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The potential impact of climate change and forest management practices on *Heterobasidion* spp. infection distribution in northwestern Russia – a case study in the Republic of Karelia

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ABSTRACT: *Heterobasidion* spp. is considered as a major pathogen which causes butt and root rots and impairs the forest health. The increasing Earth's temperature could be favourable for *Heterobasidion* spp. in terms of the increased duration of dispersal period. The results of the field work showed that about 35% of visually observed stumps in the southern part of Karelia are rotten, although the laboratory analysis showed that 6% from the total number of observed stumps were infected by *Heterobasidion* spp. Moreover, there are evident long-term trends of increased average annual temperature and number of days per year with mean temperature above +5°C in the Republic of Karelia. It has positive effects on possible distribution of the pathogen and, consequently increased damage to the wood caused by *Heterobasidion* spp.

Keywords: butt rot; root rot; pathogen; decay; coniferous

The first records concerning damage caused by *Heterobasidion* spp. in artificially regenerated pine stands were found in the former Russian Empire which refer to the beginning of the 20th century. Later, when the pathogen's activity was connected with silvicultural practices, the issue concerning damage to pine stands started to be solved by many specialists from different parts of the former USSR. Current publications in Karelia evidently showed that in Kizhskiy reserve and Valaam museum-reserve from five investigated strictly protected natural reserves the existence of *Heterobasidion* spp. was found, in both cases the fungus was identified on spruce samples (Bondarceva et al. 2000). In spite of that according to Krutov *Heterobasidion* spp. is rather a rare species which mainly specializes on old-growth and dying spruce trees (Krutov 2004). While Zavodovskiy identified the *Heterobasidion* spp. occurrence on both spruce and pine dominated stands in the Pudozsky district in Karelia (Zavodovskiy 2005).

Heterobasidion spp. belong to the major fungi causing root and butt rot, infecting Norway spruce and Scots pine. The spores of *Heterobasidion* spp. dispersed mainly by wind are introduced into Norway spruce fresh stumps and damaged trees by harvesting operations (Rishbeth 1951) during the warm season whenever the temperature is above 0°C. They spread by the growth of mycelium to adjacent trees via root contacts and grafts. Spores out of reach for wood tissues are not surviving in the litter layer of the soil without wood substrate, moreover soil bacteria and microorganisms concentrated mostly in the humus layer show antagonistic effects (Vasiliauskas

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1981). While infected after harvesting operations the stumps can provide psychological activity for the fungus up to 30 years (Greig, Pratt 1976).

The incidence of decayed trees enormously varies between the stands due to differences in penetration ability, which is mainly determined by history and age of the stand, forest management and type of the soil (Stenlid 1987). The root infection incidence is highly correlated with previous land use, e.g. stands on former agricultural lands incline to more frequent infections than stands with previous forest history (Rishbeth 1950). Rich soils show slightly more frequent infections than poor soils. According to Vasiliauskas the soil moisture affects the incidence of infection in spruce stands, thus fresh soils (sandy, sandy-loam) contain more infection than the damp ones (Vasiliauskas 1989); at the same time a positive correlation was reported between the age of trees and the amount of infection, as a result in spruce stands the proportion of rotten wood was increasing (Vasiliauskas 1981), which could indicate the infection accumulation. The incidence of rot infection is positively correlated with increasing stump diameter, while the rot frequency decreased with an increased proportion of deciduous trees in the stand (Enerstvedt 1979; Vasiliauskas 1989). Wounded roots, stems, damage to tree crowns with simultaneous general impairment of the stand lead to the epiphytical character of infection. It spreads enormously fast to adjacent trees through the nidus of root systems (Alekseev 1969).

According to the World Meteorological Organization the temperature on the Earth's surface has increased since measurements were first recorded in 1861 (World Meteorological Organization 2015). Thus, during the 20th century the increase was more than 0.6°C. According to Filatov the mean temperature has been increasing between 0.1 to 1.3°C during the period of 50 years (Filatov 2004), from 1950 to 2000 (Table 1), thus a general trend of the increasing mean temperature was noted from the collected data of 6 meteorological stations in different parts of Karelia and is presented in Fig. 1 (Trishkin et al. 2008).

