Chemical thinning in blue spruce (*Picea pungens* Engelm.) stands and its effects on cambioxylophagous fauna

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ABSTRACT: Chemical thinning was applied in blue spruce (*Picea pungens* Engelm.) stands by the application of Roundup Klasik and Garlon 4 EC. The thinning efficacy of Garlon 4 EC was negligible, while that of Roundup Klasik reached nearly 100% when the full strength concentration was applied in quantities of 1 ml per 10 cm of stem girth using the method of drilling holes for the arboricide injection. Treated blue spruce trees died within 6 month after application. No difference was found in the response of silver and green varieties of blue spruce to the application of arboricides. Several species of cambioxylophages colonizing blue spruce were killed by Roundup. The economically insignificant *Hylurgops palliatus* (Gyll) was the most abundant negatively affected insect species found on the stem, followed by significant pests such as *Ips amitinus* (Eichh.) and *Pityogenes chalcographus* (L.). In these species, partial mortality of larvae was probably caused by the lowered quality of phloem. A significant mortality of *Cryphalus abietis* (Ratz.) was noted on branches.

Keywords: arboricides; chemical thinning; *Ips amitinus*; Krušné hory Mts.; *Picea pungens*; Scolytidae

In the period of culminating air-pollution stress in the 1980s, stands of tree species substitute to Norway spruce were established on the area of 30,000 ha in the Krušné hory Mts. Blue spruce (*Picea pungens* Engelm.) was a dominant species in these stands. Its proportion (13.2%) in forest stands of the eastern Krušné hory Mts. accounts for an area of 8,400 ha (Balcar et al. 2008). At present, thinning and reconstructions of these stands are carried out on a large scale. Silvicultural procedures applied in these stands are demanding both economically and technologically. Manual tree felling or energy-demanding chipping by harvesters are the most commonly applied techniques. Where stands are regenerated by underplanting, retained individuals of blue spruce create a protective storey for the newly established plantations. The blue spruce trees are usually thinned out when the height of the terminal shoot of the new plantation outgrows the negative effects of ground frost (Hobza 2008). However, considerable damage is inflicted upon the target species during the thinning of left blue spruce trees, since they are characterized by large and dense cylindrical crowns with firm inflexible branches.

An alternative technological procedure aimed at the removal of undesired trees consists in the use of arboricides for "chemical thinning". Relative to the conventional mechanical thinning, this technique is far less time and resource demanding (Kudela 1968). In the past, arboricides were applied by painting or spraying onto the stems of trees by means of hypohatchets, injectors, arboricide cartridges and, according to Vyskot et al. (1972), by means of a petrol engine drill. An important advantage of chemical thinning consists in the fact that trees killed by chemical treatment and left in the stand to their natural

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decomposition increase its stability from abiotic factors, particularly snow. Therefore, thinning measures can be more intensive and can be repeated at longer time intervals (Kudela 1968; Jurča, Vašíček 1966). Dead standing trees maintain higher relative air humidity in the stand, do not hinder the development of newly planted seedlings and their eventual break-up and decomposition aid nutrient cycling. Moreover, the fast decomposition of dead tree wood enriches a site with organic matter and contributes to humus formation (Kudela 1968).

Drawbacks of the arboricide application method consist in the potential for environmental contamination by toxic substances. At the same time, during the slow dieback of chemically treated trees, it is not possible to exclude the hazard of providing a suitable habitat for cambioxylophagous insects which could subsequently spread to healthy neighbouring stands (Procházka 1973). Thinning regimes which leave logging residues in young stands are known to create suitable conditions for the development of some members of cambioxylophagous and wood-boring insect species (Kula, Kajfosz 2006, 2007). Specific changes in the condition of the phloem occur in standing stem breaks in young spruce stands broken by snow or in older stands after wind breakages. Such stem breaks in spruce stands of the 2nd and 3rd age classes are characterized by irrigated phloem and the presence of secondary fauna (*Hylurgops palliatus* [Gyll.], *Hylocoetes dermestoides* [L.], *Dryocoetes* sp., *Monochamus* sp.), which however do not endanger living spruce stands. A similar situation can be found in standing stem breaks in spruce stands aged more than 60 years which are colonized by species typical of dying trees (*Xyloterus lineatus* [Oliv.], *H. dermestoides, H. palliatus, Isarthron fuscum* [Fabr.] and *Poly-graphus polygraphus* [L.], while species typical of stems, such as *Ips typographus* [L.] and *Pityogenes chalcographus* [L.], do not attack standing stem breaks – Kula, Zabecki 2006).

