Collection: IUFRO 7.01.00 - COST Action FP0903, Kaunas (Lithuania - 2012)
“Biological Reactions of Forest to Climate Change and Air Pollution”
Guest Editors: Elena Paoletti, Andrzej Bytnerowicz, Algirdas Augustaitis

Assessment of sanitary conditions in stands of Norway spruce (*Picea abies* Karst.) damaged by spruce bud scale (*Physokermes piceae* Schrnk.)

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Received: Jul 24, 2012 - Accepted: Dec 03, 2012

Citation: Miezite O, Okmanis M, Indriksons A, Ruba J, Polmanis K, Freimane L, 2013. Assessment of sanitary conditions in stands of Norway spruce (*Picea abies* Karst.) damaged by spruce bud scale (*Physokermes piceae* Schrnk.). iForest 6: 73-78 [online 2013-02-07] URL: http://www.sisef.it/iforest/contents/?id=ifor0703-006

Communicated by: Alberto Santini

Spruce bud scale (*Physokermes piceae* Schrnk.) affects tree growth directly and indirectly. Direct injury appears in the form of tissue damage, as insects suck sap from tree phloem. Indirect injury appears as “honeydew”, which results in negative effects on tree growth. Plant sap is saturated with various carbohydrates called photosynthates that are difficult for scaly insects to digest. Therefore it is secreted in excrements, which are subsequently a food source for the black sooty mold (*Apiosporium pinophilum* Fuckel). The fungus covers needles blocking stomata, causing decreased transpiration and photosynthesis. An inexplicable wither of Norway spruce was reported in Latvia during 2010 due to black sooty mold. However, spruce bud scale was not evident. In 2011, mass propagation of spruce bud scale was observed following the 2010 Norway spruce loss. One objective of this research was to determine if Kraft tree growth classes could be applied to establish the factors responsible for tree foliage damage. Six 21 - 40 year old (second age class) Norway spruce stands were evaluated. Two circular sample plots with a 7.98 m radius, and a 200-m^2 area were randomly established per each forest stand hectare. Diameter at breast height (dbh, 1.3 m), and height of approximately 30 trees was measured to model a trend. For all trees, Kraft class, and foliage damage level caused by spruce bud scale and black sooty mold were determined. Significant differences were not observed in tree damage levels among stands, however significant differences among damage levels in different Kraft classes were detected ($F = 3.45 > F_{crit.} = 2.80$, $\alpha = 0.05 > P = 0.02$) found. Overall damage intensity was 29.3 %. Total forestry loss was 1153 LVL (1640 EUR) for all surveyed stands (10 ha), and 115 LVL (164 EUR) per hectare.

Keywords: Norway Spruce, Spruce Bud Scale, Kraft’s Classes, Damage Intensity, Economical Losses

Introduction

Norway spruce is the second most abundant tree species in Latvian forests, occupying 0.52 million hectares, and nearly 0.14 million are second age class (21-40 years old) forest stands (Latvian State Forest Service 2011). Therefore, it is critical to assess the management risks in growing stand volume now, because it is these stands that will comprise the majority of the cutting volume in 40-60 years. Spruce is a species quite vulnerable to biotic and abiotic factors; therefore its cultivation is increasingly associated with high-risk levels. One of the most widespread causes of Norway spruce stand damage is development of large spruce bud scale colonies.

The first cases of Norway spruce damage were observed in 2009 in middle-aged stands on drained soils. In August of 2010, monitoring by Riga Forests revealed 24% of the stands were damaged, and 10% of *Picea abies* stands were reported dead. Management made the decision to avoid further spruce bud scale propagation by felling 300 ha of Norway spruce forests in sanitary clear-cuts (Lazdins et al. 2011).