The objective of the study was to assess the potential impacts of climate change on the *Heterobasidion* spp. distribution in the Republic of Karelia. While the specific aims were: (*i*) to determine the occurrence of the pathogen, (*ii*) to evaluate the input of climate change on its development, (*iii*) to assess the input of forest management to the *Heterobasidion* spp. distribution in the Republic of Karelia.

MATERIAL AND METHODS

The study areas are located in the northwestern European part of Russia, in Russian Karelia. The field study has been carried out in six territorial-administrative districts (Prionezhsky, Pryazhinsky, Kondopozhsky, Olonetsky, Suoyarvsky, Pitkyarantsky), which are located in the southern part of Russian Karelia and correspond to the middle taiga zone (Table 2). The tree species composition in Karelia is dominated by conifers. About half of the territory in the Republic of Karelia is occupied by forests, more than 50% are dominated by pine, one-third are spruce forests and about 10% are deciduous forests (Khlustov et al. 2007).

During the field work 22 forest stands have been checked in total. The size of the cutting area varied from 1.0 to 23.7 ha. The average age of spruce trees varied from 70 to 150 years. Stand density varied between 540 and 1,280 stumps per hectare and most cutting areas were previously stands dominated by spruce, however no pure stands were among the chosen ones.

According to the methodology the field work includes visual observation of the stump cross-cut surfaces, establishment of sample plots and cutting discs from the stumps. The main objectives of the field work were fresh Norway spruce (*Picea abies* (Linnaeus) H. Karsten) stumps on fresh logging sites, which were harvested during the winter or spring time of 2007. The number of visually observed stumps was adjusted to represent 10% of the area, thus stumps were verified into 2 categories:

Table 1. Changes of average air temperature for the period 1951–2000 according to data provided by meteorological stations (Filatov 2004)

Meteorological station	Changes of average monthly air temperature (°C)												Average fluctuation during 50 years (°C)
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Louchi (northern)	0.7	3.3	4.6	0.8	2.3	0.0	–0.5	–1.8	0.1	–0.6	–0.7	–0.4	0.4
Kesten'ga (northern)	–0.3	1.5	3.1	0.7	0.7	0.7	–0.2	–1.0	0.3	0.7	–1.1	–0.4	0.1
Padani (middle)	0.4	3.5	4.5	0.4	1.3	–0.3	–0.3	0.2	0.5	0.4	–0.8	–0.5	0.9
Medvezhyegorsk (middle)	0.4	3.0	5.1	0.8	1.7	0.8	–0.1	–0.6	–0.1	0.1	–0.7	–1.5	0.6
Petrozavodsk (southern)	2.0	2.3	3.6	1.9	0.6	0.8	1.1	0.0	0.6	1.1	–0.6	0.2	1.1
Olonets (southern)	2.5	2.5	4.7	2.9	0.9	1.4	1.1	–0.6	0.1	0.6	–0.4	–0.4	1.3

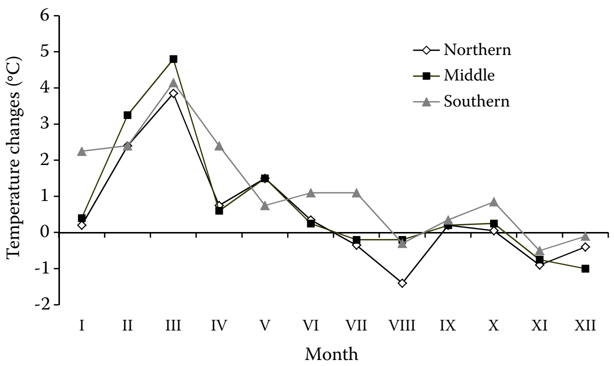

Fig 1. Temperature changes from 1951 to 2000 meteorological stations: northern – Louchi, Kesten'ga, middle – Padani, Medvezhyegorsk, southern – Petrozavodsk, Olonets

healthy and decayed. The systematic sampling within the cutting site was done by making the sample plots of 10 × 10 m. Five plots were assigned per cutting site irrespective of its size. Within the sample plots tree species compositions were identified with measuring the diameters at the stump height. For the sampling and laboratory analysis phase 10 sample discs were taken from each cutting site. Discs from the spruce stumps were cut with a chainsaw making 1–2 cm thick discs, then they were immediately transferred into plastic bags to isolate them from outside infection. Incubation lasted for 7–10 days at room temperature and then the discs were analysed. Main assessment for identifying *Heterobasidion* spp. was their presence at the conidial stage.

