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AUTHORS: Gonca Ece ÖZCAN,Hazan ALKAN AKINCI,Mahmut EROGLU

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Attack Density and Distribution of *Dendroctonus micans* (Kugelann) in Standing and Felled Oriental Spruce Trees

*Gonca Ece ÖZCAN¹ Hazan ALKAN AKINCI² Mahmut EROĞLU³

¹Kastamonu University, Faculty of Forestry, Department of Wildlife Ecology and Management, 37150 Kastamonu, Turkey

²Artvin Çoruh University, Faculty of Forestry, Department of Forestry Engineering, 08000, Artvin, Turkey

³Karadeniz Technical University, Faculty of Forestry, Department of Forestry Engineering, 61080, Trabzon, Turkey

*Corresponding autor: goncaece@kastamonu.edu.tr

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Abstract

The aim of this study is to investigate attack density and distribution of *Dendroctonus micans* (Kugelann) (Coleoptera: Curculionidae) in standing and felled oriental spruce, *Picea orientalis* (L.) Link., trees. For this purpose, a total of 179 standing and 38 felled trees were evaluated. *D. micans* attacks largely concentrated in the initial several meters of the boles and particularly in the initial 1 m part of both tree groups. 62.53% and 67.22% of EHs in the initial 2 m of boles of standing and felled trees, respectively were counted in the initial 1 meter. In felled trees, the ratios of entrance holes per meter up to the initial 9 m of boles were similar to each other (%7.02-9.24), other than the significant difference in the initial 1 meter (18.96%). Above nine meters, the ratio of entrance holes per meter of boles varied in the range of 0.54% to 3.64%. In the case of standing trees, unsuccessful entrances comprised 23.40% of the total entrances. In the case of felled trees, approximately one in every four entrance holes in the bole section up to the initial 8 m was unsuccessful, as similar to standing trees, whereas one in every three EHs in upper sections was unsuccessful.

Key Words: Oriental spruce, Geater european spruce bark beetle, Attack density

Dendroctonus micans (Kugelann)'ın Dikili ve Kesilen Doğu Ladini Ağaçlarındaki Saldırı Yoğunluğu ve Dağılımı

Özet

Bu çalışmanın amacı, *Dendroctonus micans* (Kugelann) (Coleoptera: Curculionidae)'ın dikili ve kesilen doğu ladini, *Picea orientalis* (L.) Link., ağaçlarındaki saldırı yoğunluğu ve dağılımının araştırılmasıdır. Bu amaçla, 179 dikili ve 38 kesilmiş ağaç değerlendirilmiştir. *D. micans* saldırıları, her iki ağaç grubunda da büyük ölçüde ağaç gövdelerinin ilk birkaç metresinde ve özellikle de ilk 1 m'sinde yoğunlaşmıştır. Dikili ve kesilen ağaçların ilk 2 m'sindeki giriş deliklerinin %62,53'ü ve %67,22'si sırasıyla dikili ve kesilen ağaçların ilk 1 m'lik kısımda sayılmıştır. Kesilen ağaçlarda, ağaç gövdelerinin ilk 9 metreye kadar her bir metresindeki giriş deliklerinin oranı ilk 1 metredeki belirgin farkın (%18,96) dışında birbirine daha yakın (%7.02-9,24) oranlardadır. Dokuz metreden yukarıda, gövdelerin her bir metresindeki giriş deliklerinin oranı %0,54 ile %3,64 arasında değişmektedir. Dikili ağaçlarda, başarısız girişler giriş deliklerinin toplamının %23,40'ını oluşturmaktadır. Kesilen ağaçlarda, ağaç gövdelerinin ilk 8 m'lik kısmında, dikili ağaçlara benzer şekilde, her dört giriş deliğinden yaklaşık biri, daha üst bölümlerde ise her üç giriş deliğinden biri başarısızdır.

