Anadolu Orman Araştırmaları Dergisi
Anatolian Journal of Forest Research
http://dergipark.org.tr/ajfr
ANATOLIAN JOURNAL OF FOREST RESEARCH

Flight activity of *Ips sexdentatus* caught in pheromone traps in black pine forests of Kastamonu Araç Forest Management Directorate

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ARTICLE INFO
Received: 04/01/2026
Accepted : 11/03/2026
https://doi.org/10.53516/ajfr.1854067
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ABSTRACT **Research Article**

Background and aims Bark beetles (Coleoptera: Curculionidae: Scolytinae) are one of the most economically important pests of coniferous forests. With global climate change, the frequency and severity of outbreaks of these species are increasing worldwide, and the pressure from these outbreaks is negatively impacting the structure and composition of forest ecosystems.
Methods In this study, 35 pheromone traps were used to determine the capture rates, capture times, flight periods, and flight durations of *Ips sexdentatus* beetles in pure black pine forests.
Results A total of 102,218 adult *I. sexdentatus* were captured in the pheromone traps between May and November, and three different flight periods were identified. The second flight period was the shortest, and the third flight period was the longest. The highest capture rates were achieved in the second and third flight periods. 59.1% of the total captured adults were caught in nine of the 35 traps.
Conclusion It was determined that the number of beetles caught in the traps varied statistically significantly across the three different flight periods.

Key Words: Flight period, *Ips sexdentatus, Pinus nigra*, pheromone trap

Kastamonu Araç Orman İşletme Müdürlüğü Karaçam ormanlarında feromon tuzaklarına yakalanan *Ips sexdentatus*'un uçuş aktivitesi

ÖZ

Giriş ve Hedefler Kabuk böcekleri (Coleoptera: Curculionidae: Scolytinae), iğne yapraklı ormanların ekonomik açıdan en önemli zararlılarından biridir. Küresel iklim değişikliği ile birlikte, bu türlerin salgınlarının sıklığı ve şiddeti dünya çapında artmakta ve bu salgınlardan kaynaklanan baskı, orman ekosistemlerinin yapısı ve bileşimi üzerinde olumsuz etkiler yaratmaktadır.
Yöntemler Bu çalışmada, saf karaçam ormanlarında bir kabuk böceği türü olan *Ips sexdentatus* erginlerinin yakalanma oranlarını, yakalanma zamanlarını, uçuş dönemlerini ve uçuş sürelerini belirlemek için 35 adet feromon tuzağı kullanılmıştır.
Bulgular Feromon tuzaklarında, Mayıs ve Kasım ayları arasında toplam 102.218 *I. sexdentatus* ergini yakalanmış olup üç farklı uçuş dönemi tespit edilmiştir. Bunlardan ikinci uçuş döneminin en kısa, üçüncü uçuş döneminin ise en uzun sürdüğü belirlenmiştir. İkinci ve üçüncü uçuş dönemlerinde en yüksek yakalama oranlarına ulaşılmıştır. Toplam yakalanan erginlerin %59,1'i 35 tuzağın dokuzunda yakalanmıştır.
Sonuçlar Tuzaklarda yakalanan böcek sayısının üç farklı uçuş zamanında istatistiksel olarak anlamlı şekilde değiştiği tespit edilmiştir.

Anahtar Kelimeler: Feromon tuzağı, *Ips sexdentatus*, *Pinus nigra,* uçuş dönemi

Citing this article:
Özcan, G. E., Sivrikaya, F., Enez, K., 2026. Flight activity of *Ips sexdentatus* caught in pheromone traps in black pine forests of Kastamonu Araç Forest Management Directorate. Anatolian Journal of Forest Research, 12, 1854067.

1. Introduction

Given the significant contributions of forest biodiversity and ecosystem services to society (Mori et al., 2017), abiotic factors like fire, storms, and drought, along with biotic factors such as insects and pathogens (Canelles et al., 2021), influence the structure, composition, and functioning of forest ecosystems (Franklin and Harper, 2016). Forests worldwide experience outbreaks involving various insect species (Wermelinger, 2004), and the incidence, intensity, and frequency of insect infestations in forest ecosystems have increased in recent years (Millar and Stephenson, 2015).

