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Full Length Research Paper

Impacts of site effects on losses of oriental spruce during *Dendroctonus micans* (Kug.) outbreaks in Turkey

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The study showed some site and stand factors affecting host colonization, quantitative and qualitative losses in wood of oriental spruce as a source of raw material during the outbreak of *Dendroctonus micans* (Kug.). A total of 22.8 million m^3 standing trees were damaged. In 11.43 million m^3 standing trees infestations were observed and 6.96 million m^3 of trees were cut which occupied 120,000 ha of *D. micans* infestation areas. In pure spruce stands, 26.5% of the trees were infested. There was no statistically significant difference among the volume of crowns, crown base height and ages in infested and healthy trees. There was a positive correlation between stand density and number of *D. micans*, and number of attacks inversely correlated with altitude.

Key words: Insect epidemic, site and stand factors, bark beetles, volume of infested trees.

INTRODUCTION

Most bark beetle species infest recently dead trees (Wood, 1982), but some species are known to attack and kill living trees and which cause large economic losses (Berryman and Ferrell, 1988; Reeve, 1997; Turchin et al., 1991). In this way they offset the ecosystem balance by affecting stand dynamics, forest structure and wildlife population (Byers et al., 1998; Christiansen and Bakke, 1988; Schroeder, 1999).

The great European spruce bark beetle, *Dendroctonus micans* (Kugelann) (Coleoptera, Scolytidae), is a pest to natural and planted spruce forests in Eurasia (Fielding and Evans, 1997; Fielding et al., 1991; Grégoire, 1988). It has gradually spread westwards from its original location in Sackhalin Peninsula and north Japan during twentieth century (Fielding et al., 1991; Grégoire, 1983) and has established in Georgian (Kobakhidze, 1967), Turkish (Acatay, 1968; Benz, 1984), French (Carle et al., 1979) and British (Fielding et al., 1991) spruce forests.

Oriental spruce, *Picea orientalis* (L.) Link. distributes throughout eastern blacksea mountains in Turkey and Caucasus mountains in Georgia. Oriental spruce is the native species of forests in this distribution. *D. micans* was first discovered in oriental spruce forests in the republic of Georgia in 1957 and infested over 100,000 ha of oriental spruce stands in 1963 (Benz, 1984; Fielding et al., 1991; Kobakhidze, 1967). The beetle was first discovered in Turkey in 1966 (Acatay, 1968) and infested 36% of the spruce trees in the native distribution range of the spruce in the eastern blacksea region (Eroglu, 1995). Millions of trees are dead as a consequence of infestations in the oriental spruce forests (Keskinalemdar and Ozder, 1995).

Spruce forests have an uppermost function expected from forests in water supplying, soil protection and preventing natural destructions in the region (Eroglu et al., 2005). The effects of insect pests, which are in strong relation with these fragmented forests, have great importance (Alkan Akinci et al., 2005). Some site, stand and utilization impacts involved in the process of orientation to the spruce trees, beetle damage and consequently quantitative and qualitative losses in wood of oriental spruce in eastern blacksea region of Turkey have been evaluated in this study. As a result, some answers to orientation to certain trees or stands and the affects of pests on a tree species, on sustainability of the benefits from forests as

