Intracenotic patterns in damage of *Abies sibirica* Ledeb.-dominated stands by infectious diseases in the south of Central Siberia

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Abstract. Abies sibirica Ledeb.-dominated stands degradation is of special concern. Nevertheless, insufficient attention is paid to the role of pathogens in this process. The aim of the present study is to assess the coenotic role of infectious diseases in fir-dominated stands in the south of Central Siberia. The research was based on a forest pathological examination conducted in A. sibirica-dominated forest stands in the Krasnoyarsk Krai. The cenotic role of the identified diseases is unequal. Stem decay and fir broom rust are typical diseases that weaken trees and induce rotten windsnap accumulation. Fir broom rust randomly affects trees of different age and size. The prevalence of fir broom rust in the studied fir stands reached 10% or more. The most hazard diseases in the studied stands are bacterial soft rot and root rot. Bacterial soft rot damages up to 20% of trees and causes their gradual dieback. The main cause of tree mortality in fir-dominated stands is root rot. The root rot- causing fungi lead to rapid dieback of trees of different cenotic status. In synergy with other factors, root rot acts as a significant endogenous factor in the current reorganization of coniferous forest ecosystems in the south of Central Siberia.

1 Introduction

Nowadays, forest degradation takes place in boreal coniferous forests and particularly so-called dark coniferous stands (fir/spruce/Siberian pine-dominated forests) in Eurasia [1-6, etc.]. It is especially true for *Abies sibirica* Ledeb.-dominated stands growing in the south of Central Siberia. A quality decrease in fir-dominated stands` condition causing their disturbances and dieback occurs on a vast area. Forest degradation is a process driven by a combination of exogenous and endogenous environmental factors [7]. Climate change makes temperature and moisture conditions unfavorable for forest communities [5, 8, 9]. Moreover, anthropogenic impact (hydropower facilities, industrial pollution, etc.) triggers forest degradation at the local level [7, 10, 11].

Wood-inhabiting insects and fungi act as an endogenous factors triggering fir forests degradation. Different wood-inhabiting organisms attack a tree simultaneously having a synergistic effect and affect trees weakened by exogenous factors. Nowadays, an invasive

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bark beetle *Polygraphus proximus* Blandford is the main biotic factor inducing large-scale *A. sibirica* stands dieback across its entire range [12–15]. A number of researchers proved that wood-inhabiting pathogens causing canker diseases, necrosis and rot have a significant negative impact on the state of forests [6, 7, 9, 16, 17]. Nevertheless, the impact that infectious diseases have on forest stands and their role in dark coniferous (particularly, fir-dominated) forests dieback is often underestimated.

The aim of the study is to assess the role of the main infectious diseases in forests dominated by *A. sibirica* in the south of Central Siberia. The present research is complementary to a previously published material [18].

2 Materials and methods

The study was carried out in *A. sibirica*-dominated forest stands located in the Biryusinsky district forestry of Krasnoyarsk Krai Government-Owned Publicly Funded Emelyanovskoye Forestry. The studied forests belong to the Altai-Sayan Ecoregion of the South Siberian mountain forest zone. We conducted forest inventory following generally accepted methods [19, 20], including route reconnaissance survey and detailed examination. The data of a detailed examination conducted on two research plots placed in fir-dominated stands served as a basis for the present research. The research plots were placed in stands typical for the study area. The health status of the studied stands is unsatisfactory. Table 1 shows the main silvicultural and forest inventory details from our studies.

Table 1. Silvicultural and forest inventory of the studied forest stands.

Research plot (forest compartment/ forest unit)*	Stand composition, forest type	Average values for fir			bonitet class	density	growing stock, m^3/ha
		age, years	height, m	diameter, cm			
1 (37/11)	10F+S, L,A, tall grasses-dominated forest floor	110	21.6	24.3	III	0.6	250
2 (25/1)	7F3S+P, moss/herbs-dominated forest floor	130	26.3	27.7	II	0.6	290

Note: *Forestry administrative division in Biryusinsky district forestry of Krasnoyarsk Krai Government-Owned Publicly Funded Emelyanovskoye Forestry; F – fir; S – spruce; L – larch; A – aspen; P – pine; + indicates that following tree species occupy 2.5-5.0% in the total growing stock on the research plot.

