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THE OVERVIEW OF EXISTING SILVICULTURAL APPROACHES UNDER THE INFLUENCE OF ADVERSE WEATHER PHENOMENA AND RECOMMENDATIONS FOR INCREASING THE FOREST RESILIENCE TO HIGH WIND EVENTS IN BELARUS

COMPONENT 2:
SUPPORTING RESILIENCE
AND RECOVERY
IN THE FORESTRY
SECTOR

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List of main abbreviations, symbols, units of measurement, terms and definitions

Scots pine	*Pinus sylvestris;*
Common oak	*Quercus robur;*
European silver birch	*Betula pendula;*
European alder	*Alnus glutinosa;*
Black alder	*Alnus glutinosa;*
Small-leaved linden	*Tilia cordata;*
Aspen	*Populus tremula;*
°C	degrees Celsius;
%	percent;
ha	hectare;
m³	cubic meter;
Belhidromet	State institution «Republican center for hydrometeorology, control of radioactive contamination and environmental monitoring»;
Bellesozaschita	State institution for the protection and monitoring of forests
Belgosles	Forest management republican unitary enterprise
BSTU	Belarusian State Technological University
Clear sanitary felling	clear felling conducted in stands that due to unfavorable weather conditions, fire, pests and diseases completely lost their resistance;
Clearing works	removal of single trees damaged by unfavorable weather conditions, fires, pests or diseases;
Forest fund	lands allocated to carry out forestry activities;
Forest lands	lands belonging to forest fund and allocated to forest growing;
FSC	FOREST STEWARDSHIP COUNCIL
Partial forest plantations	forest plantations located on the area in places devoid of the undergrowth of the main species, in order to increase the stand density or improve the species composition of the stand;
Selective sanitary felling	felling on an area of less than 0.1 hectares. Removal of trees damaged by unfavorable weather conditions, fires, pests or diseases;
SPFA	State Production Forestry Association;
Windbreak	trees or stands are broken by the wind
Windblow, windthrow	trees or stands are blown down by the wind.

Executive summary

The main objective of the work is to study the experience of reforestation, the restoration of windblows of 2016 and the development of recommendations for improving the work and increasing the resistance of plantations to windblows based on international experience.

Method

The assessment of the prevalence and harmfulness of unfavorable weather phenomena was carried out on the basis of statistical materials presented by the Ministry of Forestry. The study of the features of the wind regime was carried out using monthly and annual materials on the climatic characteristics of the Republic of Belarus, compiled by Belhydromet. The distribution of the occurrence of winds with a speed of more than 20 m/s and their directions was drawn up on the basis of annual information on the occurrence of adverse weather phenomena and Belhydromet's monthly reports for the period from 2003 to 2017.

The distribution of windblow areas and clear sanitary felling areas was based on the annual reports of "Bellesozashchita" for the period 2013 – 2017.

The analysis of existing forestry approaches in forest management under climate change conditions was made by assessing the risks of forest creation in the Republic of Belarus and the problematic issues raised by forestry specialists during scientific and practical seminars.

Approaches to the restoration of windblow stands on the basis of FSC standards and policies were outlined on the basis of a meeting with the national coordinating representative of FSC projects in Belarus Lev Fyodorovich.

The environmental assessment of windblow sites and the assessment of their restoration methods took place on the basis of a survey of the most damaged forest areas in Smolevichy (C 53° 52′21″; B 28° 07′20″), Cherven forestry enterprises (C 53° 53′35″; B 28° 19′01″) and Borovlyany special forestry enterprise (C 53° 47′52″; B 27° 27′55″).

In order to identify problematic issues and assess the characteristics of reforestation of windblows of 2016, the meetings with the head of the forestry department of the Ministry of Forestry of the Republic of Belarus Nikolay Yurevich, head of the department of forestry and reforestation of Minsk SPFA Mikhail Doropey, former chief forester of Smolevichy forestry Nikolai Yushko, forester of Drachkovsky unit of Smolevichy forestry enterprise Alexei Rakovsky, chief forester of Cherven forestry enterprise Viktor Kazakov, the chief forester of the Berezinsky forestry enterprise Andrei Zhigar, the chief forester of the Borovlyany special forestry Maxim Migun, forester of the Ratomka unit of the Borovlyany special forestry enterprise Alexander Bulak were held. The issues of providing meteorological information were discussed with Natalia Klevets, the head of the climate change study department at Belhydromet.

For a spatial assessment of the location of the windblow sites the capabilities of the program Google Earth Pro were used.

Analysis of international experience and assessment of its use on the territory of the Republic of Belarus was carried out with the direct participation of international experts: Dr. Barry Gardiner (European Forest Institute), Jaanis Donis (Latvian State Forest Research Institute "Silava").

Recommendations for the restoration of windblow sites were carried out on the basis of the data obtained in the course of the work, and also on the results of a working meeting with international experts held in Minsk in the framework of the seminar "Evaluation of current losses and improvement of economic analysis of the expenses on catastrophic events occurring in the present time in the forestry sector that are connected with the climate based on international experience" organized by the Belarusian State Technological University and the Ministry of Forestry of the Republic of Belarus with the support of the Global Fund for Disaster Reduction and Recovery (GFDRR) and the World Bank.

In Belarus, windblows and lowering of the groundwater level are the main problems of forest mortality. Windblows are annually observed throughout the Republic. Windblows accounts for more than 64% of the damaged forest area and almost 52% of the volume of damaged wood. However, in most cases they are of a local nature and do not cause complete mortality of plantings on large areas. Exceptions are years, such as 2016, for example, when tens of thousands of hectares were damaged, mostly in the central part of Belarus. Coniferous plantings are vulnerable to dryings due to the lowering of groundwater level and the subsequent colonization of trees by pests. In recent years, common pine has been mostly vulnerable to dieback. The mortality of which exceeded 120 thousand hectares. The fire areas are reduced from year to year due to the development of a forest fire protection management system. The main problem is caused by cross-border fires coming from Ukraine. Over wetting of forest plantings as well as snowbreaks are restrictively distributed.

Western winds prevail on the territory of the Republic, but there is no clear pattern in the occurrence of strong winds and windblows. The average wind speed in the Republic rarely exceeds 4 m / s. One or two cases of wind speed exceeding 20 m / s with the south-west to north-west directions are usually recorded a year. Sometimes, in different years, winds that caused windblows of opposite directions were recorded. It makes it impossible to develop global recommendations for the spatial distribution of wind resistant plantations. There are also regional peculiarities of windblows occurrence that should be taken into account while designing plantings. The territory of Minsk SPFA is mostly damaged. Here not only the maximum area of windblows is observed, but also the maximum area of clear sanitary felling. In Vitebsk SPFA there are significant areas of windblows with the minimal volumes of clear sanitary fellings. It shows another nature of tree damage by strong winds. Moreover, in each regional association there are the most and least damaged forest enterprises. A detailed analysis of the causes of windblows occurence depending on the region of the planting location and its characteristics is needed. At present time in Belarus there is no data on wind resistance of plantations with different characteristics. In order to carry them out it is necessary to perform computer simulations of the effect of wind on plantings with different characteristics, taking into account the peculiarities of Belarusian forests.

Formation of plantings that are resistant to adverse climate change can be carried out at various stages of forest life, but this can be done most easily and effectively at the initial stage when a new forest is created or restored. In Belarus, in the production of seeds, more attention should be paid to plus stands, as the most productive and sustainable in the region of their growth. It is necessary to increase the share of the participation of natural regeneration in reforestation, also through combined use with forest plantations. For artificial reforestation of conifer stands, the practice of sowing should be expanded. The work on optimization of the maximum areas of clear fellings should be done in order to facilitate the emergence of natural renewal and increase the wind resistance of forests.

Windblows that have passed through the large areas and methods for their restoration can cause certain difficulties during the audit by representatives of international forest certification systems. It is necessary to recreate the damaged areas, making the most of native species and their natural regeneration. However, the certification system itself should take into account the peculiarities of large-scale windblows and the real possibilities of the forest industry.

When restoring windblows of 2016, the creation of forest plantations, mixed in composition, with a predominance of conifers, was mainly used. These events were covered in the media and attracted thousands of people and hundreds of organizations. Significant areas of damaged plantings made it necessary to attract forestry enterprises from all over the country for the creation of forest plantations. For the first time, after a long break, Scots pine sowing was used on significant areas, which showed a good result. Natural regeneration was limited, but its use is possible only near the surviving stands. The use of coniferous species for the creation of forest cultures creates a problem of increased fire danger of areas. This problem should be addressed. In Belarus, there are recommendations for reforestation of windblow sites developed at the Forest Institute of the National Academy of Sciences of Belarus. However, for their accurate application and for the development of detailed recommendations for improving the wind resistance of plantings it is necessary to work on modeling the effects of wind on stands of various species, created according to various mixing and planting schemes, as well as with different levels of intensity of forest management.

Based on the experience of reforestation of windblow 2016 in Belarus, it is necessary to develop a plan for managing wind-related crisis phenomena, as well as to adapt existing risk models of plantings damage by the wind for the conditions of Belarus for the development of measures to improve the wind resistance of forests. The windblow of 2016 showed high efficiency of the measures to overcome the effects of hurricane winds. The experience gained should be presented in the form of a wind crisis management plan, as well as a practical guide, which will contain possible work options with an assessment of their effectiveness and conditions of use. Adaptation of the model of the damage to the planting by the wind ForestGALES will make it possible to determine plantings the least resistant to windblow and to evaluate the effect of various forestry measures on the wind resistance of the forest. Combined use of the modeling results and wind hazard maps that can be combined with digital forest maps will allow forestry workers to effectively influence the wind resistance of existing and future plantings.

1. Silvicultural characteristics of adverse weather phenomena, especially windblows, in Belarus and their impact on reforestation processes.

In Belarus, phenomena associated with global climate change have been observed over the past few decades. There is a constant annual temperature rise. The number of hot days is increasing. At the same time a decrease in precipitation days occurs. There is a negative impact on river regime that is through general decrease in the level of groundwater.

Silviculture is one of the most vulnerable sectors to climate change. Woody plants respond to changes in the habitat parameters by increasing productivity, growing energy or, conversely weakening of growth processes, decreasing resistance to adverse weather conditions and pathogenic organisms.

According to the Ministry of Forestry of the Republic of Belarus, the largest areas of forests are damaged by windblows and dieback due to the lowering of the groundwater level (table 1).

