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Diseases of *Populus tremula* L. in the subtaiga forests of the Yenisei Siberia: pathogens and their impact

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Abstract. *P. tremula* (aspen) stands in boreal forests usually act as an intermediate stage of regenerative successions. One should not underestimate the role of ecological functions provided by aspen forests and their resource potential. Aspen forests occupy up to 25% of the most intensively exploited forests of the Krasnoyarsk Krai. Dendropathogenic organisms often determine *P. tremula* stands condition. The research is aimed to study the phytopathological state of *P. tremula* stands in the subtaiga forests of the Krasnoyarsk Krai. The study was carried out in the subtaiga aspen forests of the Educational and experimental Karaulny forestry enterprise of the Reshetnev Siberian State University of Science and Technology (Reshetnev University). Research methods included route and detailed forest pathological examination (on four sample plots), complex macroscopic diagnosis of diseases, identification of signs and symptoms of the diseases, and the diameter distribution series analysis. A significant part of the aspen forests in the study region suffers varying degrees of disturbance. Pathogenic biota composition includes fungi and bacteria differing in their parasitic activity and specialization. Hymenomycete *Ph. tremulae* is the most common in aspen stands. Stem rot caused by *Ph. tremulae* increases the risk of wind damage and reduces the value of forest stands. The main biotic factors affecting aspen forests are bacterioses causing necrosis canker and root rot caused by *A. mellea* s. l. These widespread diseases have a systemic negative effect on trees of different cenotic status in aspen forests; they usually form foci in adjacent areas, which accelerate the destruction of forest stands. Accumulation of *A. mellea* s. l. infection in aspen forests is potentially dangerous for coniferous plantations. Micromycetes affecting the phyllosphere lead to the weakening of young aspen trees. *V. tremulae* sometimes causes the undergrowth to dry out.

1. Introduction

Populus tremula L. (aspen) is widespread within boreal forests [1-5]. Along with other forest-forming species, aspen is a valuable resource that performs essential ecological functions. Aspen-dominated forests in the Yenisey Siberia (Krasnoyarsk Krai) occupy 3% of the total area of the Russian Forest Fund. [6]. Moreover, aspen forests occupy up to 25% of the most intensively exploited forest taiga and subtaiga forests of this region's central and southern parts. *P. tremula* is assumed to be primarily seral-dominant following fires and cutting [6] and acts as an intermediate stage of restorative successions. Aspen forests may be primary when growing on relatively rich soils of moist and wet habitats of subtaiga/forest-steppe altitudinal belts [7].

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Aspen-dominated stands are largely affected by phytopathogens, primarily fungi, throughout their entire range [3, 8, 9]. Infectious diseases often become the main endogenous factor causing disturbances and reducing aspen forests' resistance.

The research is aimed to study *P. tremula* forests pathology in the subtaiga forests of the Krasnoyarsk Krai. These were the steps taken to achieve the objective: to assess the pathological quality of aspen forests; to identify pathogens and the prevalence of diseases caused by them in aspen forests; to discover intracenotic features of damage caused by dominant diseases; to assess the harmfulness of pathological processes.

2. Objects and methods of research

The research was carried out in the subtaiga aspen forests of the Educational and experimental Karaulny forestry enterprise of the Reshetnev Siberian State University of Science and Technology (Reshetnev University). The forestry belongs to the Central Siberian subtaiga/forest-steppe ecoregion.

We carried out field research by conducting forest pathological surveys according to generally accepted methods [10, 11]: route reconnaissance survey, detailed examination. During the reconnaissance survey, we visually assessed aspen forests' sanitary and pathological state within the compartment of at least 1.5 hectares. A detailed survey was conducted on four sample plots, established in a typical Aspen/Tall Forbs plant community (Table 1). Trees (130-180 pcs.) on the sample plots were distributed by enumeration survey to four-centimeter diameter classes and the following quality classes: 1 – no signs of weakening; 2 – weakened; 3 – severely weakened; 4 – drying; 5 – dead (lost viability): fresh and old dead standing trees, windfall, windbreak. The quality class was determined mainly by tree crown conditions. We indicated diseases, which were determined by a set of specific and indirect signs.