Pfeffer (1995) provided a comprehensive overview of the communities of bark beetles colonizing *Picea* sp. (57 species) in the central and western Palaearctic region. Various members of the *Picea* genus differ in the diversity of bark beetles. Some 39 insect species live on Norway spruce (*Picea abies* [L.] Karst.) and 40 on *Picea obovata* (Led.). Other species of the genus support less bark beetle diversity – *Picea jezoensis* (Sieb. et Zucc.) (20), *Picea orientalis* (L.) Link (17), *Picea omorica* (Panc.) Purk. (9), *Picea schrenkiana* Fisch. et Mey (6), *Picea glehnii* (Fr. Schmidt) Mast. (5), *Picea sitchensis* (Bong.) Carr. (1), but the fauna of bark beetles of *P. pungens* Engelm. has not been determined yet. Cognato et al. (2003) mentioned *Ips confusus* (LeConte) commonly attacking pine species in the USA (*Pinus edulis* Engelm., *Pinus monophylla* Torr. et Frem.) and spruce *P. pungens*, which is, however, considered to be an atypical nutritive species.

Hypothesis

– Arboricides kill blue spruce within a short time, but the health condition of untreated trees is not affected negatively,
– arboricide application does not significantly increase the susceptibility of dying blue spruce tree to bark beetle colonization.

The aim of the paper was to analyze the effects of arboricide application as a method for removing undesired blue spruce trees during the thinning and reconstruction of stands of substitute species and to specify the availability of dying trees to cambiophagous insects.

MATERIAL AND METHODS

An experimental plot was established at an altitude of 800 m a.s.l. in the Litvínov Forest District in the Czech Republic (Kalek Forest Range, 50°34'20.501"N, 13°22'2.015"E). In total, 430 blue spruce trees were treated with arboricides (mean stand height 8 m, diameter at breast height [dbh] 12.7 cm), while 124 control untreated trees were left at an irregular spacing among the treated specimens. These trees should create the future protective storey for the newly established plantings. Two chemical products were applied in concentrations recommended by the producer, see Roundup Klasik (15%) and Garlon 4 EC (10%), and at the same time, also in undiluted concentration (100%).

Three methods were used to apply the chemical products onto spruce stems at breast height:

(1) Two facets 30–40 cm long and about 4–10 cm wide were made with a chainsaw on the surface of a standing stem. The chemical was applied onto the facets with a brush ("saw" treatment). The amount of the applied chemical was derived from diameter at breast height, where 1 ml of the chemical was applied per each 10 cm of stem girth.
(2) By means of a cordless drill, holes (diameter 8 mm) were drilled uniformly along the stem girth and 1 ml of the chemical was applied to them by means of a dosing pipette ("drill" treatment). The number of holes was given by the

dbh where one hole was created per each 10 cm of stem girth. This working procedure simulates the chemical application by means of arboricide cartridges or injectors.

(3) Using a hatchet, notches were made along the stem girth and 1 ml of the arboricide solution was applied into them with a dosing pipette ("hatchet" treatment). The number of notches and the amount of the applied chemical were determined in the same way as in the previous treatment. This working procedure simulates in principle the application with a hypohatchet.

The arboricide application was carried out in the second half of June 2007. The first inspection was realized one month after the arboricide application. Subsequently, two inspections were carried out at the beginning (2008-I) and at the end of the growing season (2008-II) in 2008. An entomological examination was done in September 2008 when 10 blue spruce trees of mean dbh 13.2 cm (9–15.8 cm) and mean height 7.2 m (5.9–8.4 m) killed by Roundup were felled. The presence of cambioxylophagous species was classified visually according to the presence of feeding marks (or imagos and larvae) after barking the stem and branches, continuously in one-metre sections along the whole of the stem and branches. Developmental stage (larva, pupa, imago, abandoned feeding marks) and the intensity of attack according to the methodology of Kula and Zabecki (1996) were determined for each insect species. Larvae of longhorn beetles were determined according to Švácha and Danilevsky (1986, 1987 and 1988).