Table 2. Location of the stands in Karelia

Forest stand	District	Location
1	Prionezhsky	61°42'47''N 34°14'35''E
2		61°42'24''N 34°14'32''E
3		61°42'44''N 34°12'45''E
4		61°42'46''N 34°12'25''E
5		61°29'29''N 35°00'52''E
6		61°47'50''N 34°03'40''E
7		61°47'31''N 34°04'05''E
8	Pryazhinsky	61°44'44''N 33°49'06''E
9		61°44'41''N 33°50'15''E
10		61°24'59''N 33°18'39''E
11		61°38'04''N 32°38'34''E
12		61°38'04''N 32°39'38''E
13		61°38'32''N 32°38'01''E
14	Kondopozhsky	62°06'28''N 34°30'09''E
15		62°06'36''N 34°31'45''E
16		62°06'45''N 34°31'39''E
17	Olonetsky	61°15'08''N 32°19'45''E
18		61°15'20''N 32°18'41''E
19	Suoyarvsky	62°00'51''N 32°27'40''E
20		62°00'52''N 32°28'02''E
21	Pitkyarantsky	61°42'16''N 31°34'56''E
22		61°42'16''N 31°35'03''E

In order to argue the impact of climate change the climatic data were obtained from 4 meteorological stations in Karelia based upon two characteristics: mean annual temperature and number of days with the mean temperature above +5°C (Razuvaev et al. 1995). Defined periods corresponded to two sets of 30-year intervals, from 1949 to 1978 and from 1979 to 2008. Moreover, based on the processed data from the stations the long-term 30-year modelling has been made.

RESULTS AND DISCUSSION

During the field work a total of 1,430 stumps were examined on 22 cutting sites, while the number of stumps per cutting site varied from 20 to 114. About 64% of visually observed stumps were identified as rotten and 36% as healthy (Table 3). The

Table 3. Results of the visually observed stumps

Forest stand	Number of stumps	Percentage of healthy/decayed stumps	Characteristic of felling
1	63	57/43	sanitary clear cutting
2	60	57/43	
3	83	72/28	
4	89	71/29	
5	111	45/55	clear cutting after windthrow
6	33	61/39	clear cutting
7	20	75/25	
8	36	64/26	
9	65	82/18	
10	95	87/13	
11	114	68/32	
12	81	59/41	
13	108	56/44	
14	82	67/33	sanitary clear cutting
15	49	59/41	selective cutting
16	38	66/34	
17	72	74/26	clear cutting
18	61	69/31	
19	61	46/54	
20	43	56/44	
21	20	45/55	sanitary clear cutting after fire in 2003
22	46	46/54	
Healthy/decayed stumps in total	909/521	63.6/36.4	
Total	1430	100	

Table 4. The incidence of *Heterobasidion* spp. infection on the obtained samples