Physokermes piceae Schrnk. belongs to the Coccidae family, order Hemiptera, and are characterized by sexual dimorphisms, with a high ability to adapt to a parasitic lifestyle on host plants (Rasina & Rupais 1994). Adult females are globular with a pronounced curvature, shiny, and brown to reddish-brown in color. Female length averages 3.5 mm, width 3.0 mm, and height 3.5-4.0 mm. Males are winged, average 1 mm long, and rarely encountered (Ozols 1985). Males have a discernable head, chest and abdomen, three pairs of legs, and one pair of wings (Graora et al. 2012). The species develops one generation per year. Immature stages winter at the base of terminal buds, less often on needles. In May, the instar larvae move to the base of new buds by old bud fissures. By the end of May or beginning of June, the females have already developed. Settling on the trunk and twigs, individuals suck sap through the bark vascular tissue. At the end of June or beginning of July, the insects lay eggs beneath themselves, and soon die (Ozols 1985). Several studies report one female lays 800-3 000 reddish eggs (Novak 1974, Turgut er & Ülgenturk 2006, State Forest Service 2010). Pink first instars, called “crawlers” hatch in July, and attach themselves to new buds or the underside of needles. In October, crawlers molt into the second instar, and change color from pink to brown. The second instar larvae continue to suck sap, and subsequently overwinter on the branching parts or the lower side of the spruce needles. In spring, a small portion of the overwintering population travels to the needles, where in May the individuals pass through prepupal and pupal stages, developing into winged males (State Forest Service 2011, Lazdins et al. 2011). After wintering, most second instars attach themselves among the budding forked branch apices, where molting occurs, and round yellowish females emerge that gradually darken, and are easily noticeable (State Forest Service 2010, Lazdins et al. 2011).

Spruce bud scale is considered a secondary pest that promotes processes leading to tree death (Ozols 1985). A secondary insect pest is when colonizes plants already compromised by some other currently undetermined stress factor. Lazdins et al. (2011) reported spruce bud scale often occur in such quantities that it covers the entire tree sprout. Fe-

Box 1 - List of abbreviations.

The following abbreviations are used throughout the text:
- **AS "LVM"**: Joint Stock Company "Latvian State Forests"
- **CD**: Compact disc
- **CSB**: Central Statistical Bureau
- **EUR**: The monetary unit of European Union - Euro
- **F**: G. Fisher's empirical value
- **F_{crit}.**: G. Fisher's critical value
- **LLU**: Latvia University of Agriculture (in Latvian)
- **LRMK**: Cabinet of Ministers of the Republic of Latvia
- **LVI**: Latvia's press
- **LVL**: Latvian State monetary unit - Lat.
- **LVMI "Silava"**: Latvian State Forestry Research Institute "Silava"
- **mel.**: meliorated (drained)
- **SIA**: A limited liability company
- **URL**: Universal resource locator

males suck ligneous plant sap, but also excrete "honeydew" that blocks leaf stomata, and covers branches, shoots, and needles, inhibiting plant physiological processes. Disturbance of tree physiological processes infested by bud scale is amplified by development of black sooty mold (*Apiosporium pinophilum* Fuckel), which almost completely covers the needles, branches, and trunk with black sooty dew (Novak 1974). The development and spread of black sooty mold is promoted by shade and high humidity (Vanins 1956, Novak 1974). Trees covered by the mold become more prone to pests and diseases, especially during winter desiccation. However, spruce bud scale insects and black sooty mold are only factors that increase the species vulnerability to other impacts. Transpiration occurs during winter, and when roots cannot uptake water from the soil due to freezing, there is also the risk of winter desiccation. Consequently, winter dehydration risks are increased by moisture deficits caused by the combined effects of spruce bud scale and black sooty mold (Maurina 1987).

Spruce bud scale exhibits the highest frequency on spruce growing under dry, poor soil conditions, and in seeded plantations and city parks (Rupais 1981, Graora et al. 2012). Infestation in cities might be associated with pollution that compromises spruce species. However, this is inconsistent with events observed last year, when spruce bud scale primarily colonized stands of *Myrtillosa mel.* forest type. Furthermore, in Lithuania damage first occurred in Norway spruce stands located on drained soils, and subsequently other forest types were affected (State Forest Service 2010, Lazdins et al. 2011).

A connection between damage to Norway spruce stands and spruce bud scale has also been reported from Lithuania, Poland near the Lithuanian border, and southern Sweden, among other parts of the world. Nevertheless, Lazdins (2011) indicated the scientific evidence demonstrating the mass propagation and migration of this pest has not been established for any European state. Therefore, it is vital to establish baseline data on the relationship between *Ph. piceae* and *P. abies*. Consistent with this broad research objective, we set the following goal: analyze sanitary conditions in Norway spruce stands damaged by spruce bud scale. Three alternative measures were identified to address this objective: (1) evaluate Norway spruce vitality in forest stands damaged by spruce bud scale based on tree Kraft classes; (2) analyze significant damage risks in Norway spruce stands; (3) calculate forestry economic losses as a result of spruce bud scale damage in Norway spruce survey stands.