During the field assessment, the efficacy of arboricide application for each method of application and different concentrations was noted. The occurrence of foliage discoloration was visually surveyed as well as the defoliation of each needle age class throughout the length of the tree crown. In addition, we monitored the occurrence of dead apical shoots of all trees and the dieback of whole individuals. The response of different colour forms of blue spruce (silver and green forms) was also surveyed.

The occurrence of discoloration in needles was monitored according to the following scheme:

– only in the last needle age class (I),
– only in the last but one needle age class (II),
– and in the last three needle age classes (I+II+III).

The degree of the assimilatory apparatus defoliation was classified as:

– only in the last needle age class (I),
– only in the last and in the last but one needle age class (I+II),
– in the last three needle age classes (I+II+III),
– in all needle age classes of the top part of a tree that died (defoliation of the tree top).

Since we followed the needle age classes during two consequent growing seasons, the class reported as the last needle age class (needle age class I) in 2007 and 2008-I becomes the last but one needle age class (needle age class II) in 2008-II observation.

Measured values were analyzed using the STATISTICA 9.0. CZ programme. One-factor analysis ANOVA was used for populations with the same number of elements. The significance level $\alpha = 0.05$ was determined. Mean values were calculated by the least squares method. The significance of statistical differences in particular parameters was tested by Dunnett's and Duncan's tests (comparison with a control plot). Variants with abnormally distributed data were transformed.

The results from all treatments are shown in the chapter called Results. Only the variants with the significance of differences are shown in Tables 1 and 2.

RESULTS

The application of Garlon was less effective than that of Roundup in blue spruce. In all Garlon treatments, discoloration of the assimilatory apparatus affected at most 13% of the whole crown area. The highest occurrence of discoloration was noted immediately after the arboricide application (2007). In the spring season of the second year, we observed a marked decrease in the occurrence of such discoloration. In the autumn season, a moderate increase in discolouration occurred in some treatments. The defoliation of the assimilatory apparatus began in the spring season 2008 (at most 6% of the assimilatory apparatus), but in the course of the growing season needle fall slowed down in all treatments (at most 3% of the assimilatory apparatus). Discoloration and defoliation of the assimilatory apparatus were observed in one third of the treated trees at most. The method of application did not have any significant effects on the efficacy of the arboricide treatment. Nevertheless, the application with a power saw appears to be least effective. The application of various concentrations of Garlon did not show any statistical differences in the response of spruce trees. Only in sporadic cases were statistically significant differences determined in the health condition between Garlon-treated spruce trees and control individuals (Table 1). Although the treated spruce trees showed some changes in the health condition, the use of Garlon was not effective and no dieback of spruce trees was noted even at the end of the second year after the arboricide application.

Table 1. Colour changes and defoliation of the assimilatory apparatus of blue spruce one month after the application of arboricides

