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ORIGINAL ARTICLE

Variations in the attack pattern of *Dendroctonus micans* and the colonization rate of *Rhizophagus grandis* in *Picea orientalis* stands

Aysel Büyükterzi[1] · Gonca Ece Özcan[2] · Oytun Emre Sakici[2]

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Abstract

The great spruce bark beetle, *Dendroctonus micans*, is an invasive pest that has spread to almost all of the *Picea orientalis* forests in Turkey, affecting many trees and causing active damage. The species-specific predator *Rhizophagus grandis* plays an important role in suppressing populations of this pest because it is only found in *D. micans* galleries. In this study, the attack pattern of *D. micans* and the colonization rate of *R. grandis* were investigated according to some stand characteristics, such as aspect, developmental stage, crown closure, and stand type. It was determined that 20.5% of the 2025 sample trees evaluated in 83 sample plots were attacked by the beetle and that active damage from the beetle was currently continuing in 5.8% of the trees. There was no difference in the attack pattern of *D. micans* between shady and sunny aspects. However, trees showed significant differences in terms of susceptibility to beetle attacks based on developmental stage, crown closure, and stand type. The damage rates of the beetle were 19.8% and 29.6% for the mature and overmature stages, respectively; 28.5%, 18.8%, and 16.4% for low, medium, and full coverage stands, respectively; and 10.5–32.3% for different stand types. The colonization rate of *R. grandis* was 18.2%. This rate was not affected by the aspect, developmental stage, crown closure, or stand type. However, the rate was higher in the stands heavily infested by *D. micans*. In addition, there was a moderate correlation between the total number of *D. micans* individuals in active galleries and the total number of *R. grandis* individuals in these galleries.

Keywords Oriental spruce · Stand characteristics · Bark beetle · Predator

Introduction

Bark beetles (Coleoptera: Curculionidae, Scolytinae) are considered biotic factors (Grégoire et al. 2015) because of the negative effects they cause, such as unfavorable changes in forest ecosystem dynamics (Progar et al. 2009), epidemics resulting in tree deaths in large forested areas (Raffa et al., 2008), strong ecological impacts on ecosystem processes (Bentz et al. 2010), and failures to provide ecosystem services due to the deterioration of landscape aesthetics (Morris et al. 2018). Bark beetles are among the important pests, both ecologically and economically, in the forests of Turkey (Özcan et al. 2011; Sarıkaya and Avcı 2011) as well as in other forests of the World (Reeve 1997; Raffa et al. 2015; Borkowski 2016). They considerably affect the health and assets of conifer forests in the northern hemisphere (Wood 1982), and can lead to damage at an epidemic level (Schelhaas et al. 2003).

There are 20 identified species of the genus *Dendroctonus* (Armendáriz-Toledano et al. 2015) that have a significantly negative impact on conifer forests (Six and Bracewell 2015). The great spruce bark beetle, *Dendroctonus micans* (Kugelann, 1794) (Coleoptera: Curculionidae: Scolytinae), is one of the bark beetle species that has spread in Europe

✉ Gonca Ece Özcan
goncaece@kastamonu.edu.tr

Aysel Büyükterzi
ayselbuyukterzi@ogm.gov.tr

Oytun Emre Sakici
oesakici@kastamonu.edu.tr

[1] East Black Sea Forestry Research Institue, Trabzon Regional Directorate of Forestry Campus, Trabzon, Turkey

[2] Faculty of Forestry, Department of Forestry Engineering, Kastamonu University, 37150 Kastamonu, Turkey

and Asia and has caused economically significant damage (Fraser et al. 2014; Mayer et al. 2015). *Picea* forests are its main host, and it is also occasionally found in, and causes harm in *Abies*, *Pseudotsuga*, *Larix*, and *Pinus* forests (Grégoire 1988; Fielding 2012; EPPO 2021). *Dendroctonus micans* continues to spread in France, Turkey, and the United Kingdom via spruce forests (Meurisse et al. 2008; Lukášová and Holuša 2011).

Most bark beetle species such as *Dendroctonus* sp., which generally prefer to attack live trees and cause epidemics, are considered aggressive and can kill all or some of their hosts during colonization and gallery formation (Gilbert et al. 2001; Bentz et al. 2009; Reeve et al. 2012; Alkan Akıncı et al. 2018), resulting in widespread tree deaths when they reach high population levels (CABI 2015). The possibility of outbreaks especially increases when abiotic and biotic factors such as population biology, storm damage, drought, and extreme temperatures affect the populations of the species (Billings 2011; Hushaw 2015). Accordingly, the disadvantages caused by a fragmented forest structure (Özcan and Alkan Akıncı 2003), climate change (Gaylord 2014; Kulakowski 2016), water stress (Rouault et al. 2006), drought (Hushaw 2015), and other abiotic factors that occur in forests of a region increase the effects of bark beetle outbreaks in spruce forests.