Table 1. Distribution of areas and volumes of wood damaged by adverse weather phenomena

The name of the adverse weather phenomena	Affected area		Damaged wood	
	ha	%	1000 m3	%
Windblow	37677.3	64.3	1064.0	51.9
Overwetting	281.0	0.5	16.8	0.8
Snowbreak	99.4	0.2	2.1	0.1
Fires	639.0	1.1	122.8	6.0
Decrease in the level of groundwater	19896.8	34.0	844.4	41.2
Total:	58593.5	100.0	2050.1	100.0

The share of windblows and dieback accounts for more than 98% of damaged areas and more than 92% of damaged wood. In this case, it is windfalls that are the most frequent cause of forest damage.

Adverse weather phenomena have a significant negative impact on forest stands from a silvicultural point of view.

Windblows in the Republic of Belarus are constantly observed throughout its territory. Moreover, the impact of strong winds can be of a local nature, when the individual trees or forest stands are damaged in an insignificant area, and global, when the death of forests is observed on an area of thousands of hectares.

In the first case, the removal of damaged trees from the stands, forest clearing are where the total death of woody plants occurred. Forest regeneration can be carried out as part of planned annual works using natural regeneration and the creation of forestry plantations. However, in damaged forest plantations or along the perimeter of clear felling the risk of colonization by secondary insects of the trees weakened by windfall rise sharply (Figure 1). Such sites should be of the first priority for forest pathology monitoring.

Global windblows lead to clear sanitary felling on large areas that in addition to high financial and labor costs causes serious silvicultural problems. Firstly, the presence of large open areas significantly limits the possibility of using natural renewal for restoring of damaged forest stands due to the lack of seed sources. The preservation of intact trees can slightly improve the situation (Figure 2), however, these trees have low wind resistance. In addition, they have been already damaged to some extent by the wind and may die because of the pest contamination.

Figure 1. Drying trees on the edge of the clear felling of the windblow area

Figure 2. The remaining trees after the windfall of 2016 in Smolevichy forestry enterprise.

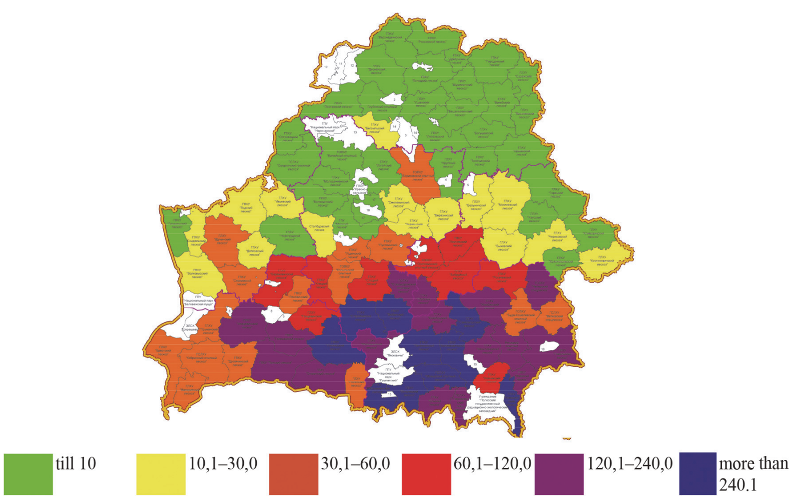
Intensive development of natural regeneration of soft-wooded broadleaved species such as silver birch or aspen, can lead to undesirable alternation of tree species. Especially it can happen on fertile soils, where aspen, for example, can reach a height of 1.5-2 m in a year. In this case, the process of natural renewal of coniferous stands can lasts for decades. When carrying out the creation of forest plantations, the intensive development of the renewal of birch or aspen leads to the need for repeated tree clearing.

Artificial reforestation of large-scale windblows makes it possible to recreate and maintain the composition of the forest stands, which was on this particular site before the damage. However, on windblow sites of natural forests when creating forest plantations especially those containing the same species, there may be some contradiction with the requirements of certification standards, in particular, FSC, which provide for biodiversity and genetic diversity conservation and the predominance of natural regeneration methods. Also it should be taken into account that there is a strong transformation on large windblow sites not only of woody vegetation but also of ground cover, meanwhile most of the forest characteristics are lost and human activity is not able to influence this process anymore. Formally, there is a transformation of natural forest in a plantation that brings challenges with obtaining a certificate by a forestry agency.

The need for artificial restoration on large areas requires a significant amount of planting material, many times exceeding the capabilities of a particular forestry enterprise. The use of planting material from other regions, especially from other seed plantations, entails a change in the genetic structure of future plantations that may have an adverse impact on their resilience to climate change. Therefore, to restore damaged plantings it is necessary to make the best use of local genetic resources actively using natural regeneration and sowing of seeds.

The second important reason for failure in forests is the drying of stands because of the groundwater level lowering and mass colonization of them by bark beetles. Coniferous plantations are most subject to drying. In Belarus, there were several waves of common spruce drying. Last year the amount of drying of this species was 14 thousand hectares. From the year 2017, the drying of Scots pine takes place the area of which last year exceeded 120 thousand hectares. Drying of the pine affected primarily the south of Belarus (Figure 3).

Figure 3. Distribution of forestry enterprises of Belarus by the volume of wood of drying pine stands in 2017 (Sazonov A. A., Zvyagintsev V. B.)., thousand m3:



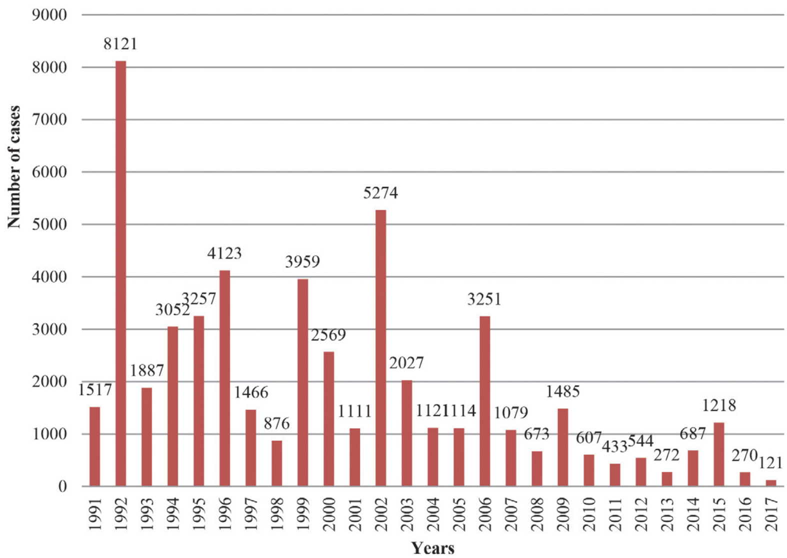
In 2018, the situation was aggravated. For the nine month of this year the drying area of pine forests has already exceeded the volumes of 2017. On October 1, the volumes of sanitary clear felling almost reached 30 thousand hectares for pine plantations and 6.2 thousand hectares for spruce (in 2017, the areas of sanitary clear felling was 25.3 and 5.5 thousand hectares, respectively).

The silvicultural problems caused by the mass drying of plantations are similar to the problems of windblows. However, the drying occurs locally and that allows to use the potential of natural regeneration more fully both independently and as part of partial forest plantations. The main problem of the felling reforestation from under the drying coniferous forests is the formation of mixed coniferous-deciduous plantations.

When creating pine stands, emphasis can be placed on the natural regeneration of silver birch. And when restoring spruce forests, successfully mixed stands can be created only with the use of planting material from such species as oak, linden, maple, ash and elm.

Such climatic factors as temperature increase, precipitation decrease and increase in the length of the dry period influence the fires occurrence probability. With an unfavorable trend in the change of these indicators, Belarus is characterized by a low level of fire frequency and a constant decrease in its number (Figure 4).

Figure 4. The number of fires in the forest fund of the Republic of Belarus



In 2017, 121 fires with a total area of 72 hectares were registered in the forest fund. Moreover, 78% of the numbers of fires are fires with an area of up to 0.1 ha. Such indicators have been achieved due to developed state system for forest fire management. The formation of a remote monitoring network using video controls systems is currently being completed. At least 100 km of forest roads are annually created in the Republic in order to ensure rapid fire suppression.

One of the main problems is trans-border fires coming to the territory of the Republic of Belarus from Ukraine. In 2015, a fire, the area of which was 2.4 thousand hectares came from Ukraine. In 2016, 81.9% of the fires occurred in Polesye and Lelchitsy forestry enterprises, directly bordering the territory of Ukraine. In 2017, 86.2% occurred in border territories of Polesye and Milosevici forestry enterprises. In 2018 Polesye and Milosevichi forestry enterprises for the operating control over the fire situation, a system of automated tracking and early detection of forest fires using remote monitoring methods was implemented.

The reforestation of the areas affected by fires due to their small areas does not cause difficulties. Artificial or natural renewal is used. Forest plantations are created 2 – 3 years after a fire to minimize the risk of crop damage by a pine weevil.

Over-wetting of forests as well as snowbreaks has a very restricted distribution. The main cause of over-wetting is incorrect work of drainage system, located in the territory of forest fund, the negative effect of polder systems and repeat swamping of cutover and drained peatlands without taking into account the peculiarities of the relief. As a result, the type of the water regime of the territory changes, and the forest plantations are in the zone of flooding and underflooding. The change in the type of conditions of the growing areas to the direction of the marsh type occurs, that leads to oppression and death of woody plants. The area of annual plantations death due to overwetting varies between 200-300 ha. However, the area of plantations located in the zone of adverse changes in the water regime is estimated at thousands of hectares.

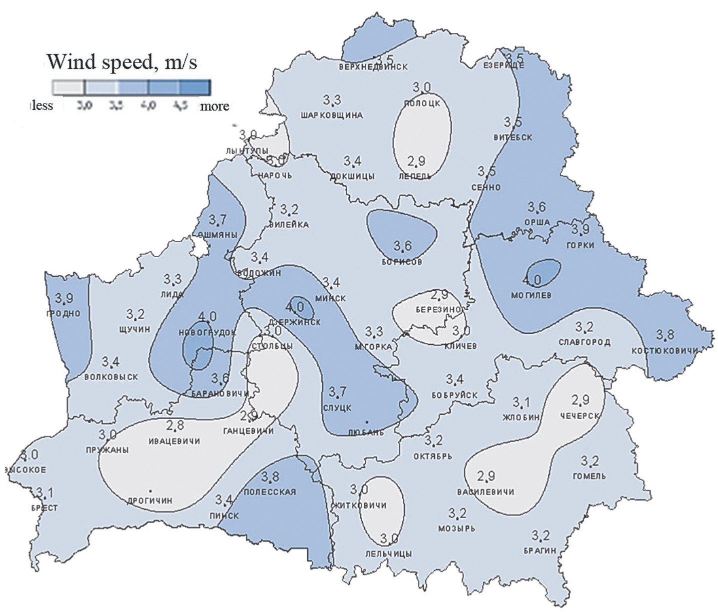
The method of natural regeneration without assistance measures for dead plantations restoring in over-wetted areas is the traditional one for Belarus. In most cases, this leads to the formation of plantations from species of low economic value, with a significant proportion of young growth. Technologies that in these conditions make it possible to use successfully artificial reforestation aren't practically develop in the Republic. There is also no relevant technology for soil cultivation and planting. The development of methods and technologies for the creation of forest plantations in overwetting conditions will allow forming highly productive plantations of black alder and silver birch of a seed origin.