Year	Arboricide	Variant	Colour changes according to the needle year-class (%)				Defoliation to the needle year-class (%)					Sum of defoliation (%)	Affected trees (%)	Dead trees (%)
			I	II	I+II+III	Σ	I	I+II	I+II+III	defoliation of tree top (%)	Σ			
2007	Roundup	Saw R-15	24.6	0.0	21.5	**46.1**	0.0	0.0	0.0	0.0	**0.0**	**46.1**	**95.8**	0.0
		Drill R-15	52.0	0.0	6.8	**58.8**	0.0	0.0	0.0	0.0	**0.0**	**58.8**	**100.0**	0.0
		Hatchet R-15	40.0	0.0	10.0	**50.0**	0.0	0.0	0.0	0.0	**0.0**	**50.0**	**100.0**	0.0
		Saw R-100	19.6	0.0	26.5	**46.2**	0.0	0.0	0.0	0.0	**0.0**	**46.2**	**100.0**	0.0
		Drill R-100	22.6	0.0	43.6	**66.2**	0.0	0.0	0.0	0.0	**0.0**	**66.2**	**100.0**	0.0
		Hatchet R-100	17.8	2.6	40.8	**61.2**	0.0	0.0	0.0	0.0	**0.0**	**61.2**	**100.0**	0.0
		Control plot	0.7	1.5	0.0	**2.3**	0.0	0.0	0.0	0.0	**0.0**	**2.3**	**5.6**	0.0
	Garlon	Saw G-100	0.4	0.0	0.8	**1.3**	0.0	5.8	0.0	0.0	**5.8**	**7.1**	**16.7**	0.0
		Drill G-100	0.0	0.8	0.0	**0.8**	0.0	3.6	0.0	0.0	**3.6**	**4.4**	**16.0**	0.0
		Saw G-10	0.0	0.0	0.0	**0.0**	1.9	0.7	0.0	0.0	**2.6**	**2.6**	**22.2**	0.0
		Drill G-10	2.3	3.5	0.8	**6.5**	4.2	0.8	0.0	0.0	**5.0**	**11.5**	**26.9**	0.0
		Control plot	3.6	0.2	0.0	**3.8**	1.7	0.0	0.0	0.0	**1.7**	**5.5**	**15.1**	0.0
2008-I	Roundup	Saw R-15	0.0	0.0	0.0	**0.0**	16.7	39.2	0.0	0.0	**55.8**	**55.8**	**100.0**	0.0
		Drill R-15	0.0	2.8	0.0	**2.8**	33.6	38.0	1.2	0.0	**72.8**	**75.6**	**96.0**	0.0
		Hatchet R-15	0.4	0.0	0.0	**0.4**	25.2	36.0	0.0	0.0	**61.2**	**61.6**	**100.0**	0.0
		Saw R-100	0.0	0.0	0.0	**0.0**	10.4	20.4	22.7	0.0	**53.5**	**53.5**	**100.0**	0.0
		Drill R-100	0.0	0.0	0.0	**0.0**	20.0	20.0	6.3	0.0	**28.5**	**28.5**	**100.0**	88.9
		Hatchet R-100	0.0	0.0	0.0	**0.0**	10.7	17.8	25.9	0.0	**54.4**	**54.4**	**92.6**	0.0
		Control plot	1.1	0.0	0.0	**1.1**	0.0	0.0	0.0	0.0	**0.0**	**1.1**	**5.6**	1.4

Table 1 to be continued

		Variant	Colour changes according to the needle year-class (%)				Defoliation to the needle year-class (%)					Sum of defoliation (%)	Affected trees (%)	Dead trees (%)
			I	II	I+II+III	Σ	I	I+II	I+II+III	defoliation of tree top (%)	Σ			
2008-II	Garlon	Saw G-10	3.1	0.8	0.0	**3.8**	0.8	0.0	0.0	0.0	**0.8**	**4.6**	**26.9**	0.0
		Drill G-10	1.5	0.4	0.0	**1.9**	0.0	0.4	0.0	0.0	**0.4**	**2.3**	**19.2**	0.0
		Hatchet G-10	0.8	9.6	0.0	**10.4**	0.8	1.2	0.0	0.0	**1.9**	**12.3**	**42.3**	0.0
		Control plot	0.0	1.3	0.0	**1.3**	0.0	0.0	0.0	0.0	**0.0**	**1.3**	**5.8**	0.0
	Roundup	Saw R-15	0.0	0.0	0.0	**0.0**	14.2	16.3	2.1	7.5	**40.0**	**40.0**	**95.8**	0.0
		Drill R-15	0.0	0.0	0.0	**0.0**	21.7	15.4	6.7	8.3	**52.1**	**52.1**	**100.0**	12.5
		Hatchet R-15	0.0	0.0	0.0	**0.0**	16.8	17.2	1.6	3.6	**39.2**	**39.2**	**100.0**	4.0
		Saw R-100	1.2	0.0	0.0	**1.2**	9.6	13.8	5.0	20.4	**48.8**	**50.0**	**100.0**	0.0
		Drill R-100	x	x	x	**x**	x	x	x	x	**x**	**x**	**100.0**	100.0
		Hatchet R-100	0.0	0.0	1.2	**1.2**	6.8	17.2	7.6	21.6	**53.2**	**54.4**	**100.0**	4.0
		Control plot	2.5	1.4	0.0	**3.9**	0.4	0.0	0.7	0.0	**1.1**	**5.0**	**12.5**	0.0

[grey box] – Statistically significant difference between control and application

x – Without visual changes

Table 2. The response of an argent (S) and green (Z) form of blue spruce on the application of arboricides

