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DYNAMICS OF CHANGES IN THE PHYSICAL AND MECHANICAL PROPERTIES OF SIBERIAN FIR (*ABIES SIBIRICA* LEDEB.) WOOD IN DEAD STANDS DAMAGED BY THE FOUR-EYED FIR BARK BEETLE (*POLYGRAPHUS PROXIMUS* BLANDF.)

Sergey Eliseev – Sergey Zhila – Sergey Kazitsin – Vladimir Ermolin – Mikhail Bayandin — Evgeniya Akinina – Tatyana Strekaleva

ABSTRACT

Under changing climate conditions in the Russian Federation, the four-eyed fir bark beetle (*Polygraphus proximus* Blandf.) is causing widespread mortality of Siberian fir (*Abies sibirica* Ledeb.) stands. Due to the scale of mortality and the patchy nature of damage to the stands, dead stands remain in a stable state for extended periods. This raises the question of the feasibility of industrial use of deadwood, given the time since stand death. This study examined changes in the physical and mechanical properties of *A. sibirica* wood across different periods after tree death. The study revealed that in the first 3-5 years after their death, dead trees experience a sharp decrease in the impact strength of wood, while most of the physical and mechanical properties of stem wood remain at levels similar to those of standing trees for decades. It is caused by the reduced moisture content of deadwood, which falls below 20%, making it unsuitable for the development of wood-destroying fungi. Intensive wood decay is observed only at the base of the stem. Also, as the time since death increases, dead trees are selected based on their physical and mechanical properties. By 20 years of death, remaining trees in the stand have wood density and strength values above the average for *A. sibirica*. Based on the data obtained, stem wood from dead trees could be a valuable raw material for a wide range of wood processing industries.

Keywords: Siberian fir (*Abies sibirica*); four-eyed fir bark beetle *(Polygraphus proximus)*; wood; physical and mechanical properties of the *Abies sibirica* wood; dead standing tree; deadwood; use of deadwood.

INTRODUCTION

In the context of climate change, natural ecosystems are undergoing radical changes. In large areas of the planet's northern regions, climate change has led to improved forest growth conditions, and the timberline is shifting northwards (Rotbarth *et al.,* 2023). At the same time, in more southern regions, changes in growing conditions and climate imbalance have led to the mass death of ligneous plants resulting from the changes in the hydrological regime(Zhuravlev, 1960; Stocks, 1998; Johnstone, 2006; Allen *et al.*, 2010; Groisman *et al.*, 2018; Kharuk *et al.*, 2020; Pavlov *et al.*, 2020; Roberts *et al.*, 2020; Voronin *et al.*, 2020; Kozlov *et al.*, 2023), large forest fires (Chetverikov, 1903; Zhuravlev, 1960; Rozhkov, 1963; Kharuk *et al.*, 2017; Hansen *et al.*, 2021), widespread outbreaks of pests and forest diseases

(Kondakov, 1963, 1974; Lighthill *et al.*, 1994; Aber *et al.*, 2001; Zalomodchikov, 2009; Shvidenko and Schepaschenko, 2014; Gauthier *et al.*, 2015), invasions of harmful species (Lighthill *et al.*, 1994; Dale *et al.*, 2001; Alexeyev and Svyazeva, 2009; Storozhenko, 2010; Sergienko *et al.*, 2015; Shchurov, 2017; Baranchikov *et al.*, 2021; Demidko *et al.*, 2023).

The Krasnoyarsk Territory holds a leading position in the structure of the total forest area of the Russian Federation and is a key region in shaping the national forest potential. According to the state forest register (Federal Forestry Agency, 2025), the total area of forest land in the region exceeds 168.1 million ha, with a total stock of timber of 14.4 billion m^3, which determines the strategic importance of the region for the country's forest industry complex (Natural Resources of the Krasnoyarsk Region, 2025).

At present, in the Krasnoyarsk Territory, there is a massive dieback of natural stands of Siberian fir (*Abies sibirica* Ledeb.) due to the influence of *Polygraphus proximus* Blandf, an invasive bark beetle (Krivets *et al.*, 2024). The natural habitat of this species is in the far eastern part of Russia, where the climate is milder and warmer than in Siberia. Nevertheless, in the context of global warming, *P. proximus* has successfully acclimatized to the Siberian region and, in the absence of natural biological barriers, has destroyed fir stands across vast areas (Krivets *et al.*, 2024). An important factor in the successful attack on Siberian fir by *P.proximus* is a characteristic feature of this species. Siberian fir lacks effective mechanisms of resistance to the complex of pathogenic ophiostoma fungi spread by this pest, leading to extremely rapid drying of trees affected by bark beetles (Pashenova *et al.*, 2012, 2018; Baranchikov *et al.*, 2014; Voronin *et al.*, 2020). Contemporary predictive models indicate further expansion of the secondary area of *P. proximus* with the formation of new invasive foci (Soldatov *et al.*, 2019). According to the latest official data of monitoring conducted by the Federal Funded Institution "Russian Center of Forest Health", the total area of the forest destroyed by the four-eyed fir bark beetle (*P. proximus*) in the Krasnoyarsk Territory exceeds 570,000 hectares (Branch of the Federal Budgetary Institution «Russian Forest Protection », 2022).