Snow breaks in the Republic are quite rare. The annual damage area ranges about 100-150 hectares. Meanwhile the damage of the individual trees in the stand is typical that requires selective sanitary felling. Trees remaining in the plantation may be in a weakened state and therefore may become objects of pest colonization that will lead to their drying. At the same time, in 2016, heavy snowfalls were observed, that led to snowbreak on the territory of 12.211 hectares with a total amount of damaged wood of 266.54 thousand hectares. Clear sanitary fellings (CSF) had to be carried out on 252 hectares. The forests of Mogilev region were the most damaged (91.9% by area and 96.6% by volume of damaged wood). In the Osipovichi forestry forests were damaged on an area of 4.221.9 hectares, in the Glussk forestry on an area of 3.213.6 hectares. At the same time, the area of clear sanitary felling in the Glusk forestry amounted to 181.9 hectares, while in Osipovichi forestry only 41.5 hectares.

2. The prevalence of windblows in the forest fund of Belarus and a list of the forestry enterprises mostly vulnerable to windblows in future.

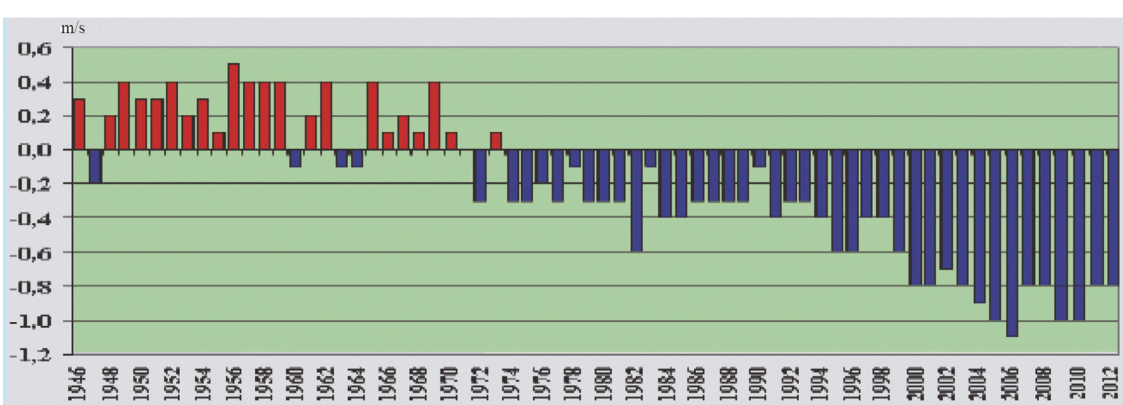
Belarus belongs to the regions with relatively calm wind regime. The average wind speed in much of the country rarely exceeds 4.0 m/s (Figure 5). Maximum speeds are mainly observed at the heights with an altitude of more than 250 m, where average wind speeds can vary from 5 to 8 m/s.

Figure 5. Average wind speeds (according to Belhydromet)



At the same time, in Belarus, starting from the 70s of the last century, there is a sustained trend in a decrease of the average wind speed (Figure 6).

Figure 6. Deviation of average wind speeds (according to G. G. Kamlyuk)



The distribution of adverse weather phenomena, made by the Republican Center for Hydrometeorology, Radioactive Pollution Control and Environmental Monitoring, showed (Figure 7) that strong winds account for a noticeable share in the total number of adverse phenomena. The maximum number of such phenomena occurred in the end of the 90s. Within the period of 1996 – 2000, 32 storms were observed. At the same time, according to instrumental observations 52 storms were observed during the period of 1966 – 1970, and in the next five-year period – 20. The distribution of winds occurrence with a speed of more than 20 m/s is shown in Figure 8. In 2014 and 2015, such phenomena were not observed, however, in 2016, one of the strongest windblows occurred in the Republic.

Figure 7. Distribution of adverse weather phenomena (according to Belhydromet)

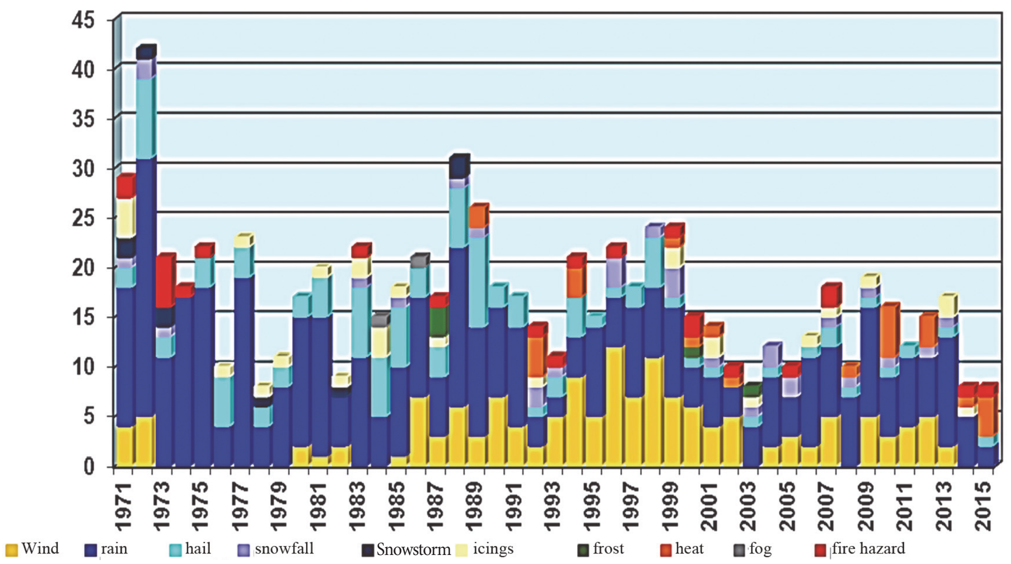


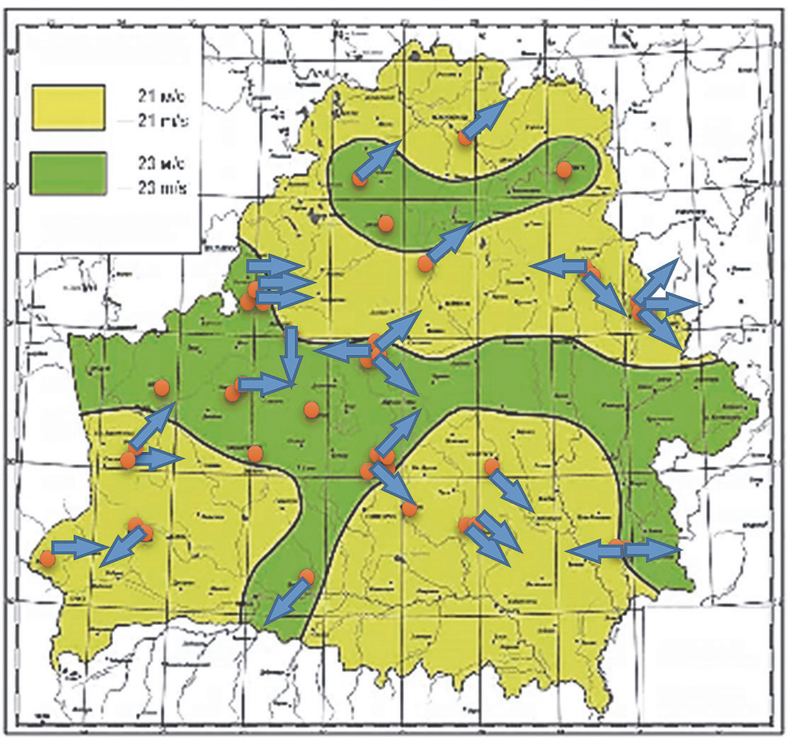
Figure 8. Distribution of strong wind occurrence (N) and its maximum speed (Vmax)

The year 2016 itself, wasn't characterized by the maximum number of cases, but the maximum wind speed of 35 m/s was recorded in the Berezinsky nature reserve. However, on the territory of the Minsk-2 airport located near the most damaged Smolevichy forestry enterprise, the maximum wind speed was 25 m/s, that correspond to the maximum speeds of other years. Thus, trends in the occurrence of strong winds and windblows in Belarus are not observed, that makes it almost impossible to predict the occurrence of this adverse weather phenomenon for the future.

Windblows occurs throughout the whole territory of Belarus. However, they have different intensity and area. That is why it is very important to identify the most dangerous regions that first of all require the measures aimed at increasing the sustainability of forest plantations.

A map of wind regions, reflecting the maximum wind speeds is used when building in Belarus (Figure 9).

Figure 9. Map of the wind regions of Belarus, the place of registration and direction of strong winds



Actually there are two elongated zones with increased wind hazard. One of them is located almost in the middle of the Vitebsk region and stretched from west to east. The second is located from west to east along the center of the territory of the republic and has two directions one of which is typical for the Dnieper lowland. The second is located in the valleys of the upstream of the Pripyat and Goryn rivers.

The areas of strong winds emergence and their directions were marked on the map. It is shown that 52% of strong winds emergence lies within the green zone that indicates the unreasonableness of using this card for planning the wind-protective measures in forests.