We measured all the trees on the research plots (at least 100 trees) dividing them into 4 cm-diameter classes and the following health classes: 1 – no signs of weakening; 2 – weakened; 3 – severely weakened; 4 – dying; 5 – dead (lost viability). Trees in deadwood class were also divided into following groups: recently dead trees, old snag, windthrow and windsnap. We assessed crown condition to determine trees health status. We also detected if trees were affected by diseases, which were identified by a set of symptoms (macroscopic signs).

Based on the materials provided by a plant pathology diagnosis, we identified two main indicators of the dominant tree diseases on each research plot: prevalence and hazard rate. The prevalence of a disease within a research plot was calculated as the share (%) that the growing stock of sick trees took in the total growing stock of all the measured trees. The

hazard rate was determined by the weighted average health index (K_{av}). K_{av} was calculated for the trees affected by the disease using the following formula:

$$K_{av} = (P_1*K_1+P_2*K_2+P_3*K_3+P_4*K_4+P_5*K_5)/100 \quad (1)$$

where P_i is the share (%) that the growing stock of sick trees of each health class takes in the total growing stock of all the sick trees; K_i is the trees health index (1 - no signs of weakening; 2 - weakened; 3 - severely weakened; 4 - dying; 5 - dead). At $K_{av} \leq 1.5$, trees affected by the disease do not have visible signs of weakening; $1.5 < K_{av} \leq 2.5$ – weakened; $2.5 < K_{av} \leq 3.5$ – severely weakened; $3.5 < K_{av} \leq 4.5$ – dying; $K_{av} > 4.5$ - lost viability.

In order to reveal the features of fir forests damage by diseases at the coenotic level, we analysed the distribution of affected trees by diameter classes relative to the total stand diameter structure. We used the λ criterion (Kolmogorov-Smirnov test) to assess the reliability of differences in the compared trees distribution series by diameter classes.

3 Results and discussion

Among all the pathogens affecting trees, the most dangerous ones are infectious diseases that damage roots, stems and branches. These infectious diseases determine health status of forest stands (especially mature and old ones). Thus, here we focused on diseases causing necrosis, canker and rot in fir-dominated stands. Table 2 shows the characteristics of the main diseases (mostly, fungal ones) that we detected in the studied fir forests.

Table 2. Infectious diseases in *Abies sibirica* - dominated stands.

Disease (pathogen)	Signs and symptoms
Fir broom rust (Melampsorella caryophyllacearum G. Schrot.)	open cankers on stems and branches, often in combination with an excessive proliferation of twigs from a single point on a branch
Bacterial soft rot (Erwinia sp., Pseudomonas sp.)	cracks in the bark, seepage from affected areas; wet wood, dark spots and stripes in the phloem, infected tissues are sharply delineated from healthy tissue by dark brown or black margins
Root rot (Armillaria mellea sensu lato)	white mycelial films and dark rhizomorphs under the bark of the roots and in the lower part of the trunk; in autumn - mushrooms
Stem decay (Phellinus hartigii (All. et Schnab.) Bond. etc.)	fungal fruiting bodies, openings into the stem interior

Xylotrophic fungi hosting in the stems of living trees cause wood destruction leading to stem decay. The prevalence of stem decay directly correlates with the age of a stand. In coniferous species, fungal fruiting bodies are not always present. Therefore, stem decay prevalence happened to be law in the studied fir forests since we conducted visual assessment of trees (Table 3). Stem decay usually occurs around the base of the tree and affects sapwood to a small extent. Hence, although trees stay vital for a long time, stem decay increases the risk of windsnap. Table 3 proves that trees affected by stem decay but having no other diseases, are of the satisfactory average health index.

Table 3. Manifestation indicators of the diseases: numerator – prevalence (P, %), denominator – weighted average health index of affected trees (K_{av}).