Table 1. Characteristics of the sample plots (SP).

SP (compartment / sub-compartment)*	Forest inventory						
	species, forest type	average values for the dominant tree species			bonitet	density	Stem volume, m3/ha
		age, years	height, m	diameter, cm			
1 (37/7)	9A1B**, Tall Forbs	77	26	31,6	1	1,0	400
2 (37/25)	7A2P1B, Tall Forbs/Eagle Fern	82	21	28,6	2	0,8	280
3 (5/5)	8A2B, Tall Forbs	92	23	23,6	2	0,6	220
4 (2/47)	9A1B, Tall Forbs	87	23	31,4	2	0,5	170

* – within the Educational and experimental Karaulny forestry enterprise of the Reshetnev University;
** – A – Aspen; B – Birch; P – Pine.

According to forest pathological examination, we determined the sanitary condition of forest stands and signs of the identified diseases: prevalence and severity. The prevalence of diseases in aspen was defined as the proportion (%) of affected trees from the total sample of dominant tree species on a sample plot. The condition of aspen stands was assessed by the weighted average forest condition indicator (K_{av}) calculated using the formula (1):

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

where P_i – the proportion of stem volume for trees of each quality class, %; K_i – the quality class index (1 – no signs of weakening; 2 – weakened; 3 – severely weakened; 4 – drying; 5 – dead). At $K_{av} \leq 1{,}5$,

the stand has no visible signs of weakening on average; $1,5 < K_{av} \leq 2,5$ – the stand is on average weakened; $2,5 < K_{av} \leq 3,5$ – severely weakened; $3,5 < K_{av} \leq 4,5$ – drying; $K_{av} > 4,5$ – lost its viability.

Diseases severity was assessed by the weighted average forest condition indicator, calculated similarly for the part of the stand affected by a particular disease.

To establish the characteristics of disease progress in aspen forests at the cenotic level, we analyzed the graphs of the distribution of the affected trees by the stem diameter classes at a height of 1.3 m relative to the general diameter distributions.

3. Research results and their discussion

It is impossible to unambiguously assess the current sanitary state of the aspen forests in the study area since stands with varying degrees of disturbance prevail. According to a detailed survey, the sanitary state of *P. tremula* stands ranged from having no visible signs of weakening (K_{av} = 1,3) to severely weakened (lack of sustainability) (K_{av} = 2,5). The total tree cover loss (drying and dead trees) ranged from 5% to 29% of the total stem volume (Table 2). In dry forest areas, the average diameter of dead trees was close to the average or exceeded it (sample plots 3, 4).

Table 2. Aspen forest health indicators.

SP	Forest inventory					Average quality class (K_{av})	Average diameter for dead trees, cm
	no signs of weakening	weakened	severely weakened	dead trees			
				current	total		
1	83.3	11.6	0.2	-	4.9	1.3	22.5
2	43.5	34.6	6,4	0.9	15.5	2.1	25.8
3	30.7	27.4	12.6	3.5	29.3	2.5	24.8
4	33.5	45.2	6.5	1.8	14.8	2.2	29.0

State of aspen forests in the study area vary due to differences in biotopes (orographic, edaphic, and microclimatic conditions), the age structure of stands, and the impact of endogenous biotic factors. The latter, first of all, include infectious diseases of aspen. Table 3 shows the detected pathogens and the diseases initiated by them (main signs indicated). The pathogenic biota includes fungi and bacteria differing in parasitic activity and specialization. Clarification of the taxonomic composition of bacterial associations requires additional microbiological studies. Predominant pathogens assimilate trees' branches, stems, and roots. The role of the identified organisms in weakening and drying out of *P. tremula* and is unequal.