		Variant	Colour changes according to the needle year-class (%)				Defoliation to the needle year-class (%)					Sum of defoliation (%)	Affected trees (%)	Dead trees (%)
			I	II	I+II+III	Σ	I	I+II	I+II+III	defoliation of tree top (%)	Σ			
2007	Garlon	Hatchet G-100-S	0.0	5.5	0.0	**5.5**	0.0	0.0	0.0	0.0	**0.0**	**5.5**	**18.2**	0.0
		Hatchet G-100-Z	3.8	4.6	7.7	**16.2**	0.0	0.0	0.0	0.0	**0.0**	**16.2**	**38.5**	0.0
		Saw G-10-S	0.0	1.7	2.5	**4.2**	0.0	0.0	0.0	0.0	**0.0**	**4.2**	**16.7**	0.0
		Saw G-10-Z	11.3	4.0	4.0	**19.3**	0.0	0.0	0.0	0.0	**0.0**	**19.3**	**53.3**	0.0
	Roundup	Drill R-100-S	23.3	0.0	34.4	**57.8**	0.0	0.0	0.0	0.0	**0.0**	**57.8**	**100.0**	0.0
		Drill R-100-Z	22.2	0.0	46.5	**68.8**	0.0	0.0	0.0	0.0	**0.0**	**68.8**	**100.0**	0.0
		Hatchet R-100-S	15.0	4.3	36.2	**55.5**	0.0	0.0	0.0	0.0	**0.0**	**55.5**	**100.0**	0.0
		Hatchet R-100-Z	20.8	0.8	35.6	**57.1**	0.0	0.0	0.0	0.0	**0.0**	**57.1**	**100.0**	0.0
2008-I	Garlon	Saw G-100-S	0.0	0.0	1.5	**1.5**	0.0	10.0	0.0	0.0	**10.0**	**11.5**	**15.4**	0.0
		Saw G-100-Z	0.9	0.0	0.0	**0.9**	0.0	0.9	0.0	0.0	**0.9**	**1.8**	**18.2**	0.0
		Hatchet G-10-S	1.9	0.0	0.0	**1.9**	0.0	6.3	0.0	0.0	**6.2**	**8.1**	**12.5**	0.0
		Hatchet G-10-Z	8.0	1.0	0.0	**9.0**	6.0	0.0	0.0	0.0	**6.0**	**15.0**	**40.0**	0.0
	Roundup	Hatchet R-15-S	0.6	0.0	0.0	**0.6**	21.9	38.1	0.0	0.0	**60.0**	**60.6**	**100.0**	0.0
		Hatchet R-15-Z	0.0	0.0	0.0	**0.0**	31.1	32.2	0.0	0.0	**63.3**	**63.3**	**100.0**	0.0
		Saw R-100-S	0.0	0.0	0.0	**0.0**	10.0	18.9	25.0	0.0	**53.9**	**53.9**	**100.0**	0.0
		Saw R-100-Z	0.0	0.0	0.0	**0.0**	11.3	23.8	17.5	0.0	**52.5**	**52.5**	**100.0**	0.0
		Drill R-100-S	0.0	0.0	0.0	**0.0**	2.2	4.5	12.2	0.0	**18.9**	**18.9**	**100.0**	77.8
		Drill R-100-Z	0.0	0.0	0.0	**0.0**	1.1	1.1	3.3	0.0	**5.6**	**5.6**	**100.0**	94.4
		Hatchet R-100-S	0.0	0.0	0.0	**0.0**	8.6	18.6	21.4	0.0	**48.6**	**48.6**	**85.7**	0.0
		Hatchet R-100-Z	0.0	0.0	0.0	**0.0**	13.1	16.9	30.8	0.0	**60.8**	**60.8**	**100.0**	0.0