The monotomid beetle *Rhizophagus grandis* (Gyllenhal, 1827) is one of the specific predators with strong predator–prey interactions (May 1973) that follows the active galleries of *D. micans* (Grégoire 1988). Due to their ability to detect prey from a long distance, their potential for spreading is high (Fielding et al. 1991; Grégoire et al. 1992). Under natural conditions, excessive numbers of the predator are highly effective for pest suppression (Evans and Fielding 1994). Before the beetle population reaches the numbers that could be considered an epidemic level, it is essential to control them via biological control practices (Özcan et al. 2021). Therefore, rearing *R. grandis* in laboratory conditions and releasing it in active galleries could prove to be beneficial (Grégoire et al. 1984; King and Evans 1984). It has been proven that the predator controls bark beetle populations, especially in endemic conditions (Grégoire et al. 1989).

Approximately 29% of the total area of Turkey is covered by forests; the productive forest area is nearly 13 million ha, and 6.8 million ha of forested areas are made up purely of conifers. Oriental spruce (*Picea orientalis* (L.) Link.) stands are present in 3.4% of the conifer forests (around 234 thousand hectares) (Forestry statistics 2018), and they have a natural regional spread on the northern side of the Eastern Black Sea Mountain. The oriental spruce is one of the valuable tree species of the Eastern Black Sea Region in Turkey in terms of its economic, ecological, and sociocultural functions. Action should be taken to ensure the species' sustainability, especially in terms of protecting it from pests. Since *D. micans* has an impact on the assets and productivity of these forests, monitoring its attack pattern and the colonization of its predators will help to determine forestry strategies. Pest control techniques such as natural enemies, pheromone activities, mechanical controls, and semiochemical controls have effective roles in the suppression of bark beetle outbreaks (Wermelinger 2004; Trigos-Peral et al. 2021). Therefore, the main hypothesis of this study is that biological and mechanical control activities applied in forests infested with *D. micans* can reduce the damage caused by this species. In this context, this study was conducted in forests where outbreaks have lasted for nearly 20 years and the attack pattern of *D. micans* and the colonization rate of its predator *R. grandis* have been evaluated according to some stand characteristics, such as aspect, developmental stage, crown closure, and stand type. In addition, the impact of the presence of wounds on trees on the attack rate and the interactions between prey and predators in active galleries were determined.

Materials and methods

Study area

This study was carried out in oriental spruce stands in the Maçka planning unit (Trabzon) in the Eastern Black Sea Region of Turkey (Fig. 1). The total forest area of the planning unit is 7361 ha. In forest management activities in Turkey, forests are defined as productive (crown closure more than 10%) or unproductive (crown closure less than 10%). The distribution of the forests in the study area is 81% (5956 ha) productive and 19% (1405 ha) unproductive forests. Nearly 35% (2061 ha) of productive forests and 18% (254 ha) of unproductive forests are made up of pure oriental spruce stands. Of the productive pure oriental spruce forests, 67.5% (1391 ha) are mature (M) or overmature (OM) stands. The elevation of the study area ranges between 996 and 1609 m above sea level, with an average of 1204 m, and the average slope is 58%. The average annual temperature is 14.7 °C, and the average annual precipitation is 830 mm.

Data collection

In this study, *D. micans* damage in oriental spruce stands was noted from June to September of 2018. In the stands that were determined to be damaged by *D. micans*, a total of 2025 trees in 83 sample plots were evaluated. Since the aim was to determine the impact of stand characteristics on attacks by *D. micans*, sample plots were selected to represent the available range of aspects, crown closures, and developmental stages. Care was taken to choose sample plots that