Since the stands' mortality is patchy and often occurs in areas with underdeveloped transport infrastructure, it is virtually impossible to cut down dead stands within a short period of time. Therefore, clearing dead trees is a lengthy process, and a significant area occupied by dead trees creates a threat of mass reproduction of secondary pests and catastrophic forest fires.

At the same time, the issue of using and disposing of harvested deadwood poses several problems. Practical experience shows that the stem wood of dead trees rapidly loses its commercial value – already within 2-3 years after death (Belyea, 1952; Basham, 1986; Barrette *et al.*, 2015). Moreover, there is currently virtually no data on changes in the physical and mechanical properties of *A. sibirica* wood depending on the period of death, which makes it extremely difficult to use deadwood rationally.

The main reason for the decline in the physical and mechanical properties of deadwood is the development of rot caused by wood-destroying fungi (Basham, 1984; Barrette *et al.*, 2015). However, the data found in the literature is quite contradictory. Based on these studies, it is unclear why, in some cases, physical and mechanical properties gradually decline with increasing time since death (Larinina *et al.*, 2014). In contrast, in others, they remain virtually unchanged for a long time (Mukhortova *et al.*, 2009). In some cases, the condition of wood depends on which part of the stem it is located in (Basham, 1984).

To solve the problem of predicting the condition of *A.sibirica* wood depending on the period of death and to develop scientifically robust approaches to the processing of deadwood, it was decided to study the dynamics of changes in the physical and mechanical properties of deadwood during the mass death of stands caused by the impact of the four-eyed fir bark beetle.

MATERIAL AND METHODS

For study purposes, in the first stage of the work, based on data from the Krasnoyarsk Territory Forest Protection Center, dead trees killed by the four-eyed fir bark beetle were selected. When selecting study objects, the period of death (PD) of a tree stand, its composition, age, and bonitet were taken into account.

For the study, mature stands with the predominance of Siberian fir (more than 7 units) and the bonitet of at least 3 were selected. From the pre-selected sites, two dead stands that met all requirements were identified during on-site investigations. The selection of the sites was subjective. Siberian fir stands damaged by the four-eyed fir bark beetle were selected, taking into account the possibility of harvesting models with death periods of 5, 10, 15, and 20 years, and a control was also selected – standing trees from areas adjacent to the outbreak site.

To determine the condition of forest areas damaged by the invasion of the four-eyed fir bark beetle, a survey of stands was conducted on sample plots using generally accepted taxonomic methods (Zagreev *et al.*, 1992).

Based on the results of the taxation of the stands on the sample plots, the most common dead trees according to taxation indicators were identified. Based on these parameters, model trees were selected from the stands being studied. The selected model trees should not have any visible defects in standing trees, such as frost cracks, dryness, sprouting, cancerous growth, or large splay knots. In addition, if heart rot was detected in the stem during the crosscutting of a felled tree, such models were rejected.

Thus, 100 model trees with the required parameters were selected in each plot. The cause of tree death was also monitored during the selection. A model tree had to have numerous exit holes made by the four-eyed fir bark beetle, which can reach a density of 60-70 pieces per decimetre. The beetle's egg-laying tunnels had to be visible under the bark of the damaged trees (Fig. 1 b, c) (Baranchikov *et al.*, 2011, 2014).

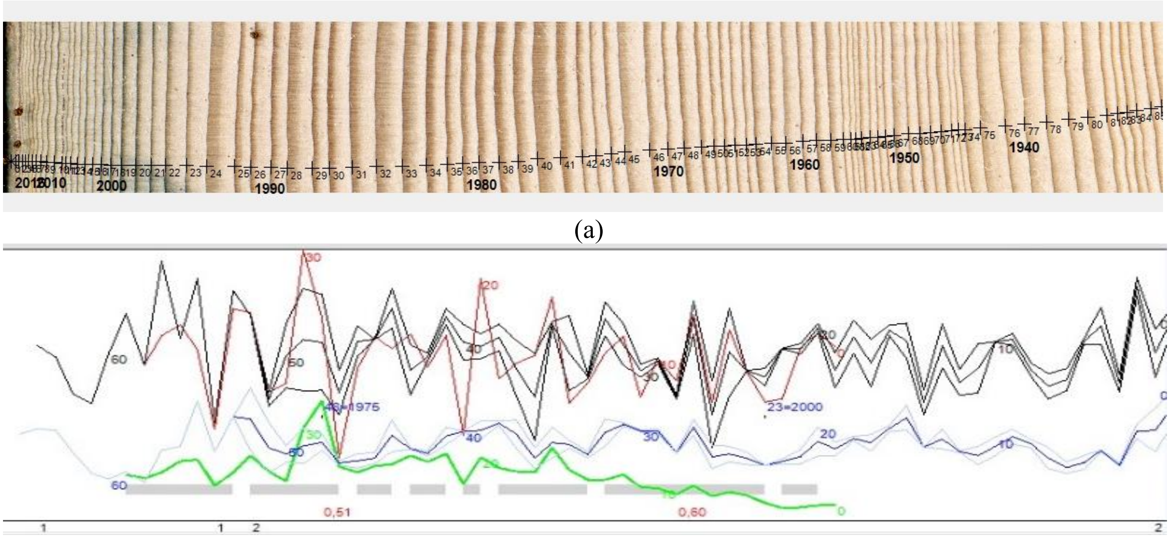

(a) (b) (c)