Table 2 to be continued

		Variant	Colour changes according to the needle year-class (%)				Defoliation to the needle year-class (%)					Sum of defoliation (%)	Affected trees (%)	Dead trees (%)
			I	II	I+II+III	Σ	I	I+II	I+II+III	defoliation of tree top (%)	Σ			
2008-II	Garlon	Saw G-10-S	0.0	0.8	0.0	**0.8**	0.0	0.0	0.0	0.0	**0.0**	**0.8**	**8.3**	0.0
		Saw G-10-Z	5.7	0.7	0.0	**6.4**	1.4	0.0	0.0	0.0	**1.4**	**7.9**	**42.9**	0.0
	Roundup	Saw R-15-S	0.0	0.0	0.0	**0.0**	22.0	13.0	3.0	8.0	**38.0**	**38.0**	**100.0**	0.0
		Saw R-15-Z	0.0	0.0	0.0	**0.0**	8.6	18.6	1.4	7.1	**28.6**	**28.6**	**92.9**	0.0
		Drill R-15-S	0.0	0.0	0.0	**0.0**	23.8	16.9	6.9	5.4	**47.7**	**47.7**	**100.0**	7.7
		Drill R-15-Z	0.0	0.0	0.0	**0.0**	19.1	13.6	6.4	11.8	**39.1**	**39.1**	**100.0**	18.2
		Saw R-100-S	0.0	0.0	0.0	**0.0**	8.3	16.1	3.9	22.2	**28.3**	**28.3**	**100.0**	0.0
		Saw R-100-Z	3.8	0.0	0.0	**3.8**	12.5	8.8	7.5	16.3	**28.8**	**32.5**	**100.0**	0.0
		Hatchet R-100-S	0.0	0.0	0.0	**0.0**	5.8	17.5	8.3	21.7	**31.7**	**31.7**	**100.0**	0.0
		Hatchet R-100-Z	0.0	0.0	2.3	**2.3**	7.7	16.9	6.9	21.5	**31.5**	**33.8**	**100.0**	7.7

▭ – Statistically significant difference between variants

After the application of Roundup, marked changes in the colour of needles were noted in all treatments. The needles fell in the course of the first-year winter season (up to 70% of needles). Terminal buds of branches with defoliated annual shoots did not burst buds in the next year. In the spring season, the dieback of the majority (almost 90%) of trees was observed in the "drill" treatment where 100% Roundup concentration was applied. Until the end of the 2008 growing season, all individuals in this treatment died. In the other treatments, the health condition of spruce trees deteriorated, particularly in treatments with the 100% concentration of Roundup, where the dieback of whole crown tops was noted (in variants chainsaw R-100 and hatchet R-100 it was 21% of individuals). The "drill" method appears to be the most effective whereas the chainsaw method was the least effective. The highest extent of discoloration and defoliation of particularly the youngest needle age class occurred in spruce in treatments with 15% concentration of Roundup. At 100% Roundup concentration, several needle age classes were affected simultaneously. In most cases there were statistically significant differences between the health condition of trees after the application of Roundup and that of control trees. Although the treated trees showed marked changes in the health condition, the use of Roundup was sufficiently effective only at application with a drill and 100% arboricide concentration.

The response of different colour forms of blue spruce (Table 2) to the application of arboricides became evident by slightly higher and more frequent damage to the green form than to the silver form of blue spruce, but statistically significant differences were scarce. However, it is not possible to state unambiguously that this form would be more sensitive to the application of chemical products.

On the stems and branches of dead blue spruce trees, 10 species of cambioxylophagous and wood-destroying insects from the following families were found: *Scolytidae* (6), *Cerambycidae* (2), *Curculionidae* (1) and *Lymexylonidae* (1) (Tables 3–5). On the stems, the highest infestation was caused by *H. palliatus* (67.6%), *Ips amitinus* (Eichh.) (25.7%) and *X. lineatus* (13.5%). The family of longhorn beetles (*Cerambycidae*) includes *Isarthron castaneum* (L.) and *Rhagium inquisitor* (L.). Other species such as *P. chalcographus* were of minor proportion (Table 3) while *Cryphalus abietis* (Ratz.) (50.8%) and *P. chalcographus* (29.7%) developed simultaneously with high cover on branches.

The structure of the cambioxylophagous fauna changes due to even relatively small differences in

Table 3. The fauna of cambioxylophages of blue spruce killed by a herbicide (Roundap) (Kalek 2008)

	Food relation	Pests	Economic		Attack (m)		Cover (%)
			importance	slight	medium	heavy	
Species/stem							
X. lineatus	xylophage	secondary	**	7	1	2	13.51
P. chalcographus	cambiophage	primary	***	3	0	0	4.05
I. amitinus	cambiophage	primary	***	9	9	1	25.68
H. palliatus	cambiophage	secondary	*	18	17	15	67.57
H. dermestoides	xylophage	secondary	*	2	0	0	2.70
D. autographus	cambiophage	secondary	*	1	0	0	1.35
Cerambycidae	cambioxylophage	secondary	*	16	6	1	31.08
Pissodes sp.	cambiophage	secondary	*	2	0	0	2.70
Species/twig							
C. abietis	cambiophage	primary	**	24	6	2	50.79
P. chalcographus	cambiophage	primary	***	11	6	2	29.69