Materials and Methods

Six second age class forest stands were evaluated in the current research. Stand coordinates and primary characteristics are given in Tab. 1. In August 2011, two circular sample plots with a 7.98 m radius and a 200-m^2 area were randomly established per each forest stand hectare. The classification system of the German forester Kraft that subdivides trees into five growth classes was applied to evaluate tree condition. Kraft classes were determined for all trees, *i.e.*, a cumulative designation derived from tree condition in the stand was established by evaluating height, diameter at breast height (dbh, 1.3 m above ground), and crown width. An individual tree was characterized as predominant, dominant, co-dominant, suppressed, or completely suppressed (Kraft 1884). Forest stands were selected for sampling in the beginning of summer 2010, and verified in June 2010 and June 2011 by establishing species attacked by insects. Every damaged tree crown was visually divided into three parts: upper, middle, and lower. All trees in sample plots were assigned five damage levels. All damage levels were represented on a sample tree; subsequently a branch saw was used to collect sample branches and establish *Ph. picea*. Crown damage was rated applying the following five point system: 0 - healthy tree; 1 - needle quantity decreased by one third; 2 - needle quantity decreased by two thirds; 3 - tree withering with yellow-green needle color; and 4 - tree withered

Tab. 1 - Dendrometric indicators of the surveyed Norway spruce stands damaged by spruce bud scale *Physokermes piceae* (Schrnk.). (D): average breast height (1.3 m) diameter, cm; (H): average tree height, m; (G): basal area, m^2 ha^{-1}; (M): stand volume, m^3 ha^{-1}; (E): Norway spruce; (P): Scot's pine; (B): silver birch.

Stand location, quart/ subquart	Coord.	Area of tree stand (ha)	Forest site type/stand composition	Age (years)	Site index	D (cm)	H (m)	Density	G (m^2 ha^{-1})	M (m^3 ha^{-1})
Livberze, 189/25	56°41'44.1" 23°35'42.8"	1.8	*Oxalidosa* 10E+P	26	II	14.5	11.9	7	17	103
Livberze, 196/24	56°41'41.3" 23°35'37.5"	1.1	*Hylocomiosa* 9E1P	27	I	15.7	12.8	8	19	119
Jelgavas MPS, 32/10	56°43'17.9" 23°45'6.1"	2.5	*Myrtillosa mel.* 9E1P+B	34	Ia	15.6	15.0	9	26	207
Jelgavas MPS, 42/9	56°42'59.9" 23°45'06.5"	1.8	*Myrtillosa mel.* 10E+B	38	I	15.8	16.6	9	28	251
Dzelzamurs, 292/24	56°39'28.9" 24°20'01.0"	1.5	*Myrtillosa-sphagnosa* 10E+B	22	Ia	11.5	11.5	8	19	127
Viesite, 51/25	56°24'12.6" 25°27'53.3"	1.3	*Hylocomiosa* 10E	40	Ia	16.0	17.6	9	27	253

in the current year with yellow and brown needles.

The damage level differences (*a priori* $\alpha = 0.05$) in individual tree Kraft classes were quantitatively evaluated using an analysis of variance (ANOVA) with three factors (F-test) in MS Excel 2010 (Arhipova & Balina 2003). Factor "A" was the number of damaged young spruce growth by spruce bud scale, factor "B" was individual Kraft class, and factor "C" was the average calculated tree crown damage level in each sample plot.

The smallest sample plot number was three, therefore for individual stands, one or two sample plot values were randomly eliminated.

To assess damage risk, two equations were used. The first equation determines damage incidence in a stand, *i.e.*, the percentage of trees damaged (eqn. 1):

$$P = \frac{n}{N} \cdot 100$$

where P is the damage incidence in a stand (%); n is the number of damaged trees in a given stand, pcs. per hectare; and N is the total number of trees in a given stand, pcs. per hectare. The second equation determines the degree of damage to a stand (eqn. 2):

$$R = \frac{\sum (n_i \cdot b_i)}{n \cdot k} \cdot 100$$

where R is the damage intensity (%); N is the total number of counted trees, pcs.; k is the highest damage level, grade; n_i is the number of trees in the given damage level, pcs.; and b_i is a given damage level.

