Spatial distribution of losses in growth of trees caused by the feeding of pine shoot beetles *Tomicus piniperda* and *T. minor* (Col., Scolytidae) in Scots pine stands growing within range of the influence of a timber yard in southern Poland

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ABSTRACT: This study deals with the assessment of increment losses in Scots pine trees caused by the maturation feeding of pine shoot beetles *Tomicus piniperda* (L.) and *T. minor* (Hart.) (Col., Scolytidae) in even-aged stands growing during their entire life span within range of the influence of a sawmill and its timber yard. In spring 2004, on three sample plots, 0.2 ha in size, situated 60, 200, and 500 m from the yard, height and dbh of all trees were measured and increment cores were taken from randomly selected sample trees. An agreement between the spatial distribution of losses in tree increments and the distribution of damage to crowns of investigated stands indicated that the losses resulted from the maturation feeding of pine shoot beetles migrating from the sawmill timber yard. Divergence of growth in the about 25-years-old stand indicated the beginning of intensive feeding of beetles in pine shoots with a high level of probability. In comparison with the control stand the basal area losses in stands growing 60 and 200 m from the beetle source amounted to 57% and 46%, respectively. The difference in the height of trees was as large as almost 100%.

Keywords: *Pinus sylvestris* (L.); *Tomicus piniperda* (L.); *Tomicus minor* (Hart.); shoot damage; growth

Pine shoot beetles *Tomicus piniperda* (L.) and *T. minor* (Hart.) (Col., Scolytidae) are widely distributed in the Palearctic Region infesting various pine species in their natural ranges (Nunberg 1947; Lekander et al. 1977; Eager et al. 2004). In the early 1990s *T. piniperda* was introduced into North America, and for the first time it was detected near Cleveland, Ohio (Haack, Kucera 1993). The absence of natural enemies that would reduce the levels of its Eurasian population probably aided its spreading to other areas in the United States and Canada (Haack et al. 2001; Kennedy, McCullough 2002; Poland et al. 2003; Eager et al. 2004). *T. piniperda* breeds in stem sections with thick bark of felled or strongly weakened pines. The feeding of this insect under bark may lead to a decline of stands growing on burns (Chararas 1962), areas affected by outbreaks of foliophagous insects (Anilla et al. 1999; Långström et al. 2001; Cedervind et al. 2003), or growing around centres of its reproduction (Michalski, Witkowski 1962). Only in Mediterranean countries the infestation of healthy trees leading to their death took place as the consequence of a simultaneous attack of *T. piniperda* and *Tomicus destruens* Woll. (Ghaioule et al. 1998; Ben Jamâa et al. 2000). In southwestern China *T. piniperda* was considered to be the cause of large damage in stands of *Pinus yunnanensis* (Fr.) on the area of over 1.5 million hectares during the last twenty years (Ye 1991; Ye, Zhao 1995; Långström et al. 2002). However, detailed genetic investigations showed that this damage was caused by the species having a genome different from that of *T. piniperda* (Lieutier et al. 2003).

In Europe and North America the feeding of pine shoot beetles in pine shoots causes losses in the growth of trees (Michalski, Witkowski 1962; Nilsson 1976; Łęgowski 1987; Långström,

Table 1. Characteristics of Scots pine stands in Zagnańsk in 2004

Variable	Stand		
	A	B	C
Distance from beetle source, m	60	200	500
Mean dbh	17.4	21.4	22.8
Site type	fresh coniferous forest	fresh coniferous forest	fresh coniferous forest
Stand age, years	83	83	85

Hellqvist 1990, 1991; Czokajlo et al. 1997; Borkowski 2001). Until now no estimation of secondary effects of outbreaks of these insects has been made in stands of older age classes growing during their entire growth period within range of the influence of their reproduction centres. The main problem of loss assessment is to find homogeneous study sites which often have to be located within a distance of 2,000 m. Differences in stand age, species composition, stand quality, site conditions, amount of timber stored, time of storage, climatic, soil and other factors cause that the conclusions concerning the effect of insects on increment losses may be burdened with a large error.

The aim of this study was to estimate the losses of tree increments caused by the maturation feeding of pine shoot beetles in stands homogeneous in respect of site, species composition and age, growing during their entire growth period within range of the influence of sawmill yards.

