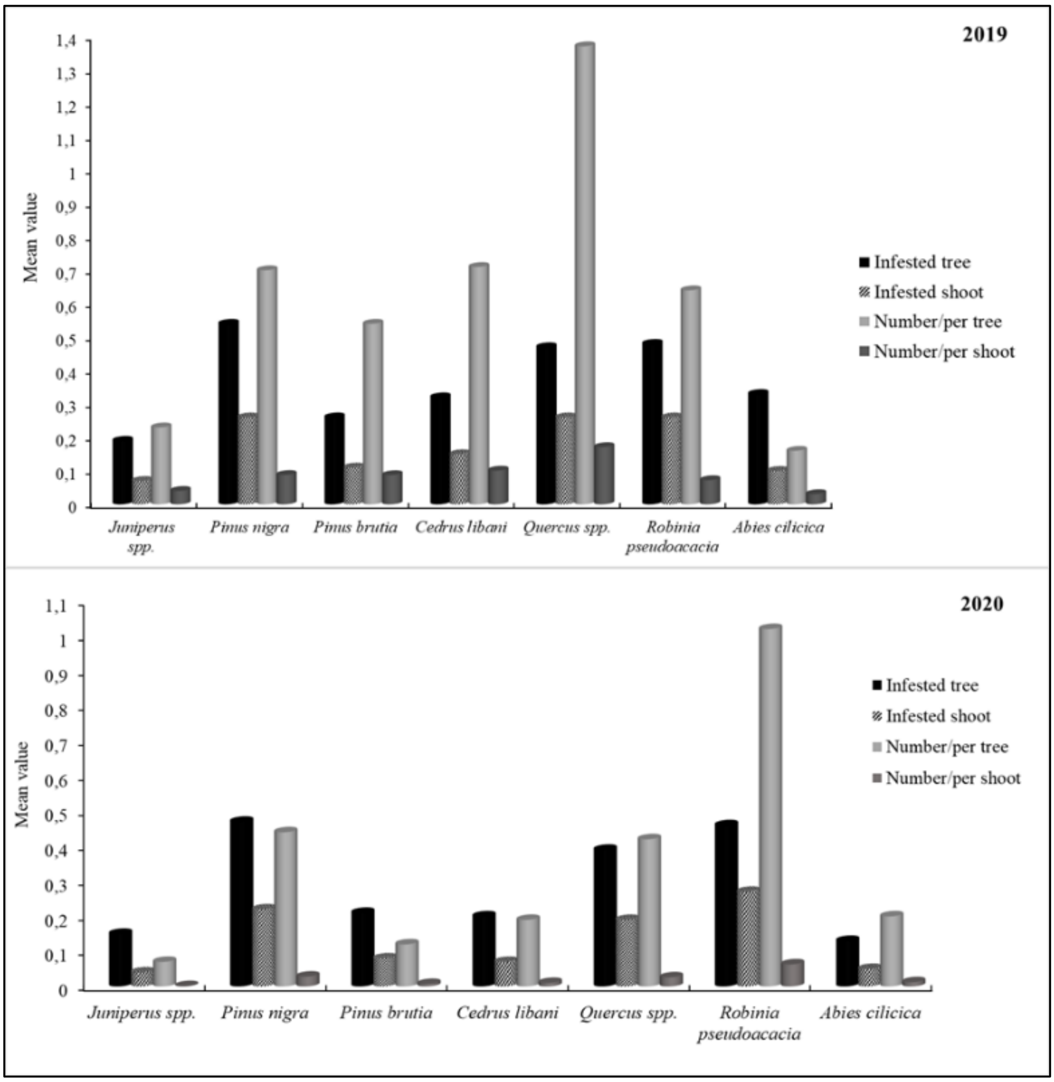

Figure 9. Average infestation and density values according to host tree species

Relationship Between Aphid Abundance Values and Some Environmental Factors

Pearson correlation analyses were performed to establish correlations between aphid abundance values and daily minimum, average, and maximum temperatures, as well as precipitation values during sampling times. For abundance values, in July 2019, a negative correlation was observed with minimum temperature (PCC: -0.381, $p<0.05$) and maximum temperature in September (PCC: -0.446, $p<0.05$), and a positive correlation with precipitation in October (PCC: 0.609, $p<0.01$). In July 2020, negative correlations were found with both average (PCC: -0.379, $p<0.05$) and maximum temperatures (PCC: -0.402, $p<0.05$), and a positive correlation was identified with average temperature in August (PCC: 0.442, $p<0.05$) (Table 2).

The Kruskal-Wallis test was used to determine the relationship of abundance values with some environmental factors (slope, aspect, elevation, climate classification, canopy cover, development stages). There was a statistically significant relationship between aphid abundance values and development stages in both years. Therefore, in areas with mature vegetation, such as pine, oak, and cedar, the population density is higher. No statistically significant relationship was found at the significance level of $p>0.05$ among other environmental factors (Table 3).

Table 2. Relationship between abundance values and climate parameters by month

Year	Month	Correlation	Climate parameters			
			Minimum temperature	Average temperature	Maximum temperature	Total precipitation
2019	April	PCC	0.012	0.143	0.207	-0.081
		P	0.948	0.419	0.241	0.651
	May	PCC	0.182	0.226	0.192	-0.043
		P	0.304	0.198	0.277	0.810
	June	PCC	-0.311	-0.247	-0.222	0.012
		P	0.073	0.160	0.207	0.945
	July	PCC	-0.381	-0.178	-0.296	-
		P	0.026	0.314	0.089	-
	August	PCC	-0.083	-0.018	-0.040	-0.099
		P	0.641	0.919	0.823	0.576
	September	PCC	-0.153	-0.279	-0.446	-
		P	0.387	0.110	0.008	-