* slight, ** medium, *** heavy

diameter classes (Table 4). *H. palliatus* was noted along the whole stem profile, decreasing only in the upper third of the tree crown. The retreating trend with diameter characterizes *I. amitinus*, which occupied even the thin top sections. *Xyloterous lineatus* was found only on lower sections with a minimum diameter of 12 cm. Representatives of the family *Cerambycidae* were not present only in the thin top sections of the crown (Table 4). Branches on the large-diameter (butt) stem sections were naturally dead and non-attractive to the insects. From the bottom edge of the live crown towards the crown

Table 4. Cambioxylophagous fauna of blue spruce depending on the stem section diameter (Kalek 2008)

Diameter of a stem section (cm)	16.1–20	12.1–16	8.1–12	4.1–8	0.1–4
			(%)		
Species/stem					
Cerambycidae	83.3	66.7	27.8	16.7	
D. autographus			5.6		
H. dermestoides	16.7		5.6		
H. palliatus	100.0	100.0	83.3	50.0	29.4
I. amitinus		26.7	33.3	33.3	17.6
P. chalcographus			5.6	5.6	5.9
Pissodes			11.1		
X. lineatus	66.7	40.0			
Total sections	6.0	15.0	18.0	18.0	17.0
Species/twig					
C. abietis		81.82	87.5	38.89	5.88
P. chalcographus		41.67	29.41	33.33	17.65
Total sections	1.0	12.0	17.0	18.0	17.0

Table 5. The actual condition of development of the synusia of bark beetles of blue spruce 1.5 years after the arboricide application (Kalek 2008)

	Larvae – death	Larvae	Imagoes	Abandoned gallery systems
	(%)			
Species/stem				
D. autographus				1.35
H. dermestoides				2.70
H. palliatus			2.70	64.86
I. amitinus	14.86		6.76	4.05
P. chalcographus	1.35		2.70	0.00
Pissodes		1.35		1.35
Cerambycidae		31.08		
X. lineatus				13.51
Species/twig				
C. abietis			16.22	27.03
P. chalcographus	2.70	2.70	1.35	18.92

top, the proportion of attack by *C. abieti* decreases progressively while the retreat of *P. chalcographus* was slower and did not reach such high cover in the lower part of the crown (Table 4).

Eighteen months after the application of Roundup and 10–11 months after the tree dieback, it is possible to describe the development of the particular members of cambioxylophagous fauna colonizing blue spruce by analyzing abandoned feeding marks and the occurrence of imagos. *I. amitinus* showed an evidently increased mortality of larvae, nevertheless, the development of some imagos was completed. A part of abandoned feeding marks contained remaining overwintering beetles. *P. chalcographus* also showed a partial mortality of larvae both on the stems and on the branches. Although imagos were caught in feeding marks, the decisive part of the population abandoned the place of feeding. *C. abietis* showed the most balanced proportion between wintering imagos and abandoned feeding marks. Members of the family *Cerambycidae* occurred only in the larval stage (Table 5).

DISCUSSION

Although the changes in the health condition of treated blue spruce were marked, the resulting effect was not satisfactory in the majority of monitored treatments. Vyskot et al. (1973) reported rusting and mass fall of needles from the upper parts of crowns of Norway spruce (*Picea abies* [L.] Karst.) trees 2–4 weeks after treatment while lower whorls of treated spruce trees remained mostly green. Increased insolation and air temperature subsequently accelerated the dieback of injected trees. Procházka (1973) found out that as many as 90% of Norway spruce trees already died two months after the application of arboricides. Differentiated response and the progress of dieback are particularly dependent on the tree species and its sensitivity to arboricides. Blue spruce, compared to Norway spruce, appears to be more resistant. Under natural conditions, its dieback takes place very slowly and clear manifestations of defoliation appear only after the death of the phloem. However, we know very little about the physiological response of spruce trees to the applied arboricides.