Forest stand	Mean stump diameter (cm)	Occurrence of mycelium on the stump surface (number of stumps)			Visual distribution of decayed samples (number of stumps)			
		without mycelium	mycelium of *Heterobasidion* spp.	mycelium of other agents	no decay	spotted decay	decay < 50%	decay > 50%
1	23	3	0	7	0	7	2	1
2	23	3	0	7	4	3	1	2
3	21	1	0	9	0	0	5	5
4	20	2	1	7	0	3	5	2
5	26	2	0	8	0	2	3	5
6	22	3	0	7	0	1	3	6
7	23	1	0	9	0	4	2	4
8	29	2	3	5	1	4	3	2
9	23	2	1	7	0	5	4	1
10	22	2	1	7	0	3	4	3
11	19	3	0	7	0	7	3	0
12	20	2	0	8	0	4	3	3
13	20	3	1	6	1	7	2	0
14	23	2	2	6	0	5	4	1
15	42	0	1	9	0	6	4	0
16	38	2	2	6	0	3	5	2
17	25	2	0	8	0	4	5	1
18	25	3	1	6	0	4	3	3
19	26	1	0	9	0	4	2	4
20	20	3	1	6	1	4	3	2
21	33	5	0	5	0	3	1	6
22	31	2	0	8	0	3	1	6
Total number of stumps/total number of obtained samples		49/220	14/220	157/220	7/220	86/220	68/220	59/220
Total number of stumps/total number of obtained samples (%)		22	6	72	3	39	31	27

proportion of rotten stumps varied from 13 to 55%. The number of rotten stumps is evidently high, and the respective consequences are wood losses.

The laboratory analysis indicated that 97% of examined samples were rotten to a different extent. The amount of infected samples varied from 0 to 30% (Table 4). The proportion of samples infected by other agents was up to 90%; this number includes also mould fungi if their mycelium was found on the surface of the stumps. The results of an interview among forestry specialists revealed that most of the respondents were aware of the problem with *Heterobasidion* spp. while they estimated their knowledge of forest health issues as "high enough" and evaluated the real losses in forestry from 3 to 5% of the total harvesting volume.

According to Filatov the mean temperature in Karelia has evidently risen from 0.1 to 1.3°C during last 50 years (Filatov 2004). Based on the obtained temperature statistics milder winters could be expected in the future, warmer springs and autumns, but slightly cooler summers.

Moreover, based on the data obtained from Razuvaev the long-term scenarios of main factors limiting the distribution of *Heterobasidion* spp. have been developed regarding mean annual temperature changes (Fig. 2) and number of days with mean temperature above +5°C (Fig. 3). Both figures have evidently shown an increased number of days per year with mean temperature above +5°C and mean annual temperature changes, which have a positive influence on the distribution of *Heterobasidion* spp. infection and expansion of dispersal period and consequently increased wood damage due to the pathogen.

It can be seen from Table 1 that average temperature increased from 0.1 to 1.3°C. Fig. 3 shows demonstrably the changes in mean temperature, which have occurred during 50 years.