	October	PCC	-0.106	-0.188	-0.084	0.609
		P	0.551	0.287	0.638	0.000
2020	April	PCC	0.007	-0.105	-0.095	-0.100
		P	0.968	0.555	0.592	0.574
	May	PCC	-0.068	-0.054	-0.037	0.272
		P	0.702	0.761	0.834	0.119
	June	PCC	-0.073	0.163	0.296	0.020
		P	0.680	0.357	0.090	0.912
	July	PCC	-0.244	-0.379	-0.402	-
		P	0.164	0.027	0.018	-
	August	PCC	-0.127	0.442	-0.245	-0.147
		P	0.476	0.009	0.162	0.406
	September	PCC	0.274	0.279	0.278	-0.016
		P	0.117	0.109	0.112	0.929
	October	PCC	0.136	0.227	0.215	-0.146
		P	0.443	0.197	0.221	0.409

PCC: Pearson Correlation Coefficient, P: significance level, -: no data

Table 3. Relationship of abundance values with categorical environmental factors

Parameters		Years	
		2019	2020
Altitude	Kruskal-Wallis H	1.638	3.859
	Df	3	3
	P	0.615	0.277
Slope	Kruskal-Wallis H	5.736	1.612
	Df	3	3
	P	0.125	0.657
Aspect	Kruskal-Wallis H	1.557	5.905
	Df	3	3
	P	0.669	0.116
Canopy	Kruskal-Wallis H	0.712	4.230
	Df	2	2
	P	0.701	0.121
Development stages	Kruskal-Wallis H	12.851	12.266
	Df	4	4
	P	0.012	0.015
Climate Classification	Kruskal-Wallis H	0.689	1,061
	Df	2	2
	P	0.709	0.588

P: significance level

The aphid population in 2019 and 2020 shows similarity in terms of climate classification, development stages, and canopy parameters (Figure 10). Therefore, in areas with a development stage (b) of 8-19.9 cm, population density is higher. When evaluated according to climate classification, higher population values were observed in humid and semi-arid areas in both years. Based on canopy, in 2019, aphid abundance was higher in moderately closed areas, while in 2020, it was higher in highly closed areas. Population values were high in areas with a steep slope in 2019 and in areas with a moderate slope in 2020. According to the aspect, in 2019, the population was higher in north and east, while in 2020, it was higher in south and west. Regarding the elevation, in 2019, almost the same population density was determined in the elevation ranges of 1000-1500 and 1501-2000, while in 2020, it was found that the population density was higher in the elevation range of 1501-2000 m (Figure 10).

