Monitoring the impact of major adverse factors on sustainability of Novgorod forests

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Abstract. The study analyzes the major adverse factors that caused destruction of forest stands in Novgorod region over the past 10 years based on the data on monitoring the state of forest ecosystems. Adverse effects such as weather conditions, fires, forest diseases, and insect forest pests were considered. The crucial reason of forest stand mortality in the region over the period under study was revealed. The features and patterns of the mortality of forest stands were studied with regard to their taxation characteristics and confinement to the natural landscapes of the region.

1. Introduction
The problem of abnormally aggressive effects of climatic factors on forest biogeocenoses has been widely studied by many authors. Wind is one of the most important factors. Professor H. Mayr assessed the impact of wind on forests as “wind is a creator of the forest, wind is a destroyer of the forest, and wind is a limiting factor for forest propagation” [1].

Scientists from different countries focused on the study of forest sustainability. At the beginning of the twentieth century, Russian scientist G.F. Morozov touched upon the concept of forest stand sustainability for the first time in the national science of forestry. In his study On the Forestry Principles, he emphasized great importance of “natural sustainability of forest stands” and “independence of the forest in its development” [2].

In studies by foreign scientists, the relationship between sustainability of ecosystems is considered with respect to their species diversity [3], and the growth rate, productivity, and damage to vegetation are assessed [4, 5, 6]. The impact of landscapes on the susceptibility of forest stands to windfall and the formation of the microrelief in wind-damaged areas in Potter County, Pennsylvania (USA) were reported by C.S. Denny [7]. Scientists highlight the role of forest fires, but studies of vegetation in the areas of mass windfalls are fewer in number [8, 9, 10], whereas, in recent decades, repeated catastrophic (large-scale) destructions of forests caused by winds have been observed. Experts relate climatic changes to further increase in the number of hurricanes and, hence, in the areas of mass windfalls [11, 12, 13, 14, 15].

Thus, a number of issues that require long-term monitoring studies are particularly relevant for scientists:

– assessment of the impact of various factors on forest ecosystems;
– analysis of the spatial structure of damages;
— confinement of various damages to certain landscapes.

Long-term studies have revealed a hierarchy of factors that affect forest sustainability in Novgorod region [16], and monitoring of forest ecosystems is recognized as a necessary element in the set of measures to form the basic strategies for sustainable forest management and forest growing.

This study aims to assess the role of the major adverse factors in the general trend of forest mortality in Novgorod region, and to identify the features and patterns of damage to stands in natural landscapes.

2. Methods and objects of study

Geographically, Novgorod region is located in the northwest of the Russian plain within the Priilmen lowland and the northern spurs of the Valdai upland. According to the state forest register, the total forest area of Novgorod region is 3920,1 thousand ha, including the forested area of 3357.2 thousand ha. Forests occupy 62% of the region.

The main forest-forming species are birch (Betula pendula, Betula pubescens) that occupies 42% of the forested area, common pine (Pinus sylvestris) – 18%, European spruce (Picea abies) – 18%, aspen (Populus tremula) – 12%, speckled alder (Alnus incana) – 8%, and common alder (Alnus glutinosa) – 1%. The rest of the tree species accounts for about 1% of the total forest area.

The climate in Novgorod region is temperate continental. It is characterized by excessive moisture, mild winters, cool lengthy spring, cold short summers and warm lengthy autumn. Significant territorial extension of the region from north to south and from west to east, diverse surface topography and the presence of a large water body Lake Ilmen significantly change climatic conditions.

Novgorod region is located in the zone of taiga and subtaiga landscapes in the North-West province. Districts and landscapes are the main taxonomic zones of Novgorod region. The landscape zones include 24 forest landscapes, which are united in 9 physical-geographical districts [16].

The dynamics of forest mortality in Novgorod region was assessed based on data of the 30-year study on forest sustainability [16], data from the state forest pathological monitoring, and statistics from the forest management body. To identify patterns of wind effects associated with forest stand mortality over the last 10 years, dead stands were assessed using data from 179 trial plots laid in the areas exposed to windfalls and windbreaks.

3. Results

According to the data of the Novgorod branch of the Russian Forest Protection Center, over 34 thousand ha of dead forest stands have been recorded in Novgorod region since 2010.