The economic loss resulting from spruce bud scale was assessed by calculating results for trees with crown damage rated at Kraft class levels 3 and 4, because these trees cannot be saved. The economic gain of using wood from damaged trees as firewood was also calculated, because pest damaged wood cannot be used for saw logs or pulpwood. The potential industrial wood amount (had the trees not been damaged) was also calculated according to average diameter and tree species. The assortment outcome was calculated, and multiplied by price range (Central Statistical Bureau of Latvia 2011), and the potential income, had the wood not been pest damaged, was obtained. The economic loss resulting from spruce bud scale was obtained by subtracting the income gained by using the wood for firewood from the potential income.

Forest roads border most of the survey stands. Despite traffic intensity being much lower on forest roads than city roads, air pollution is still greater in comparison to the interior forest. Five surveyed forest stands are located between drainage ditches. In addition, five stands are bordered by other Norway spruce stands. The high proportion of spruce increases the probability for spruce bud scale to spread; bud scale migrates over short distances *via* wind or direct tree crown contact. However, one Norway spruce stand (Jelgava, 42/9) is surrounded by Scots pine (*Pinus sylvestris* L.), which suggests bud scale migrated to healthy Norway spruce, and propagated by some unknown stress factor, or conditions favorable to bud scale.

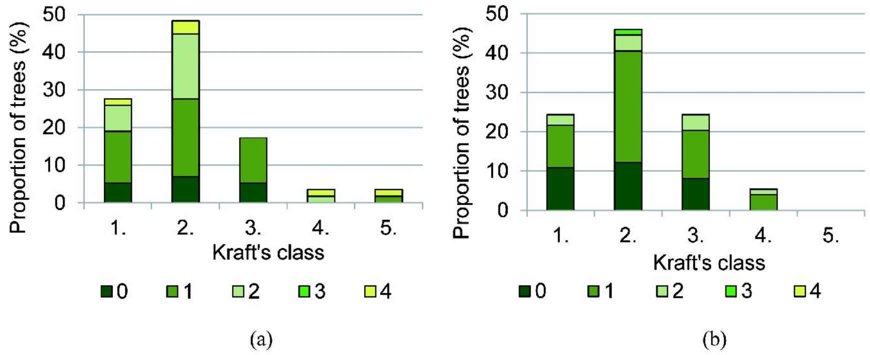

Fig. 1 - Tree proportion (%) by damage level in Kraft's classes in Norway spruce stands damaged by bud scale. (a): Livberze 189/25; (b): Livberze 196/24.

Results and Discussion

Dispersion of spruce bud scale damage based on Kraft classification classes

Tree growth is dependent on various environmental factors (biotic and abiotic) in a specific geographic region. As a result of the interaction among these factors, some trees grow more rapidly, have wider stems, and broader crowns, while growth is stunted in others, *i.e.*, tree differentiation occurs according to size. It is necessary to characterize and classify trees in a forested area to conduct silvicultural activities. The results of our forest survey stands showed middle damage level trees were more abundant in less tall trees. Kraft class of predominant trees exhibited a lower value (0.96), than suppressed trees, which showed a higher value (1.58). The significance of the factors was verified using Fisher's empirical value (F) compared to the critical value (F_{crit}). Significant differences between damage levels were detected ($F = 3.45 > F_{crit.} = 2.80$; $p = 0.02$). However, no significant differences in tree damage levels were observed among stands ($F = 2.27 < F_{crit.} = 2.41$; $p = 0.06$). Damage level of forest stands was dependent on the cumulative Kraft class of all individual trees, therefore it was essential to analyze stands by Kraft class and damage level, as well as overstory damage stages (predominant, dominant, co-dominant), and understory (suppressed, completely suppressed). Six graphs were created (Fig. 1, Fig. 2, Fig. 3) to represent these relationships, where 100 % indicates all stand trees.

In the spruce bud scale damaged Livberze 189/25 stand (Fig. 1a), healthy trees were only identified in the overstory, and totaled 17 %. The majority of trees were rated a 1 point value (48 % of the stand trees). Irreversibly damaged trees comprised one-half of the understory. Understory trees constituted only 8 % of the total stand trees, which had relatively small dimensions. Therefore, it can be assumed that serious damage had not yet affected the survey stands. In the overstory, 5% of trees were irreversibly damaged, resulting in more serious economic losses. Completely healthy trees (31 %) were also identified, but only in the overstory of the spruce bud scale damaged Livberze 196/24 stand (Fig. 1b). In contrast to the first stand, the majority of the second stand trees were rated at damage level 1 (55 %). At damage level 3 Kraft class 2 (dominant), 1 % of trees were identified. Lastly, no withered trees were observed.