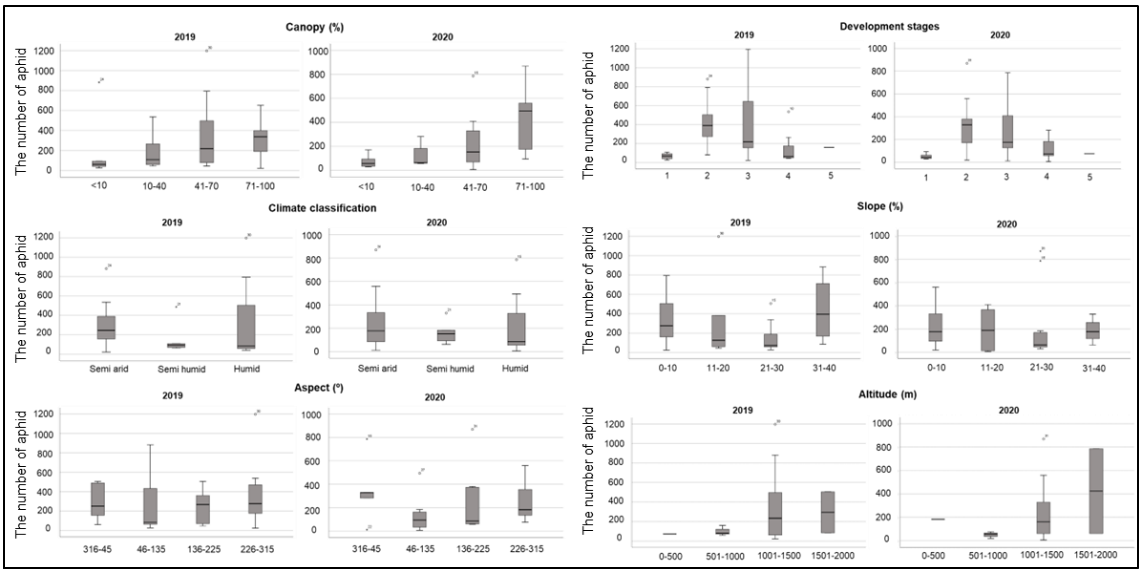

Figure 10. Relationship of abundance values with environmental factors (Kruskal-Wallis Test)

Discussion

Population density of a species is one of the most important factors in classifying that species as harmful (Kebede & Mulugeta, 2021). In this study, population densities in areas were determined systematically based on tree species and months using sampling in 2019-2020. In both years, aphid populations varied across sampling areas, with a general decrease in population density in the majority of the sampling areas in 2020. A significant decrease in population density was observed in three *Quercus* spp. and one *Cedrus libani* sampling area in 2020. Seasonal population density was high in spring and summer in 2019 and in summer and fall in 2020. When comparing the monthly average temperature values of meteorological stations for the years 2011-2020 with those of 2019 and 2020, a noticeable increase in temperature is observed in the summer and fall months of 2020. In 2019, it was determined that there was an increase in temperature in the spring months, especially in May, and a decrease in temperatures in the summer months (July and August) and autumn in September. Therefore, it can be said that there is a positive relationship between seasonal densities and temperature in the sampling areas, but it is negatively associated with high temperatures. Indeed, populations of *Elatobium abietinum* in *Picea sitchensis* trees reached their highest levels in May and June, with a subsequent decline in September to November (Straw et al., 2006). In Scotland, the population of *Cinara pini* showed an increase from mid-June, decreased from mid-July to mid-August, and then increased again after mid-August (Larsson, 1985). Numerous studies have reported variability in the population dynamics of aphids throughout the year (Dixon, 2012; Platkova et al., 2020).