Bark beetles (Coleoptera: Curculionidae: Scolytinae) represent a significant threat to northern hemisphere forests (Lee et al., 2007), particularly coniferous forests (Franceschi et al., 2005), and play a crucial role in ecosystem processes (Raffa et al., 2015). Rising temperatures, droughts, wildfires, storms, and improper forest management induce stress on trees, hence promoting bark beetle infestations (Afzal et al., 2023). Bark beetles have a considerable economic and ecological impact on forests (Kirkendall et al., 2015), and their infestations can be detrimental to trees (Raffa and Berryman, 1983). Epidemics influence the composition of forest ecosystems (Morris et al., 2017; Raffa et al., 2008) and the growth and viability of forests (Black et al., 2010), potentially resulting in significant losses (Franceschi et al., 2005). Climate change initiatives (Marini et al., 2017; Hlásny et al., 2021) anticipate a rise in these infections.

Ips sexdentatus (Boerner) (Coleoptera, Curculionidae, Scolytinae), a highly detrimental beetle in Eurasian pine forests, exhibits significant dispersal capabilities (Jactel and Gaillard, 1991; Romero et al., 2007) and places among the most destructive pests affecting both natural and afforested pine ecosystems (Etxebeste et al., 2012; Jeger et al., 2017). While typically regarded as secondary pests at endemic level within its distribution region (Gil Sánchez and Pajares Alonso, 1986; Romero et al., 2007), this aggressive bark beetle species may cause epidemics under favorable conditions (Chakraborty et al., 2020; Etxebeste et al., 2013). The primary hosts of *I. sexdentatus* include *Pinus nigra, P. sylvestris, P. pinaster, P. heldreichii*, and *Picea orientalis* (Agbaba and Celepirovic, 2008; Jeger et al., 2017; Özcan et al., 2011; Özcan, 2017; Sarıkaya and Avci, 2011); however, it has also been observed in spruce and fir. In Turkish forests, it is documented to inflict harm on *P. nigra, P. silvestris, P. brutia, Picea orientalis, Abies nordmanniana*, and *A. bornmülleriana* (Beşceli and Ekici, 1969; Öymen, 1992; Selmi, 1998), and during an epidemic, it leads to tree mortality, threatening the integrity of the forest ecosystem (Özcan, 2017).

Controlling forest pests is essential for maintaining forest sustainability and ecological balance (Özcan and Tabak, 2021). Bark beetles identify appropriate host trees and colonize them via aggregation pheromones released by pioneer beetles (Byers, 2004). Pheromone traps are a more successful method than trap trees and have been used in integrated pest management programs (Sierra and Martín, 2004). Pheromone traps serve as a way to monitor adult populations of pest species (Baker 2008; Bakke, 1991). Mass trapping, implemented by the suspension of pheromone traps in affected forests, is not a conclusive control strategy, yet it helps minimize the devastation of millions of cubic meters of coniferous forests globally each year (Panzavolta et al., 2014). They particularly assist in controlling beetle populations at endemic levels (Özcan et al., 2011). The data collected from these traps enables the determination of species flight periods, the scheduling of control programs (Faccoli and Stergulc, 2006; Suckling and Karg, 2000), and insights into beetle population variations. Habitat qualities, ecological factors, and geographical variations can influence the number of adults captured in the traps (Özcan et al., 2011). Epidemics start due to weather conditions (Samman et al., 2000), and temperature fluctuations directly affect beetles (Bale et al., 2002). Consequently, daily temperatures can influence the quantity of beetles captured, leading to variations in beetle populations based on temperature (Bakke, 1992).

This study aims to ascertain the catch rates and capture durations of *I. sexdentatus* in pheromone traps inside pure black pine forests, as well as the species' flying periods and durations. Furthermore, it examined whether the quantity of insects captured in traps exhibited statistical variation throughout three distinct flying periods.

2. Materials and Methods

2.1 Study area

The study area comprises the pure black pine forests inside the Araç Forest Enterprise, situated on the boundary of the Kastamonu Regional Directorate of Forestry (RDF) (Figure 1). A susceptible forest area to *Ips sexdentatus* has been identified. The Pelitören Forest Storage is situated inside the research area.