Diseases		On the research plot	
		1	2
Fir broom rust only		4.3 / 2.9	4.0 / 1.3
Bacterial soft rot only		8.3 / 3.4	10.8 / 2.9
Stem decay only		0	4.9 / 1.0
Root rot	Root rot only	29.3 / 5.0	34.7 / 5.0
	+ Fir broom rust	3.9 / 5.0	1.9 / 5.0

	+ Bacterial soft rot	5.0 / 4.8	0
	+ Stem decay	0	2.2 / 5.0

Diseases causing necrosis and cancer (fir broom rust and bacterial soft) were characterized by a medium level of manifestation. The total prevalence rate of fir broom rust did not exceed 9% in the analyzed sample (Table 3). Nevertheless, since fir broom rust is typical for fir-dominated stands, its prevalence may reach the higher level (> 10%). Fir broom rust prevalence depends on the concentration of basidiospores of the micromycete *M. caryophyllacearum* produced in spring. *M. caryophyllacearum* requires alternate hosts in the family Caryophyllaceae. Thus, the presence of Caryophyllaceae family-plants in the forest floor also determines the prevalence of fir broom rust. Fir broom rust randomly infects trees of different diameters (hence, different status), regardless of the stand diameter structure (Figure 1). Fir broom rust damages young fir trees as well. *Melampsorella caryophyllacearum* is obliged parasitic fungus that usually lives in trees for many years and does not lead to their rapid death. The rate of a tree weakening depends on its age and the location of cankers. Table 3 shows that trees infected with fir broom rust (in the absence of other diseases) fall into the following health status classes: from satisfactory to severely weakened.

The total prevalence of bacterial soft rot in the study area indicated the presence of foci of the disease with a low degree of trees infection (11-13%). Figure 1 shows that bacterial soft rot was most common in trees of medium diameter classes (hence, I-II Kraft's classes, dominant status). The systemic development of bacterial soft rot in trees causes their gradual weakening and subsequent dying. The analysis showed that the average health index (K_{av}) of trees affected by bacterial soft rot (in the absence of other diseases) was 2.9-3.4. The damage to coniferous species, including fir, by bacterial soft rot was observed in the forests of Central Siberia earlier [21]. In recent years, bacterial soft rot has been affected forest health in the dark coniferous mountain forests of the Baikal region [17].

The most widespread in the *Abies sibirica* stands was root rot caused by *Armillaria mellea* s. l. According to available data, in the coniferous forests of the Krasnoyarsk Krai (Central Siberia), *A. borealis* Marxm. & Korhonen is the most common species among all *A. mellea* s. l. fungi [22]. The prevalence of root rot (including in combination with other diseases) according to the detailed examination exceeded 35% (Table 3). Table 3 shows that fir-dominated stands in the study area are severely affected by root rot. By comparing diameter distributions of the sick trees with that of all the firs in the stands we revealed that root pathogen infects trees of different diameters (sizes) in accordance with their representation in the stand diameter structure (Figure 1). This is confirmed by the absence of significant differences between the compared tree diameter distribution rows according the λ criterion (Kolmogorov-Smirnov): Research plot 1 – $\lambda_{fact.}(0,89) < \lambda_{05}(1,36)$; Research plot 2 – $\lambda_{fact.}(0,61) < \lambda_{05}(1,36)$.