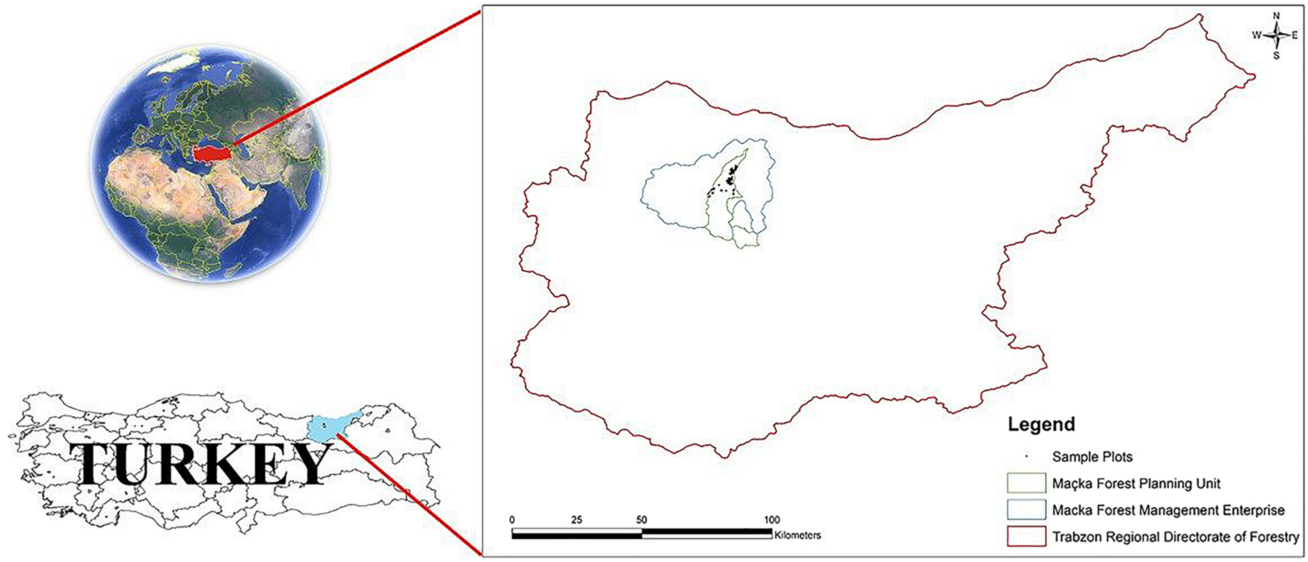

Fig. 1 Geographical location of study area in Trabzon, Turkey, and outline of sample plots

represented different aspect locations, crown closures, and developmental stages.

Crown closures were coded as 1 for low coverage (11–40%), 2 for medium coverage (41–70%), or 3 for full coverage (> 70%) during a field study of sample plots. The size of the circular sample plots was decided according to the crown closure of the stands to ensure they contained a certain number of trees; they were 800, 600, or 400 m^2, respectively, for low, middle, or full coverage stands. Then, the geographical coordinates and aspects of the sample plots were measured using the GPS and geological compass, respectively. Two aspect groups, sunny (112.5°-292.5°) and shady (292.5°-112.5°), were considered, and the aspects of the sample plots were grouped based on the degree of the aspect. All trees with a diameter at breast height (dbh) above 8 cm were numbered and measured, and the quadratic mean diameter of each sample plot was calculated. The developmental stages (mature: mean diameter of 20-35.9 cm; overmature: mean diameter of ≥ 36 cm) of sample plots were determined using the mean diameters. In addition, stand types were defined according to the crown closure and developmental stage jointly (Table 1).

All trees in the sample plots were examined. Trees with signs of *D. micans* attacks were defined as damaged trees, and others were described as healthy trees. Because it is known that wounded trees are likely to have increased damage from beetles, the trees in the sample plots were examined for wounding and signs of wounding (i.e. human-induced

Table 1 Criteria for the grouping of stand characteristics

Stand characteristics	Group	Criteria
Aspect	Sunny	South, Southwest, West, Southeast (112.5°-292.5°)
	Shady	North, Northeast, East, Northwest (292.5°-112.5°)
Development stage	M	Mature stands with a mean dbh of 20-35.9 cm
	OM	Overmature stands with a mean dbh of ≥ 36 cm
Crown closure	1	Low coverage (11–40%)
	2	Medium coverage (41–70%)
	3	Full coverage (> 70%)
Stand type	M-1	Mature stands with low coverage
	M-2	Mature stands with medium coverage
	M-3	Mature stands with full coverage
	OM-1	Overmature stands with low coverage
	OM-2	Overmature stands with medium coverage
	OM-3	Overmature stands with full coverage

dbh – diameter at breast height; M – mature; OM – overmature wounds occurred during harvesting, hollows created by birds such as woodpeckers, wounds by wildlife, and openings caused by natural branch pruning, broken branches and blows) were recorded. Active galleries located on attacked tree trunks up to 2 m above ground level were opened with an axe, and the number and biological stage of the beetles present were determined (Fig. 2). It was found that 117 of the sample trees had active *D. micans* galleries. The number of *D. micans* individuals in these active galleries was between 1 and 406. Some of the active galleries had not been colonized by *R. grandis*. *Rhizophagus grandis* numbers in active galleries under colonization ranged from 1 to 92. The *D. micans* damage rate was calculated as the ratio of damaged trees in the sample plots to the total number of trees. The *R. grandis* colonization rate was the ratio of how much of the active *D. micans* galleries was invaded by the predator.