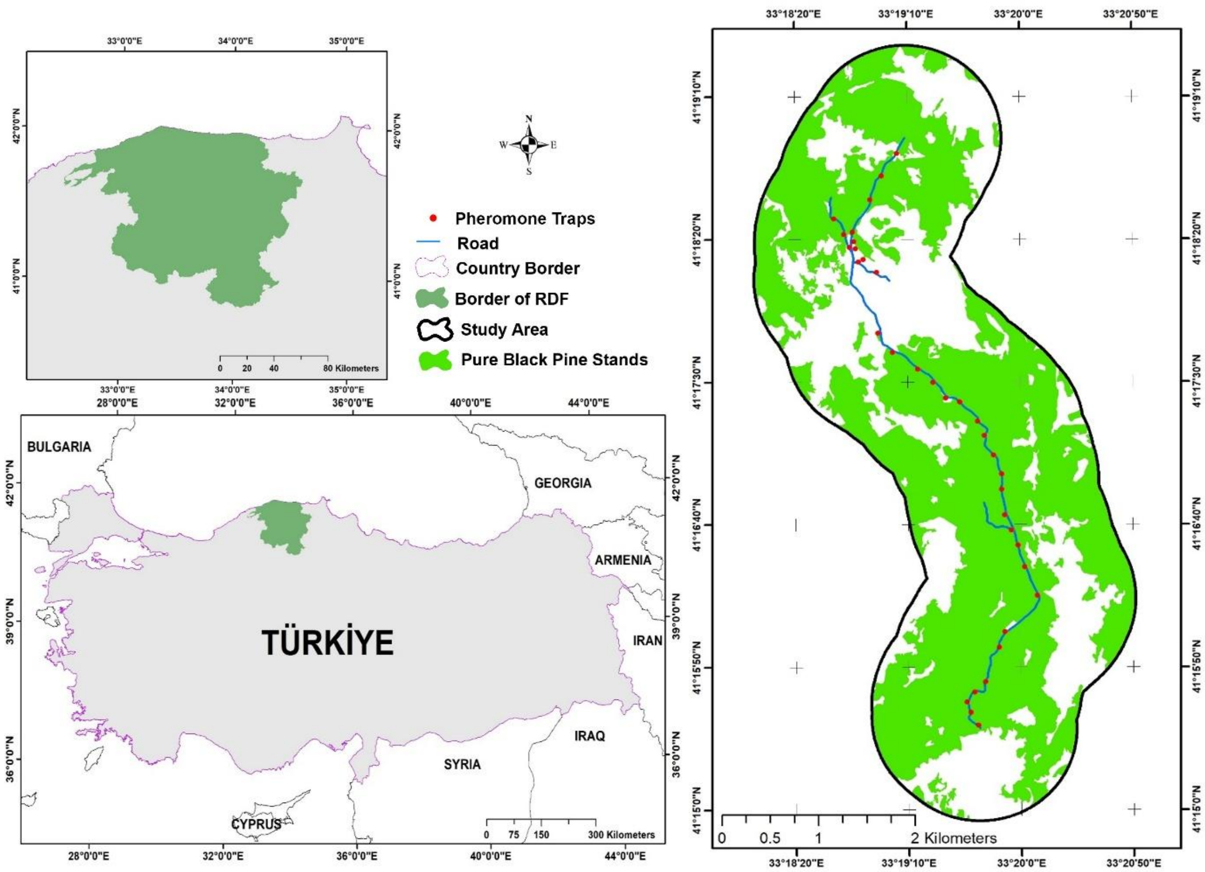

Figure 1. Study Area

2.2 Dataset

A total of 35 pheromone traps were set up in the research area. Pheromone traps were deployed in the field on May 12, 2023, to ascertain the capture rate of *Ips sexdentatus* and their flight durations, with counts conducted weekly thereafter. The traps were placed at a minimum distance of 6–10 meters from the trees, and their coordinates were recorded. The IPSSEX® brand dispensers were utilized, and the initial pheromone dispensers were set in the traps subsequent to their deployment. Subsequently, the initial pheromone dispensers were replaced with new ones on July 7, August 18, and September 18. During the investigation, 140 pheromone dispensers were utilized. The initial examinations of the traps occurred on May 19, while the final examinations took place on November 10, resulting in a total of 25 weeks of monitoring and counting of the traps. Climate data was obtained from the Araç Meteorological Station, which encompasses the study area.