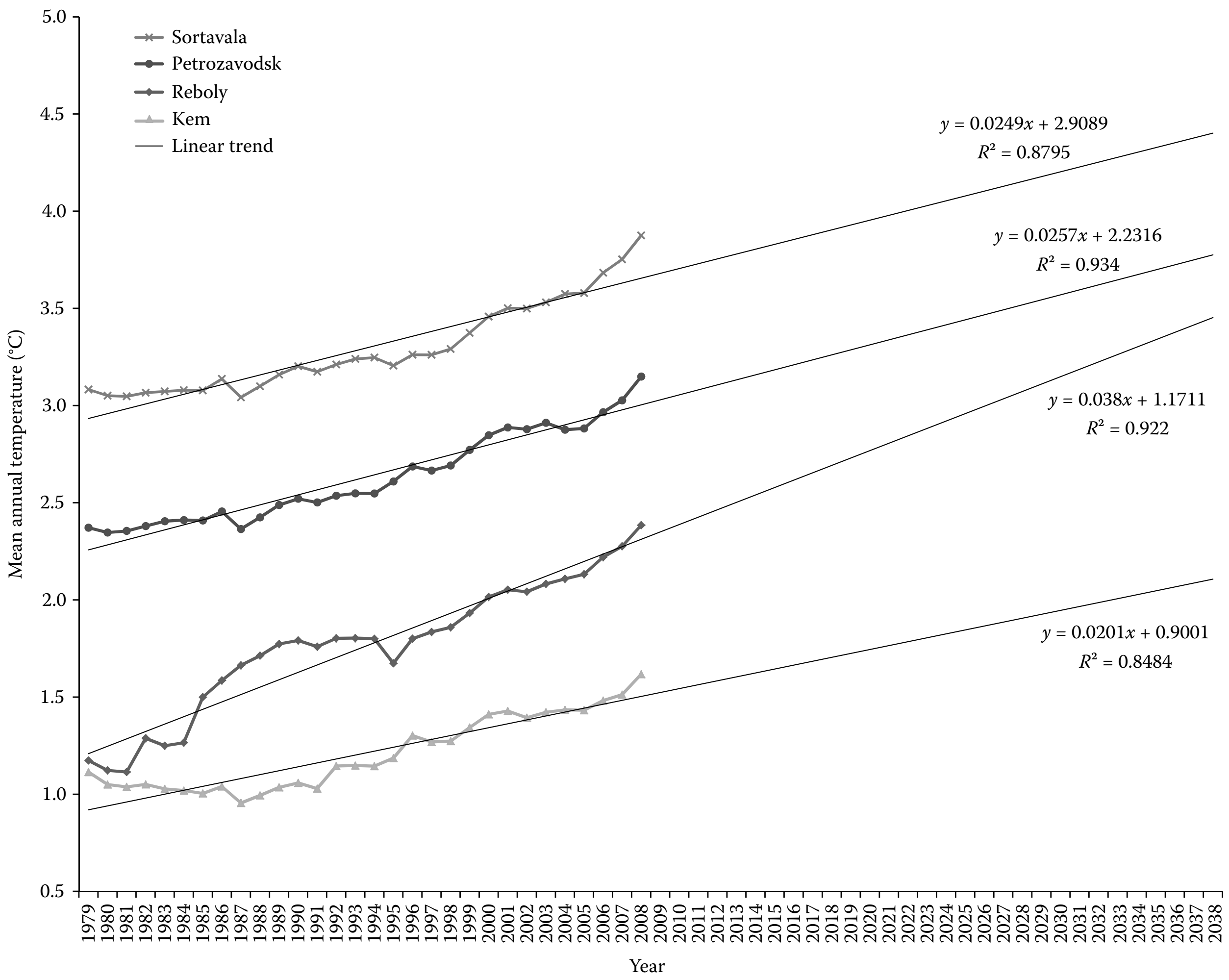

Fig. 2. The trend of changes in mean annual temperature for a 30-year period up o 2038 (meteorological stations in settlements: Reboly, Kem, Sortavala, Petrozavodsk)

Forest management has a huge impact on the current age structure of forests in Karelia which looks quite unevenly distributed, especially middle-aged and mature and overmature classes. About 31% of mature and overmature stands pose a potential threat to the forestry due to the fact that infection caused by *Heterobasidion* spp. could be accumulated in the stand. Thus, interviewing the enterprises showed that harvesting operations are applied quite evenly during the whole year, 54% during the winter and 46% during the summer time, which might imply a high risk of infected stumps during the warm period (Table 5).

The revealed predominance of coniferous tree species in the Republic of Karelia, totally 88% are forests dominated by pine and spruce (Khlustov et al. 2007). There is a high potential infection threat of *Heterobasidion* spp. because it is restricted to coniferous species in the Northern Hemisphere. The current tree species age structure in Karelia reflects quite well the history of forest management in the territory. Karelian forests in their structure have uneven distribution of especially middle-aged and mature and overmature classes. Thus, about 31% of mature and overmature stands would mean that potentially Karelian forests could accumulate infection caused by *Heterobasidion* spp., as it was reported by Vasiliauskas (1981) for stands dominated by spruce. However, no attempts were made to correlate the amount of infection with the stand age in this research.

It should be admitted that on the Russian side, particularly in Karelia, domestic researches concerning *Heterobasidion* spp. are still missing. In addition, there is no official statistics in Karelia concerning *Heterobasidion* spp. occurrence, however Karelian scientists have suggested its potential existence and its scattered distribution has been identified in some parts of southern Karelia: in Kizhskij reserve and Valaam museum-reserve (Bondarceva et al. 2000) on spruce trees; in the Pudozsky district (Zavodovskiy 2005) on both spruce and pine dominated stands. Russian Karelia has a neighbouring location with Finland and also quite simi-