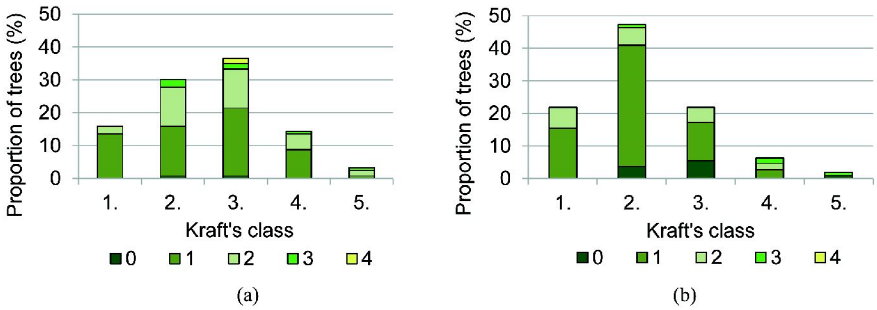

Fig. 2 - Tree proportion by damage level in Kraft's classes in Norway spruce stands damaged by bud scale. (a): Jelgava 32/10; (b) Jelgava 42/9.

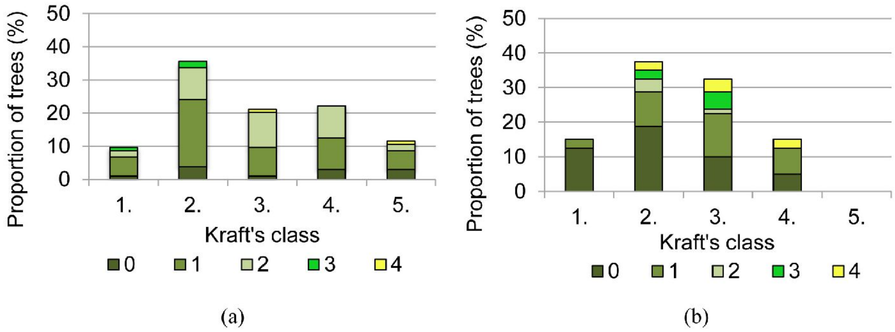

Fig. 3 - Tree proportion by damage level in Kraft's classes in Norway spruce stands damaged by bud scale. (a): Dzelzamurs 292/24; (b): Viesite 51/25.

At the spruce bud scale damaged Jelgava 32/10 (Fig. 2a) stand, only 2 % of the trees were healthy. Consistent with previous stands, 59 % of all Jelgava 32/10 trees exhibited damage level 1. Irreversibly damaged trees were also identified at an increased rate; 2 % in each of the 2nd and 3rd Kraft classes; and 1 % in each of the 4th and 5th Kraft classes. Therefore, based on the study plots, 6 % of the tree viability in this stand will not be restored. Withered trees (*i.e.*, damage level 4) were only identified in Kraft class 3 at a rate of 1 %. Results indicated 10 % healthy trees at the spruce bud scale damaged Jelgava 42/9 forest stand (Fig. 2b), 67 % with crown damage at damage level 1. However, the stand contained no completely withered trees (*i.e.*, damage level 4), and only 1 % of the overstory trees received three points (*i.e.*, damage level 3). The remaining 3 % of nonviable trees resided in the understory.

Results identified 12 % healthy trees at the spruce bud scale damaged Dzelzamurs 292/24 forest stand (Fig. 3a). Fifty percent of the trees were identified at damage level 2. Damage level 3 was observed in Kraft classes 1 and 2, totaling 3 %. Withered trees (*i.e.*, damage level 4) were in Kraft classes 3 and 5, each at 1 %. A total of 5 % of spruce bud scale damaged trees were irreversibly damaged. Results identified different conditions at the spruce bud scale damaged Viesite 51/25 stand (Fig. 3b), where nearly half the trees were healthy (46 %). However, this stand also showed the highest irreversibly damaged tree percentage (16 %). The least damaged trees were in Kraft class 1 (predominant trees). It is notable that trees from this stand of Kraft classes 2 and 3 (dominant and co-dominant) were largely damaged, with 7 % withered, and 8 % irreversibly damaged.

All forest stands damaged by spruce bud scale exhibited trees with varying Kraft classes and damage levels, withered trees in Kraft class 1 were not identified in any stands.