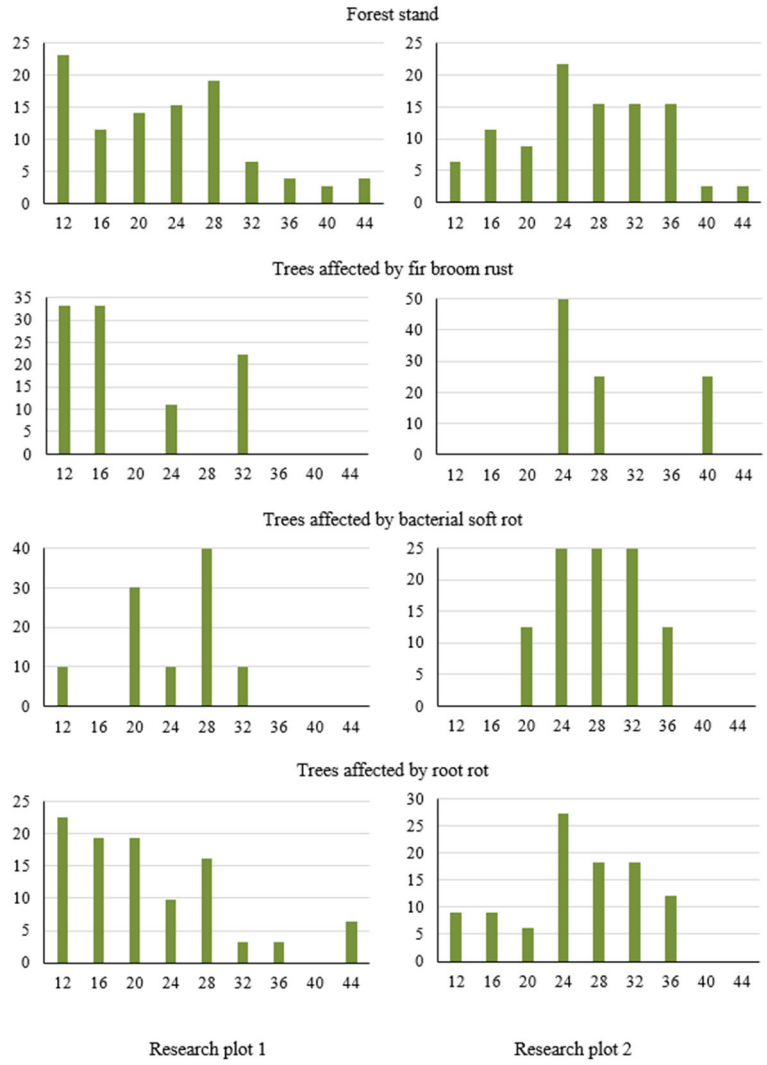

Fig. 1. Trees distribution (%) by diameter classes (cm).

The toxic effect produced by *A. borealis* leads to rapid root dieback and death of infected trees. Table 3 shows that K_{av} of the trees affected by root rot is 4.8-5.0. In case of combined effect with other diseases, root rot acts as the main factor causing the death of trees (60-80%).

4 Conclusion

Intracenotic factors inducing *Abies sibirica* stands weakening and dieback in the south of Central Siberia include wood-eating insects (primarily, *Polygraphus proximus*) and pathogens causing necrosis, rot and cancer diseases.

Stem decay and fir broom rust are typical diseases in fir-dominated forests. Stem decay does not affect forests health status, but worsens stands condition due to the accumulation of rotten windsnap. The infestation by fir broom rust my reach 10% and more. Fir broom rust-causing pathogen (micromycete *Melampsorella caryophyllacearum*) requires the presence of alternate hosts. Thus, the presence of Caryophyllaceae family-plants in the herb layer

determines the prevalence of fir broom rust. Fir broom rust randomly affects trees of different age and size becoming a factor of chronic weakening.

The main causes of pathogen-induced tree mortality in fir stands are bacterial soft rot and root rot (pathogen - *Armillaria mellea* s.l., including *A. borealis*) which usually infect trees disturbed by exogenous factors. Bacterial soft rot mainly affects trees of I-II Kraft's classes and forms diffuse foci with up to 20% stands damage.

Root rot-causing fungus is highly aggressive and affects trees of different cenotic status. Root rot infects trees in large numbers forming foci of the disease that become groups of dead trees over time. The prevalence of the disease reaches more than 30%. Therefore, root pathogens (in particular, *A. mellea* s. l.), in synergy with other biotic factors, play a significant role in the current reorganization of dark coniferous forest ecosystems in the south of Central Siberia.

For a more complete understanding of the role that pathogens play in the functioning and dynamics of dark coniferous forests, further research is needed.

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