Following the setting up of pheromone traps in the study area, particularly the areas adjacent to the traps, the stands were routinely examined to see whether they were drying out due to beetle infestation. The bark of trees exhibiting severe beetle damage, either desiccated or nearing desiccation, was excised, and galleries of *I. sexdentatus* beneath the bark were identified (Figure 2).

Figure 2. The galleries under the bark of trees in the study area

Beetle counts throughout three distinct flight times were evaluated using the Kolmogorov-Smirnov (K-S) one-sample test for a normal distribution. Additionally, the variations in the number of beetles captured in traps across three distinct flight periods were analyzed using the Kruskal-Wallis H test. As nonparametric tests lack a multiple comparison procedure, the pairwise comparison of beetle counts during flight periods was again conducted with the Mann-Whitney U test. All statistical analyses were conducted using IBM SPSS version 23.

3. Results

At the end of the study period, a total of 102,218 *Ips sexdentatus* (Coleoptera: Curculionidae, Scolytinae) and 748 *Thanasimus formicarius* (L.) (Coleoptera: Cleridae) adults were captured in pheromone traps. The mean quantity of *I. sexdentatus* captured per trap was 2920, while the quantity of *T. formicarius* was 21.99% of the captured beetles were *Ips sexdentatus*, whereas one percent were *Thanasimus formicarius.* 59.1% of *I. sexdentatus* adults (60,401) were captured in nine traps. The traps were hung in and around the woodyard. The mean quantity of beetles captured in these traps was 6711, but in the remaining 26 traps, it was 1608. The mean catch quantity in these 9 traps, characterized by extensive captures, was around four times greater than that of the other traps. Due to the inability to distinctly delineate the generation numbers and flight times of the detrimental species, along with the overlap of flight periods influenced by temperature, accurate date ranges for separations cannot be provided. Previous research in Kastamonu forests indicated that *I. sexdentatus* exhibited two flight periods; however, this study found that *I. sexdentatus* had three flight periods in this region in 2023, owing to climatic conditions (Figure 3).

The initial documented capture date was May 19; however, it can be reasonably inferred that the beetle's first flights began between May 12 and May 19, coinciding with the installation of the traps, and persisted until the first week of July, lasting approximately 50 to 55 days. The second flight started in the first week of July and continued until the third week of August, lasting around 35 to 40 days. The third flight commenced in the third week of August and persisted until the second week of November, lasting around 75 to 80 days (Figure 3). The results indicated that the second flight time had the lowest duration, while the third flight period had the longest duration. Moreover, 65.7% of the total beetles captured were documented during the assessments conducted on July 28, August 4, and September 22-29. These time intervals occur during the second and third flying periods. The mean daily temperatures on the initial flight start dates are around 9.8°C, the mean temperature during the second flight period is 21.4°C, and the mean temperature in the third flight period is 15.7°C. On certain days, the average and maximum daily temperatures reach 20°C or more during flight periods (Figure 3).

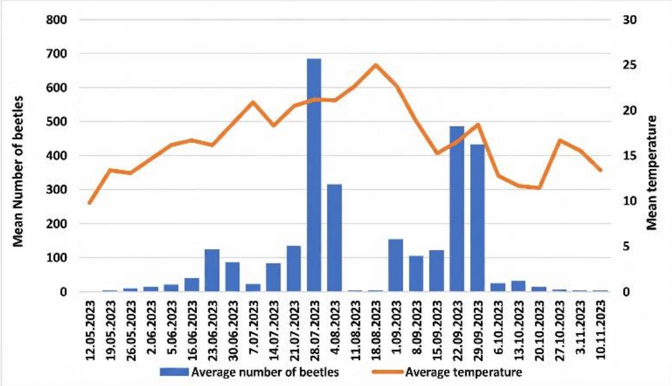

Figure 3. Distribution of the number of beetles caught according to time and temperature in flight periods

The evaluations aimed to ascertain the variations in the quantities of *I. sexdentatus* captured in traps throughout three distinct flight periods. Due to the inability to delineate the flight periods with an exact time, the first flight period was assessed as approximately May 19-July 7 (8 weeks), the second flight period as July 14-August 18 (6 weeks), and the third flight period as September 1-November 10 (11 weeks). A total of 11,262 *I. sexdentatus* adults were captured during the first flight period, 42,769 during the second flight period, and 48,187 during the third flight period. The beetle counts from 35 traps in the research region were assessed for normalcy using the Kolmogorov-Smirnov K-S test, revealing a non-normal distribution ($p>0.05$).