Damage risk significance in Norway spruce forest stands

Risk analysis is an evaluation process that includes the definition of undesirable events, and potential cause and effect analyses (Kaktins & Arhipova 2002). Supervising forest risks, particularly in tree stands, is becoming increasingly important. Pests are among the highest risks (Arbez et al. 2002). Spruce bud scale affects tree growth directly and indirectly. Direct injury occurs through tissue damage, as the insect sucks sap to feed from

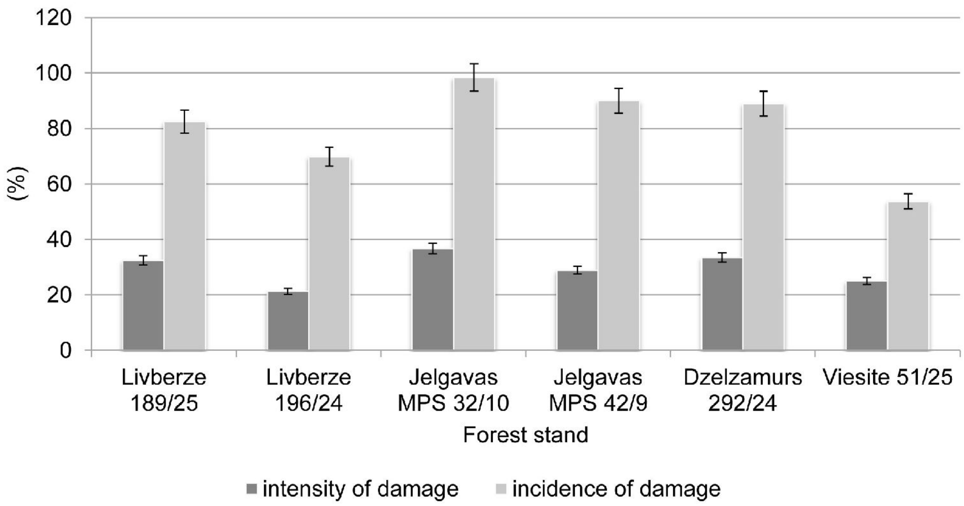

Fig. 4 - Spruce bud scale damage intensity and incidence in the surveyed Norway spruce stands.

Tab. 2 - Potential industrial- and firewood yields resulting from sanitary cuts of spruce bud scale damaged stands.

Stand location, quart./subquart.	D (cm)	Number of industrial trees (%)	Outcome of industrial wood (%)	Damaged wood (m^3 ha^{-1})	Area of tree stand (ha)	Industrial wood (without residues - m^3 ha^{-1}) thin logs %		pulp-wood %		total	Firewood (m^3 ha^{-1}) %	
						thin logs %	thin logs m^3	pulp-wood %	pulp-wood m^3	total m^3	%	m^3
Livberze, 189/25	14.5	92	81	6.2	1.8	28	1.4	72	3.6	5.0	8	0.5
Livberze, 196/24	15.7	92	82	0.1	1.1	47	0.039	53	0.043	0.08	8	0.01
Jelgava, 32/10	15.6	92	82	9.2	2.5	47	3.5	53	4.0	7.5	8	0.7
Jelgava, 42/9	15.8	92	82	3.5	1.8	47	1.3	53	1.5	2.9	8	0.3
Dzelzamurs, 292/24	11.5	88	72	7.5	1.5	0.0	0.0	100	5.4	5.4	18	1.4
Viesite, 51/25	16.0	92	82	27.6	1.3	47	10.6	53	12.0	22.6	8	2.2

Tab. 3 - Potential incomes from sanitary cuts of bud scale damaged stands.

Assortment	Average volume (m^3 ha^{-1})	LVL per m^3	Income per ha	
			LVL	EUR
Thin logs	2.77	41.40	114.78	163.32
Pulpwood	4.31	29.70	127.90	181.99
Firewood	0.81	18.00	14.65	20.85
Total			257.34	366.16

tree phloem. This sap contains organic substances, *i.e.*, photosynthate required for normal tree growth, and this supply is depleted. Secretions from spruce bud scale, the so-called "honeydew", indirectly affects tree growth. Spruce bud scale cannot digest certain carbohydrates in the phloem sap, and these carbohydrates are subsequently secreted in the insect excrement. These carbohydrates are then used as nourishment by various organisms, including the black sooty mold saprophyte (Sabelis 1997). In all surveyed forest stands, the fungus created a dark coating covering tree needles, which blocked stomata, inhibiting transpiration and photosynthesis.