Data analysis

The attack of *D. micans* was evaluated in the trees, and the relationships between the damage status and stand characteristics (aspect, crown closure, developmental sage, and stand type) were analyzed. The colonization rate of *R. grandis* was calculated per each sample plot as the ratio of the number of galleries colonized by the predator to the active galleries of *D. micans*. Thus, the relationships between predator colonization rates and stand characteristics were investigated through the sample plot data. Since the colonization rate of *R. grandis* could not be calculated in the sample plots without a *D. micans* active gallery, these rates were calculated for only 62 of the 83 sample plots (Table 2). When the distribution of sample plots by stand type was examined, it was found that the number of sample plots for OM stands was low. However, considering that 90% (1248 ha) of the stands in the study area were M stands, the distribution of the number of sample plots was acceptable.

The relationships between *D. micans* attack patterns and stand characteristics, *D. micans* attack patterns and the presence of tree wounding, and the presence of *D. micans* active galleries and the presence of tree wounding were analyzed using the Chi-square test. The control of the differences between the stand characteristics and the colonization rates of *R. grandis* was evaluated by the Kruskal–Wallis test, and the differences between the groups were checked with the Mann–Whitney *U* test. In addition, correlation analysis was used to determine the relationships between the number of active *D. micans* galleries and the number of galleries colonized by *R. grandis*, the number of trees with active *D. micans* galleries and the number of trees containing *R.*

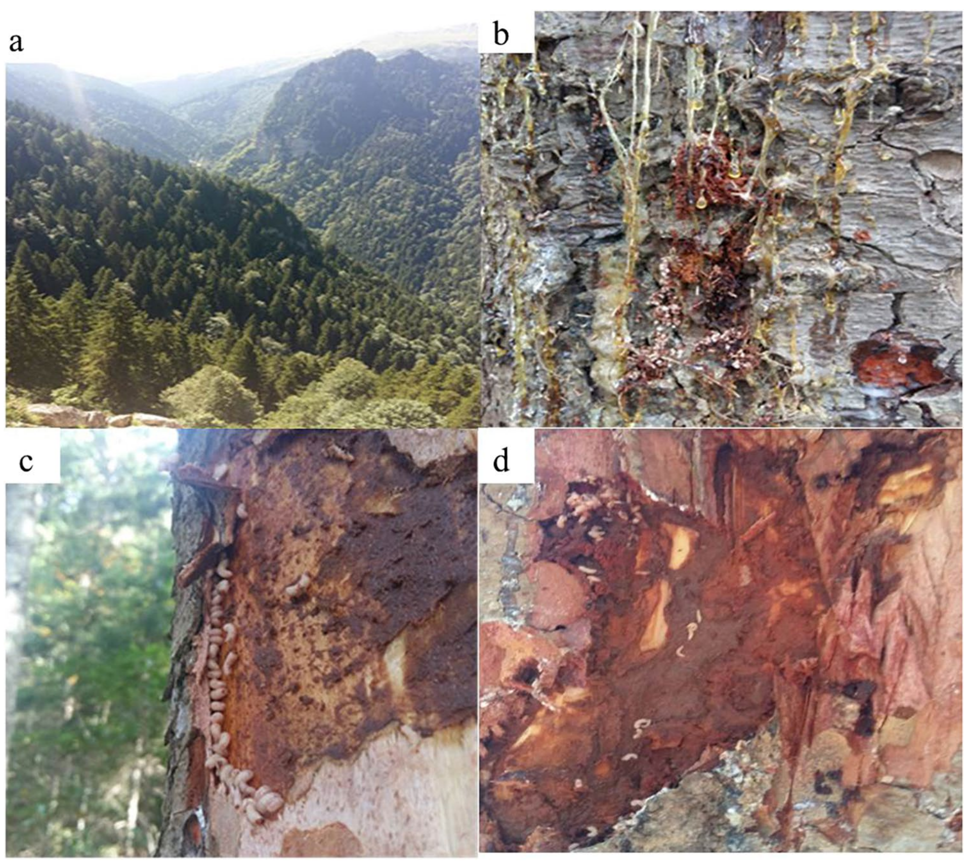

Fig. 2 A view of the study area forests (**a**), the trunk attacked by *Dendroctonus micans* (**b**), active gallery of *Dendroctonus micans* (**c**), and active gallery colonization by *Rhizophagus grandis* (**d**)