Fig. 1 Stand damaged by the four-eyed fir bark beetle
a – general view of the stand; b, c – characteristic traces of bark beetle damage on fir tree stems.

To cross-date each sample area, 100 cores were cut from dead model trees and 30 cores from standing Siberian fir trees growing on adjacent forest plots. The selection of cores was carried out with the aid of Presler's drill at a height of 1.3 meters.

The processing and analysis of the cores were performed using CooRecorder 9.3.1, while construction and cross-dating were performed using CDendro 9.3.1 (Cybis Elektronik & Data AB, 2025).

For further processing, we retained only those rows whose correlation coefficient with the master chronology, constructed via leave-one-out, was at least 0.4. Tree-ring statistics were calculated using the dplR package (Bunn, 2008). An example of the fragment of the core being processed is shown in Fig. 2.



(a)

(b)

Fig. 2 Study of radial growth in CooRecorder 9.3.1 (a) and cross-dating graphs (b).

Then, 10 model trees with the required death periods were selected from the models based on cross-dating results. The selected model trees were felled; and three 1-metre-long sections were cut from each model tree for physical and mechanical testing of wood from the lower part at a height of 1.3 metres, the upper part and the middle part of the full-length log (Fig. 3). In addition, to obtain a more detailed picture of the distribution of wood moisture content along the height of the stem, three 10 cm thick discs were sawn from the base of the stem and the middle sections of the stem between the logs.

Immediately after felling and crosscutting of the model trees in field conditions, the moisture content of the freshly harvested samples was measured using the Logica LG43 electric moisture meter. The measurements were taken on the end surface of the logs, and the moisture content of the wood was determined from the center to the periphery at 10 mm intervals.

The logs, cut from the model trees, were sawn into the blanks of the required size. The samples were then dried in a drying chamber at a temperature of 40-45 °C to a moisture content of 12±2 %. Next, standard-sized samples were made from the dried blanks for physical and mechanical testing of the wood in accordance with the international standards ISO 13061-1:2014, ISO 13061-2:2014, ISO 13061-3:2014, ISO 13061-10:2017, and ISO 13061-17:2017.

Fig. 3 Logs sawn from model trees.

The physical and mechanical properties of the wood were determined using the ABS ASIMETO 317-06-0 digital caliper, CAS XE-300 laboratory scales, Binder ed 115 drying oven, and Testsystems UTS 110MN-30R-5 universal testing machine. The impact bending strength of the wood was determined using a pendulum hammer with a 15 mm radius.

RESULTS AND DISCUSSION

Wood moisture content is one of the key factors that influence not only the properties of wood but also the possibility of rot development caused by wood-destroying fungi, which is the main reason for a sharp decrease in the physical and mechanical characteristics of wood (Basham, 1984). In accordance with the previously described methodology, measurements of deadwood moisture content under field conditions yielded the following results (Tab. 1, Fig. 4).

In the first 3-5 years after the death of trees, the moisture content of deadwood decreases by almost 37% compared to standing trees, but remains at a fairly high level, exceeding the saturation limit of wood cell walls. Such moisture parameters favor the development of wood-destroying fungi in deadwood (Schwarze *et al.*, 2002).

By 8-10 years after the death of a stand, the moisture content of dead trees decreases by 60% relative to the initial values. It becomes unfavorable for the development of wood-destroying fungi. All the studied groups with a period of death of over 8 years show moisture parameters below the saturation limit of cell walls within the range of 23-27 %.

Tab. 1 Deadwood moisture content.

Period of death, years	Number of measurements, units	Mean moisture content, %	Mean square deviation, %	Coefficient of variation, %	Accuracy of the experiment, %
0	55	58.1±2.9	10.6	18.3	2.5
3-5	95	36.7±3.6	17.6	47.8	4.9
8-10	54	23.2±1.9	6.8	29.4	4.0
12-14	96	24.5±2.1	10.6	43.3	4.4
19-20	63	27.1±2.4	9.6	35.5	4.5