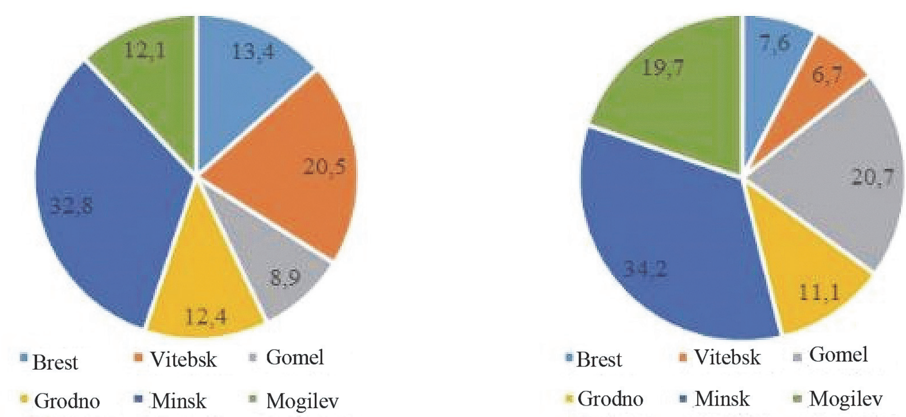
Strong winds in Belarus are predominantly of the western direction however, the direction can vary from south-west to north-west, i.e. differ by 90 °. Moreover, winds of opposite direction can be observed in the same place. For example, according to eyewitnesses, in 2016, in Smolevichy forestry enterprise, the windblow flowed approximately from west to east, in 2010 – from east to west, and in 1997 from south to north.

Thus, different strong wind directions, including those causing windblows, do not allow to develop global recommendations on the spatial arrangement of plantations with increased wind resistance. There are some regional peculiarities of the occurrence of strong winds in various areas, which should be taken into account when planning measures to improve the sustainability of forest plantations. For that purpose, deep analysis of multi-year data on speed and wind directions in various regions of Belarus is needed, but it can be performed only in cooperation with Belhydromet. However, for successful work, it is necessary to know the critical wind speeds, under which a windblow and windbreak will be observed in a forest stand growing in certain soil conditions, of a certain species composition, height and density. Such data are not available for Belarus, and it can be obtained using computer modeling programs of the wind on forest plantations effect. After obtaining the necessary data and analyzing the characteristics of forest plantations for a given region, it is possible to analyze wind directions above the established critical speed and determine the prevailing wind directions that can cause a windblow. However, as it was mentioned above, regularities in the wind direction for a particular region may not work out, so then it will be necessary to deal with each stands or group of stands individually when planning measures to improve their wind resistance.

Windblows are the main consequence of the passage of strong winds over forests. However, it is not always the strong wind that causes windblows in large areas. Moreover, windblows can be observed in those regions where strong winds and storms have not been recorded. From this point of view, it is interesting to analyze the occurrence of windblows in the territory of the Republic.

Distribution of windblows and clear sanitary felling areas carried out on these plots in the context of the State Production Forestry Associations (SPFA) for the period of 2013–2017 can be seen in Figure 10. While preparing the distribution, the year 2016 was not taken into account, since it was not typical in terms of the amount and extent of forest damage.

Figure 10. Distribution of windblows areas in percentage: a – by total area; b – by the area of clear sanitary felling.



a *b*

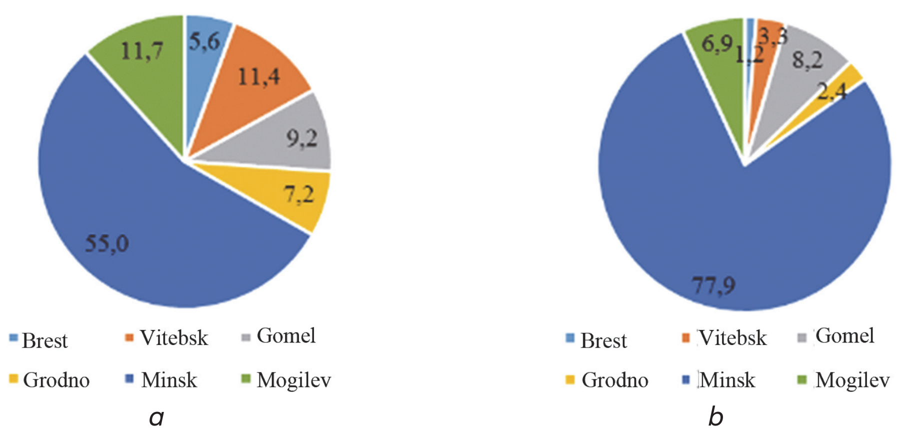
The largest areas of windblows and clear sanitary fellings are observed on the territory of Minsk SPFA, that indicates the high level and frequency of forest stands damage by windblows. At the same time, Vitebsk SPFA which has the following result in the total area of windfalls after Minsk is characterized by practically the smallest volume of clear sanitary felling. Such distribution tells about a low degree of forest damage caused by the wind but also about a significant coverage of the territory. In contrast, Gomel and Mogilev SPFA which have the smallest areas of windblow are distinguished by significant volumes of clear sanitary felling. In general, if to make a list of damaged areas in descending order, SPFAs can be arranged in the following order: Minsk, Vitebsk, Brest, Grodno, Mogilev and Gomel. According to the area of clear sanitary fellings, the distribution will be as follows: Minsk, Gomel, Mogilev, Grodno, Brest and Vitebsk.

The distribution of windblows and clear sanitary felling areas following the results of 2016 is presented in Figure 11. More than a half of the windblows areas and almost 80% of the total clear sanitary felling area are observed in Minsk SPFA. Further in the descending order of the windblow areas: Mogilev, Vitebsk, Gomel, Grodno and Brest SPFAs.

By the area of clear sanitary felling, the distribution is as follows: Minsk, Gomel, Mogilev, Vitebsk, Grodno and Brest. If there is a significant difference in distribution over the total area, there is practically no difference in the area of clear sanitary felling.

On the basis of data on the distribution, it can be said that the most dangerous from the windblow point of view are Minsk, Mogilev and Gomel SPFAs; the latter are distinguished by a high degree of stands damage. In Gomel SPFA, the share of clear sanitary felling accounts for 11.6%, in Mogilev – 8.8%, and in Minsk only 6.1%. Less problematic are Grodno, Brest and Vitebsk SPFAs, where the share of clear sanitary felling accounts for 3.5, 2.6 and 1.6%, respectively.

Figure 11. Distribution of windblow area in 2016 in percentage: a - by total area; b - by the area of clear sanitary felling.



The comparison of the total area of windblows and the area of clear sanitary fellings is presented in Table 2.

According the above data, it can be seen that the wind regime in 2016 led to a significant increase in the windblow areas in Minsk, Mogilev and Gomel SPFAs though didn't effect the wind situation in other regions. Despite the fact that meteorological stations did not record strong winds in 2015, the area of windblows throughout the Republic was significant and accounted for more than 50% of the windblow area in 2016. However, the area of sanitary felling was almost 6 times smaller. The year 2017 was characterized by almost two times decrease in windblow areas, although the volume of clear sanitary fellings was at the level of 2015.

On the whole it is difficult to identify the least dangerous region in terms of the occurrence of windblow. For example, in 2015 in Brest SPFA, significant windblow areas with the smallest volumes of clear sanitary felling were observed. In 2017, the area of winblows fell by almost 3 times, however, the area of clear sanitary fellings increased by the same amount. In Mogilev SPFA with approximately equal areas of winblows, sanitary fellings in 2015 were carried out on the territory 5.5 times more than in 2017. The trend can be seen over the time. All this shows the irregularity of windblows in the context of the SPFAs territories, however, the territory of Minsk SPFA is the most exposed to windfalls. Vitebsk SPFA is on the second place by total windblow area. However, the area of clear sanitary fellings there is one of the smallest. Mogilev and Gomel SPFAs are characterized by one of the largest areas of clear sanitary fellings with lower values of total areas of windblows. Therefore, the nature of windblows in different SPFAs is different.

Such an ambiguous situation with the intensity and nature of windblows requires the development of differentiated recommendations at least for the territories of the SPFAs.

It should be also mentioned about the difference of forested areas in different SPFAs, therefore it is necessary to compare the volumes of windblows and the areas of clear sanitary fellings per one thousand hectares of forested area per year. The average distribution of the total area of windblows and clear sanitary fellings is shown in Figure 12. Solid lines demonstrate the average value for the Ministry of Forestry of the total area of windblows that is 7.01, and for the area of clear sanitary fellings 0.27 hectares per 1000 hectares of forested area per year. The year 2016 wasn't also taken into account.

This distribution clearly showed that the forests of Minsk SPFA are mostly at risk from strong winds, where the maximum value of both the total area of windblows and the area of sanitary fellings is observed. A less dangerous situation is observed in the forests of Mogilev and Grodno SPFAs, where, together with a high area of windblows, there are also high volumes of clear sanitary fellings.

Table 2. The total area of windblows and clear sanitary fellings by years, hectares

SPFA	2017		2016		2015		2014		2013	
	Total area	CSF area	Total area	CSF area	Total area	CSF area	Total area	CSF area	Total area	CSF area
Brest	3194,9	233,3	6178,5	204,0	8019,4	205,1	8834,7	75,9	7692,1	95,6
Vitebsk	7852,7	130,4	12598,2	546,3	12527,5	101,8	12037,2	189,4	9849,7	118,5
Gomel	3400,3	252,6	10134,4	1360,8	5844,1	452,1	5792,3	815,6	3324,8	149,7
Grodno	4461,8	205,9	7936,9	400,9	7429,8	181,2	9093,0	274,4	4520,9	230,8
Minsk	13057,2	1448,0	60899,4	12925,3	23929,9	430	20702,8	615,6	9970,5	261,3
Mogilev	5710,4	159,5	12937,4	1148,9	8364,5	439,5	6147,5	878,8	4666,29	112
Total for the Ministry of Forestry	37677,3	2429,7	110684,8	16586,2	66115,2	1809,7	62607,5	2849,7	40024,26	967,87

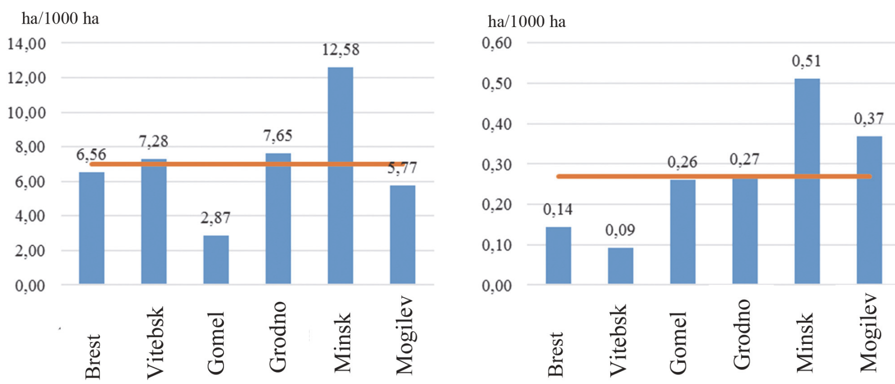
Note: SPFAs with the largest volumes of windblows and clear sanitary fellings (CSF) are highlighted in red font, green font signifies the smallest volumes

At the same time, forest plantations in Gomel SPFA are damaged on the smallest area, however, they have an area of clear sanitary fellings that can be compared with the average area of the Ministry of Forestry in general. The areas of windblows in Brest and Vitebsk SPFAs are close to a common value, but the areas of clear sanitary felling are the least there.