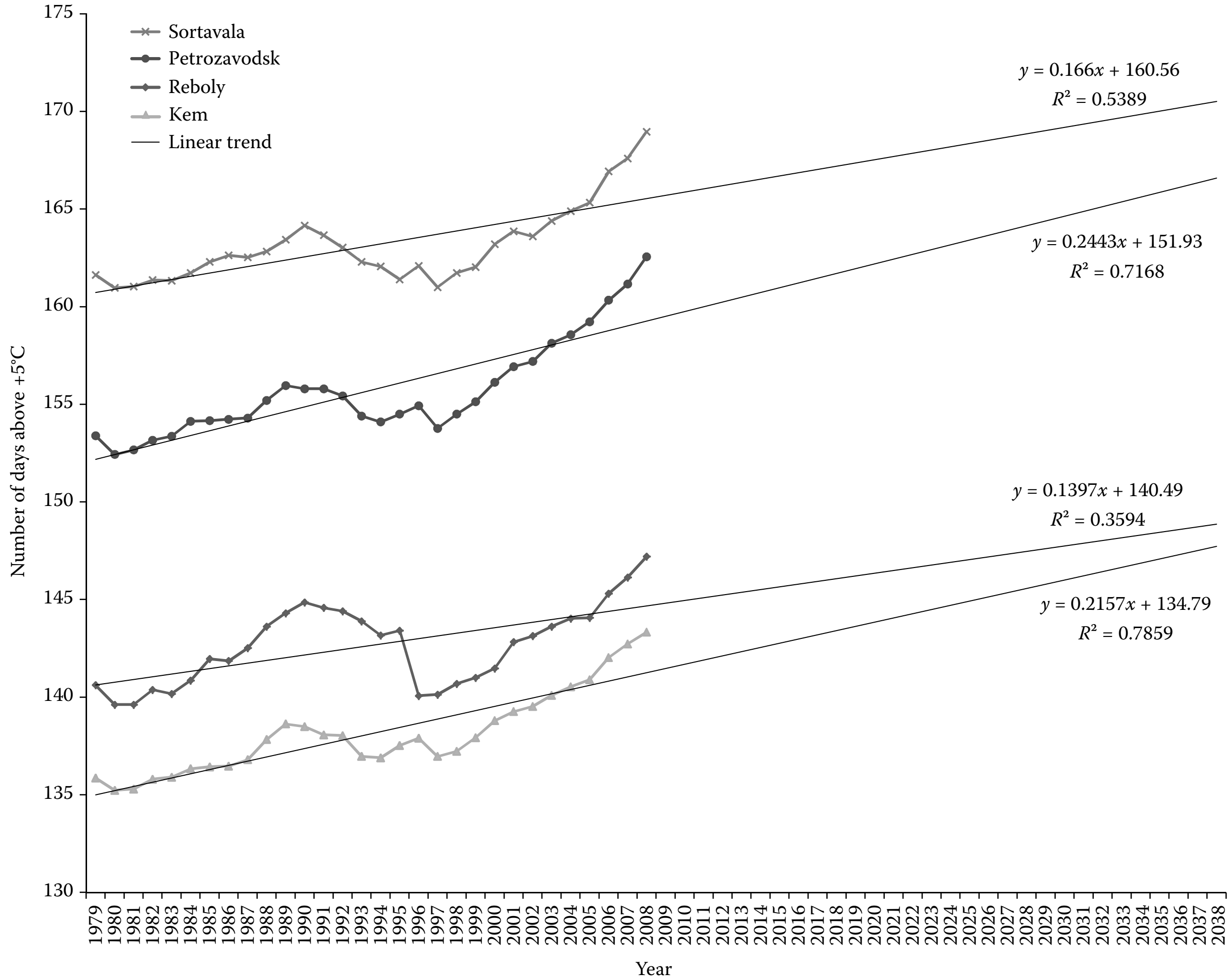

Fig. 3. The trend of the number of days with temperature above +5°C for a 30-year period up to 2038 (meteorological stations in settlements: Reboly, Kem, Sortavala, Petrozavodsk)

lar climatic conditions with central and northern parts of Sweden, hence the knowledge concerning *Heterobasidion* spp. which was acquired in neighbouring countries could be applied to Karelia, and it might have a positive influence on practical forestry. Thus, general distribution of P and S types of *Heterobasidion* spp. and host preference described by Korhonen and Piri could be used for Karelian