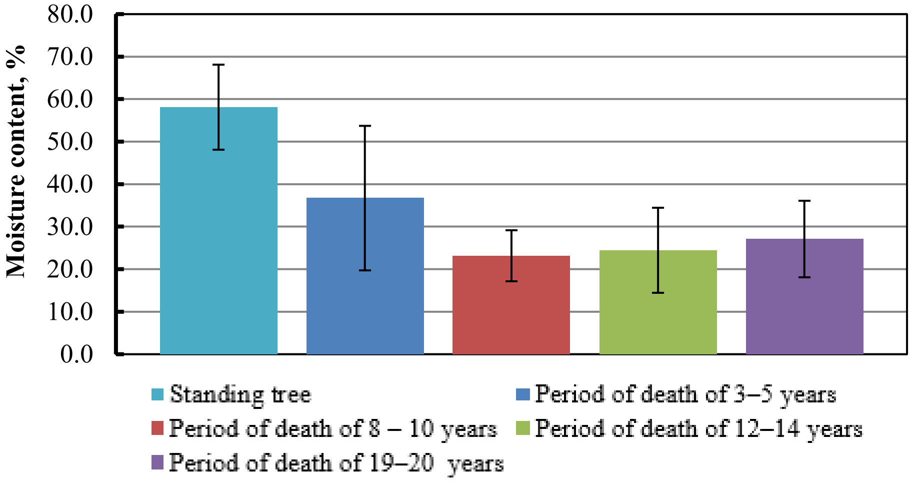


Fig. 4 Deadwood moisture content.

During the research, uneven distribution of moisture in the stems of dead trees along their height was noted (Fig. 5).

The highest wood moisture values were predictably observed at the base of the stem, located at a low height from the ground, within 20-30 cm. Compared to standing trees, the highest moisture values were 11% higher in trees that had been dead for 12-14 years. The lowest moisture content values in the group with a period of death of 8-10 years were 18% lower than in standing trees. In general, the moisture content of the lower part of the stem in all the groups of dead trees, depending on the period of death, is in the range favorable for the development of wood-destroying fungi, at a level of 38-47 %.

Herewith, at a height of 1.3 meters from the base of the stem, the moisture distribution pattern changes significantly. The moisture content of wood in standing trees increases by 27%, while in dead trees it decreases by 26-49%.

The only exception is the trees with a period of death of 3-5 years. At breast height, the dead trees in this group have a moisture content of about 50%, which is 17% higher than at the base of the stem. In general, dead trees have a wood moisture content that is 16-59% lower than that of standing trees.

At a height of 2.5 m from the base of the stem, standing trees continue to show a slight increase in wood moisture content, approximately 7 % higher than at a height of 1.3 m and 35% higher than at the base of the stem. By comparison, in dead trees, all groups, regardless of the period of death, continue to experience a decrease in moisture content of 20–38 %. Compared to the base of the stem, the moisture content of deadwood at this height is 13–68 % lower, and when compared to standing trees, it is 44–74 % lower. It should be noted that when the period of death is 8–10 years and 12–14 years, wood at a height of 2.5 m has a moisture content of less than 20%. This moisture content is critically low for wood-destroying fungi, leading to their death (Gavrilov and Stankevich, 2022).

At a height of 5 meters and above, the wood moisture in standing trees remains approximately at the same level, corresponding to the moisture content of fresh wood. Deadwood with a period of death of more than 8 years at a height of 5 meters has a moisture content of less than 20% and is therefore unsuitable for wood-destroying fungi. The most favorable wood moisture content for xylotrophs is found in dead trees with a period of death of 3-5 years. At a height of 2.5 meters, the moisture content remains approximately the same (30-35%), exceeding the saturation limit of the wood cell walls.