Anahtar Kelimeler: Doğu ladini, Dev kabuk böceği, Saldırı yoğunluğu

Introduction

The greater European spruce bark beetle, *Dendroctonus micans* (Kugelann) (Coleoptera: Curculionidae) is found in natural as well as man-influenced spruce forests throughout Eurasia (Grégoire, 1988). It has been reported that *D. micans* females can successfully invade apparently healthy spruce trees unlike the individuals of other

Dendroctonus species which massively attack and kill trees (King and Fielding, 1989). Among bark beetles that attack living trees, a common strategy to exhaust the hosts' defences is a pheromone-mediated mass-attack (Lieutier, 2007).

However, *D. micans* neither uses aggregation pheromones to coordinate its attacks nor has any pathogenic fungi that are

characteristic of many bark beetles (Everaerts et al., 1988). Solitary females attack trees and may end up establishing a successful brood irrespective of tree mortality (Storer et al., 1997).

D. micans is the European counterpart of a few bark beetle species which have developed a solitary attack strategy. It is capable of attacking any tree, even healthy ones. Moreover, a tree under successful attacks does not die and hence future generations can benefit from a successfully colonized tree, except during outbreaks (Grégoire, 1985; Voulard, 1991; Gilbert et al., 2001; Lieutier, 2007). It was demonstrated that trees attacked by *D. micans* are randomly distributed in a forest plot and may suffer several years of frequent attack (Gilbert, 2001). Beetles can attack trees several times but adjacent and nearby trees may remain unattacked, and attacked trees may either suffer or escape further successful attacks (Bevan and King, 1983). In oriental spruce, Alkan-Akinci et al. (2014) reported a limited number of attacks for many attacked trees (1–5 attacks on a tree) but significantly higher numbers (40–160 attacks on a tree) for certain trees. Certain areas and trees are highly susceptible to attacks which can reach epidemic levels (Eroğlu, 1995).

Economically important quality losses can happen in the wood of attacked trees depending on attack density (Alkan-Akinci et al., 2009). Presence of abundant resin exudation and resin tubes in attacked boles allows determination of *D. micans* attacks externally (Fielding and Evans, 1997; Alkan-Akinci et al., 2010). However, it is difficult to guess attack rates and success in upper sections of trees by direct observation. The aim of this study is to make a contribution to the understanding of the solitary attack strategy of *D. micans* by investigating attack density and distribution of the beetle in standing and felled trees. Results will contribute to former studies in Turkey of which performed on standing trees, and integrated pest management strategies.

Materials and Methods

This study was conducted on oriental spruce stands infested by *Dendroctonus micans* in Macka Forestry Administration, Yeşiltepe and Macka Forest Sub-District Directorates in Eastern Black Sea Region, Turkey. A total of 179 standing and 38 felled trees in the study areas were evaluated. In these trees, 4090 entrance holes (EH) of *D. micans* and 5258 *D. micans* individuals in different biological stages were counted in galleries. The number of EHs that were at the bottom and root collars of felled trees were also counted and added to the total number belonging to the same tree.

The numbers of EHs on the bole up to 2 m above the ground of standing trees and on the entire bole of felled trees were counted and their heights on the bole were measured with a tape measure. It was decided whether EHs have been successful based on whether there are at least any egg systems or more mature brood systems under the bark. The bark on active galleries of *D. micans* was carefully moved using a small ax and the number of eggs, larvae, pupae and adults of the beetle was counted. Watercolor brushes, pincers and small plastic boxes were used to collect and count the beetles from their galleries. A chainsaw was used to cut down trees. The number of EHs on the bole up to 1 and 2 m above the ground of standing trees and the number of those on the initial 1 and 2 m of the bole and the entire bole of felled trees were also recorded.

In statistical procedures conducted for this purpose, logarithmic transformation was applied to the total number of EHs, which were counted on the entire bole of felled trees and which do not show normal distribution. Independent samples t-test was applied in order to identify if there is any statistical difference between mean total number of EHs counted in the initial 1 and 2 m and above 2 m of felled trees.