Population density tends to increase during extremely prolonged dry periods or consistently dry periods. In a study involving the *Pineus boerneri* (Aphididae) species, it was found that the population density in *Pinus kesiya* trees was negatively correlated with rainfall (Chilima & Leather, 2001). It is noted that aphid populations on woody plants decrease during the summer season (Heie, 2009). Platkova et al. (2020) found the highest population value in June and the lowest population value in August. They have also mentioned that there is variation in seasonal abundance values among tree species. In Iran, the highest aphid population on *Pinus mugo* trees (45.84%) was observed during the spring months (Heidari Latibari et al., 2022). Seasonal density is particularly associated with seasonal temperature and humidity values, and it is reported to be influenced by bud burst timing, leaf development, flowering/fruiting, and leaf lifespan (whether the leaf is young or old) (Dixon, 1998). The reason why the aphid density is very low in April is interpreted as the late development of buds and leaves in broad-leaved tree species, especially due to unsuitable temperature values, and the low temperature even though there is foliation in conifers.

Such as other phytophagous species, aphids are generally dependent on their host. This dependence is explained under four main headings: (1) characteristics such as the chemical and phenological structure of the host, (2) competition with other phytophagous species on the same host, (3) the presence of natural enemies on hosts, and (4) characteristics within species such as competition, population density, and dominance of superior individuals (Dixon, 1998). In this study, variability in population density among host species is observed. A 150% increase in population density is observed in *Quercus* spp., *Pinus nigra*, *Cedrus libani*, and *Robinia pseudoacacia* areas when comparing populations in 2019 and 2020 in this study. In terms of population density, these tree species are followed by *Pinus brutia*, *Juniperus* spp. and *Abies cilicica*. High aphid population density has been reported in *Pinus* spp. forests (Larsson, 1985; Rodas et al., 2015) and *Picea* spp. forests (Fidgen et al., 1994; Halldórsson et al., 2003; Straw et al., 2005; 2006; 2011; Pilichowski et al., 2014). Some aphid species in pine plantations in Africa (*Pineus pini* and *P. boerneri*) have caused damage (Zwolinski, 1989; Madoffe & Austrara, 1993). Exotic aphid species *P. pini* and *P. boerneri* have led to a 2-5% growth loss in young *Pinus* spp. trees in Kenya and Malawi (Mailu et al., 1978; Chilima & Leather, 2001). In Australia, *Essigella californica* caused an estimated growth loss equivalent to approximately 230,000 m^3 of total tree volume due to leaf drop in *Pinus radiata* plantations between 1999 and 2001 (May & Carlyle, 2003). Furniss and Carolin (1977) stated that aphids cause yellowing of needles and reduce growth, especially in young trees. *Cinara* (*Schizolachnus*) *pineti* from the Lachininae subfamily causes yellowing and premature shedding of needles in young pine trees (Carter & Maslen, 1982). Cebeci (2003) reported that *Pineus pini* (Goeze, 1778) caused drying of the needles and shoots of *Pinus sylvestris* in afforestation areas in Istanbul. Öktem (1987) stated that colonies of *Cinara palaestinensis* caused damage to the branches and shoots of red pine. *Elatobium abietinum* (Walker, 1849) was reported to cause significant needle losses on *Picea sitchensis* (Straw et al., 2005). In the Isparta region, it was indicated that *Cinara cedri* feeds mainly on the previous year's shoots of *Cedrus libani*, causing the needles to dry and turn brown. It was particularly noted to be harmful to young trees, where the drying needles fall off, resulting in defoliation at the top and shoot tips of the tree (Oğuzoğlu & Avci, 2019).