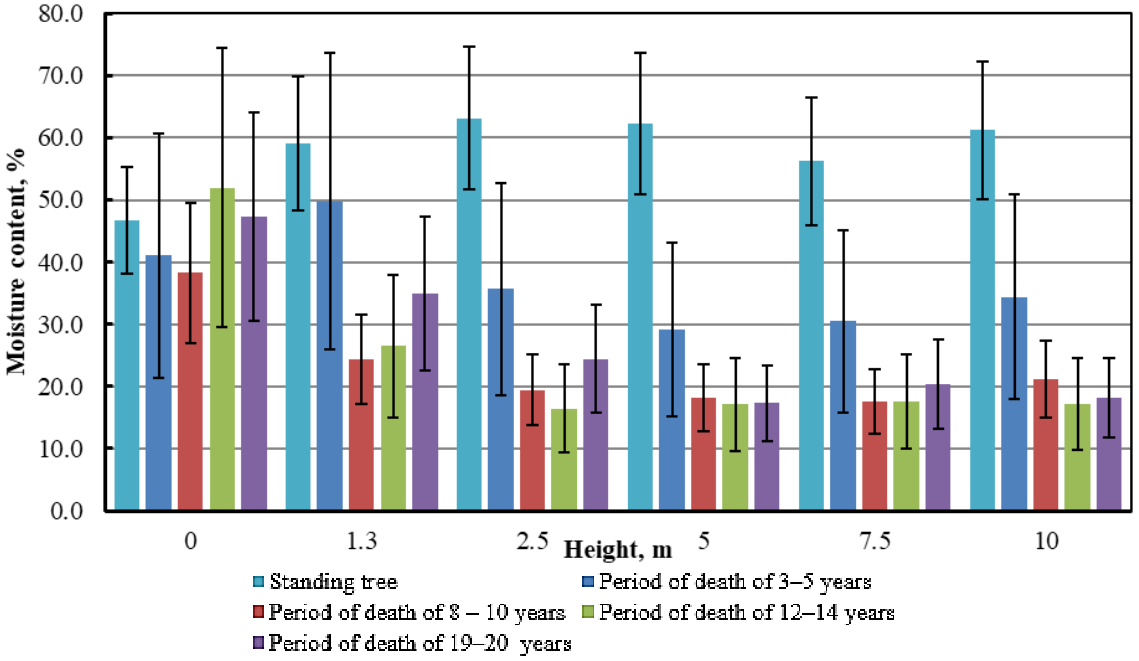


Fig. 5 Change in dry wood moisture content along tree height.

The density and strength of *A. sibirica* deadwood was studied in the next phase of the research under laboratory conditions (Tab. 2, Fig. 6-10).

Tab. 2 Physical and mechanical properties of deadwood.

Period of death, years	Number of samples, pcs.	Indicator	Mean square deviation, %	Coefficient of variation, %	Accuracy of the experiment, %
Wood density, kg/m^3					
0	122	405±4.8	23.15	5.71	0.52
3-5	122	408±3.3	36.87	9.14	0.83
8-10	122	406±5.0	28.63	7.82	0.71
12-14	122	403±3.2	29.61	7.21	0.65
19-20	122	445±2.6	20.98	4.66	0.42
Impact strength, J/cm^2					
0	65	5.4±0.1	0.44	8.11	1.01
3-5	65	3.2±0.1	0.56	17.45	2.16
8-10	65	2.9±0.1	0.39	13.33	1.65
12-14	65	3.3±0.1	0.54	16.35	2.03
19-20	65	3.6±0.1	0.72	18.74	2.32
Compressive strength along the grain, MPa					
0	538	36.0±0.6	5.87	16.31	0.87
3-5	538	36.9±0.2	4.71	12.74	0.55
8-10	538	35.3±0.3	3.75	11.14	0.48
12-14	538	36.9±0.9	3.66	9.84	0.42
19-20	538	41.3±0.3	4.36	10.35	0.45
Ultimate static bending strength, MPa					
0	57	58.8±1.4	9.68	17.05	2.26
3-5	57	58.9±1.0	7.18	12.16	1.61
8-10	57	54.9±1.6	6.25	11.94	1.58
12-14	57	59.6±1.2	7.78	13.13	1.74
19-20	57	65.8±1.4	7.88	11.88	1.57

Density is one of the most important indicators characterizing the technical properties of wood. A reduced wood density is one of the signs of its destruction by wood-destroying fungi (Broda, 2020).

The study of the change in wood density in the stand that died due to the effects of the four-eyed fir bark beetle showed the following (Fig. 6). Over the 14 years since the trees died, wood density has remained virtually unchanged. The density of the test wood and the wood with all the periods of death, except for the group with the period of death of 19-20 years, does not have significant differences. At the same time, in the group with the highest period of death, there is an increase (not a decrease) of the mean wood density by about 10 % compared to the control. The increase in the mean wood density of trees with the highest death rates appears to be due to selection. Up to 20 years from the moment of death, only those trees that have a higher original wood density than the mean density in the stand are kept upright, because it takes more time for fungi to destroy the roots of tree stems with higher density.

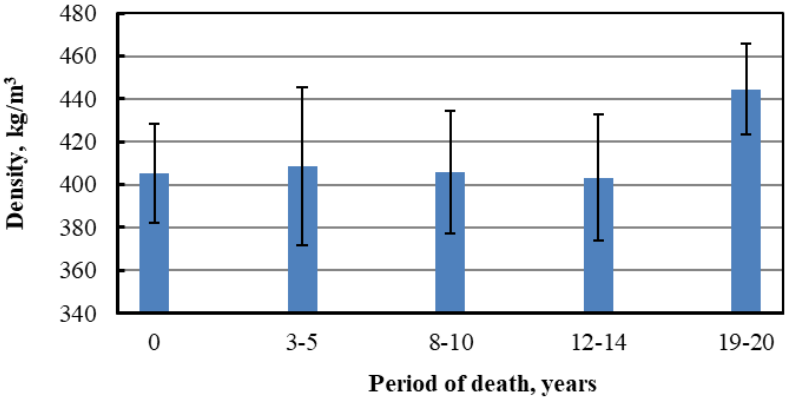


Fig. 6 Dependence of wood density on the period of death.

The study of changes in density along the stem height in almost all groups, according to the period of death, was insignificant within the limits of experimental error. The model trees showed a small decrease in wood density along the stem height only in the group with a period of death of 12-14 years. The difference between the apex and the base of the stem was about 9%.