![Figure 1. Areas of dead forest stands in Novgorod region recorded over a 10-year period.](image-url)
The largest areas of dead forest stands were recorded in 2010 (15761.16 ha) and 2011 (12078.92 ha). This was due to hurricane winds that caused damage and death of tens of thousands of hectares of forest in the Borovichi, Lyubytinsky and Khvoyninsky forestries of Novgorod region. This is one example of the impact of wind, which is a catastrophic factor. At the same time, from 2010 to 2014, due to sanitary felling, the area of dead stands gradually reduced. Large areas of dead forest stands in 2012 (3023.17 ha) and in 2013 (1257.77 ha) were due to the mortality of forest stands during this period that were partially damaged by the winds of previous years. In 2014, the area of dead stands attained 309.44 ha, and in 2015 and 2016 it increased. Since 2017, the area of dead forest stands tended to reduce, and in 2019 the values reached their 10-year minimum and amounted to 191.5 ha.

Factors that have a negative impact on the forests in Novgorod region over a 10-year period make four main groups. These are forest diseases, forest fires, forest pest insects and weather conditions.

The disease-induced mortality of forest stands is cyclical in nature and most likely depends on detectability of these stands. The average value of the area of forest stands destroyed by forest diseases over the past 10 years is 15.1 ha.

Typical forest diseases identified in Novgorod region are caused by *Fomes fomentarius*, and necrosis and canker, which do not typically result in simultaneous death of forest stands. They oppress individual trees gradually and destabilize the entire stand, which is followed by an increase in the number of stem pest populations and, ultimately, to its destruction and death.

Thus, in most cases, diseases weaken stands but do not cause their death. This is confirmed by low number of dead trees destroyed by forest diseases recorded over the period under study. The maximum area of forest stands destroyed by diseases was recorded in 2013 and amounted to 44.5 ha.

The area of forest stands destroyed by fires over a 10-year period attained its highest value in 2010 and amounted to 110.4 ha. This year can be characterized as one of the driest and hottest in the period under study. After that, the area of forests destroyed by fires decreased significantly and did not exceed 19.9 ha per year. The average annual rate of fire-caused forest mortality over the period under study was 18.3 ha.

Low rates of fire-caused forest mortality in the period under study were due to long-term cold weather and a large amount of precipitations during the fire hazard period, which caused severe water-logging of forests in the majority of landscapes in the region.

Over the entire 10-year period, the investigation of dead forests did not reveal mortality caused by needle- and leaf-eating insects. During this period, forest mortality occurred only as a result of damage by stem pests. The highest rate of insect-caused forest mortality was observed in 2011 and 2012 (56.9 and 76.9 ha, respectively) due to a sufficient food supply for insect propagation as a result of mass windfalls in 2010–2011. After that, forest mortality caused by insect pests began to decline, and no more significant jumps of the mortality rate were recorded. It should be noted that in 2012–2019, the low rate of insect-caused forest mortality is associated with weather conditions extremely unfavorable for insect propagation, which can lead to the mortality of forest stands. Over the study period, the average rate of insect-caused forest mortality was 22.4 ha.

The highest rate of forest mortality due to adverse weather conditions was noted in 2010. Windfalls and windbreaks as a result of hurricanes in the northern part of Novgorod region destroyed 15.650.8 ha of forests. Large areas of dead forests in 2011 (11.901 ha) are due to an inventory of dead and damaged stands in 2010. The area of dead forests destroyed by adverse weather conditions was observed to decrease until 2014 and amounted to 301.2 ha.

The windfalls in the southern parts of the region in 2015, 2016 and 2017 increased the area of dead forests, the forest mortality rates were 685.3, 817.3 and 434.6 ha, respectively. Since 2018, the area covered by dead forests had decreased and attained its minimum in 2019 (159.2 ha).

Analysis of the data presented revealed that the main cause of forest mortality in recent decades is the wind. The distribution of wind-thrown stands depending on the terrain conditions (landscapes) has a number of characteristic features. In percentage terms, the highest share of dead forest stands destroyed by the wind in the period from 2010 to 2016 was observed in the Nebolch landscape and amounted to 94.9% in 2010 and 63.5% in 2014. A characteristic feature of the Nebolch landscape is its location in
the zone of the windward slope of the Tikhvin ridge. Lacustrine-glacial flat sand plains with kama relief are often found among moraine plains. In addition, the landscape features poor economic development and a large number of bogs of the upper type occupying up to 30–45% of the territory [17].