MATERIALS AND METHODS

Study site

The study site was located in Zagnańsk in southwestern Poland (20°45´E; 50°55´N; 350 m above sea level). Research was conducted in pure Scots pine stands, above 80 years old, growing during their entire life within range of the influence of a sawmill timber yard. The sawmill was established in 1916. During the period from 1950 to the late 1970s about 100 m^3 of pine timber was sawn a day, and a reserve for monthly production was stored in the yard. During 1980–1994 sawmill daily production decreased to about 30 m^3, while since 1988 stored timber was neither barked nor treated chemically against insect attacks (Sawmill records 1996). In 1996 the state owned sawmill was liquidated, and smaller private sawmills were created. They operate without timber storage. A high demand for bark prevents its accumulation in sawmill yards.

Table 2. The mean amount of dropped shoots per 1 m^2 in the investigated stands

Year	Stand		
	A	B	C
2001	2.60	0.80	0.24
2002	24.3	4.31	0.35
2003	0.73	0.27	0.23
2004	0.43	0.23	0.11

Experimental procedures

Research was conducted in a Scots pine stand situated 50 m away from a sawmill timber yard. In spring 2004 three permanent sample plots, 0.2 ha (40 m × 50 m) in size, were established 10 m (stand A), 150 m (stand B), and 500 m (stand C – control) away from the stand edge. All pines present on the plots were numbered. To ensure that the comparison of growth will be made in stands being in a similar increment period, the 60-year-old stands, growing 200–500 away from the beetle source, were omitted. The forest site types were determined on the basis of soil type, litter, indicator plants, and quality class of Scots pine. Characteristics of stands on sample plots are presented in Table 1.

The heights, rounded to 0.25 m, and dbh outside bark (N-S and E-W), rounded to 0.5 cm, of all Scots pine trees present on sample plots were measured. Then, a sample of 31 trees (every twentieth tree according to their numbers) was chosen. From the trunk of each tree two increment cores were taken with the Suunto borer along the radii perpendicular to each other, 1.3 m above the ground. The width of annual rings on the cores was measured with an electronic increment gauge BEPD-5 to the nearest 0.01 mm. The tree-ring series (so called actual dendroscales) were dated using the COFECHA program (Holmes 1995). To determine the age of stands, from every second sample tree selected earlier on each plot, a core was taken at the tree base. Age was calculated as an arithmetic mean.

In January the damage to crown tops of 15 felled sample trees (5 trees in each stand) was estimated, and the degree of deformation of crown tops was determined according to the following scale:

– high, the absence of distinctly separated height increments or their strong deformation;
– low, increments partially deformed;
– no deformation, a healthy crown, characteristic of the model of a healthy tree (Borowski 1974).

Since 2001, from August to December, a monthly check-up of the amount of fallen pine shoots damaged by the pine-shoot beetles has been conducted using a method of entomological monitoring. A sample consists of shoots collected on strips, 25 m long and 1 m wide, running from a sample tree in four cardinal directions.

There were no outbreaks of foliophagous insects during the growth period of stands.

Statistical analysis

The assessment of significance of differences in mean heights and 10-year radial increments at breast height was carried out on the basis of the analysis of variance ANOVA followed by Tukey's test. Statistical analyses were carried out using the statistical program Statistica 6.1 (StatSoft, Inc. 2004).

RESULTS

Growth

In 1925–1943 the investigated stands did not differ in respect of mean 10-year increment periods (Fig. 1). During the period from 1944 to 1983 the differences were significant. After 1983 periodic increments in stands A and B were different from that of stand C. Basal area in stand A was by 57%, and in stand B by 46% smaller than that in stand C. The increment loss in stand A was about 25% in relation to stand B.

Mean heights of stands A (9.93 m) and B (13.7 m) significantly differed from that of the control stand C (18.52 m) (F = 2,103.12; df = 528; p < 0.001; Tukey's test, p < 0.05). The height of stand A differed from the height of control stand by almost 100%.

Damage to tree crowns

Stand A – a high degree of deformation, umbrella-shaped crowns, tree tops dead or strongly deformed in a section 1 to 2 m long, occurrence of witches' brooms formed by shoots developed from dormant buds;

Stand B – a low degree of deformation, umbrella-shaped crowns, crown tops alive with leaders, no witches' brooms;

Stand C – the crown characteristic of the model of a healthy tree (Borowski 1974).

Pine shoot fall

During individual years the amount of fallen shoots decreased as the distance decreased (Table 2). Its high level in 2002 was caused by the feeding of beetles migrating from the sawmill yard to the area where over 500 m^3 of unbarked pine timber, unprotected by insecticides, was left in the forest during summer (Borkowski 2003).