Mechanical testing of the selected model trees showed the following results. The impact strength of deadwood already in the first 3-5 years after death has a sharp 40% decrease (Fig. 7). This indicates that the stem wood of a dead tree is being actively exploited by wood-destroying fungi (Troxell *et al.*, 1980). After 5 years from the moment of death, the rate of decline slows, and over the next 5 years, the tree is in a dead state; the impact strength is reduced by only 9 %. On the contrary, in the groups with death ages of 12-14 and 19-20 years, the selected models showed an increase in impact strength. Their values exceed those of the group with a period of death of 8-10 years by 13.8% and 24%, respectively. Nevertheless, in comparison with the control, their performance is 33-39% lower than that of standing trees. Such patterns of change, as already mentioned, seem to be explained by selective tree felling, which is most evident in the group with a period of death of 8-10 years. Accordingly, by 20 years after the moment of death, only the trees with higher density and wood strength remain upright.

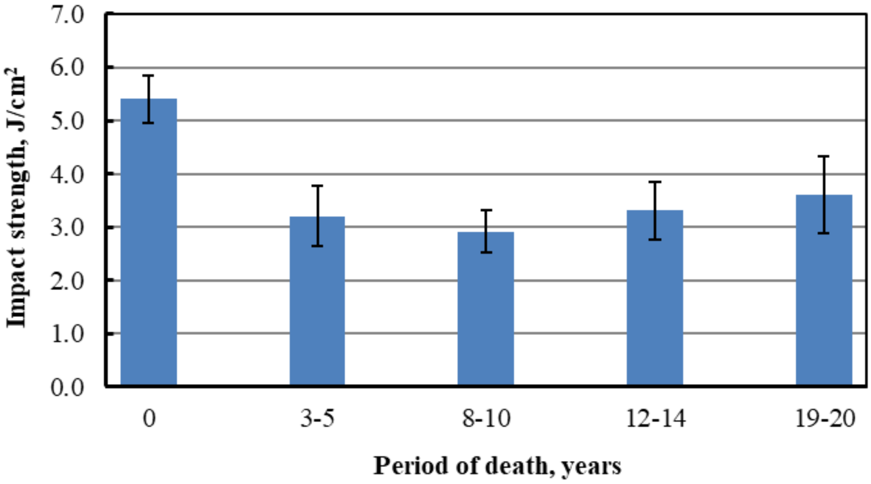


Fig. 7 Dependence of impact bending stress on the period of death.

The study of the change in the impact stress of wood along the height of the stem showed (Fig. 8) that in standing trees, higher impact strength is observed in the lower and upper parts of the stem, while the central part of the stem has an impact strength of 15-18% lower compared to the base and apex. The same pattern of distribution is observed in the model trees with a period of death of 3-5 years, despite the overall decrease in this indicator. In models with a 8-10-year period of death, there is a reduction in impact strength from the base to the top of the stem. In this case, the difference between the lower and central part of the stem by this period of death is practically leveled (within the limits of experimental error). The upper part of the stem shows an impact strength 14% lower than the central one and 17% less than the lower part of the stem. The increase in the fragility of the upper part of the stem may cause intense flattening of the apices in the dead stand observed for this period of death.

In the group with a period of death of 12-14 years, the impact strength in the central part of the stem was approximately 20% lower than in the lower part and 7% lower than in the upper part. In the group with a period of death of 19-20 years, the impact strength in the central part of the stem was almost 8 % higher than in the lower part and 17 % higher than in the upper part.

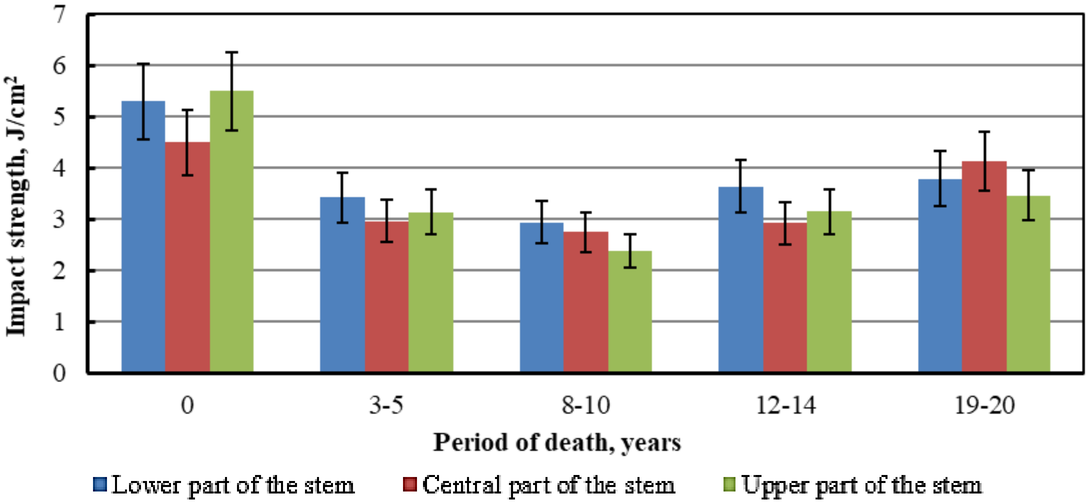


Fig. 8 Dependence of the change in the impact strength of wood on the period of death along tree height.