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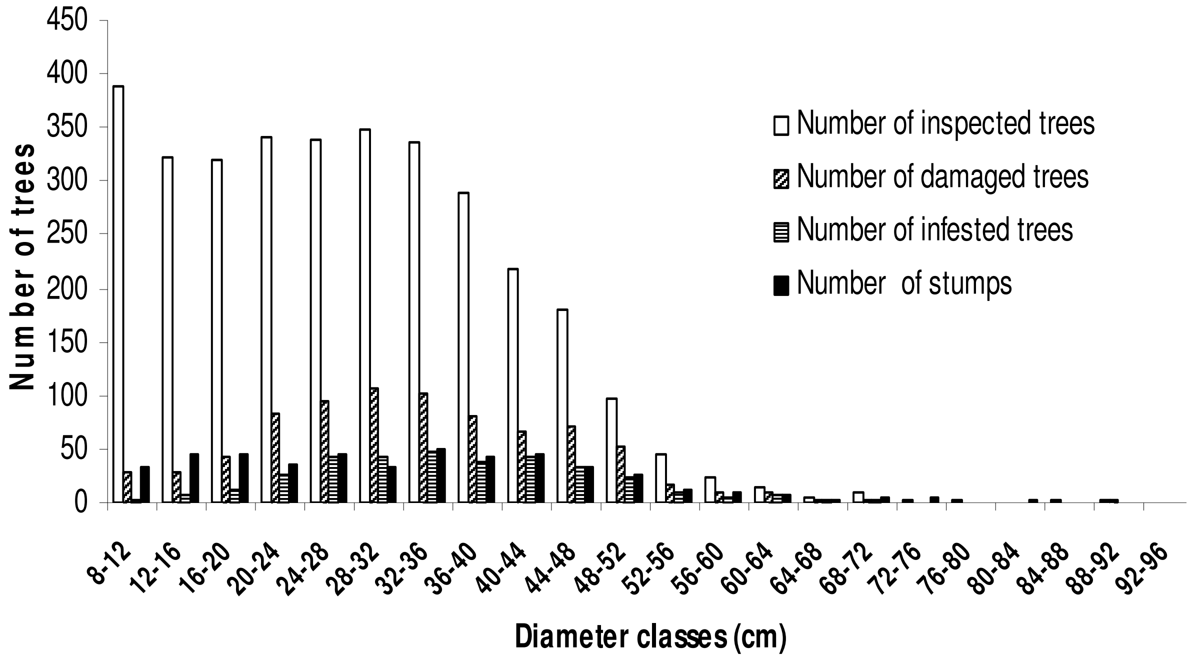

Figure 1. Number of inspected, damaged and infested trees and stumps in the experimental plots by diameter classes.

well as impacts on production of quality wood were determined. In this way we wanted to emphasize the importance of sustainable forestry in meeting society's needs to forest products.

MATERIALS AND METHODS

Experimental plots and data collection

This study was conducted in the areas that were damaged dominantly by *D. micans* in native distribution of oriental spruce forests in north eastern of Turkey in the years 2001-2007. Field measurements and evaluations were made in 30 × 10 m experimental plots. Caliper, altimeter, scale, increment borer were used in field measurements and hatchet was used to debark trees. Plastic boxes, forceps and little brushes were used in taking the beetles out of their gallery systems and counting. Stumps that were cut in the last 20 years, determined by the decomposing of wood, were evaluated in experimental plots. Diameter of breast height, crown base height and diameter of crown base was measured in all trees in plots and ages were determined in 3 trees that can represent the stand. An Olympus 245500 binocular microscope was used to count individuals of some species in bark samples that were in different developing stages.

In the plots average altitude was 1670 m (900 m-2075 m), average slope was 40% (5 - 90%). Of the plots 30.8% was in north, 19.2% was in south, 9.2% was in the east and 40.8% was in the west aspect. A total of 3285 trees were evaluated and 475 stumps were counted in 158 experimental plots in 4.74 ha area in spruce forests in *D. micans* distribution area. Of the trees 88.7% were spruce, 6.4% were fir, 1.8% were Scotch pine, 2.8% were beech, 1.3% were chestnut, aspen, hornbeam, alder, oak and maple. Distribution of the inspected, damaged and infested trees and stumps to the diameter classes is shown in Figure 1.

Determination of tree crown and height

Heights of 3 trees that can represent the stand in every plot were measured during the field studies. So the volumes of the crown of trees were calculated after the estimation of the heights of all trees in plots by a regression equation.

Regression analysis was performed between diameter and measured height values. The best fitting model was chosen and heights of all trees were calculated with the equation:

$$\text{Tree height} = e^{(b0+(b1/d1{,}30))}$$

where *e* represents Euler constant, b0 and b1 are coefficients and $d_{1,30}$ represents diameter of breast height. Crown base height was measured in every tree in the plots. After the estimation of tree heights, height of crown was calculated by subtracting crown base height from the tree height. Then volume of crown was calculated by the formula of cone volume.

Crown closure and stand density

Crown closure was calculated by dividing the total surface area of the base of the crowns in a plot to the horizontal surface area of the plot.

Stand density of every stand that the experimental plots were located in were calculated according to Akalp (1978) that was developed for oriental spruce and depends on the relation of stand mean diameter and number of trees in a hectare.

Wood loss determination

The volume of the damaged, infested and cut trees because of the beetle damage was calculated in 158 experimental plots in 4.74 ha area in spruce forests. Double-entry volume table that was developed for oriental spruce by Akalp (1978) was used in this calculation. Then these values were calculated for the 120,000 ha whole damaged area according to the diameter classes of damaged, infested and cut trees. To use in calculating the quality loss in logs and embracing to bole of infested trees, consumed areas that were below 2 m were measured in infested trees and surface areas were calculated.