The parameters selected for determining the damage status of aphids include the infestation rate on trees, infestation rate on shoots, number of individuals per tree, and number of individuals per shoot (Demeke, 2020; Kebede & Mulugeta, 2021). In this regard, it was determined that there was a significant difference in both 2019 and 2020. The infested tree count was highest in *Quercus* spp. areas in May and June in 2019, while in 2020, it was observed in *Pinus nigra* areas in June and July. The infested shoot count, individuals per tree, and individuals per shoot were found to be high in *Quercus* spp. areas in 2019 and *Pinus nigra* areas in 2020.

In Ethiopia, *Cinara cupressi* has caused infestation rates of up to 90% on the branches of *Cupressus lusitanica* trees. In the same study, tree mortality rates between 80% and 100% were observed in 2015 (Demeke, 2020).

It is known that aphids can easily adapt to climate change (Coeur d'acier et al., 2010). Aphids typically increase their populations in warm and humid regions, and under temperate weather conditions, they can lead to aphid epidemics (Lima et al., 2008). However, in conditions of low humidity and high temperatures, there is a decrease in aphid populations (Kök, 2019), while some aphid species exhibit high tolerance to drought and can increase their populations in dry conditions (Simpson, 2013). In this study, aphid abundance values and infested tree percentage values were evaluated based on the Thornthwaite method, calculated according to the relationship between precipitation-evaporation and temperature-evaporation. It was determined that the number of aphids in the sampling areas of classified as humid and semi-humid, and in classified as semi-humid, was higher compared to other areas. A study on *Pineus boerneri* revealed that precipitation was an important factor on the aphid population and was negatively related to population density at the end of the study. It is stated that population density is high during long-term dry periods and epidemics may occur in times of extreme high temperature and drought (Chilima & Leather, 2001).

Conclusion

It is known that temperature and precipitation regimes are changing both in Türkiye and globally. When annual changes in consecutive rainy days are examined under the climate change scenarios of the RCP4.5 scenario, a comparison was made between the periods 1971-2000 and 2021-2050. The results indicate a severe decrease, namely intense aridification, in precipitation in the regions, including the Mediterranean Region where the study area is located, such as the Marmara and Aegean Regions (Türkeş et al., 2020). With the expected increase in temperature, decrease in precipitation, and increased evaporation, it is anticipated that soil moisture will decrease, evapotranspiration will increase, and drought severity will intensify in agriculture and forestry areas (Türkeş, 2021). In addition to the stress that trees will experience due to drought, it is inevitable that leaf aphids, which can adapt to changing climatic conditions, will create additional stress on trees. Changes in trees in response to drought, such as leaf/needle length, width, content, can affect the presence of aphids. Furthermore, leaf aphids, which lay eggs in the autumn and overwinter continue to reproduce parthenogenetically if the temperature is high during the winter months. Therefore, they continue to feed on conifers needle-leaved trees during the winter, thereby increasing their population.

The protection and sustainable management of forests and forest resources against biotic and abiotic pests hold a significant place in forestry practices. Therefore, determining the population densities of pest species in forest areas is crucial for controlling these species in an environmentally friendly manner and for maintaining ecological balance and sustainable management in forest areas. This approach contributes to the continuity of Türkiye's forest assets and the preservation and enhancement of biological diversity. The limited number of studies on the damage status/population density of aphids in forests in Türkiye supports the need for more research in this field. As with other harmful species, these species need to be monitored due to climate change and climate parameters, which are among the factors affecting the population density and damage of aphids.

Ethics Committee Approval

Not applicable

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: Ş.O.; M.A.; Investigation: Ş.O.; M.A., Material and Methodology: Ş.O.; M.A., Visualization: Ş.O.; M.A., Writing-Original Draft: Ş.O.; M.A., Writing-review & Editing: Ş.O.; M.A. All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The author has no conflicts of interest to declare.

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