Spruce Radial Increment and Risk to *Ips typographus* L. Attacks

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Abstract

Tree vigour indicated by tree ring increment could be one of the most important factors predisposing spruce trees to bark beetles attacks. Tree ring analysis shows that spruce trees attacked by *Ips typographus* were growing faster most of their studied life-time in comparison with un-attacked ones nearby, except the last five-year period before attack. Attacked and unattacked spruce trees with codominant crown (Kraft class 2) show the biggest differences in the annual radial increment. Spruce, killed by *Ips typographus*, suffered more severe drought stress a few years prior to attack and recovered growth slower and weaker than survived trees.

Key words: Norway spruce, *Picea abies*, spruce bark beetle, *Ips typographus*, radial increment, cumulative growth, attack risk

Introduction

Spruce bark beetle *Ips typographus* (L.) is the most important pest in premature and mature stands of Norway spruce (*Picea abies* Karst.) in Lithuania and in the most of Europe. Damage of spruce bark beetle on average is being recorded on a few thousand hectares of spruce stands in Lithuania every year. Heavy outbreaks repeat every 8-10 years. Recent significant outbreaks were recorded in 1970-1973 (with 6,000-6,500 ha of damaged forests every year) and in 1984-1985 (5,000-5,300 ha/year). Heavy windthrows in 1993 and climate anomalies in 1992 and 1994 (drought, high temperatures) caused the heaviest known outbreak of spruce bark beetle in Lithuania, when 450,000 ha of forests were damaged and 8 million m^3 of wood were harvested in 1994-1997 (Grodzki *et al*. 1998). Most of bark beetle species are able to breed only in dead or dying trees, but *Ips typographus* can successfully colonize living trees, when population increase to epidemic level and large quantities of the pest can overcome defensible mechanisms of living tree by attacking in mass (Horntvedt *et al*. 1983). Therefore one of pest management objectives is to remove susceptible or *Ips typographus* attacked trees as soon as possible and avoid population growth.

To plan stand management in spruce forests, it is essential to determine how spruce bark beetle *Ips typographus* chooses a tree to attack. There is no suitable method to measure tree vigour, so a need for more tangible indicators of possible bark beetle attacks is evident. Different authors studied relations between bark beetles attacks and different variables such as stand basal area, tree diameter at breast height, vitality, diseases, soil conditions, windfall, drought, etc. For example, Dutilleul *et al* (2000) found out that the nitrogen and magnesium contents in the soil have a significant direct causal link with the number of *Ips typographus* attacks. Worell (1983) stated that most frequent and severe attacks have occurred in areas with Permian geological formations, in large continuous areas of spruce forest, on valley side sites, especially on steep north and east facing slopes, in areas of higher site class. However, no universal indicator has been confirmed yet.

Resins have been regarded as important for the defence against bark beetles in Norway spruce. Living parenchyma cells of the phloem and sapwood produces the wound resins (Christiansen 1991), which may prevent bark beetle establishment. There is a trend toward a higher yield of duct resin per wound among the larger trees. Therefore tree growth rate could be one of the most important indicators of tree vigour and, respectively, of *Ips typographus* risk. To verify this hypothesis, the following question was addressed in this study: are there any differences in the radial increment of attacked and unattacked tree on tree level within stand? One of the potential data sources of tree growth history is the annual radial increment. It can show annual growth rate, data can easily be obtained and compared. To analyse growth differences of attacked by *Ips typographus* and unattacked spruce trees, the annual tree ring width was examined.

Materials and methods

The study was conducted at endemic (non-outbreak) population level of *Ips typographus* during 2000-2002. Fixed radius plots (0.01 or 0.02 ha) were established around one or a few spruce trees, infested by *Ips typographus*. Control plots were established at the distance of 75 m from infested plot at random direction within the same stand. A total of 87 infested and 90 control plots were established throughout the territory of Lithuania.

All attacked and a few unattacked spruce trees (representing 1-3 Kraft crown class) in each infested plot and several spruce trees in each control plot were sampled with Pressler borer. A total of 168 attacked and 164 healthy spruce trees in infested plots and 218 spruce trees in control plots were sampled. Tree ring widths in the period 1973-1975 were measured in laboratory with precision of 0.01 mm. Mean annual and cumulative 5-year tree ring growth was used in the analysis.