Table 2 Distribution of sample plots in terms of stand characteristics

Aspect	Development Stage	Crown closure	Stand type	Number of sample plots	
				Evaluation of *Dendroctonus micans* attack	Evaluation of *Rhizophagus grandis* colonization rates
Shady	M	1	M-1	9	4
		2	M-2	17	12
		3	M-3	11	9
	OM	1	OM-1	4	2
		2	OM-2	-	-
		3	OM-3	-	-
Sunny	M	1	M-1	10	10
		2	M-2	19	15
		3	M-3	11	8
	OM	1	OM-1	1	1
		2	OM-2	-	-
		3	OM-3	1	1
	Total			83	62

M – mature; OM – overmature; 1 – low coverage; 2 – medium coverage; 3 – full coverage

grandis, and the numbers of *D. micans* and *R. grandis* individuals present at different biological stages. All statistical analyses were performed using IBM SPSS Statistics 23 software.

Results

It was determined that 20.5% of the 2025 sample trees evaluated in the sample plots had been attacked by *D. micans*. Of these, 52.1% of the trees were in sunny stands and 47.9% were in shady stands. Among these, 20% and 21% of the trees located in sunny or shady stands, respectively, were attacked by the beetles. The percentage of trees attacked by *D. micans* in sunny and shady stands had no significant differences in aspect ($p > 0.05$). The evaluation of developmental stages revealed that 92.5% of the sample trees were mature (M) and 7.5% were overmature (OM). *Dendroctonus micans* attacked 19.8% and 29.6% of trees in the M and OM stages, respectively. There was a significant difference between the developmental stages in terms of beetle attacks ($p < 0.05$); the attacks to trees at the M stage were 9.8% greater than attacks to trees at the OM stage. For the sample trees, 24.6% were in low coverage stands, 46.5% in medium coverage stands, and 28.9% in full coverage stands, and 28.5%, 18.8%, and 16.4% of these trees, respectively, were attacked by D. micans. There was a significant difference between crown closure in terms of trees attacked by D. micans ($p > 0.05$). The evaluation of developmental stages revealed that 92.5% of the sample trees were mature (M) and 7.5% were overmature (OM). *Dendroctonus micans* attacked 19.8% and 29.6% of trees in the M and OM stages, respectively. There was a significant difference between the developmental stages in terms of beetle attacks ($p < 0.05$); the attacks to trees at the M stage were 9.8% greater than attacks to trees at the OM stage. For the sample trees, 24.6% were in low coverage stands, 46.5% in medium coverage stands, and 28.9% in full coverage stands, and 28.5%, 18.8%, and 16.4% of these trees, respectively, were attacked by *D. micans*. There was a significant difference between crown closure in terms of trees attacked by *D. micans* ($p < 0.05$). Low coverage stands were affected more by *D. micans* than medium stands or full coverage stands. *Dendroctonus micans* attacks were 9.7% greater in trees in low coverage stands compared with those in medium coverage stands and 12.1% greater compared with those in full coverage stands. Considering the stand types, 18.0% of the sample trees were located in M-1 stands, 46.5% in M-2 stands, 28% in M-3 stands, 6.6% in OM-1 stands, and 0.9% in OM-3 stands. There was a significant difference between trees in five different stand types in terms of *D. micans* attacks ($p < 0.05$); trees in OM-1 stands and M-1 stands were attacked by beetles at higher rates (27.1% and 32.3%, respectively). The lowest attack rate was observed in trees in OM-3 (10.5%) stands (Table 3).

Local wounds were identified in 11.7% (237 trees) of the sample trees included. A significant difference was observed between wounded and healthy trees in terms of *D. micans* attacks ($p < 0.05$); the beetles attacked 18.3% of the healthy trees and 37.1% of the wounded trees. Of the trees attacked by *D. micans*, 21.2% (415) were wounded trees. There were active *D. micans* galleries in 5.8% of the trees. The presence of *D. micans* active galleries caused a significant difference between healthy trees and wounded trees ($p < 0.05$).