Results

Attack density in standing trees

A total of 2608 EHs were counted in boles up to 2 m above the ground of 179 standing trees, with an average EH number of 14.57 counted for each tree (Figure 1). Mean numbers of EHs up to 1 m and 1 to 2

m above the ground were 9.11 and 5.46, respectively. Only 130 standing trees had 12.55 EHs on average per tree up to 1 m above the ground. In that case, the mean number of EHs in standing trees up to 2 m above the ground was 14.57, with that up to 1 m being 9.11 or 12.55.

In these boles, the total number of successful EHs and the total of number of unsuccessful EHs were 1998 and 610, respectively. The mean number of successful EHs was 11.16 (1-116), with the mean number of unsuccessful EHs being 3.41 (1-34) up to 2 meters above the ground. The percentages of trees with successful and unsuccessful EHs were 89.39% and 60.34%, respectively. Unsuccessful entrances made up 23.40% of the total entrances. 22.93% of the EHs were new holes, which were made in the year of the study. 77.07% of the EHs resulted from activities of the beetle in previous years. While 78.61% of the EHs of the previous years were successful, 21.39% failed. 69.90% of new entrances were successful, whereas 30.10% failed.

Attack density in felled trees

A total of 1482 EHs were counted in 38 felled trees attacked by *Dendroctonus micans*. 18.96% of the total number of EHs was counted in 0 to 1 m of felled trees, whereas 9.24% in 1 to 2 m. The mean numbers of EHs up to 1 m and in 1 to 2 m of these trees were 7.40 (Figure 1) and 3.61, respectively (Table 1). A total of 418 EHs were counted up to 2 m of these trees, with the mean number of EHs being 11.01 per tree. Figure 1 shows the average number of EHs and their percentages on every one meter height of boles of felled trees and also first two meters of standing trees.

A total of 1075 successful and 407 unsuccessful EHs were counted in the felled trees. The mean number of successful EHs was 28.29 (6-97) in the felled trees, with the mean number of unsuccessful EHs being 11.31 (1-40). There were successful entrances in all felled trees, while successful entrances were detected in 94.74% of the trees. In that case, the mean number of failed EHs in all trees was 11.30. Unsuccessful entrances comprised 27.46% of the total entrances.

41.77% of the EHs were new entrances opened in the year of the study and 58.23% of the EHs resulted from activities of the beetle in previous years. 72.21% of new EHs were successful, 27.79% were unsuccessful, whereas 72.77% of EHs of previous years were successful and 27.23% were unsuccessful. 75.80% of EHs up to 1 m and 77.03% of EHs up to 2 m of felled trees were successful, whereas 24.20% of EHs up to 1 m and 22.97% of EHs up to 2 m of felled trees were unsuccessful, respectively

The height of felled trees varies in the range of 14 to 25 meters (Figure 2). The highest points at which successful and unsuccessful EHs were determined were 16.5 m and 17.6 m of boles, respectively. 18.96% of EHs were counted in the initial 1 m of boles, while 28.21% were counted in the initial 2 m. The attack density of *D. micans* was highest with a percentage of 85.56% in the initial 9 m of boles. The numbers of EHs counted in the boles were statistically different ($p<0.05$).