The extent of damage caused by spruce bud scale in the forest survey stands was determined by calculating two values: incidence of damage (eqn. 1), and intensity of damage (eqn. 2 - Fig. 4). Analysis of damage incidence to Norway spruce stands by spruce bud scale showed it was not influenced by stand density, as the damage incidence was 29 % greater in the Livberze 189/25 stand with a density of 7 (Tab. 1) compared to the Viesite stand with a density of 9. The highest damage incidence was in Jelgava 32/10, which occupies the largest area, and the lowest incidence was in Livberze 196/24 stand, with the smallest area. Stands located on mineral soils (forest site types *Hylocomiosa* and *Oxalidosa*) appeared to have a lower damage incidence than stands on drained mineral soils (forest site type *Myrtillosa mel* .), which was consistent with data reported by Lazdins (2010). The lowest prevalence of spruce bud scale damage was at the Viesite stand, where the average tree height was the highest (17.6 m).

It is also important to assess, whether tree basal area has decreased below the minimum set by legislation (Latvian Cabinet of Ministers Regulation No. 892 "Regulation on the tree cutting in woodlands", Annex 1 - LRMK 2006). None of the stands have damage significant enough to require decreasing basal area. Therefore, it is advisable to perform sanitary felling of pest invaded and damaged trees where viability has been totally or partially compromised. The largest loss is at the Viesite 51/25 stand, although damage spread is lowest. The number of damaged trees, and not damage level determines damage spread, and a correlation cannot be drawn between spread and loss. The Viesite 51/25 stand trees are the largest dimensionally, which explains the comparatively large losses.

Economic losses to forestry as a result of spruce bud scale in Norway spruce survey stands

Stand sanitary conditions influence productivity, which is an important index for forest owners and managers. Tab. 2 provides the calculated timber volume damage for forest survey stands. The volume of irreversibly damaged Norway spruce tree stems was 87.7 m^3. Four forest stands (Livberze 196/24, Jelgava 32/10 and 42/9, Viesite 51/25) had the same industrial wood volume (82 %); therefore the range of outcome was also the same. The industrial wood volumes at Livberze 189/25 were 81 %, and 72 % at Dzelzamurs 292/24. Five of the stands yielded the same firewood (8 %) amounts, with the exception of Dzelzamurs 292/24 (18 %). The residual sum for each stand was 10 %.

Total yields were 5.1 m^3 and 43.6 m^3 of firewood and industrial wood, respectively. The range of outcomes is defined based on average tree diameter and percentage of timber, therefore here it was not feasible to yield large sized sortiments, *e.g.*, saw logs.

Firewood and pulpwood are the only possible yield from the Dzelzamurs 292/24 stand. The other stands will also yield thin logs.

Average price for round wood was obtained from 2011 CSB statistical data (Central Statistical Bureau of Latvia 2011). The greatest income is expected from pulpwood, since dbh in the stands ranged from 11.5 - 16 cm (Tab. 3).

Potential income was calculated by adding the various incomes gained from all six maintained stands, which totaled 257 LVL (366 EUR) per hectare. Adjusting the potential income for total surveyed stand area (10 ha), the sum was 2573 LVL (3662 EUR). The income following adjustment for damaged trees harvested as firewood was 1421 LVL (2022 EUR). By subtracting the sum for firewood from potential income, the losses caused by spruce bud scale in all survey stands were ascertained. The total loss was 1153 LVL (1640 EUR) for all survey stands, and 115 LVL (164 EUR) per hectare.

Conclusions

1. Damage levels between tree Kraft classes significantly differed ($P < 0.05$), and average damage level increased as tree dimensions decreased.
2. A higher damage incidence was observed for spruce bud scale in Norway spruce stands located on drained hydro-morph mineral soils (forest site type - *Myrtillosa mel.*) and lower incidence on dry mineral soils (forest site type - *Hylocomiosa*, *Oxalidosa*).
3. The total loss to forestry in the survey stands with total area of 10 ha was 1153 LVL (1640 EUR), or 115 LVL per hectare (164 EUR per hectare).
4. The results of this study indicate sanitary felling is advisable in the survey stands. Second instar larvae winter on branches; therefore remains of all cut trees following stand harvest should be removed.

Acknowledgments

This research is financed through the European Regional Development Fund project: "Decision support system for sustainable forest management" (No. 2010/0208/2DP/2.1.1.0/10/APIA/VIAA/146).

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