The study of the compressive strength of dead trees along the grain revealed the following characteristics (Fig. 9). In the range of the period of death from 3 to 14 years, all the model trees had a similar strength index of 36 MPa. All minor deviations in the index observed across the individual groups by period of death were within the limits of experimental error and did not show significant differences.

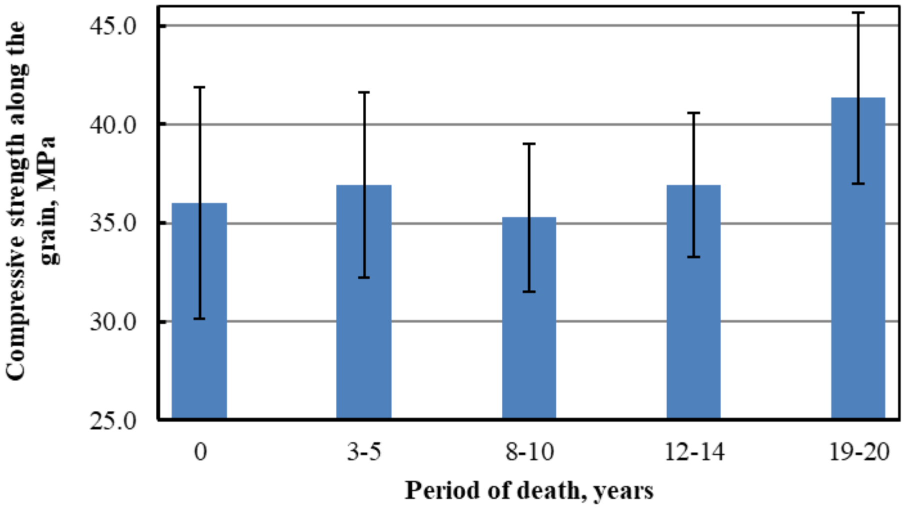


Fig. 9 Dependence of the compressive strength of dead trees along the grain on the period of death.

The group with the period of death of 19-20 years stood apart from the others. In this group, the model trees had wood compressive strength that was almost 15% higher than that of the non-biologically damaged control wood. This feature once again confirms the assumption that only trees with above-average physical and mechanical properties remain upright by the age of 19-20.

Studies of changes in wood compressive strength along the grain and along the height of the stem showed that, in most groups of model trees, compressive strength tended to decrease from the base of the stem to the top. Overall, the change in strength along the height was insignificant and within the limits of experimental error. The exception among all the variants studied was the group with a period of death of 8-10 years, which showed a slightly greater decrease in strength.

During studies of the strength of deadwood under static bending, the following features were identified (Fig. 10). The mean bending strength values for the groups with periods of death of 3-5 years and 12-14 years, and the control samples, did not differ. The model trees from the group with the period of death of 8-10 years had a slightly lower index than the groups under consideration, but the difference was less than 7%. The model trees from the group with a period of death of 19-20 years had a bending strength 10% higher than that of the control group. In general, the results obtained correspond to the previously made assumption about the natural selection of trees with high technical wood properties.

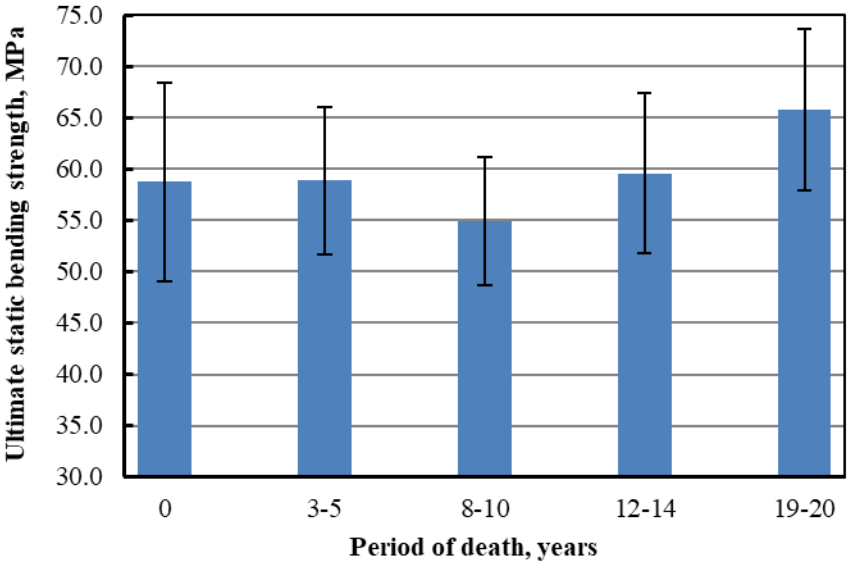


Fig. 10 Dependence of the static bending strength of wood on the period of death.