For data analysis spruce trees were divided into three groups: infested by *Ips typographus*, healthy trees in infested plots and healthy trees in control plots. The average value of the radial tree increment differs considerably year in and year out; therefore cumulative radial increment of 5 year periods also was used in data analysis (Mahoney 1978, Grodzki *et al* 2003, Bleiker *et al* 2005) in addition to the annual tree ring growth. Spruce tree biosocial position in the stand (Kraft's crown class) as a measure of competitive stress on individual trees was encountered. Standard statistical procedures were applied to the data, significance of difference has been estimated using Student-t statistic (Campbell 1989).

Results

A total of 550 spruce trees were sampled with increment core – 168 successfully attacked by *Ips typographus* and 382 healthy (Table 1). No differences in the average annual radial increment of all spruce trees on infested and control plots can be seen during the period 1973-2002. The data did not show statistically significant differences between the mean tree ring growth, except for year 1981 and 2002, when the growth of spruce in control plots was faster. Tree ring width was 1.76±0.18 mm in control plot and 1.54±0.06 mm in infested plot in 1981 (0.74±0.07 and 0.54±0.04 mm in 2002, respectively, Fig. 1).

Table 1. Number of trees sampled

Tree social position in the stand (Kraft class)	Infested plots		Control plots	Total
	attacked	unattacked		
Dominant (1)	28	29	39	96
Codominant (2)	113	76	104	293
Intermediate (3)	26	51	72	149
Overtopped (4)	0	8	3	11
Suppressed (5)	1	0	0	1
Total	168	164	218	550

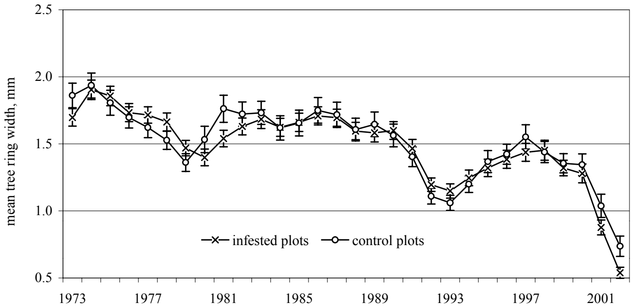

Figure 1. Tree ring growth of spruce trees in different plots. Bars show standard error

Differences in the average annual tree ring width in the period 1973-2002 was not statistically significant either: 1.48±0.05 mm in infested and 1.50±0.05 mm in control plots.

In general, attacked spruce trees had significantly faster annual tree ring growth than unattacked ones in the period 1973-1992 in infested plots (except in the year 1981, Fig. 2). Especially good growth of spruce bark beetle attacked trees was observed in 1980-1989. In 1992 attacked and unattacked spruce trees showed remarkable drop in tree ring growth, most possible due to the severe drought. The radial increment of unattacked spruce trees was regained in 1993 and that of attacked ones in 1994, but in general average tree ring growth was lower than earlier, in 1973-1991. Attacked and unattacked spruce trees had no differences in the annual tree ring growth in the period 1995-2001.

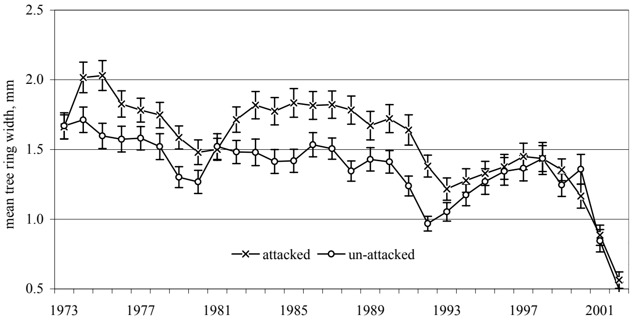

Figure 2. Tree ring growth of attacked and unattacked spruce trees in infested plots. Bars show standard error

The radial increment pattern of spruce trees dominant in the stand (Kraft class 1) did not show distinct differences between attacked and unattacked trees. Attacked spruce trees have been growing faster in the period 1984-1992, but the radial increment of unattacked ones was greater some time before bark beetle infestation 1994-1999 (Fig. 3).

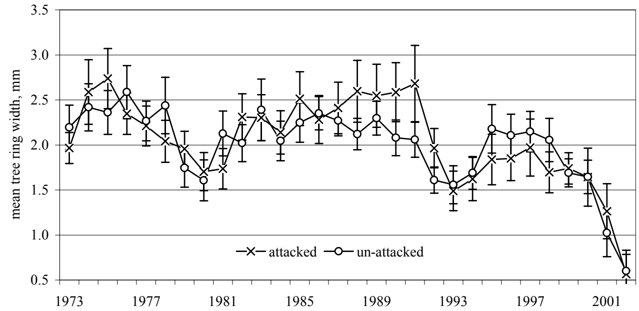

Figure 3. Average tree ring growth of dominant spruce (Kraft class 1) trees in infested plots. Bars show standard error

Unattacked spruce trees with codominat crown (Kraft class 2) grew slower than later attacked ones in the period 1974-1993. After severe drought stress in 1993, tree ring growth of attacked and unattacked spruce trees was almost the same (Fig. 4).