Evaluations about the wood losses in logs that were cut from the dead trees were made in sawmills and by interviews were conducted in construction areas where cut planks were used. Besides the damage of *D. micans* in standing spruce trees and quality loss in logs, quantitative and qualitative losses caused by other wood pests and fungi in timbers produced from infested trees were also evaluated.

Statistical analysis

Crown volume, crown base height and tree age were compared in healthy and infested trees, average volume of crown, crown base height and tree age was calculated for every diameter class and paired samples T test carried out.

Logarithmic transformation was performed for the altitude, aspect, slope, number of attacks and number of *D. micans* that did not show normal distribution. Then correlation analysis was carried out to understand the relation between number of *D. micans* and number of attacks per plot and altitude, aspect, slope, crown closure, stand density.

RESULTS AND DISCUSSION

The results revealed that spruce accounted for 100-90, 89-70, 69-50 and 49-25%. The percentages of damaged trees in the plots were 21, 21, 8 and 7%, respectively, were predominant in pure spruce stands. It is reported that spruce is less susceptible in mixed stands where spruce is 30% or less in stands with beech, fir and pine in Georgia (Grégoire, 1988). The results also showed that there were only 2 sites that spruce accounted for 30% of the trees in the stand. In the rest of the sites spruce trees accounted for 43% or more of the stands.

There were old and deep artificial wounds on 8.2% of the trees and 1% of the trees were forked in plots. *D. micans* damaged 84.4% of wounded spruce trees and 81% of forked trees. Storer and Speight (1996) report changes in larval survival, larval dry weight and oviposition in *D. micans* around and under artificial wounds. All these characteristics are higher around and under wounds. Nutrition elements found more abundant after bark wounding (Wainhouse et al., 1998).

The number of attacks in north aspect was 49%, while ones in south and east aspects accounted 25 and 36% respectively. Benz (1984) expresses that the choice of the side may have nothing to do with compass orientation but beetle may prefer the side towards the mountain slope.

Average numbers of attacks per plot were 72, 40 and 32 between the altitudes 900-1300, 1300-1700 and 1700-2100 m, respectively. These values per plot decreased with the increasing altitude. The results of correlation analysis showed that number of attacks inversely correlated with altitude ($r = 0.24$, $n = 120$, $P < 0.05$). The findings corroborate with the works of Safranyik (1985) and Gilbert et al. (2003). In fact tree expresses more vitality at lower temperatures at higher altitudes. Stands in lower altitudes will be warmer, support more generations over the same time period and facilitate the dispersal of the beetle that are capable of flying in high temperatures (Gilbert et al., 2003).

Average numbers of attacks per plot were 42, 30, 30 and 67 between the slopes 3-17, 17-36, 36-58 and 58-100%, respectively. This may be the effect of steep slope causing water stress in trees in summer like expressed in Gilbert (2001). In general droughts tend to facilitate outbreaks of many bark beetles. Factors that are adverse to host like water stress are known to increase beetle's success (Grégoire, 1988). Many outbreaks in Eurasia have been documented to correlate with periods of drought (Carle, 1975; Fielding et al., 1991).

There was no difference in the volume of crown, crown base height and tree age between healthy and infested trees. Gilbert et al. (2003) report positive correlation between attack density and plantation age and explain this relation with beetle's relationship with its host. *D. micans* needs a minimal bark thickness for development. The average age of the stands was 26 and ranged up to 80 in the studied area. It was observed that young trees may have local zones of high bark thickness at particular sites while older trees have a much larger bark area with suitable thickness for development of the larvae. Thus, stands with older trees may host larger populations and favor faster population growth (Gilbert et al., 2003). The trees in study sites were older than the trees in the former study. So results fit with the oldest stands in Gilbert et al. (2003). There was a positive correlation between stand density and number of *D. micans* ($r = 0.25$, $n = 120$, $P < 0.05$). In France, a relation between attacked trees and tree density was determined in a stepwise multiple regression ($r^2 = 0.17$, $n = 54$) (Gilbert and Grégoire, 2003).