Table 3. Infectious diseases in *P. tremula* forest stands.

Pathogens	Caused diseases (signs)	Affected object	
		canopy	understory
Phellinus tremulae Bondartsev & P.N. Borisov	stem rot (appearing of basidioma, punk knots, hollows on a stem)	+	-
Erwinia sp., *Aplanobacterium* sp., Pseudomonas sp.	bacterioses: dropsy, canker diseases (bast fiber and sapwood retting; brown stains on the bark; knots and wet wounds on branches and stem)	+	-
Entoleuca mammata (Wahlend.) J.D. Rogers & Y.M. Ju	black knot (black wounds on a stem)	+	-

Armillaria mellea sensu lato	root rot (root rot; flat sheets of fungal tissue (mycelial fans) that grow just below the bark and at the base of the trunk, dark rhizomorphs)	+	+
Erysiphe adunca (Wallr.) Fr.	powdery mildews (white powdery spots on the leaves)	-	+
Venturia tremulae Aderh.	blight (dark brown spots on the leaves, darkening and drying of the current-year growth)	-	+

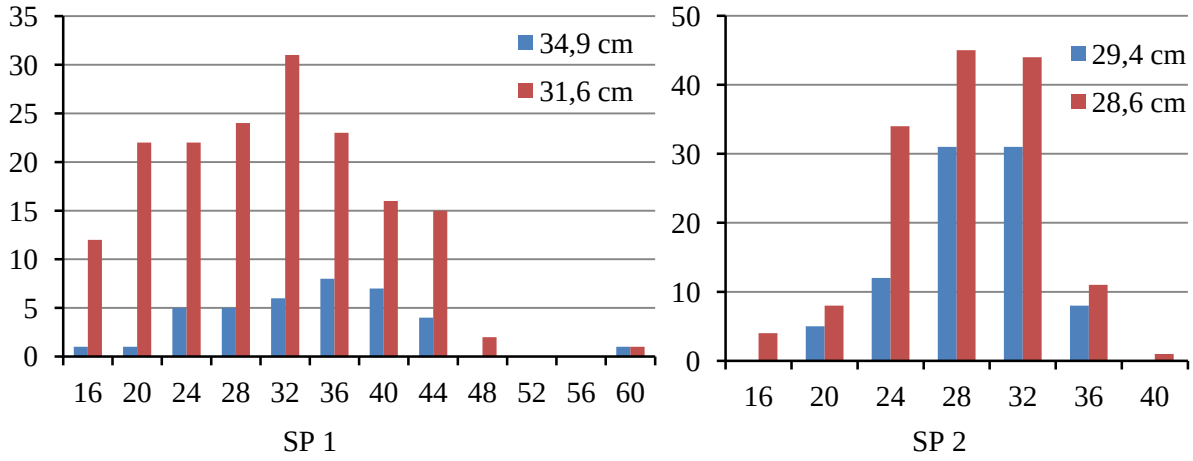
The most common decay of aspen is caused by the white rotting fungus *Ph. tremulae* (False Tinder Conk). According to a detailed survey, *Ph. tremulae* incidence rate was on average 28.5% and reached more than 50%, which corresponds to a severe degree of damage (Table 4). Our results confirm phytopathological studies of aspen forests in many regions [1, 12-15]. The fungus decays living tree stem wood affecting aspen trees of different diameter according to forest stand diameter structure (with some predominance of large-sized trees) (Figure 1a). Although stem rot diseases play a particular ecological role (especially in old-growth stands), they significantly reduce the quality and value of aspen wood. The average quality class of trees affected by stem rot (Table 4) corresponds to the general quality class of the stand (Table 2). However, affected trees are primarily susceptible to wind and snow damage.

Table 4. Signs and symptoms of the diseases in *P. tremula*.