Such nature of distribution determines possible approaches to the development of measures to improve the wind resistance of forests, in which for some regions they may be of a rather general character. For others, there should be a detailed elaboration of recommendations, based on the study of local features of windblow formation and increasing wind resistance at least groups for forests that are similar in growing conditions and plant characteristics. To select approaches to the formation of wind-resistant plantations, it is necessary to analyze the characteristics of the occurrence of windblows in terms of the forestries.

In Brest SPFA the following forest enterprises in descending order had the largest damaged forest area for the period of 2013-2017: Baranovichi, Luninets, Pruzhany, Pinsk and Brest. In the first three forest enterprises the windblows were observed almost every year on the large areas. However,

Figure 12. The averaged annual distribution of the total area of windblows and clear sanitary fellings per thousand hectares of forested area



only Baranovichy and Pruzhany had one of the largest areas of continuous sanitary fellings. The areas of clear sanitary fellings were mainly in the limit of 50 hectares for the forestry enterprise. Malorita and Drogichen forest enterprises are the least damaged by the wind.

Polotsk, Rossony, Verkhnedvinsk, Disna and Postavy forestry enterprises were the most damaged on the territory of the Vitebsk SPFA. Every year, the windblows were observed in these forestries on the area from 800 to 2.8 thousand hectares. However, the areas of annual clear fellings rarely exceeded 35 hectares for any enterprise. The least number of windblows are observed in Dretun forestry, where the windblows did not exceed 100 hectares and there were no clear sanitary fellings.

In Gomel SPFA, the maximum area of wind-damaged forests fell on Budo-Koshelev, Gomel, Petrikov, Mozyr and Khoiniki forestry enterprises. In contrast to the previous SPFAs, in Gomel region, there is practically no pattern observed in the volumes of windfalls by years. For example, in Budo-Koshelev forestry enterprise with a relatively small area of windfalls in 2015 – 2017, there was a windblow on an area of 974 hectares in 2013. At the same time, in Gomel forestry enterprise with a windblow area of 89.1 hectares in 2017, in 2014 trees were damaged by wind on an area of more than 1,100 hectares with a volume of clear sanitary felling of more than 620 hectares. The same tendency among other forest enterprises that actually does not allow to identify the most dangerous forestries in the region. The similar situation is observed with the least damaged forest enterprises in this region. The forests of the Chechersk forestry enterprise are the least damaged, however, clear sanitary fellings had to be carried out almost in all areas.

In Grodno SPFA the most damaged forestry enterprises are in Shchuchin, Novogrudok, Ivie, Smorgon and Lida. Repeated windblows on the areas from 500 to 2.600 hectares were observed in Shchuchin, Ivie and Smorgon forestries. In 2013 – 2015 intensive windblows were observed in Novogrudok forestry enterprise while 2016–2017 were characterized by minimal values of damaged forests. The smallest damage in Grodno SPFA was observed in Volkovysk forestry enterprise. The similar situation was typical for Grodno and Astravets forestry enterprises. However, in 2016, a windfall on an area of 974 hectares occurred in Grodno forestry enterprise, which was ten times higher than the usual windblow areas in this forestry. During the period of 2013 – 2016, in Astravetz forestry enterprise the maximum area of 31 hectares was observed in 2016 (in other years, the areas of windblows did not reach even 10 hectares), but in 2017 there was a windblow over an area of more than 1.800 hectares.

Without taking into account the windblows of 2016 in Minsk SPFA, the maximum area of windblows was observed in the Borisov, Minsk, Smolevichi, Molodechno and Krupsk forest enterprises. Borisov forestry is the most damaged. The areas of windblow areas range from 2 to 4.4 thousand hectares per year. Every year, significant areas of windblows are observed on the territory of Smolevichy and Minsk forestry enterprises, which range from 900 to 3.2 thousand hectares.

The windblow of 2016 caused the greatest damage to forest stands on the territory of Cherven (11.955 hectares), Smolevichy (8.796 hectares) forestries and Borovlyany special forestry (5.866 hectares). Borovlyany special forestry enterprise borders directly with Minsk forestry, but the forest plantations of the latter were damaged to a lesser extent (1.796 ha). Significant areas were damaged in Molodechno (3 508 ha) and Borisov (3 369 ha) forestries. As it can be seen, the windblow of 2016 affected the same forestries, where wind damages forests every year. In 2017, in Smolevichy and Cherven forestry enterprises, the windblow damaged the forest on an area of 1.663 and 1.337 ha, respectively, where clear sanitary fellings were carried out on the territory of 359 and 607 hectares.

The windblows on the territory of Minsk SPFA are the least observed in Kletsk, Pukhovichi and Stolbtsy forestry enterprises, although in 1998 in Stolbtsy there was a hurricane, which damaged a large area of forests.

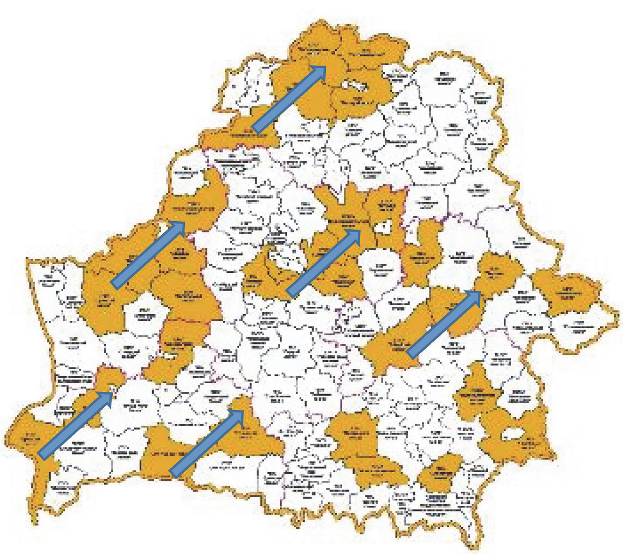
On the territory of Mogilyov SPFA, the strongest winds damage plantations in Chaussy, Bykhov, Belynichy, Bobruisk and Klimovichi forestry enterprises. Every year, windfalls on large areas are observed in the Chaussy, Belynichy and Bobruisk forestry enterprises. In Bykhov forestry in 2014, windblows were observed on a large area (1.222 ha) and 2015 (1.679 ha), while the areas of clear sanitary fellings were 306 and 119 ha, respectively.

The distribution of forestry s with the largest areas of windblows is shown in Figure 13.

On the basis of this distribution, a preliminary conclusion can be made about the fact that winblows pass mainly from south-west to north-east. However, taking into account the directions of strong winds, presented in Figure 9, this conclusion can be viewed as a working hypothesis, for the confirmation of which it is necessary to work with windblow areas and people who participated in their harvesting, at the forestry level. It is advisable to mark all the windblow locations in the forest enterprises (indicated in Figure 12) and areas adjacent to them for an accurate picture of the wind passage through the territory of Belarus. At the same time, it is necessary to conduct the work on studying the characteristics of plantations damaged by the wind in order to determine the parameters affecting their stability.

Data analysis of the total area of windblows and the areas of clear sanitary fellings showed that there is no always a direct relationship between them. As it was already noted, the areas of clear sanitary fellings show the destructive force of the hurricane, since the stands where such felling is carried out completely or almost completely died. If any of forestries is characterized by large permanent areas of such fellings that means that the winds over this territory are of a considerable force.

Figure 13. Distribution of forest enterprises with the largest areas of windblows



At the same time, the presence of significant areas of windblows with a small area of continuous sanitary fellings can show that the wind intensity over the territory is insufficient to cause significant damage or that the plantations are not wind-resistant. The wind-resistance of the plantings largely depends on the soil conditions, the level of wetting of the territory, forest stand composition, its height and density. At present, in Belarus there are no data on wind resistance of plantations with different characteristics. It can be obtained by examining windblow areas or using computer modeling programs. In the latter case, the availability of data from the survey of windblow areas is also necessary for testing the operation of models, but the volume of plantings surveys will be significantly less compared to the first variant.

Figure 14 shows the locations of strong winds registration forestry enterprises with the largest areas of windblows and with the largest areas of clear sanitary fellings, which were carried out on the windblow areas.

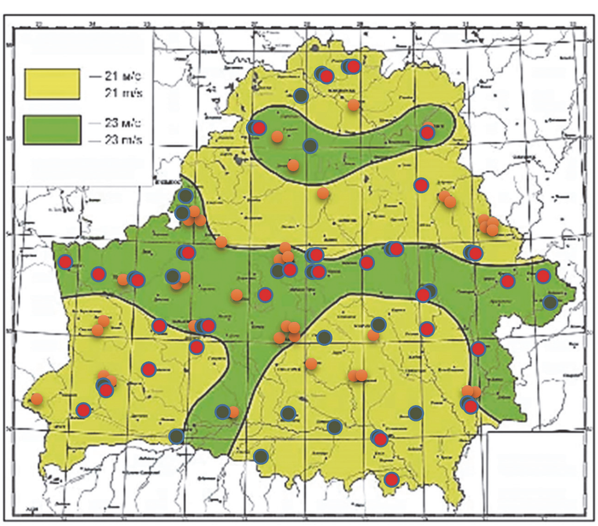
Figure 14 shows that in most of the cases, yellow and green dots coincide or are close enough however, intense windblows were observed in the areas where no strong winds were recorded for the last 15 years. At the same time, the forest enterprises with the maximum areas of windblows and continuous sanitary fellings in lots of cases do not coincide, that indicates the absence of a relationship between these values.

Thus, there are local peculiarities for individual forest enterprises, caused by a specific wind regime, relief and windblows. The detailed research on the interaction of wind flows with forest plantations for various forestry institutions is needed. For that purpose, it is important to get an access to multi-year data about wind speeds by weather stations, as well as models of wind direction, which will determine its speed in areas where there are no weather stations and create a map of wind speeds. Moreover, it is desirable to determine the probability of occurrence of speeds of a certain value, that will allow to predict the likelihood of forest plantations damage caused by winds of different speeds. Such work can be conducted only in close cooperation with the specialists of Belhydromet.