Table 3 Chi-square test results for the effect of stand characteristics on *Dendroctonus micans* damage

Stand characteristic	Group	Undamaged ($n=1610$)		Damaged ($n=415$)		χ^2	p
		n	%	n	%		
Aspect	Sunny ($n=1055$)	844	80.0	211	20.0	0.330	0.566
	Shady ($n=970$)	766	79.0	204	21.0		
Development stage	M ($n=1873$)	1503	80.2	370	19.8	8.373	0.004
	OM ($n=152$)	107	70.4	45	29.6		
Crown closure	1 (%10–40) ($n=498$)	356	71.5	142	28.5	27.377	<0.001
	2 (%40–70) ($n=941$)	764	81.2	177	18.8		
	3 (>%70) ($n=586$)	490	83.6	96	16.4		
Stand type	M-1 ($n=365$)	266	72.9	99	27.1	29.413	<0.001
	M-2 ($n=941$)	764	81.2	177	18.8		
	M-3 ($n=567$)	473	83.4	94	16.6		
	OM-1 ($n=133$)	90	67.7	43	32.3		
	OM-3 ($n=19$)	17	89.5	2	10.5		

M – mature; OM – overmature; 1 – low coverage; 2 – medium coverage; 3 – full coverage

While 10.9% of wounded trees have active galleries, there were only 5.1% in healthy trees. Out of the total active galleries, 22.2% were in wounded trees and 78.8% in healthy trees indicating that the pest primarily prefers wounded trees (Table 4).

The highest colonization rate of *R. grandis* was 100% with the invasion of all active *D. micans* galleries, and the lowest colonization rate was 0% with no predators in the active galleries of the pest; the average rate was 18.2% (±35.6%). In the sunny sample plots, the colonization rate was 56.4% and in the shady plots, 43.6%. There was no significant difference in the colonization rates between sunny and shady aspects ($p>0.05$), the average rate was 20.1% in the sunny sample plots and 15.9% in the shady plots. Based on the developmental stages, 93.5% and 6.5% of the sample plots were in the M stage and OM stage, respectively. There was no significant difference between the sample plots in the M and OM developmental stages in terms of colonization rates ($p>0.05$). In the M stage sample plots, the average rate was 17.8%, and in the OM stage plots, it was 25%. The colonization rate did not change in either the M or OM stage sample plots, though it was 7.2% higher in the OM stage sample plots. Among the sample plots where the colonization rate was calculated, the rate was 27.4% in low coverage stands, 43.6% in middle coverage stands, and 29% in full coverage stands. The average rates of the sample plots in the low, middle, and full coverage stands were 12.3%, 19.6%, and 21.8%, respectively. There was no significant difference between stand crown closure levels in terms of colonization rate ($p>0.05$). The colonization rates were similar in the middle and full coverage stands, but the rate was lower in low coverage stands compared with the other crown closure groups. When evaluated according to stand types, 22.6% of the sample plots were at the M-1 stage, 43.6% at the M-2 stage, 29% at the M-3 and OM-3 stages (since there was only one sample plot in OM-3 type, they were combined), and 4.8% at the OM-1 stage. The colonization rate was 7.8% in M-1 stands, 19.6% in M-2 stands, 21.8% in M-3 and OM-3 stands, and 33.3% in OM-1 stands. The colonization rate was not significantly different between the stand types ($p>0.05$). However, the colonization rate was higher (33.3%) in OM-1 stands than other stand types (Table 5).

When the active attack rate of *D. micans* exceeds 20 trees per hectare, the invasion is considered heavy (Grégoire 1984; Grégoire et al. 1989). Accordingly, 60% of the sample plots were under heavy invasion and the colonization rate of *R. grandis* in these plots was 20%; the rate was 14% in other sample plots. There was a high correlation

Table 4 Chi-square test results for the effect of wound situation on *Dendroctonus micans* damage and active gallery

	Group	Healthy trees ($n=1788$)		Wounded trees ($n=237$)		χ^2	p
		n	%	n	%		
D. micans attack	Undamaged ($n=1610$)	1461	81.7	149	64.9	45.596	<0.001
	Damaged ($n=415$)	327	18.3	88	37.1		
Active gallery	Undamaged ($n=1908$)	1697	94.9	211	89.1	13.295	<0.001
	Damaged ($n=117$)	91	5.1	26	10.9		

Table 5 Comparison of stand characteristics in terms of *Dendroctonus micans* gallery colonization by *Rhizophagus grandis*