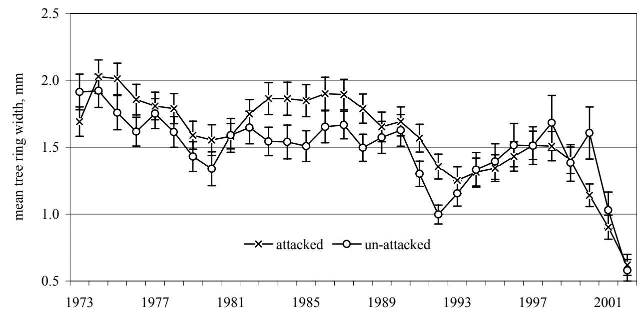

Figure 4. Average tree ring growth of co-dominant spruce (Kraft class 2) in infested plots. Bars show standard error

Attacked and unattacked spruce trees with intermediate crown (Kraft class 3) had the same tree ring growth in the period 1973-2002 (Fig. 5). Differences between attacked and unattacked spruces were not statistically significant and the trend of decreasing radial increment throughout all the period studied may be attributed to tree differentiation in the stand and increasing competition on trees of Kraft class 3.

Cumulative 5-year radial increment of un-attacked and attacked trees in infested plots differed significantly (Table 2). Spruce trees infested in 2000-2002 had significantly better tree ring growth in the period 1973-1997, but diameter increment (5.4±0.08

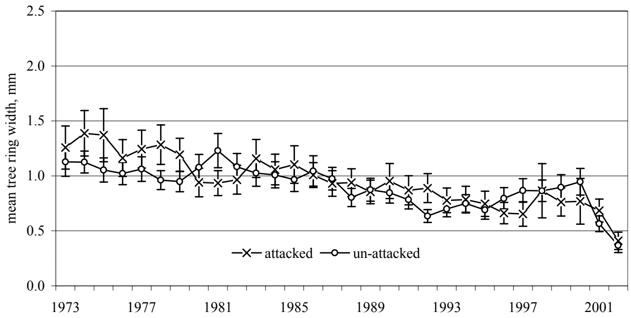

Figure 5. Tree ring growth of intermediate spruce (Kraft class 3) in infested plots. Bars show standard error

Table 2. Cumulative 5-year radial increment of spruce trees in infested plots

Period/trees	Tree ring width, mm±standard error		significance of differences
	attacked	unattacked	
1973-1977	9.32±0.10	8.14±0.09	t=8.921; p<0.05
1978-1982	8.03±0.09	7.09±0.09	t=7.686; p<0.05
1983-1987	9.06±0.10	7.35±0.09	t=13.06; p<0.05
1988-1992	8.20±0.10	6.39±0.07	t=14.67; p<0.05
1993-1997	6.65±0.09	6.21±0.09	t=3.604; p<0.05
1998-2002	5.40±0.08	5.38±0.09	t=0.176; n.s.

mm) of the last 5 years before bark beetle attack was not significantly different from that (5.38±0.09 mm) of unattacked spruce trees. Cumulative radial increment of attacked spruce trees in the period of droughts (1993-1997) has decreased by 19% in comparison with the previous period (1988-1992) while unattacked trees show only 3% decrease in the tree ring growth.

Attacked and unattacked spruce trees with co-dominant crown (Kraft class 2) exhibit essential differences in the annual radial increment, so their 5-year cumulative radial increment was compared. Attacked spruce trees were growing significantly better during four 5-year periods (Table 3). In the period of droughts (1993-1997) attacked and unattacked spruce trees had no statistically significant differences in the radial increment, although cumulative radial increment of attacked spruce trees had decreased

Table 3. Cumulative 5-year radial increment of 2 Craft class spruce trees in infested plots

Period/trees	Tree ring width, mm±standard error		significance of differences
	attacked	unattacked	
1973-1977	9.39±0.11	8.96±0.12	t=2.604; p<0.05
1978-1982	8.26±0.11	7.62±0.12	t=3.993; p<0.05
1983-1987	9.37±0.12	7.91±0.11	t=8.797; p<0.05
1988-1992	8.06±0.11	6.99±0.10	t=7.236; p<0.05
1993-1997	6.86±0.10	6.91±0.13	t=0.308; n.s.
1998-2002	5.58±0.09	6.28±0.16	t=3.868; p<0.05

by 15% in comparison with 1% growth drop of unattacked ones. Later, during last 5-year period before beetle infestation (1998-2002), unattacked spruce trees recovered growth significantly better than attacked ones.