On the basis of data about the likelihood of certain wind speeds and the results of a windblow areas survey, it is possible to develop wind hazard maps for the entire territory or a specific region that would identify potentially dangerous places and allow forestry specialists to adjust activities for the establishment and maintenance of plantations.

Figure 14. Distribution of the place of strong winds registration, forestry enterprises with the largest areas of windblows and with the largest areas of clear sanitary fellings:

● – places of strong winds registration; ● – forestry enterprises with the largest windblow areas; ● – forestry enterprises with the largest areas of clear sanitary fellings



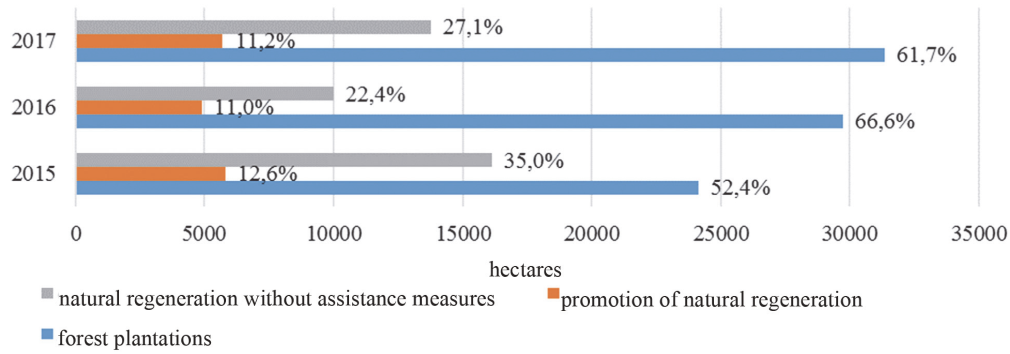
3. The analysis of the existing silvicultural approaches to forest management in conditions of climate change (windblows, snowbreaks, icings, forest fires, etc).

Formation of stand resistant to adverse climate change can be carried out at various stages of forest life, but more easily and effectively it can be done at the initial stage of new forest creation or restoration.

In Belarus, several methods are used for the purpose of reforestation: artificial restoration, promotion of natural regeneration, and natural regeneration without assistance measures.

On average, artificial reforestation accounts for 50–55% of the total reforestation (Figure 15).

Figure 15. Correlation of reforestation methods



Large-scale windblows, such as the windblow of 2016, or mass dryings, observed in 2017 (and that are still observed in Belarus) led to an increase in the share of forest planting by more than 10%. Artificial reforestation is considered as a fast and reliable method of damaged plantations restoring.

However, the terms allotted by the government of the Republic for the elimination of hurricane consequences of 2016 play an important role in increasing the share of artificial reforestation. Accessible areas should have been harvested till November 1, 2016, inaccessible areas – by March 1, 2017. Work on soil cultivation for the creation of forest plantations was carried out practically at the same time. Works on the artificial reforestation of damaged areas began in August. In general, work on the creation of forest plantations was planned in the way to make the most of autumn and spring seasons for planting.

Selection work is the basis for the creation of sustainable and highly productive plantations of artificial origin. In Belarus, it was carried out mainly in terms of the plantation course of development. At the same time plus trees were selected and seed plantations of first and second generations were established using special methods. At present, in the Republic there are more than 1000 hectares of first-generation forest seed plantations and nearly 800 hectares of the second generation. The plantation course of development is primarily aimed at increasing the productivity of forest plantations. However, the processes of climate change put forward the increased demands to the sustainability of established plantations that makes the development of population direction important. Belarus has allocated more than 1.100 hectares of plus stands, which are the most productive and sustainable forests in their growing region. These plantations apart from common oak aren't practically used for seed harvesting primarily because of the complexity of harvesting. Therefore, it is necessary to introduce technologies for creating forest seed plantations on the basis of local plus stands.

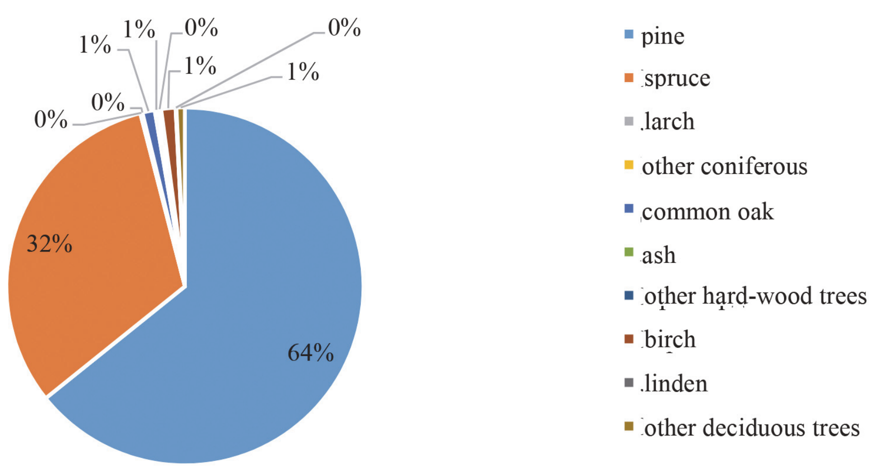
It will make it possible to use the unique gene pool of plus plantations more widely and increase both the sustainability and the productivity of the created forests.

Planting or seeding is used to create forest plantations. Planting material is used for planting, which is grown on 77 specialized forest nurseries with a total area of 1342 hectares. About 400 million units of forest plant material with both open root systems and in container are grown annually. About 25% of the cultivated plants is a reserve that can be sold to consumers, but it is also a reserve that can be used, if necessary, for the creation of forest plantations on large areas. Due to the presence of such a reserve, it was possible in 2016 to significantly increase the volumes of artificial reforestation on windblow areas and create plantations on areas of mass drying in 2017 and as well as this year.

The active development of technologies for obtaining of container forest planting material in greenhouses also makes it possible to increase the number of plants grown for reforestation of significant violated areas. In addition, such planting material can be used almost throughout the vegetative period, that allows to reduce the concentration of labor resources in restoring damaged plantings. In 2017, 14.1 million units of container planting material or 3.5% of the total planting material were cultivated. The opening of new centers in Ivatsevichi and Glubokoye in 2018, as well as the planned opening in Mogilyov and Minsk, will allow to increase this percentage. Unfortunately, the refusal of the Ministry of Forestry to build two centers in Grodno and Gomel regions will lead to an uneven distribution of centers throughout the country and problems in the logistics of the delivery of such planting material to the forestry institutions of these areas. Moreover, the center that was supposed to be built in Gomel region was directed at growing of planting material with closed root system of common oak. And at the moment the redistribution of volumes of the species to other centers wasn't carried out. It should be mentioned that only this common oak planting material allows to form tap root system is extremely important for creating both wind-resistant and climate-resistant plantings.

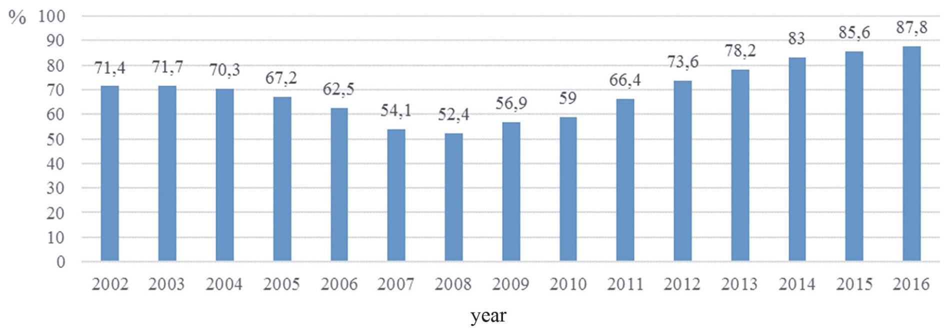
However, a serious problem in forest nurseries of the Republic is the disproportion among coniferous and deciduous species (Figure 16).

Figure 16. Distribution of species grown in forest nurseries



The share of conifers accounts for 96% of the total volume of seedlings and saplings grown. This situation is a legacy of the period when the most of pure conifer plantations were created. Now, however, while conducting reforestation, priority is given to mixed stands (Figure 17). It is necessary to create forest plantations together with deciduous species in order to increase the sustainability of pine and spruce trees, when restoring windblow and mass drying areas.

Figure 17. The share of created mixed forest plantations



And if during reforestation of pine plantations, we can count on the occurrence of natural regeneration of birch, while restoring the plots located in rich growing conditions, mixed plantations can be created from the ecologically and economically valuable species only using planting material.

Another problem is the absence of machines for planting of seedlings and saplings in forestry enterprises. Reforestation in Belarus is almost carried out manually. The use of tree planting machines allows to increase the speed of planting and the quality of work, as it eliminates the human factor, which strongly influence on the survival rate of plants, especially under hard time limit, that is observed when creating forest plantations on large areas of windblows and mass dryings.

Sowing, as a method of reforestation, hasn't practically been used in Belarus recently. Only the need for reforestation on large areas after the windblow of 2016 caused the return to sowing. This method, with expenditures comparable to costs of planting material, had a significantly higher productivity of labour. However, currently there is no experience of forest plantations creation by sowing under various conditions that in some cases led to an unsatisfactory result. Because of the outdated equipment usage for sowing purposes, there is an overexpenditure of seeds and creation of very dense forest plantations that require intensive thinning.

Natural regeneration has limited use and is created primarily in the process of work towards promoting. First of all, it includes soil mineralization. Additional planting or seed sowing can be also carried out. The main reason for the lack of the method dissemination is the unstable result, which can occur because of the inconsistency of the selected area, lack of appropriate care, the climatic reason. On sandy soils in poor soil conditions in most cases there is a satisfactory natural regeneration of Scots pine. In better conditions the growing ground cover and the natural regeneration of birch, which drastically reduce the chances on successful renewal of pine plantations, compete with it. In rich soil conditions, where the main species are European spruce and common oak, the natural regeneration of these species can be obtained only under the conditions of intensive tending since the developing natural regeneration of birch and aspen, as well as shrubs and herbaceous plants, in the first year practically smooth the sprouts of spruce and oak. However, in the conditions of small areas fellings located among pure coniferous plantations, the success of the appearance and preservation of the natural renewal of spruce or pine is high.