DISCUSSION

An agreement between the spatial distribution of increment losses and the distribution of crown damage in stands investigated during this study showed that these losses resulted from the shoot feeding of pine shoot beetles migrating from the sawmill timber

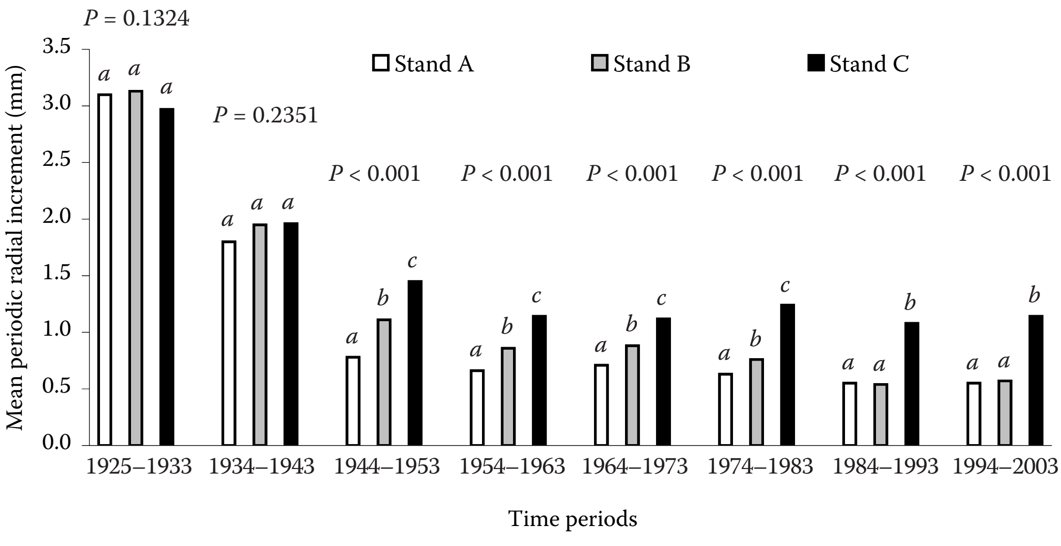

Fig. 1. Mean 10-year periodic radial increment at breast height; a, b, c – means with the same letter do not differ significantly. Tukey's test, P < 0.05

storage site. Divergence of growth in about 25-years-old stand may be assumed with a high probability to be the beginning of an intensive feeding of beetles in pine shoots. Such a feeding in Poland may already take place in 20-year-old stands (Michalski, Witkowski 1962). This was confirmed by studies of Czokailo et al. (1997) in New York. In their case the divergence of growth patterns of severely and moderately damaged trees coincided with the date of introduction of *T. piniperda* into North America. The spatial distribution of losses of tree increments found during the present study pointed to an intensive feeding of pine shoot beetles in shoots of Scots pine in stands A and B. The decrease of sawmill production after 1980, the ownership changes in 1996, and sawing of timber without its storage in the yard, and also a high demand for bark, resulted in a reduction of the pine shoot beetle population. This was reflected by similar periodic radial increments in stands A and B in 1984–2003. Beetle feeding during previous periods caused disturbances in the normal development of crowns leading to a complete or partial dying of top parts, of which the assimilative apparatus plays a very important role in the process of photosynthesis (Troeng, Linder 1982). This limited possibilities of a significant increase in the values of current diameter growth.

Most of literature data demonstrated a significant effect of the shoot feeding of pine shoot beetles on losses of tree increments. In studies conducted in uneven-aged stands surrounding a timber yard in Mönsterås (Långström, Hellqvist 1990) the reduction in radial growth at breast height during a 5-year period was from 3% to 46%. In the stand growing in a direct neighbourhood of beetle reproduction centre a 3-year timber storage period in Aneby caused a 6-year period of reduction in radial growth, about 60% loss of basal area, and about 1.5 m decline in height growth compared to the control stand (Långström, Hellqvist 1991). Studies in New York demonstrated that the mean periodic basal area increment of trees with severely damaged crowns was 37% less than that of trees with moderately damaged crowns. In Poland, the losses of increments in younger stands amounted to 20–40% (Michalski, Witkowski 1962), and in older stands to about 50% (Borkowski 2001). Some studies demonstrated that increment losses of 20–40% lasted for several years following a 1-year insect outbreak (Nilsson 1974), while others reported lower losses, even at a high density of attack (Ericsson et al. 1985).