Stand characteristics	Group	*n*	Average	Standard deviation	*p*
Aspect	Sunny	35	20.1%	38.6%	0.868
	Shady	27	15.9%	32.0%	
Development stage	M	58	17.8%	35.0%	0.911
	OM	4	25.0%	50.0%	
Crown closure	1	17	12.3%	33.1%	0.620
	2	27	19.6%	37.6%	
	3	18	21.8%	36.4%	
Stand type	M-1	14	7.8%	26.7%	0.642
	M-2	27	19.6%	37.6%	
	M-3&OM-3	18	21.8%	36.4%	
	OM-1	3	33.3%	57.7%	

M – mature; OM – overmature; 1 – low coverage; 2 – medium coverage; 3 – full coverage

between the number of active galleries of *D. micans* per tree and the number of trees colonized by *R. grandis* ($r=0.720$; $p<0.001$), and there was a moderate correlation between the number of trees with an active gallery of *D. micans* per tree and the number of trees colonized by *R. grandis* ($r=0.556$; $p<0.001$). There was a moderate correlation between the total number of *D. micans* individuals in active galleries and the total number of *R. grandis* individuals in these galleries ($r=0.489$; $p<0.001$). In addition, there was a moderate correlation ($r=0.516$; $p<0.001$) between the total number of *D. micans* larvae and the total number of *R. grandis* larvae, whereas a weak linear correlation ($r=0.045$; $p<0.001$) was found between the number of *D. micans* and *R. grandis* adults.

Discussion and conclusion

The economic and ecological impacts of bark beetle outbreaks in forests that provide products of ecological, economic, and social value and on local people related to forests are considerable (Turchin et al. 1991; Reeve 1997; Flint et al. 2009; Rosenberger et al. 2012). *Dendroctonus micans*, considered the most dangerous of pests in these forests (Furniss and Carolin 1977), causes serious loses of trees in oriental spruce forests in Turkey. Since it was first detected, *D, micans* has continued to cause damage despite the fact that large-scale and high-cost prevention activities have been carried out (Alver and Ertürk 2018). It is very difficult to fully assess the development and structure of the infestations because the bark beetle infests large forest areas (Samalens et al. 2007). In this study, *D. micans* outbreaks in oriental spruce forests of the Maçka region, which have been damaged for about 20 years, were evaluated.

Table 6 Attack rates of *Dendroctonus micans*

Dendroctonus micans attack rates	Active attack rates	References
36%	-	Eroğlu (1995)
24.6%	12%	Özcan et al. (2006)
26.5%	10.5%	Alkan Akıncı et al. (2009)
27.5%	4.7%	Özcan (2009)
-	3%	Alkan Akıncı (2017)
20.5%	5.8%	The present study

Accordingly, 20.5% of the trees were found to be attacked by the beetle and the active damage rate was 5.8%. In former studies conducted in the oriental spruce forests of Turkey, the attack rate of *D. micans* ranged from 24.6 to 36% (Table 6). In the Maçka region where this study was carried out, this rate was reported as 27.5% by Özcan (2009). Therefore, it was found that the attack rate in the oriental spruce stands in the region of the study had decreased by 7% in the decade of the 2010s. Therefore, it is understood that the attack rate in the oriental spruce stands in the region of the study has decreased by 7% in the last decade. Also, the active attack rates varied between 3% and 12% in previous studies (Table 6). Based on the study by Özcan (2009) and the present study, which was conducted at the same seasonal period as the Özcan´s study, there was an increase of more than 1% in the active damage rate by the beetle in the same decade. In addition, 60% of the sample plots with active damage were also heavily infested. Based on the current situation, the attack rates have decreased owing to the biological and mechanical controls that have been put into place (Forestry statistics 2019) since the detection of the beetle but the active attack rate has remained approximately the same. Intensive control efforts implemented during periods of large epidemics have been reduced considerably in recent years, and this has been reflected in the active attack rates. These results show that although the control efforts against the beetle in previous years were successful, the pest could not be fully suppressed, and its attacks are prevalent again.