The variation in the quantity of beetles captured in the traps during three distinct flying periods was assessed using the nonparametric Kruskal-Wallis H test. The variation in the quantity of beetles captured in the traps throughout three distinct flying periods was determined to be statistically significant ($p<0.05$) (Table 1).

Table 1. Control of the difference between the number of beetles caught in the traps during the flight periods, Kruskal-Wallis H test

Flight periods	N	Mean rank	df	p*
I	35	31.23	2	0,000
II	35	55.43		
III	35	72.34		

*p<0,05

The quantity of beetles captured throughout the three distinct flying periods significantly differed ($p<0.05$) (Table 2). The mean number of beetles captured in the traps during the first flight period was 312.77, in the second flight period 1221.97, and in the third flight period 1376.77. The maximum number of beetles captured occurred during the third flight time, whereas the minimum was recorded in the first flight period. The quantity of beetles captured in the traps during the second and third flight periods was roughly 4 and 4.5 times greater than that of the first flight period, respectively.

Table 2. Pairwise comparison of the number of beetles caught during the flight periods using the Mann-Whitney U test

Flight periods	N	Mean	Min.	Max.	Mean rank	Rank sum	p*
I	35	312.77	3	2479	26.57	930	0.000
II	35	1221.97	7	11497	44.43	1555	
I	35	312.77	3	2479	22.66	793	0.000
III	35	1376.77	22	2862	48.34	1692	
II	35	1221.97	7	11497	29	1015	0.000
III	35	1376.77	22	2862	42	1470	

*p<0,05

4. Discussion

Pheromone traps help monitor and regulate beetle populations (Galko et al., 2016). Mass trapping, either independently or in conjunction with other control strategies, is also useful in managing bark beetles (Jakuš, 1998; Schlyter, 2001). Currently, pheromone traps are employed for monitoring rather than for control (Galko et al., 2016). This study involved the deployment of 35 pheromone traps in pure black pine forests to determine the capture rates, flight periods, and durations of *I. sexdentatus*. Literature indicates that traps in pure black pine forests were positioned at a height of 1.5 m above ground along roadsides (Özcan et al., 2011), with the nearest trap located 10 m away (Serez, 1987) and the farthest at 80 m, facilitating beetle detection of the pheromone source (Jactel, 1991). A cumulative total of 102,218 *I. sexdentatus* were captured in 35 traps at the conclusion of their flying periods, yielding an average of 2,920 *I. sexdentatus* per trap. It was noted that 59.1% of the catches were centered in nine traps. Özcan et al. (2011) indicated that 61.48% of the total *I. sexdentatus* adults captured in pheromone traps were obtained from 10 traps and 59.93% from 12 traps during a study done over two distinct years. Similarly, Özcan (2017) highlighted that 56.9% of the total beetles were captured in 10 traps. The populations and flying patterns of bark beetles are influenced by numerous biotic and abiotic factors (Faccoli, 2002; Sturrock et al., 2011). The efficacy of the traps may fluctuate based on their proximity to appropriate host trees, stand density, wind direction (Safranyik et al., 2004), pheromone attraction potential (Jactel, 1991), species biology (Baca et al., 2006), and geographical factors (Lobinger, 1995). This investigation revealed that the traps with the highest number of catches were those suspended around the woodyard. The beetles present in the unpeeled evals transported to the wood yards are believed to have augmented this quantity.