The volumes of the trees that were damaged by *D. micans* and trees in which the infestation was continuing and cut trees in the experimental plots in the epidemic area is shown in Table 1. *D. micans* damaged 26.5% of the live spruce trees including dead standing trees. There were active beetle galleries in 10.5% of the trees. Of the wounded trees 84.4% was damaged. In the last 2 decades 12.6% of the spruce trees were cut. Volumes of damaged trees were 34% of the volumes of total standing spruce trees. This % increased to 37% when the volumes of cut trees were included. The volume of standing trees that *D. micans* damaged was 900.7 m^3 in the area reflecting 190.02 m^3/ha. The volume of trees that the damage was 451.4 m^3 and trees that were cut had a volume of 274.9 m^3. The results showed that 120,000 ha accounting for 22.8 million m^3 standing trees were damaged by the beetle and a total of 6.96 million m^3 trees were cut over the last 2 decades.

The volume difference of the trees that were cut under the 28-32 cm diameter was 81.2 m^3 accounted for 56%

Table 1. Numbers and volumes of trees infested or killed by *Dendroctonus* micans (Kug.) in experimental plots.

Diameter Class (cm)	Inspected trees	Damaged trees	Infested trees	Stumps	Damaged trees (m^3)	Infested trees (m^3)	Cut trees (m^3)	Consumed surface area on the bole (m^2)
8 - 12	389	29	2	32	1.5	0.1	3.8	1.6
12 - 16	322	29	7	44	3.3	0.8	5.1	1.6
16 - 20	319	43	11	45	9.0	2.3	16.9	2.4
20 - 24	342	82	26	36	27.8	8.8	11.5	4.5
24 - 28	339	95	43	45	48.1	21.8	24.8	5.3
28 - 32	348	106	43	34	75.3	30.5	63.2	5.9
32 - 36	336	103	47	49	96.7	44.1	31.9	5.7
36 - 40	288	81	39	43	100.5	48.4	32.3	4.5
40 - 44	218	66	43	46	102.0	66.5	30.9	3.6
44 - 48	180	72	34	34	138.7	65.5	13.5	4.0
48 - 52	96	51	23	26	119.3	53.8	4.7	2.8
52 - 56	44	17	10	11	47.6	28.0	25.2	0.9
56 - 60	24	10	4	9	33.0	13.2	3.3	0.6
60 - 64	15	9	7	7	34.7	27.0	7.7	0.5
64 - 68	5	2	2	2	8.9	8.9		0.1
68 - 72	9	3	2	5	15.3	10.2		0.2
72 - 76	2	1	1	4	5.8	5.8		0.1
76 - 80	2	1	1	1	6.5	6.5		0.1
80 - 84	1			2				
84 - 88	2	1			8.3			0.1
88 - 92	3	2	1		18.3	9.1		0.1
92 - 96	1							
Total	3285	803	346	475	900.7	451.4	274.9	44.4

loss of trees. Volume loss in the projected area was 2 million m^3 where the older trees that have the greater share in increment of forests and wood production reduce speedily, that is, the percentage of the trees that had the diameter bigger than 48 cm was decreased from 9% (Eroglu, 1995).

Oriental spruce forests that were infested by *D. micans* and other bark beetles such as *Ips typographus* (L.), *I. sexdentatus* (Boerner), *Cryphalus abietis* (Ratzeburg), *Cryphalus piceae* (Ratzeburg), *Pityokteines spinidens* (Reitter), *Hylurgops palliatus* (Gyllenhal), *Trypodendron lineatum* (Olivier) (Coleoptera, Scolytidae) constitute 150,000 ha of 2 million ha (Anonymous, 2004) pest damaged forests in Turkey. In the last decade, dead trees or trees that were infested by these beetles and would die in a short time were nearly the main allowable annual cuts from spruce forests. The oriental spruce forest is 1.4% of Turkish forests, it constitutes 2.5% of wood production in Turkey. The share of spruce forests in coniferous forests is 2.34% with 4.38% of annual softwood production.

About 44.4m^2 surface area of the bark was consumed in the first 2 m on the bole of the infested trees. Bark, phloem and cambium were damaged in 2% of the surface area of the logs that were produced from the infested trees in the first 2 m on the bole and which susceptible to the damages of other wood pests and blue stain fungi. The consumed surface area at the whole-bole level was more than 10 times of the first 2 m. 20% of the cambium and phloem layers of the logs that were cut from these trees were damaged while standing in forest. Wood decay starts with the tunneling activity of buprestid and cerambycid beetles and activity of fungi in the damaged part of these logs.