The application of an arboricide solution at the beginning of or during the growing season increases its efficacy. Trees appear the most sensitive to chemical treatment during the time of intensive growth from budbreak to June (Jurča, Vašíček 1966). Procházka (1973) noted that the arboricide application in the growing season was more reliable than in the period of dormancy. In this study, the period of application was therefore selected in accordance with these recommendations, i.e. in the growing season (June).

Tree species, arboricide concentration and its amount are the main factors limiting the efficiency of chemical thinnings. Although both arboricides are recommended to eliminate shrubs and trees, their efficacy was rather low when the prescribed 10% (or 15%) concentration was applied. We found that Garlon was unsuitable to suppress blue spruce trees even at 100% concentration, unlike Roundup, which showed nearly total efficacy when applied undiluted. Thus, there remains a question of the application rate which was markedly lower than that applied in Norway spruce by Procházka (1973) and Vyskot et al. (1973).

Regarding the potential contamination of the environment by chemical substances, it is necessary to point out that both monitored arboricides (Garlon 4 EC and Roundup Klasik) can be diluted in water and are approved for use in the forest management sector. They do not leave any residues in contrast to formerly used arboricides containing arsenic and diluted in oil products (Vyskot et al. 1972).

When chemical thinning is used, it is inevitable that the phenomenon of increased danger of insect pest occurrence must be considered, chiefly because trees can become very attractive to cambiophages. In most cases of chemical thinning, this risk can be minimized by ensuring the fast course of the process of dieback of treated trees. Appropriate dosage and application ensure the fast penetration of an arboricide which rapidly disturbs the assimilatory apparatus causing the stem phloem to markedly increase its water content. The phloem ferments and becomes highly attractive to *H. palliatus*, which ranks among secondary invasive species. This species uses available trees for the spring invasion and becomes an important food competitor for other potentially more noxious bark beetle species developing on stems. In spite of the potential for mass outbreaks, *H. palliatus* does not represent a significant danger for forest stands because it does not attack living trees. The presence of *I. amitinus* on treated blue spruce trees, a species preferring spruce stands aged more than 60 years and typically occurring simultaneously with *Ips typographus*, appears to be surprising and interesting from the forest protection aspect. It can develop on blue spruce because it is able to use even thin phloem layers of the stem, similarly like on *P. abies*, where it colonizes the crown top part of the stem and the thick branches. The decreased quality of the phloem (high water content) is probably the reason behind the increased mortality of larvae and hindered insect development on the stem. We do not foresee the direct toxicity of arboricides to cambioxylophages to be a factor affecting their mortality. The elimination of blue spruce by arboricides will require partial inspection of the occurrence of *I. amitinus* on the stems as well as on logging residues originating from thinning.

P. chalcographus and *C. abietis* did not become markedly evident on the stem parts but attacked primarily the branches of the lower part of the crown. As a consequence of dying branches at the tree top, a higher degree of attack was observed on the large-diameter branches in the lower part of the crown. The occurrence of longhorn beetles, particularly of *I. castaneum*, reflects changes in the quality of the phloem and proves its high attractiveness e.g. "lightning trees" (Kula, Zabecki 1997a,b). Similarly, the presence of *Xyloterus lineatus* on relatively small-diameter stems is interesting. This type of dieback and species spectrum are close to qualitative changes in the phloem and the structure of fauna on standing spruce breaks in stands of the 2nd and 3rd age classes but also in mature stands (Kula, Zabecki 2006; Kula et al. 2006).

CONCLUSION

Both arboricides tested in this study showed very low efficacy when applied in prescribed concentrations to carry out chemical thinning. When undiluted concentrations were applied, Garlon was not effective, while Roundup eliminated a significant proportion of blue spruce trees if applied using a drill. No significant differences were found in the response of the silver and green forms of blue spruce to the application of arboricides.

In the community of cambioxylophages colonizing blue spruce trees killed by herbicides (Roundup only), a dominant position was taken by the economically unimportant *H. palliatuss*, accompanied by *I. amitinus* and *P. chalcographus*, both important from the aspect of mass outbreaks. In these species, partial mortality of larvae was observed probably attributable to the decreased quality of the phloem.

Chemical thinning of blue spruce stands appears to be a viable technique of restoring these stands to their original tree species composition. However, care must be taken to avoid a significant increase in the risk of bark beetle mass outbreaks by providing suitable breeding habitats in dying trees.

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