Table 5. Mechanization level of logging companies in the Republic of Karelia

Company	Harvest in final felling ($m^3 \cdot year^{-1}$)		Harvest in thinning ($m^3 \cdot year^{-1}$)		Silvicultural regime	Harvest during year (m^3)	
	harvester	chainsaw	harvester	chainsaw		winter	summer
OAO Ladenso	203,437	5,320	3,893	16,135	3	126,340	102,445
OAO Olonetsles	–	–	–	–	–	129,099	160,857
ZAO Zapkarelles	328,892	140,954	–	–	–	269,077	200,769
OAO Ledmozerskiy	65,746	63,868	–	–	1	56,436	73,178
OAO Muezersky	111,163	103,437	2,600	1,800	1	131,360	87,640
OAO Lahdenpohsky	–	40,500	–	9,000	2	24,000	25,500
OAO Karellesprom	292,870	175,120	–	–	–	452,290	361,010
FGU Khvojny Voenny leskhoz	–	10,398	–	13,078	3	8,438	15,038
OAO Kondopozhskoye	–	161,154	–	5,159	4	89,705	76,608
Total	1,002,108	700,751	6,493	45,172		1,286,745	1,103,045
Average	–	–	–	–	1.4	–	–
Percentage	58.8	41.2	12.6	87.4	–	53.8	46.2

OAO – open joint-stock company, ZAO – closed joint-stock company, FGU – federal governmental unit model in order to describe possible distribution of S and P types based on Finnish data (Korhonen, Piri 1994). Vasilauskas and Stenlid reported that the S group is better adapted to growth in Norway spruce wood than the P group (Vasiliauskas, Stenlid 1998a). Consequently, adequate measures and correctly chosen tree species and management approaches depending on a certain forest site may substantially decrease possible wood losses caused by *Heterobasidion* spp. according to experience from Sweden and Lithuania (Vollbrecht et al. 1995; Brandtberg et al. 1996; Daniel et al. 1998; Vasiliauskas, Stenlid 1998b; Wang et al. 2014). Nevertheless, another vision in forest management approaches and in intensification of forest operations should be considered.

CONCLUSIONS

Insufficient sanitary conditions of spruce forests and existence of many pathogens were obtained from visual observations of the stumps. Thus, 36% of totally examined stumps on cutting sites were rotten, while the proportion of rotten stumps varied from 13 to 55%, huge fluctuation is distinguished by variation of the following factors: tree species composition, stand, number of stems per hectare, number of observed stumps per each site etc. However, evidences for comparison were found neither in Karelian nor in Russian official statistics. The laboratory sampling results showed 6% of infected samples by *Heterobasidion* spp., although its incidence varies up to 30%, moreover 45% of harvesting sites were infected by *Heterobasidion* spp. Obtained laboratory results are close to survey results, which makes them comprehensive. Survey results indicated 3–5% of the possible wood losses due to *Heterobasidion* spp. infection from total harvested spruce volumes; additionally respondents demonstrated high interest in the issues raised in the questionnaire, particularly in those concerning the problem of the butt and root rot occurrence.

It is noteworthy that global temperature has been rising and consequently climate change is one of the most obvious challenges we are currently facing. The spores of *Heterobasidion* spp. penetrate into the Norway spruce fresh stumps (Rishbeth 1951) mainly, while the temperature is above 0°C (Brandtberg et al. 1996). Thus, long-term changes in mean annual temperature as well as the mean number of days with positive temperature will make climatic conditions favourable for *Heterobasidion* spp. in terms of the increased duration of dispersal period and its distribution in the northern direction. That fact has to be assumed, it may have a negative influence on the future health conditions and general impairment of forest stands in the Republic of Karelia. Temperature changes have an influence on the present forestry and awareness of the fact that has a huge impact on forests generally in the future.

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