In 2017, forest stands growing in the West Valdai (44.2%) and Nebolch landscapes (31.5%) were most affected. In 2018, the highest mortality of stands was recorded for the West Valdai (52.7%) and Kholovsky landscapes (22.7%). The West Valdai landscape is located along the edge of the Carboniferous limestone, on the lower surface of the Devonian. This is the area of dissected terrain. Glacier deposits form moraine ridges and hills separated by depressions represented by sandy and loamy plains with kames. The terraced slope towards the Priilmen lowland can be clearly observed on the landscape relief [16].

A characteristic feature of the Kholovsky landscape is its terraced relief due to decreased level of lake-glacial reservoirs. Quaternary deposits of the landscape are represented by bottom moraine of Valdai glaciation overlain by the layers of glacial-lake sands 5–6 m thick [17].

In 2019, the distribution of dead stands was similar to that recorded in 2017 – 39.2% of stands in the West Valdai landscape and 24.1% of stands in the Nebolch landscape. Thus, high mortality of forest stands caused by winds was recorded in the Nebolchsky and West Valdai landscapes. Over the entire 10-year period, the largest area of wind-thrown stands (92.6%) was noted in the Nebolchsky landscape.

Analysis of the data from the trial plots revealed the dependence of windfall timber formation on taxation characteristics of stands. The distribution of wind-thrown trees by species showed the lowest wind resistance of such species as spruce (Picea abies) and birch (Betula pendula, Betula pubescens), which are the main forest-forming species in the Novgorod region. The percentage of dead spruce and birch stands was 40% and 31%, respectively. The susceptibility to windfall of these tree species is explained by structural features of the underground and aboveground parts. Pine (Pinus sylvestris) and aspen (Populus tremula) stands were less affected and mortality rate attained 21% and 5%, respectively. Other tree species accounted for less than 3% of the total area of dead stands.

The age structure of wind-thrown trees was distributed as follows. Dead trees of 71–80 years old made up the largest share of 28.2%, the share of trees aged 61–70 years old attained 24.4%, and 81–90 years old trees amounted to 18.4%. In general, the age of the majority of dead trees varied from 61 to 90 years (71%). The share of dead trees older than 91 years was 16.5%. Obviously, older trees are more prone to wind damage due to both the greater susceptibility to windfall and stem and root rot compared to young growths.

Analysis of the distribution of wind-thrown stands depending on the type of forest showed that highly productive stands of oxalis and blueberry forests were most affected (54% and 28%, respectively). The percentage of dead stands found in haircap-moss forests made up 3%, in sedge-sphagnum forests – 2%, in riverine forests – 4%, in bog moss forests 0.5%, in grass-meadowsweet forests – 7%, and in horsetail forests – 0.5%.

Forest stands of Grade (bonitet) II exhibited the highest percentage of dead stands (71%), the share of dead stands of Grade (bonitet) III was 15.5%, the share of dead stands of Grade (bonitet) IV and lower was only 1.5%. The share of dead stands of Grade (bonitet) I was 12%.

The most affected were medium-density stands with density indices of 0.5, 0.6 and 0.7 (91%). The highest rate of mortality was recorded for forest stands with a density of 0.6 (48%). The share of low-density stands with density indices of 0.3 and 0.4 made up 4% and 5%, respectively.

4. Conclusion
1. Adverse weather conditions, the wind in particular, have been the major cause of forest mortality in Novgorod region over the past ten years.
2. The Nebolchsky, West Valdai and Kholovsky landscapes exhibited the highest percentage of wind-thrown trees. Slopes and terraced relief are characteristic of these landscapes.
3. It was established that the majority of dead stands were medium-dense plantations of Grade (bonitet) II–III growing in oxalis and blueberry forests.
4. Depending on the species composition, spruce stands were most often destroyed by winds.
5. The age structure of dead stands indicates the greatest susceptibility to windfall of 61–90 years old trees.

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