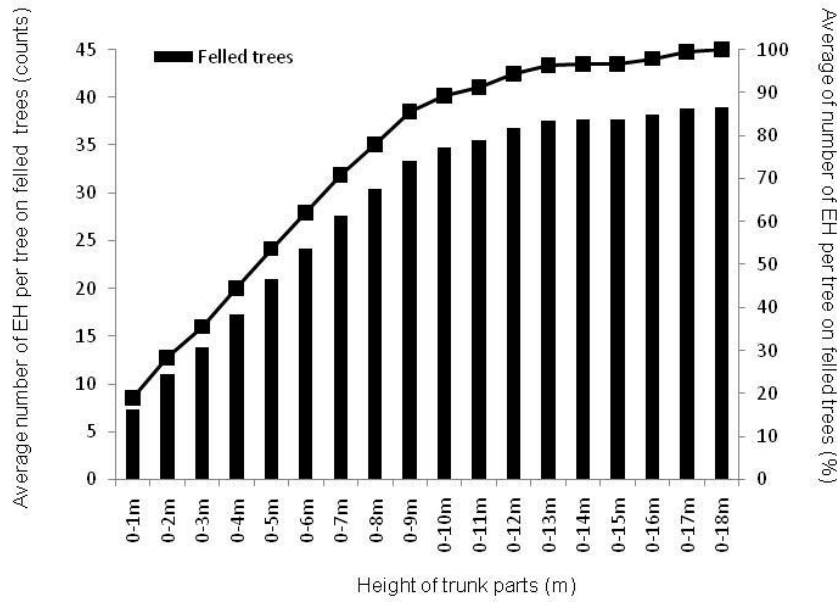


Figure 1. Average number of EHs and their percentages on every one meter height of boles of felled trees and also first two meters of standing trees

Table 1. The number of *D. micans* EHs per meter of felled trees, the mean number of EHs per tree, entrance hole percentages and cumulative percentages

Height of bole parts (m)	Total number of entrance holes	Number of entrance holes average per tree	Entrance holes percentages (%)	Entrance holes cumulative percentages (%)
0-1	281	7.39	18.96	18.96
1-2	137	3.61	9.24	28.21
2-3	109	2.87	7.35	35.56
3-4	131	3.45	8.84	44.40
4-5	137	3.61	9.24	53.64
5-6	124	3.26	8.37	62.01
6-7	131	3.45	8.84	70.85
7-8	104	2.74	7.02	77.87
8-9	114	3.00	7.69	85.56
9-10	54	1.42	3.64	89.20
10-11	29	0.76	1.96	91.16
11-12	48	1.26	3.24	94.40
12-13	28	0.74	1.89	96.29
13-14	5	0.13	0.34	96.63
14-15	0	0.00	0.00	96.63
15-16	19	0.50	1.28	97.91
16-17	23	0.61	1.55	99.46
17-18	8	0.21	0.54	100.00
Total	1482	39	100.00	100.00

Distribution of *Dendroctonus micans* individuals in standing and felled trees

There were 1185 *D. micans* individuals up to 2 m above the ground of 29 standing trees containing active galleries of *D. micans*. 4.56% of these individuals were adults, 14.43% were eggs, 80.25% were larvae and 0.76% were pupae.

In the entire boles of 25 felled trees, there were 4073 *D. micans* beetles 12.18% of which were adults, whereas 20.70% were eggs, 63.02% were larvae and 4.10% were pupae. 25.09% of these beetles were counted in the initial 3 m of the boles and 71.15% in the initial 9 m of the boles.

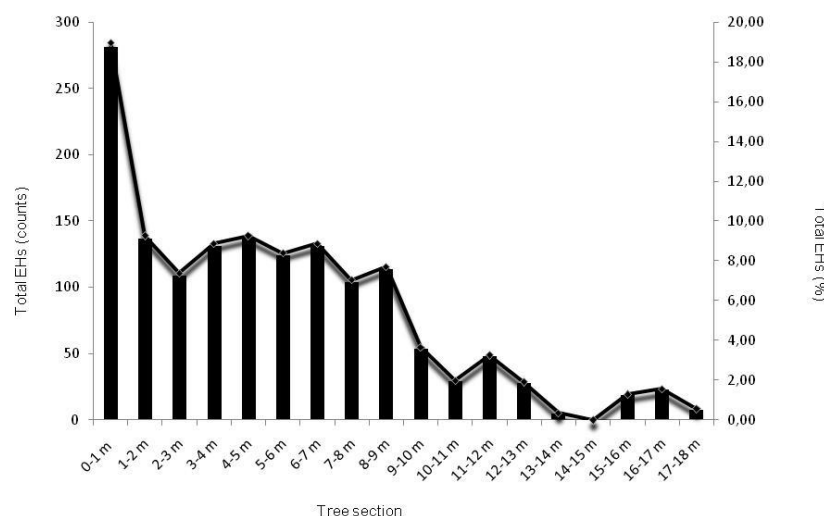


Figure 2. The mean numbers and the percentages of *Dendroctonus micans* EHs in each meter of boles