The area of undergrowth conservation during the final felling is less than 1000 hectares annually. The main reason is the impossibility, and sometimes the unwillingness to save undergrowth when carrying out clear felling. It is technologically more simple to conduct felling without undergrowth preservation and often this is a decisive argument. However, in most cases there is no satisfactory undergrowth while conducting dense stand felling.

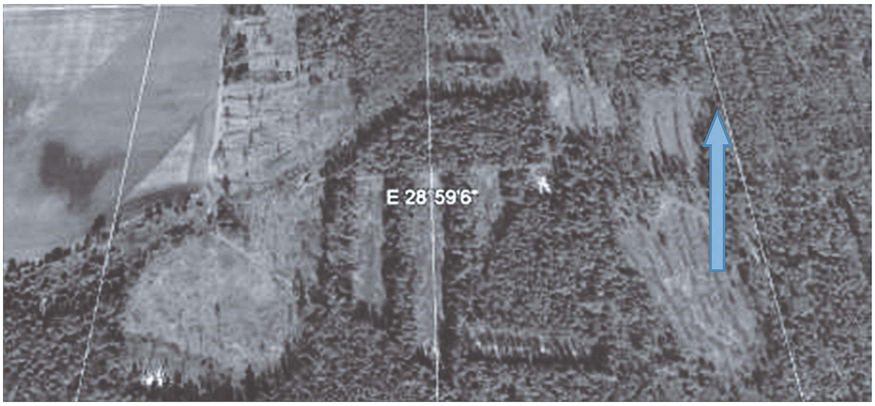
The use of natural regeneration, which appeared after felling, or the use of preserved undergrowth should be more widely used to create stands resistant to strong winds and to climate change. At present, the method when mixed plantations of Scots pine and silver birch are created by planting for pine and for natural regeneration of birch is widely used in Belarus. In the future, in this method it is possible to use forest plantations planting on one site and natural regeneration of Scots pine with natural regeneration of birch. In general, the combination of natural regeneration and artificial reforestation will increase the adaptive potential of the created plantations to adverse factors while increasing the productivity and quality of future plantations. The maximum possible preservation of the existing undergrowth will make it possible to form a mixed-age stands with different storeys that is also important for increasing the resistance of forests.

Natural regeneration without measures of assistance is distributed much wider in comparison with the previous method. However, this method is mainly used for overmoistened areas, where reforestation 2work conducting on existing in the country technologies is either difficult or impossible. An increase of areas for natural renewal without assistance measures is not a positive indicator. In most cases, reforestation takes place without human participation. As a result, plantations with species of low economic value and plantations with a large proportion of plants of vegetation origin are formed. It leads to deterioration of the tree stands quality indicators and to undesirable change of species. However, as an experience shows, in some cases under such conditions, it is possible to cultivate high-productive plantations of silver birch, black alder, and even common oak and common spruce. One of the technological methods is the use of planting material with a closed root system, thanks to which planting of forest plantations can be carried out in summer or early autumn, when overmoisted areas are available for conducting of work. It is also necessary to work on the development of soil cultivation methods in such conditions that will significantly increase the ability to adapt and quality of created forest plantations.

Selection or shelterwood fellings allow to restore forest using natural renewal. Currently, the share of such fellings accounts for 17% of the volume of wood cut. This amount is planed to increase up to 35% by 2050. The use of such felling methods will allow to form more stable, including wind resistance, stands due to the naturally formed root system. In Belarus, the main type of such fellings is shelterwood strip felling which are mainly used in pine plantations.

With positive experience of pine forests regeneration with the help of this method there is quite frequent situation when it was necessary to use planting of forest plantations in order to achieve the required number of plants according to the standards. However, the technology of shelterwood strip fellings involves the establishment of narrow strips of forest alternating with felled areas, and their thinning, which leads to a decrease in the wind-resistance of such areas. After the strip fellings, stands are affected by windblows, especially spruce plantations. In this case, location of the strips and the degree of thinning are important. It will minimize wind damage (Figure 18).

Figure 18. The strip felling site, which was preserved during the windblow in Berezino in 2012 (the arrow indicates the wind direction).



At the present moment in Belarus there is no information on the rules for shelterwood strip fellings considering the danger of windblows. Such material can give a simulation of the effect of wind on planting with various regulatory parameters of such fellings: widths of strips, their directions, percentage of tress fellings on remained strips.

Well conducted soil cultivation is the key for successful forest plantations in the future. At the present time, the main way of preparing the soil for the creation of forest plantations is listering with a plough PKL-70 or more its advanced analogue L-134. With this method of soil cultivation, fertile soil layer spreads apart, that leads to plants setting into the soil layer with poor nutrient concentration especially on low-fertility soils. It reduces plant ability to adapt and growth intensity of set plants in the first years of life and reduces their resistance to undesirable grass and shrub vegetation. The use of cultivator is very limited. In the near future, it is not planned to introduce a widespread, for example, in Finland, discrete-time processing of soil that provides plant setting almost in double layer of fertile soil.

One of the ways to increase forest cover of the area is to create forest plantations on the lands of former agricultural use. In Belarus, forest cultivation in large volumes on such lands was carried out in the 60 – 70s of the last century and during the period of 2004-2009. From 10 to 12 thousand hectares of forest plantations were annually created. Sites of former agricultural use are difficult objects for forest cultivation because of the strong growth of grassy vegetation and the presence of indurated layer at a depth of 30–40 cm. During the conventional method of soil cultivation on such areas occurs the deformation of root system and it does not develop deep into the soil (Figure 19). Such forest plantations are very vulnerable to lowering of the groundwater level and periodic droughts, which have been recently observed on the territory of the Republic of Belarus. Weakened plantings are easily colonized by pests and dry out.

Figure 19. Forest plantations on the former agricultural use: a – smothering by grassland vegetation; b – deformation of the root system of Scots pine

a

b

In addition to that, under the influence of indurated layer trees form a lateral root system without deep roots, that significantly reduces the wind resistance of plantations.

In perspective it is planned to transfer large areas that are not currently used by agricultural enterprises, for forest cultivation. An urgent issue is the development and application of mechanisms that destroy the indurated layer and effectively fight grassland vegetation.

Regulation of the species composition of forest plantations is an important component of increasing forest resistance to climate change. The least resistant are even-aged single-storeyed forest stands including single species. As it was already mentioned, in Belarus the most preferable are mixed forest plantations, however, in most cases, coniferous species are mixed or birch tree is introduced into the pine forest crop composition. The variety of species in the creation of plantations is strongly limited by soil fertility. In poor conditions, there is no alternative to local species of birch. In rich conditions, it is possible to create plantations with great biological diversity. Wider use of such species as small-leafed linden, Norway maple, black alder, and hornbeam make it possible not only to form multilayer plantations, but also to provide the necessary level of resistance to wind or fires.

Currently, in Belarus there are recommendations of the Forest Institute of the National Academy of Sciences of Belarus (author P. I. Volovich) on the creation of wind-resistant pine-birch plantations on windblow sites. They provide for the placement of forest plantations lines of Scots pine perpendicular to the direction of hurricane winds through 2.5 – 2.8 m. Through 300 – 350 m, 5 – 7 lines of birch are planted (patent BY 11907 C1 2009.06.30). On the felling sites of an area of 5–15 hectares, plantations are created from 9 – 12 lines of Scots pine and 3 lines of birch of natural origin (patent BY 13831 C1 2010.12.30). Also, the authors of the patent proposed to create protective forest edges according to the following scheme: line of a shrub, two lines of oak, line of shrubs, to increase fertility, 7 – 8 lines of pine. This scheme should be repeated for 2 – 3 times. Despite the correct approaches to the formation of wind-resistant plantations, these recommendations are rather generalized and are rarely used in forest enterprises, primarily because of the absence of wind hazard maps and not permanent nature of hurricane winds. The proposed placement layouts as well as species composition should be also verified by a simulation technique.

The easiest way to regulate the plantation composition is its formation in the process of creation. However, it is possible to influence on the composition throughout its life using cleanings and thinnings. Traditionally, in Belarus care of forest plantations was carried out for pine, spruce, oak, larch. The remaining species, especially birch, were considered as undesirable and were often completely removed from the plantation. The constant birch felling led to the appearance of young growth in forest plantations and to decrease in the quality of its wood. At present, it is necessary to reconsider approaches to such fellings with the aim of increasing the share of accompanying species in the plantations, and in some cases to allow purposeful change of coniferous plantation to plantation with a predominance of deciduous species, if it is necessary to increase its sustainability and protect adjacent areas against adverse phenomena, such as strong winds and fires.

One of the most discussed issues of artificial reforestation is the initial forest plantations density. At present, the forest plantations density depends on soil fertility, species, type of planting material and ranges from 6.6 to 2.5 thousand plants per hectare. For container planting material density standards can be reduced. However, in fact, forest plantations are created with greater density for insurance against low survival ability, damage to forest plantations by animals or adverse weather phenomena. Existing standards for conduction of cleanings and thinnings provide for the reduction of plantations density mainly to 0.6-0.7 that involves a reduction in the number of trees. For example, for a pure pine plantation of high productivity, by the age of 20 years about 3 thousand plants should remain on the site after improvement felling and by the age of 40 years – 1.2 thousand plants. In fact, by the age of 40 when it is possible to talk about the profitability of such fellings due to resulting assortments, only 30% of the number of planted plantations remains on the site. The development of technologies of artificial reforestation is constantly goes towards a greater survival ability and preservation of created forest plantations. However, this development should go hand in hand with a decrease in the number of planted plants that will lead to a reduction in the cost of creating forest plantations. The issue of reducing the initial density of created forest plantations currently is not considered in Belarus.

In terms of increasing the sustainability of forests, especially to windblows, the density of plantations formed in the process of improvement felling is important. Existing norms don't take into account the change to the wind resistance of plantations when their density changes. In Belarus, there are no studies in this field. A differentiated approach to the density of plantations is required depending on the danger of a windblow, but this can only be done by simulating the interaction of wind with plantings of various densities, taking into account other influencing parameters: soil conditions, species composition, terrain, etc. It is also necessary to develop technologies for conducting any fellings in plantations on forest edges with the aim of increasing their wind resistance.

One of the factors that significantly increases the risk of windblows is conducting of clear fellings on a large area. Now in Belarus, the maximum area of final fellings for conifers is limited to 10 ha, for hardwood species – 7.5 ha and for birch and aspen – 15 ha. Along the border of such large areas that are free from forest, there are trees that do not have sufficient wind resistance, as they grew in the middle of the plantation. On the basis of international experience in modeling and research of plantings, it is necessary to limit the areas of clear fellings on the sites with increased wind hazard. In addition to that, in the regulatory documents the provisions on the abandonment of the wind-protective forest edge located on the borders of forest areas during the felling should be enshrined. Such requirements, for example, are held in the FSC standards.