Disease	**Sample plot**			
	1	**2**	**3**	**4**
Stem rot	22.6* /1.3**	59.2 / 2.1	7.8 / 2.3	24.2 / 2.2
Bacterioses	4.8 / 2.1	4.1 / 2.3	55.2 / 3.1	31.1 / 2.4
Black knot	0.6 / 1.0	-	0.6 / 5.0	-
Root rot	-	19.0 / 4.9	37.0 / 4.4	25.0 / 4.3

* - prevalence (%);
** - the average quality class of the affected trees

a. Stem rot



b. Bacterioses

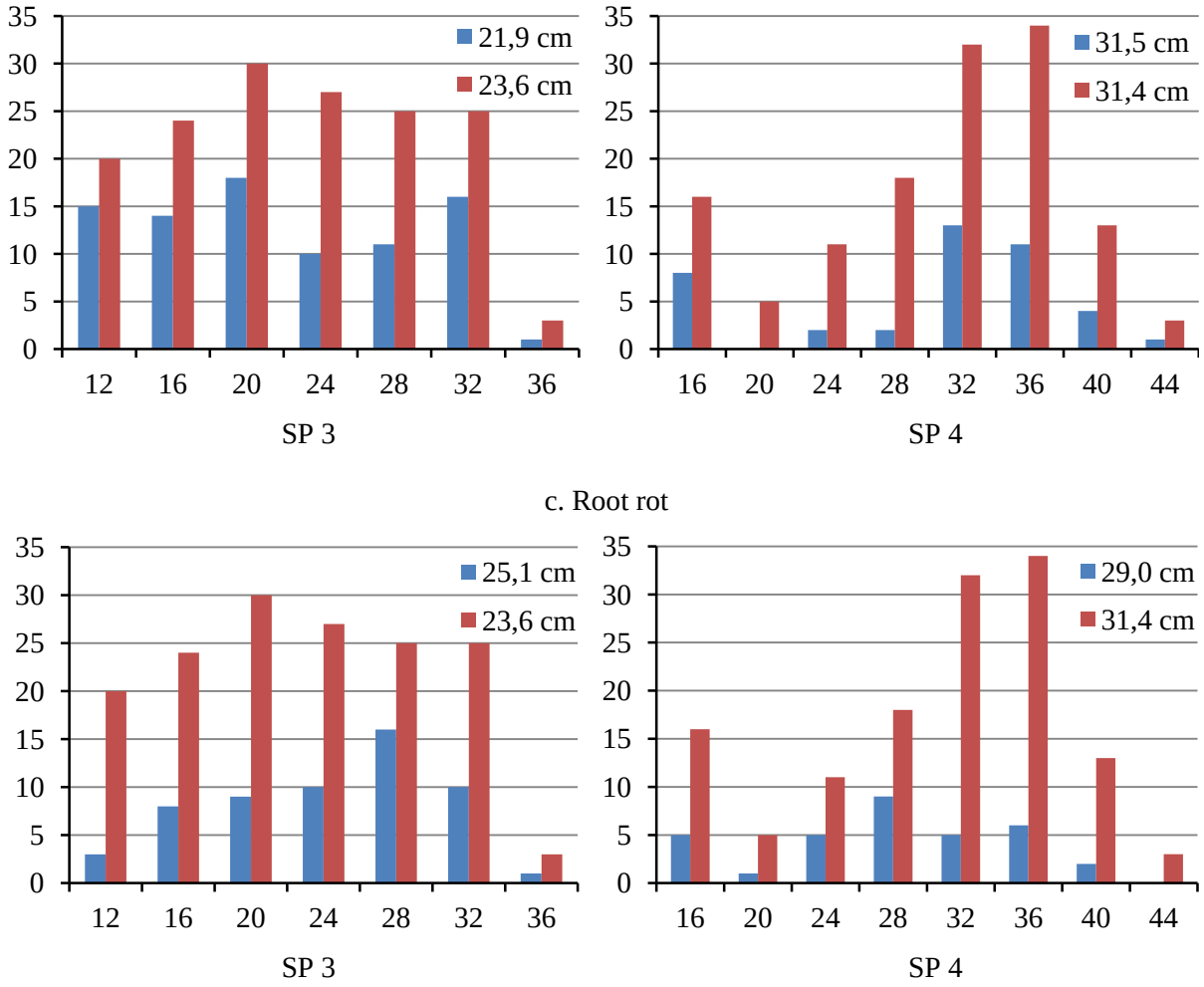


Figure 1. Diameter class distribution (cm) and average diameter of affected (blue) or all (red) trees (pcs.)