Although it has been stated that the aspect of a location affects the flight activities and intensity of bark beetle species (Akkuzu et al. 2009; Brockerhoff et al. 2017), our study determined that *D. micans* attacks were found at almost the same rates in sunny and shady aspects. It has been emphasized that this beetle prefers hosts in stands with low coverage on a sunny aspect or in stands where the earth cover on rocky ground is thin (Benz 1984). However, higher temperatures are more influential in the development and spread of the pest (Vouland et al. 1984), and local climatic changes are also very influential. Therefore, when temperatures are suitable and host trees are present, *D. micans* attacks can still occur regardless of the aspect. In terms of crown closure, *D.*

micans attacks were 9.7% and 12.1% higher in medium and full coverage stands, respectively, compared with low coverage stands. Stands with low coverage were more suitable for settlements of the beetle, and the damage rate increased with a decrease in stand coverage (Benz 1984). More open forests showed greater susceptibility to beetle attacks because sunlight and wind, and the spread of pheromones, facilitate attacks (Bentz et al. 2009). Alkan Akıncı (2017) stated that these areas had an increased impact on the development of the beetle because the edge trees received more sunlight than those inside the stand and the damage was higher in zones that had access to more light.

The results of the present study support the above observations. The *D. micans* attack pattern varied according to the stand types in this study: attacks were higher in M-1 and OM-1 stand types and lowest in the OM-3 stand type. Older trees were more suitable for pest development due to their larger bark surfaces (Gilbert et al. 2003); therefore, older stands were more susceptible to bark beetle outbreaks (Bentz et al. 2009). The results of this study showed that both the crown closure and developmental stage influenced the damage rate of *D. micans*, so stands with low coverage and a higher developmental stage could be the stands with the highest risk.

Dendroctonus micans attacked 37.1% of wounded trees, and the actual rate of active galleries on wounded trees was approximately two times higher than that of healthy trees. In previous studies, this ratio was much lower in comparison with the corresponding ones in different locations; it was higher than 70% in the Eastern Black Sea Region in Turkey (Eroğlu 1995; Alkan Akıncı 2006; Özcan et al. 2006, 2011; Alkan Akıncı et al. 2009). This rate was found to be lower in the present study. However, the rate of 37.1% was still crucial. Active beetle damage had been continuing in the forest. For this reason, it is possible that other wounded trees would also be attacked over time. The number of host trees would be likely to increase because wounded trees would be favored primarily by the beetle. Wounds that cause stress for trees increase such beetle infestations (Lempériè 1994; Gilbert et al. 2001; DeGomez and Celaya 2013), and facilitate the entry of wood-damaging organisms into the tree (Neely 1988; Hartman 2007). Removing wounded trees from stands will prevent beetles from becoming attracted to the stands. Moreover, in regions where there is a high risk of bark beetle infestation, taking precautions to prevent damage is essential. The average colonization rate of *R. grandis* in the study area was 18.2%. The rate of colonization ranged from 5 to 30% in studies of other locations (Eroğlu 1995; Alkan Akıncı 2006, 2017; Özcan et al. 2006, 2009) where *R. grandis* had been released. The actual colonization rate of the predator was found to be lower than the rate in the same region approximately 10 years ago (Özcan 2009), but it was higher than that in other studies.

Active damage by the pest indicates that the predator continues to exist in the area. Controlling the bark beetles is a long-term practice (Moeck and Safranyik 1984). The natural resistance of host trees, which can be affected by the climate, also affects the ability of bark beetles to establish settlements (Bentz et al. 2010). Therefore, the active situation of the pest must be controlled and necessary precautions should be taken in case the development of biotic and abiotic risk factors causes the population of beetles to increase.

The number of active galleries of *D. micans* per tree and the number of trees colonized by *R. grandis* had a high correlation, whereas the number of trees with an active gallery of *D. micans* and the number of trees colonized by *R. grandis* had a moderate correlation. It could be concluded that the colonization rate increased linearly with the number of galleries of its prey, independent of the attacked trees. It is a known fact that natural enemies negatively affect the population dynamics of the prey (Polis and Strong 1996; Aukema and Raffa 2004). In this study, moderate correlations were found between the total number of *D. micans* individuals in active galleries and the total number of *R. grandis* individuals and between the total number of *D. micans* larvae and the total number of *R. grandis* larvae. Predators lay their eggs in proportion to the number of prey found in the gallery, and the interaction between prey and predators occurs as a quantitative response (Fielding and Evans 1997).

Consequently, applying pest control measures against *D. micans* at intervals in oriental spruce stands and taking precautions to prevent populations from increasing and, thus, damage levels from increasing is crucial. It was observed that the intensity of the predator in the distribution areas of the pest was not sufficient to maintain a biological balance. For this reason, continuing to release the predator in order to ensure the continuity of the suppression will increase the success rate. Also, regular observations should be made in oriental spruce forests of the region to determine both the active situation of the pest in the stands preferred and the supplementary release requirement for the predator.

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