Discussion

It is generally agreed that spruce bark beetle under endemic population levels successfully colonize only weak and/or stressed trees. There was severe drought and high summer temperatures in 1992, 1994, 1999 and 2002 in Lithuania, especially in 1994 when the maximum temperature of +39˚C was recorded (Anonymous, 1992, 1994, 1999, 2002). Drought caused tree ring growth drop in 1992, but, surprisingly, the tree ring growth did not decrease in 1994 when the second drought came. During the period of droughts (1993-1997) cumulative radial increment of attacked trees has decreased relatively more when compared to unattacked spruces. This proves that unattacked trees have recovered from moisture stress faster and better than attacked ones have done.

Water deficit is the most universally documented stress factor predisposing trees to attack by bark beetles. Most authors consider that moisture stress affects the growth and vigour of trees and thereby their capacities to defend against bark beetles. After the drought of 1974-1976 in Norway several million trees died of drought alone and tree growth on large areas was seriously reduced (Worel 1983). Reduced growth and vigour is probably a result of the reduced photosynthetic capacity, mainly due to drought-induced closure of stomata (Bengtson 1980). It has been demonstrated that trees the photosynthetic capacity of which is seriously impaired suffer a depletion of carbohydrate which in turn affects the production and mobilisation of the monoterpenes by which the trees defend themselves against beetle and fungi attack (Wright *et al* 1979). As stated earlier, unattacked trees showed faster and better recovery after drought, so they built up production and mobilized monoterpenes faster too.

The study shows that trees attacked by *Ips typographus* grew faster most of their studied lifetime in comparison with unattacked ones. Similar observations were made by Christiansen and Huse (1979) who proposed that killed spruce trees had been growing faster 25 to 40 years ago than those that resisted attack of bark beetles. Shrimpton (1978), who studied the resistance of *Pinus contorta* to infestations by *Dendroctonus ponderosae*, stated that the time span from the period of fast growth in the killed trees to the infestation was even longer. Shrimpton concluded that bark beetles show an apparent preference for *Pinus contorta* trees that had been growing faster over most of their lifetime, but which were growing slower than the average at the time of attack. Our results confirm the same pattern of bark beetle risk for Norway spruce.

Bleiker's (2005) study showed that recent radial increment was positively related to the induced defence response and resistance of subalpine fir to bark beetle attack over the last 5 years. The mean cumulative radial increment of unattacked and unsuccessfully attacked trees was equal or greater than 4.0 mm when successfully attacked fir trees had mean cumulative radial increment 2.8 mm or less over the last 5 years. In our study, unattacked spruce trees of Kraft class 2 show the definite differences in the annual radial increment. Also it was the Kraft class with the biggest number of measured spruce trees, attacked and control. They had 6.28±0.16 mm cumulative radial increment for the last 5 years and attacked ones – 5.58±0.09 mm. It proves that faster growing trees have more defensive power and are less suitable for breeding of bark beetles.

Conclusions

1.Spruce trees attacked by *Ips typographus* were growing faster most of their studied life-time in comparison with un-attacked ones nearby, except the last five year period before the attack.

2.Attacked and unattacked spruce trees with co-dominant crown (Kraft class 2) show the biggest differences in the annual radial increment.

3.Spruce, killed by *Ips typographus*, suffered more severe drought stress a few years prior to the attack and recovered slower and weaker than survived trees.

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РОСТ ЕЛИ В ДИАМЕТР И РИСК ПОВРЕЖДЕНИЯ КОРОЕДОМ ТИПОГРАФОМ *IPS TYPOGRAPHUS* L.

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Резюме

Жизнеспособность дерева, выраженная радиальным приростом, может определить риск заселения деревьев жуками короедами. Анализ ширины годичных колец показал, что ели, в 2000-2002 г заселенные короедом типографом, росли лучше по сравнению с неповрежденными деревьями все время, за исключением последнего пятилетнего периода перед повреждением. Наибольшие различия в ширине годичных колец установлены у деревьев второго класса по Крафту. Ели, заселенные короедом типографом, испытывали более сильный стресс от засухи и медленнее восстанавливали радиальный прирост, чем незаселенные короедом деревья.

Ключевые слова:, ель обыкновенная, *Picea abies*, короед типограф, *Ips typographus*, рост годичного кольца, риск повреждений