Reducing grade of timber because of pests and diseases causes 10-20% loss in price. These pests and diseases cause 15% loss in log price in average, that is, logs cut from damaged trees were evaluated as third grade in spite of second grade and this means 30 Turkish Lira (TL) low prices in each m^3. At least 10 TL price loss in each m^3 of 6.96 million m^3 trees that harvested over the last 2 decades which accounted for 69.6 million TL. This means 228 million TL (approximately 140 million dollars) price loss for 22.8 million m^3 standing damaged trees. Some other characteristics such as changes in moisture content, specific gravity, blue stain and sap rot penetration depths, number and depth of checking and depth of woodborer damage were reported to occur in the first 1-2 post mortality years (Lewis, 2007). In another research project on mountain pine beetle attacked logs, it has been found that, 5 years after attack by mountain pine beetle, sampled logs yielded 12.5% less lumber and 17.5% less value compared to normal green logs (Barrett and Lam, 2007).

Volume and consequently economic losses caused by the death of vulnerable trees are higher in the first years of outbreaks. Economic losses are starting due to the outbreaks of *D. micans*, *I. typographus*, *I. sexdentetus* and other bark beetles. Most bark beetles are known to vector staining fungi and the sapwood of bark beetle killed trees is stained (Paine et al., 1997). A total of 658.483 m^3 spruce trees that were infested during the severe outbreak of *I. typographus* in 30,350 ha were cut in 7 years 2000 - 2007 in the province of Artvin (Alkan Akinci et al., 2005; Anonymous, 2007). Before the infestations of *D. micans* and *I. typographus*, *I. sexdentatus* has been the most damaging pest until the last tree decades. There is documented evidence of outbreaks dating back to 1920s. The volume of infested and cut trees rose from 250 000 m^3 in 1928 (Bernhard, 1935) to over one million in 1930s (Schimitschek, 1953) in the spruce forests of Santa and Meryemana in the province of Trabzon. Total volume of damaged trees was recorded as 1,500,000 m^3 in 1938- 1994 (Keskinalemdar and Ozder, 1995).

Longhorn beetles (Coleoptera, Cerambycidae) are economically important pests. It has reported that about 20% of longhorn beetles are of great importance for the timber industry and alien species (Bense, 1995; Hellrigl, 1974). In the region, 16 cerambycid species were recorded on the oriental spruce wood (Alkan and Eroglu, 2001). Among these species, house longhorn beetle, *Hylotrupes bajulus* (L.) is known to be one of the most important destroyers of structural woods (Fettköther et al., 2000; Höll et al., 2002). It can be seen in different altitudes from sea level to alpine zone (Alkan and Eroglu, 2001). *H. bajulus* larvae damage the structure of timbers by tunneling activity besides the economic loss in the value of timber (Fettköther et al., 2000). The life cycle of the beetle usually lasts 3 to 6 years but may be as short as 2 years or as long as 10 years, depending on food, temperature and wood moisture content (Höll et al., 2002).

Striped ambrosia beetle, *Trypodendron lineatum* (Olivier) (Coleoptera, Scolytidae) is very common in oriental spruce forests and has an economic importance from the forest industry point of view. It develops in dead and dying wood of *Picea*, *Pinus* and *Abies*. Stored woods in mill yards constitute a potential habitat for the beetle (Park and Reid, 2007).

The long-term health of oriental spruce forests will be maintained and enhanced, for the benefit as well as social, cultural, environmental and economic well-being of public. For the last 20 years in attacked area by *D. micans*, intensive biological control attempts have been conducted against this species by using its specific predator *Rhizophagus grandis* Gyll. (Coleoptera, Rhizophagidae). The effectiveness of predator was up to 78% in *D. micans* galleries and 12% in average in the whole sampled area (Ozcan et al., 2006).

The attack density of *D. micans* was higher in lower altitudes and especially in wounded and also forked spruce trees. The percentage of damaged trees was higher in pure spruce stands and there was no difference in some other site and stand factors such as the volume of crown, crown base height and tree age between healthy and infested trees. Depending on long-term environmental developments such as global warming and climate change, bark beetle damages may increase to more serious levels in forest ecosystems and cause larger losses than today. In British Columbia, infestation of mountain pine beetle has been reported to increase dramatically in recent years. It has been expressed that from 2005 to 2006, the volume of infested trees increased from 411 million cubic meters to 582 million cubic meters (Anonymous, 2007). The dynamics of recent outbreaks of the spruce bark beetles depending on the increasing damages should be integrated in forestry management plans for their function in estimating the possible losses in the future. An integrated ecosystem restoration will be provided by the reforestation of the gaps, formed by cuts due to the bark beetle damages or cuts in accordance with the control strategies, before degradation with the oriental spruce and oriental beech, *Fagus orientalis* Lipsky.

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