Discussion

It was seen that *D. micans* attacks largely concentrated in the initial several meters of the boles and particularly in the initial 1 m part of both tree groups. 62.53% and 67.22% of EHs in the initial 2 m of boles of standing and felled trees, respectively were counted in the initial 1 meter. 69% (Eroğlu, 1995) and 61% (Alkan-Akinci, 2006) of EHs of *D. micans* in the initial 2 m of boles were reported in the initial 1 meter. Starting from the upper parts of the root, *D. micans* reproduces intensively up to 8 m of the bole, even at portions up to top roof (Selmi, 1998). In our study, 77.87% of EHs were in the initial 8 m section of the boles. Attacks of this beetle primarily start at the bottom section of boles (Eroğlu, 1995) and are concentrated in the lower section (Kobakhidze, 1967; Grégoire, 1988). In the initial stage of attacks, in some trees, attacks

are more intense in the lower parts of boles, while in advanced stages of the attack, attacks can target the entire bole. *D. micans* attacks mostly take place in the lower parts of the bole and even in the root collars (Grégoire, 1988; Dajoz, 2000). In Georgia, 45% of attacks were reported to take place in the initial 1 m section of the boles (Kobakhidze, 1967).

It is possible to come across *D. micans* attacks anywhere on the bole, regardless of any special preference in terms of height. Evans et al. (1984) reported that *D. micans* attacks may take place in anywhere from the root to the top in the UK. In our study, successful and unsuccessful EHs were determined at 16.5 meters and 17.6 meters of boles of felled trees with heights ranging from 14-25 meters. The attack density of *D. micans* concentrated in the initial 9 m of boles by 85.55%. The ratios of EHs per

meter up to the initial 9 m of boles were similar to each other (%7.02-9.24), other than the significant difference in the initial 1 meter (18.96%). Above nine meters, the ratio of EHs per meter of boles varied in the range of 0.54% to 3.64%.

In the standing trees, the average number of successful and unsuccessful EHs counted up to 2 m above the ground were 11.16 (1-116) and 3.41 (1-34), respectively. On entire boles of felled trees, there were 28.29 (6-97) and 11.31 (1-40) successful and unsuccessful EHs on average, respectively. There were 8.48 (1-29) and 11.31 (1-40) successful and unsuccessful EHs on average counted up to 2 m above the ground of felled trees.

In the case of standing trees, unsuccessful entrances comprised 23.40% of the total entrances, while in the case of felled trees; unsuccessful entrances comprised 27.46% of the total entrances. 77.03% of entrances in the initial 2 m of felled boles were successful, with 22.97% there of being unsuccessful. 24.3% of EHs counted in the initial 2 m of 501 trees infested by *D. micans* was unsuccessful (Alkan-Akinci et al., 2014).

In the case of felled trees, approximately one in every four EHs in the bole section up to the initial 8 m, where 77.87% of EHs were present, was unsuccessful, as similar to standing trees, whereas one in every three EHs in upper sections was unsuccessful. This may explain why the percentage of unsuccessful entrances in the entire bole of felled trees was lower than that in the initial 2 m of standing trees. In the case of infested trees, increases in unsuccessful EH rates as a result of recurring *D. micans* attacks can be a measure of resistance developed by infested trees against the attacks of these insects. Tree resistance is reported to be the most important parameter that determines whether a female beetle is successful at colonizing a tree and laying her eggs, and can thus help to lower the population levels during the search for an available host (Lieutier, 2007).

In the case of standing trees, 22.93% of EHs in the initial 2 m of the boles are new entrances opened during the year of the study. 77.07% of EHs belong to activities of the beetle in previous years. 78.61% of EHs of previous years were successful, while 21.39% were unsuccessful. 69.90% of new

entrances were successful, whereas 30.10% were unsuccessful. The percentage of unsuccessful entrances increased from 21.39% to 30.10%. Ultimately, the success rate of the attacks carried out in the same trees decreased by 8.71% over time. It was determined that 21.66% of standing spruce trees in oriental spruce forests suffered *D. micans* attacks, however, attacks of this insect continued in 10.57% of these trees over time (Alkan-Akinci et al., 2014). Over the years, certain trees which have suffered repeated attacks of this insect strengthen their defenses against new attacks. The possibility of unsuccessful attacks in the case of individual *D. micans* attack can increase tree resistance (Lieutier, 2007), and some of the attacked trees develop a strong defense against new attacks and may remain viable for many years (Bevan and King, 1983).