A significant biotic factor in aspen stands disturbance is pathogens that cause canker diseases. Among them, systemic bacterial diseases dominate. The average total prevalence of bacterioses was 23.8%, corresponding to moderate damage (Table 4). The incidence of bacterial canker diseases reached 50% (severe damage), more significant in old-growth aspen forests growing on moist soils.

Bacterioses affected trees of different diameters in proportion to their representation in the stand's structure (Figure 1b). The average quality class of affected trees was 2.1-3.1 (weakened-severely weakened) (Table 4). Trees of different cenotic statuses (Kraft's Crown Classes) are susceptible to drying out from bacterioses.

The prevalence of the micromycete *E. mammata*, which causes black knot, did not exceed 5%, while 50% of the affected trees were standing dead trees (Table 4).

The main factor of the pathological decay in *P. tremula* trees in subtaiga forests is *A. mellea* s. l. (honey fungus) causing toxigenic root damage. Macromycete has a patchy distribution. According to a detailed survey, the proportion of affected edificator trees was 19.0-37.0% (moderate-severe damage) (Table 4). The pathogen is very aggressive; the fungus effectively passes from tree to tree by rhizomorphs. During active fruiting-body formation (basidiomas), it is additionally spread by basidiospores. The disease outbreaks affect the entire aspen cenopopulation: trees of different sizes

(Figure 1c) and Kraft classes as well as a significant part of the undergrowth. Root damage by honey fungi always leads to the drying out of trees. According to our data, in the foci of armellariosis, the quality state of the stand was $K_{av} > 4$ (drying - lost viability) (Table 4). The duration of the drying process in affected trees depends on several factors, including their morphometric parameters: as a rule, smaller trees and undergrowth die faster. It is important to note that aspen forests become reserves for *A. mellea* s. l., which, taking into account the aggressiveness and broad phylogenetic specialization of this root pathogen, may threaten the undergrowth and valuable conifers adjacent.

The identified micromycetes (*E. adunca, V. tremulae*) affect the phyllosphere making assimilation rates drop drastically, causing premature defoliation and, as a consequence, weakening young P. tremula trees. *V. tremulae* often causes drying of the current-year growth shoots and even the undergrowth's death.

4. Conclusion

In the subtaiga forests of Yenisei Siberia, aspen stands are represented by plantations of various sanitary conditions. A significant proportion of plantations suffers varying disturbances, primarily associated with the low aspen resistance against pathogens. We indicated the composition of the pathocomplex, typical for aspen, which is similar to that found in the derivatives of mountain taiga aspen forests in the Stolby National Nature Reserve [16].

Pathogens affecting the tissues of branches, stem, and roots dominate; their activity often manifests in focal damage to aspen stands. The xylotrophic macromycete *Ph. tremula*, having a patchy distribution of stem rot and damaging up to 60% of forest stands, prevail. Stem rot significantly reduces the resource potential of aspen forests, leading to the accumulation of rotten wind-damaged trees.

Considering the significant distribution and systemic negative impact on trees, bacterioses causing necrosis canker and the root pathogen *A. mellea* s. l. are the most significant disturbances in aspen forests. In most cases, they form contiguous foci, which accelerates the destruction of forest stands, especially old-growth ones. Accumulation of *A. mellea* s. l. infection in aspen forests is potentially dangerous for coniferous plantations of the study area.

Fungal infections of the phyllosphere are common on aspen undergrowth and often cause its weakening, less often drying out.

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