A total of 748 *T. formicarius* adults were captured in the traps, yielding an average of 21 individuals per trap. Mass applications of pheromone traps result in the eradication of numerous bark beetles and may also lead to the extinction of non-target predator species (Grégoire et al., 1992; Erbilgin and Raffa, 2000). The primary predators of *I sexdentatus*, *T. formicarius*, and *Temnochila caerulea* (Olivier) (Coleoptera: Trogossitidae), are inadvertently captured as non-target species in pheromone traps due to their attraction to the same pheromones as bark beetles (Aukema and Raffa, 2000; Etxebeste et al., 2012; Özcan et al., 2011; Sierra and Martín, 2004). Furthermore, it is noted that the most commonly captured predator species in traps is *T. formicarius* (Lopez and Goldarazena, 2012), and this predator exhibits a great attraction to the pheromone of *I. sexdentatus* (Akkuzu et al., 2021). Predators serve as significant natural enemies of bark beetles (Kenis et al., 2004). Adult *T. formicarius* can consume larvae and adults of bark beetle species, whereas their larvae can feed on bark beetle larvae (Koçoglu and Özcan, 2018). Meshkova et al. (2021) indicated that *I. sexdentatus* outbreaks were mitigated more rapidly in forests where *T. formicarius* was introduced. The capture of these species in pheromone traps is a disadvantage for control efforts (Özcan et al., 2011). Research indicates that predator species may endure in trap chambers for a minimum of one week (Martín et al., 2013). Consequently, predatory beetles captured in the pheromone traps were retrieved on every examination and subsequently released into the forests.

This study identified the species' initial flight period as occurring from the second week of May to the first week of July, spanning 50-55 days. The subsequent flight period lasted from the first week of July to the third week of August, lasting 35–40 days. The final flight period, which spanned from the third week of August to the second week of November, lasted 75–80 days. In a separate study conducted in the black pine forests of the Kastamonu region, it was reported that *I. sexdentatus* exhibits two flight periods: the first, from early May to mid-June, lasting 40-45 days, and the second, from mid-June to early September, lasting 50-55 days (Özcan, 2017). Research conducted in Turkish forests with various tree species revealed two distinct flight periods for the species, with flight times occurring at comparable intervals (Beşceli and Ekici, 1969). Sarıkaya and Avcı (2012) established that *I. sexdentatus* exhibits three generations in their research, which utilized trap trees and pheromone traps within black pine forests in the Isparta region. The initial flight was scheduled for late April and the first half of May, the subsequent trip for late June and the first half of July, and the last flight for the latter half of August and early September. Hlávková et al. (2024) reported in their study that the flying activity of the species began in May and continued until early September. They underscored that the potential for extending the flight duration, contingent upon climatic circumstances, must be considered. *I. sexdentaus* typically exhibits two generations in Türkiye; however, a third generation may occur under specific climatic conditions (Sarıkaya, 2008). Furthermore, understanding the flight periods is essential for monitoring and mapping the population dynamics of *I. sexdentatus* (Hlávková et al., 2024).

This study found that the beetle counts varied throughout three distinct flying periods, with average captures of 312.77, 1221.97, and 1376.77, respectively. Özcan (2017) reported that the number of beetles captured during two flying periods under endemic conditions was 59.36 and 9.93, respectively, indicating a significant difference in the number of beetles captured between the two periods. Comparing the results of this study with Özcan (2017), conducted in a comparable region, reveals that the capture rates are significantly elevated. Stand features, water economy, humidity, habitat conditions (Özcan et al., 2011), stand composition, density, site, development stage, slope, altitude, temperature, humidity, and solar radiation significantly influence the emergence of *I. sexdentatus* (Özcan et al., 2022).

5. Conclusion

Climate phenomena, including rising temperatures, droughts, and windstorms attributable to climate change, foster circumstances conducive to the proliferation of forest pests and illnesses. This condition leads to an increase in bark beetle outbreaks, consequently expanding the distribution regions of these species. Consequently, insufficient or ineffective management of bark beetles will result in heightened tree mortality and a decline in the health of the forest ecosystem. *I. sexdentatus* is a pest that needs to be monitored regularly due to its potential to harm pine forests. Otherwise, any control measures will be inadequate to control this pest. The removal of afflicted trees, the trapping of trees, and the logging of forests, together with the utilization of pheromone traps, are crucial for formulating strategies to mitigate bark beetle populations.

Acknowledgments

We would like to express our gratitude to the Kastamonu Regional Directorate of Forestry personnel for supporting the study. The study was supported by the TÜBİTAK (Project ID 122N293).

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