The average numbers of successful and unsuccessful EHs counted in the initial 2 m of standing boles were 11.16 and 3.41, respectively, whereas those in the case of felled boles were 8.48 (1-29) and 2.53, respectively. In oriental spruce, the attack density of *D. micans* on the first 8 meter of the bole is reported to be limited for many attacked trees (1–5 attacks on a tree) but significantly high (40–160 attacks on a tree) for certain trees (Alkan-Akinci, 2006; Alkan-Akinci et al., 2014). A single *D. micans* female is known to attack spruce trees and establish a successful brood irrespective of tree mortality (King and Fielding, 1989; Storer et al., 1997). Hence future generations can still benefit from a successfully colonized tree, except during outbreaks (Grégoire, 1985; Voulant, 1991; Gilbert et al., 2001; Lieutier, 2007). Attacked trees are reported to suffer several years of frequent attack by beetles (Gilbert, 2001). Certain areas and trees are highly susceptible to attacks which can reach epidemic levels (Eroğlu, 1995).

44.82% of the trees under *D. micans* attacks in standing trees were found to have adults and 58.62% were found to have larvae. 68.52% of the adults were counted on 4 trees, 68.24% of the larvae on 2 trees and all of the eggs were counted on 2 trees. 80% of felled trees were found to have adults and larvae. 64.11% of the adults were detected on

2 trees, 58.67% of the larvae were detected on 3 trees and all of the eggs were detected on 3 trees. Clustering, to a certain extent, of attacks in these trees, is associated with a tendency of adult beetles to remain in the trees in which they complete their development. Gilbert et al. (2001) observed that young females create new egg galleries in the interior of the gallery system in which they have developed; mature beetles fly from the tree in which they have developed, and then return to the same tree.

In wood of trees attacked by *D. micans*, quality losses occur depending on the intensity of attacks that can reach economically important levels (Alkan-Akinci et al., 2009). Indeed, in some trees, the intensity of attacks in the initial few meters of the bole remain at a limited level of 1 to 5 attacks per tree, but it can also reach a very high level such as 40-160 per tree (Alkan-Akinci, 2006; Alkan-Akinci et al., 2014). Ultimately, attacks of this insect are concentrated on specific areas and certain trees (Eroğlu, 1995). Therefore, it is important to fell the least number of individuals "suitable for felling" among the attacked trees. In the case of stands under *D. micans* attack, in order to prevent aggravation of regeneration conditions, it is preferred that certain trees which have suffered attacks to a lesser extent and have a higher chance of living are allowed to stay for a longer period. In the case of oriental spruce stands, felling too many trees from an area earlier than their time of cutting would result in deterioration of closure and accordingly, the area going wild rapidly and aggravation of regeneration conditions. This gives rise to very significant challenges increasing the cost in regeneration works (Eroğlu et al., 2005). Therefore, determination of in the case of which attack the attacked trees should be cut without giving the opportunity to further deterioration of wood quality is an important issue.

Quality losses depending on attack density in wood of trees that have suffered *D. micans* attack can reach levels that are economically important (Alkan-Akinci et al., 2009). Presence of abundant resin exudation and resin tubes in attacked boles allows

determination of *D. micans* attacks externally (Fielding and Evans, 1997; Eroğlu et al., 2010). However, it is difficult to guess attack rates and success in upper sections of trees by direct observation. But the results of this study showed that the majority of EHs were up to 5-6 m on the felled trees. Massive attack of the beetle up to these heights on the boles can be observed by foresters in the attacked stands. Beetle's behaviour to attack lower parts of the trees ease to figure out heavily infested trees and biological and mechanical control applications.

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