The study of bending strength in dead trees along the stem height showed that, across almost all model tree groups, depending on the period of death, bending strength decreases from the base to the top. While in the control group the change in strength is only observed as a trend within the limits of experimental error, in the group with the period of death of 3-5 years the difference between the lower and upper parts of the stem was already 7 %; in the group with the period of death of 8-10 years it was 32%; and in the group with the period of death of 12-14 years it was about 15 %. The distribution of strength along height differs only in the group with a period of death of 19-20 years. Here, in the central part of the stem, the strength is approximately 7.5 % lower than the lower and upper parts of the tree stem.

Summarizing the results of the studies conducted on the physical and mechanical properties of deadwood, the following preliminary conclusions can be drawn. The destruction of the stem wood of dead trees begins during the period of tree death and continues until the moisture content of the wood decreases to 20% by the time of death, which occurs 8-10 years later. During this period, there is no significant decrease in the density and strength of wood. A significant decrease in mechanical properties is observed only in terms of wood impact strength, which is most sensitive to the activity of wood-destroying fungi. Similar results in terms of impact strength were noted in (Sinclair *et al.*, 1979). A sharp decrease in impact strength in wood indicates that deadwood was affected by wood-destroying fungi, but the development of rot slowed and then stopped as the stem wood dried. The data that we obtained differ significantly from the results of the studies (Jelonek et al., 2020), where a 20-30% decrease in strength was recorded after three years for several indicators. The paper (Löwe *et al.*, 2022) also notes that the mechanical properties of wood decrease by 15-30% after just three years.

Meanwhile, the study (Gonzalez, 1990), as well as our work, does not report a significant decrease in wood density, even for trees with a period of death of 15 years. The preservation of deadwood properties over a long period of time is also reported in the work (Mukhortova *et al.*, 2009). The contradictory data on the dynamics of deadwood decay across studies are apparently due to both the species being studied and the geographic location of the study region.

In our study, the sapwood width in the examined *A. sibirica* model trees ranged from 10 to 20 mm.

It is practically impossible to produce standard test samples from it, and the main part of the stem consists of mature wood, which has higher biostability. Based on this, it is obvious that the main volume of stem wood will be better preserved in this species than in species with wide sapwood. After all, researchers have noted significant sapwood destruction in dead trees (Basham, 1984). The climatic characteristics of the study region also contribute significantly to the preservation of deadwood. In our case, a short hot summer in the Krasnoyarsk Territory provides a relatively short period with positive average daily temperatures. Under such conditions, wood-destroying fungi can develop for no more than 3-4 months a year. At the same time, high summer temperatures quickly dry out the main stem volume and make it unsuitable for xylophages to inhabit. And the third factor, which we believe also has a significant impact on the preservation of deadwood, is the reasons for tree death. For example, if a tree is damaged by needle-eating and leaf-eating insects, transpiration stops, the bark on the stem remains undamaged, and the stem wood retains a fairly high moisture content for a longer period of time. In the case of tree death due to bark beetles (as in our work), the tree crown does not die immediately; it continues to lose moisture for some time after the lower part of the tree has died. This dries out the stem wood. In addition, due to insect damage to the bark layer, the stem loses its bark more quickly, accelerating the drying of the wood.

CONCLUSION

1) In the *A. sibirica* stands that died as a result of damage by *P. proximus*, selective selection of dead trees based on the physical and mechanical properties of the wood is observed as the time since death increases. Dead trees with indicators of wood density and strength above average values characteristic of Siberian fir remain in the forest stand. Meanwhile, trees with low and average physical and mechanical indicators fall out.

2) The moisture content of deadwood decreases to below 20 % eight years after death, making it unsuitable for the growth of wood-destroying fungi. At the same time, the moisture content in the wood at the base of the stem remains high. This contributes to the development of rot and the subsequent falling out of dead trees due to the biodegradation of the stem base.

3) In the first 3-5 years after the death of a tree stand, dead trees experience a sharp decrease in the impact strength of their wood. This makes deadwood more brittle than the wood of standing trees. Therefore, such wood should be used with caution in load-bearing structures.

4) Most of the physical and mechanical properties of stem wood in a deadwood stand remain at the same level as in standing trees, with the intensive decay of wood observed only at the base of the stem. As a result, the stem wood of dead trees can be a valuable raw material for several wood-processing industries.

5) When predicting changes in the properties of deadwood over time, it is very important to take into account several key factors, such as the region of growth, tree species, and causes of tree death.

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AUTHORS’ ADDRESSES

Sergey Eliseev
Sergey Zhila
Sergey Kazitsin
Vladimir Ermolin
Mikhail Bayandin
Evgeniya Akinina
Tatyana Strekaleva
Reshetnev Siberian State University of Science and Technology
31 Krasnoyarsky Rabochy Av. Krasnoyarsk 660037
Russian Federation

s-555s@yandex.ru
getgain@mail.ru
sergeikaz060890@yandex.ru
vnermolin@yandex.ru
mihailbayandin@yandex.ru
eugeniya.mitina@yandex.ru
strekaleva@mail.ru