Scandinavian research showed that at a similar degree of defoliation the losses of tree increments caused by the feeding of pine shoot beetles were much higher than those caused by the feeding of foliophagous pests. The outbreak of *Neodiprion sertifer* L. in Norway caused a 75% defoliation in two consecutive years, and in consequence only about 30% losses of basal area and volume increments during 9 years (Austarå 1987), and in Finland 29% losses during a 5-year period (Jalkanen 1986). The higher losses in the case of pine shoot beetles may be explained by the concentration of beetle feeding in the top part of the crown highly responsible for the process of photosynthesis, contrary to the feeding of foliophages frequently spread throughout the entire crown (Troeng, Linder 1982). Other studies (Ericsson et al. 1980, 1985) showed that simultaneous damage to shoots and needles probably weakened the photosynthesis more than the needle loss alone. Besides, in the case of damage to apical shoots, the growth regulation controlled by the phytohormone IAA may also be disturbed (Sandberg, Ericsson 1987). It also seems that during a longer period of time the effect of insect outbreak on site fertility may be of some importance. A slow decomposition of fallen shoots damaged by pine shoot beetles takes several years while outbreaks of foliophagous insects, frequently associated with wasteful larval feeding, result in an increased fall of crumbled needles which together with a large amount of excrements and dead insects undergo fast mineralization, thus accelerating the decomposition of litter. This contributes to improvement of site quality by a release of nutrients into the soil. In the case of 1-year outbreaks it may weaken the effect of reduction of the assimilative apparatus on tree growth.

This study showed that the height growth of trees in stand A was completely stopped while in stand B it was considerably slowed down. The difference in height between stand A and the control stand C was nearly 100%. This is in agreement with the difference calculated by a mathematical model for 50-years-old stands surrounding a timber storage area in northern Poland (Łęgowski 1987). The studies agree that losses of height increments occur when the apical shoot is damaged. The difference concerns its recovery in length which may last for 2–10 years (Piene 1989; Långström, Hellqvist 1991).

The assessment of tree increment losses, especially in uneven-aged stands being in various increment phases, is difficult and it requires the assumption of the environment homogeneity, which is impossible under natural conditions. In addition, the explanation of the effect of meteorological factors on increment requires current observations of tree reactions. Studies of the past events without additional detailed information about other factors affecting growth would not solve the problem completely. This study showed a significant effect of beetle feeding in pine shoots on increments of the investigated stands. The homogeneity of stands in respect of site, species composition and age permitted to estimate the increment losses quite exactly.

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Ztráty na přírůstu borovic, poškozovaných úživným žírem lýkohubů *Tomicus piniperda* a *T. minor* (Col., Scolytidae) v závislosti na vzdálenosti od pily a dřevoskladu v jižním Polsku

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ABSTRAKT: Studie se zabývá hodnocením přírůstových ztrát borovice lesní, které byly způsobeny zralostním žírem lýkohubů *Tomicus piniperda* (L.) a *Tomicus minor* (Hart.) (Col., Scolytidae) ve stejnověkých porostech, které byly po celou dobu své existence vystaveny vlivu způsobenému provozem pily a manipulačního skladu dřeva. Během roku 2004 byla na třech pokusných plochách, vzdálených 60, 200 a 500 m od manipulačního skladu, měřena na všech stromech těchto pokusných ploch výška a výčetní tloušťka a z náhodně vybraných vzorníkových stromů byly odebrány přírůstovým nebozezem vývrty. Korelace mezi prostorovým rozdělením přírůstových ztrát a stupněm poškození korun úživným žírem lýkohubů v závislosti na vzdálenosti od manipulačního skladu naznačovala, že přírůstové ztráty jsou způsobeny zmíněným žírem lýkohubů, kteří se šířili ze dřeva přiváženého a zpracovávaného v dřevoskladu. Změny přírůstu porostů zhruba od 25 let jejich věku naznačují s velkou pravděpodobností počátek jejich významného poškozování úživným žírem od tohoto stáří. Základní ztráta na přírůstu, vztažená k ploše porostu, činila v porostech vzdálených 60 a 200 m od skladu dřeva 57 % a 46 % ve srovnání s nezasaženými kontrolními plochami. Rozdíl ve výškovém přírůstu činil až 100 % při srovnání stromů na poškozovaných a kontrolních plochách.

Klíčová slova: borovice lesní; lýkohub sosnový; lýkohub menší; poškození výhonů; přírůst

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