4. Approaches to the restoration of windblow plantations based on FSC standards and policies

For the present moment, forest certification is becoming an increasingly accessible and effective tool for demonstration of compliance with the requirements of responsible and sustainable forest management and forest use and certification of forestry practices and mechanisms is one of the first steps towards eco-sensitive "green" forest products markets. Consideration of aspects of windblow sites restoration can simplify the procedure for auditing affected forestry institutions.

FSC is an independent non-profit non-governmental organization that supports environmentally acceptable, socially beneficial and economically viable forest management in the world. Such management is carried out in accordance with a number of principles and criteria, which are checked during audits of enterprises.

Preservation and increasing the protective and resource potential of forests, preventing deforestation and degradation is the main task of sustainable forest management. Reforestation is an obligatory part of the forest growing cycle in forestry production and should ensure the preservation of the ecological and social functions of the forest. As any forest management measure, reforestation must be thoughtful scientifically based and targeted. The creation of new forests in places of their significant damage by natural and man-made factors, as well as degraded lands should lead to increased sustainability while meeting the requirements of current standards.

The purpose of such reforestation should be the creation of structured, diverse and productive forests with the preservation of single trees remaining after natural disasters based on the principles of so-called "seminatural forestry".

Preference should be given to the natural renewal of areas affected by hurricane winds taking into account the following moments:

- the emergence of natural reforestation may take some time. Thus, some areas require several years for the creation of the conditions suitable for afforestation;
- it doesn't refer to the rich conditions of vegetation and areas where the emergence of fast-growing competing woody or herbaceous vegetation is expected;
- any opportunity should be used to increase the proportion of naturally renewed, adapted to the place of growth, light-demanding tree species in areas where it is planned to create forest plantations;
- during reforestation it is necessary to take into account the types of vegetation conditions and, gradually, by improvement felling remove from the composition those species that are unusual for the given conditions of species;
- forming the composition of the forest stand, take into account natural successive processes that are typical for the disaster area. Thus, the dominance of certain deciduous species in areas of restoration of many forest ecosystems may be only a phase in the alternation of species.

In order to assess the need for forest cleaning from felling residues after the hauling of assortments that can be used, a number of factors of an economic, social and environmental nature should be considered:

- the cost of these works;
- the effect of reducing wind speed and creation of shadows;
- preservation of natural renewal;
- preventing the creation of conditions for the growth of undesirable competing vegetation;
- natural barriers for wild animals that can destroy sprouts, plantings and undergrowth;
- fire safety and the possibility of pests colonization;
- recreational areas impact.

An assessment should be carried out for each site, considering the possibility of reducing labor and financial costs, using larger plants and, therefore, refusing continuous solid tillage. Collection and burning of forest residues for forest protection should be limited by exceptional circumstances.

Active measures for reforestation (creation of forest plantations) should be limited by areas, where natural regeneration is impossible or difficult to implement within the agreed time frame. Considering the possible shortage of planting material, it is preferable to supplement natural regeneration and plantings with a small number of plants. Conducting artificial reforestation it is necessary to consider the following points:

• active measures for the creation of forest plantations are needed in areas where the width of the damaged lines is two or more times higher than the height of a preserved forest border for tree species with seeds easily spread by wind;

• if there is a shortage of planting material of conifers, it is important to implement the plantation of a small number of plants with wide inter-row spacing; oak and hard-wooded species not in lines but in clusters creating a mosaic structure;

• use only high-quality planting material regarding zoning;

• it is preferable to increase the range of species of woody plants on areas that are at risk of weed infestation.

It should be noted that sowing is particularly suitable for artificial restoration of windblow sites especially of such species as pine and birch. Considering that the ground cover is damaged during collecting and hauling of assortments, along with soil damage during the hurricane winds, sowing of the main tree species in damaged areas can be a credible alternative to creation of forest plantations by planting.

The choice of tree species for afforestation of areas damaged by storm winds must comply with the requirements of forest growth zoning.

After the winblows, the leaders of the industry, together with experts from research institutes and authorities concerned, should develop a plan that includes the selection of suitable tree species and reforestation methods, as well as the desirable long-term composition of plantations. Depending on the extent and type of damage, as well as on the composition of the affected tree species, adjustments to forest management projects are necessary.

The provisional standards of the Certification Bodies envisage a number of requirements for forestry institutions that are united by Principle 6 “Impact on the environment”, lie in the need to ensure the conservation of biological diversity and related values (water, soil, etc.) by foresty as well as unique and sensitive ecosystems and landscapes, and thus maintain the ecological function and integrity of the forest.

Thus, the criterion criterion 6.3, says that the ecological functions and forests values must be maintained in its original form, improved or restored. This includes: a) reforestation and natural development (succession) of a forest; b) diversity at the genetic, species and ecosystem levels; c) natural cycles that affect the productivity of resources involved in the field of management.

The requirements of this criterion may be in contradiction with generally accepted forest management practices when conducting reforestation and working on forest areas damaged by various natural phenomena. Ecological functions and values of forests should be restored, include successions and diversity at various levels. It should be noted, however, that in the Principles and criteria, the word “restoration” is not used to denote the renewal of any particular previous, prehistoric, pre-industrial, or other pre-existing ecosystem (Source: FSC-STD-01-001 V5-0), and natural development (succession) provides for the assessment of resource productivity. Diversity maintenance and recreation at the genetic, species and ecosystem levels is the key for creation of a sustainable forest stand in the future.

Another criterion determining the mechanisms for reforestation is 6.3.10. Preference should be given to the natural reforestation apart from the cases when the creation of forest plantations is determined by the conditions of the habitat. Of course, when developing damaged felling sites such a requirement may conflict with actual conditions. However, if possible to leave seed group or individual trees of various species, activities to promote natural reforestation should be carried out on damaged felling sites excluding such trees from felling. And it is important to consider the possibility of including in the project of creating forest plantations renewed sites, as not subjected to artificial renewal, and to implement combined renewal on the remaining sites.

It should be noted that, in spite of the fact that such trees as fir, larch and beech are defined by normative documents as the main species, according to criterion 6.9. the use of introducents should be carefully and actively monitored in order to avoid adverse environmental impacts. In particular: the paragraph 6.9.1. – forests consisting of native species should not be transferred to plantations of introduced species; the paragraph 6.9.2. – species of introducents should not be planted in the forest; paragraph 6.9.3. – the monitoring of the spread of historically introduced invasive introducent species should be carried out. And if necessary, measures for control or elimination of these species should be taken.

Moreover, in view of the growing interest to the plantation forestry on the part of woodworkers, it should also be noted that criterion 6.10 prohibits the transfer of the lands of forest fund for plantations that excludes the possibility of extensive plantations creating on lands damaged by various climatic and other disasters. However, if the land transfer takes place, such transfer should be very limited in scope, should not be more than 5% of the enterprise's forest fund area for any five year period (FSC-DIR-20-007-ADV-10).

It should be also mentioned that clear fellings and plantings by natural species on the site of natural or semi-natural forest in the absence of satisfactory natural regeneration are not considered as a forest substitution by plantations. While clear felling and planting of introduced species on the site of natural or semi-natural forest are considered as a replacement.

As we can see, the FSC perception of forest restoration is pragmatic and does not necessarily seek to restore the original, virgin ecosystems that existed before human intervention.

Constant pressure because of the population growth, especially when forests are threatened, and the growing demand for resources, creates growing competition for the use of land and natural resources along with environmental problems. FSC aims to protect and enhance the sustainability of forests and their associated ecosystems by protecting and enhancing their biodiversity, ensuring their role in the provision of environmental services such as biodiversity, water supply, soil improvement, carbon deposition.

Reforestation should also lead to the improvement of livelihoods of those who directly depend on forests, therefore effective and appropriate forest ecosystem functions should be considered. From this point of view, windblows should not be the reason of forestry industry losses with significant revenues of the processing industry.

Thus, reforestation for FSC is not just planting of fast-growing or economically valuable trees. Degraded forests need to be improved or "enriched" in order to increase the multiple benefits, from ecological to social and economic.

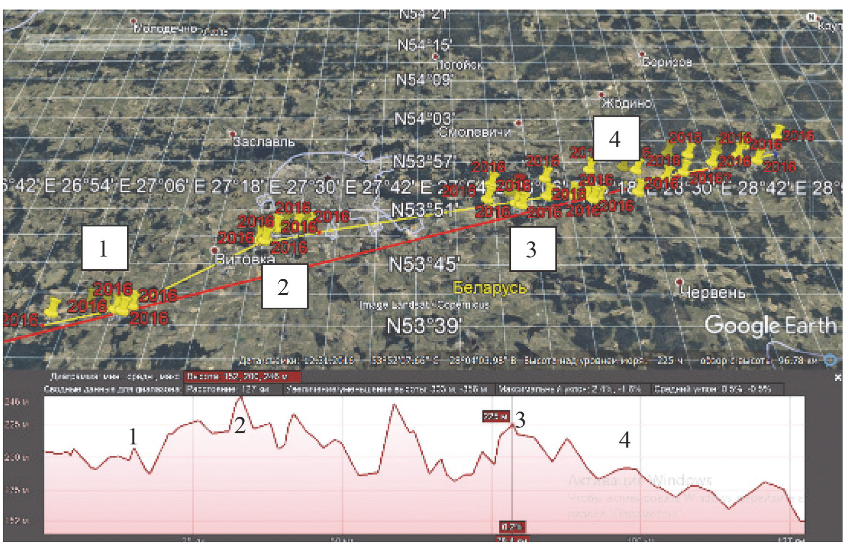
5. Ecological characteristics of the windblow sites in Minsk region after hurricane of 2016 and the assessment of restoration methods of damaged stands.

The winblow of 2016 caused the maximum damage of forest plantations in the territory of Vitebsk, Gomel, Mogilev and Minsk SPFA for the last 5 years. However, Minsk SPFA has been worst affected by the windblow, that occurred on the territory of 60.899.4 ha, and the area of clear sanitary felling was 12.925.3 ha. 4.45 million m3 of wood was damaged.

The most damaged areas were Smolevichy, Cherven, Starodorozhsky forestry enterprises and Borovlyany special forestry enterprise.

The direction of wind movement and the terrain in the direction of movement is shown in Figure 20.

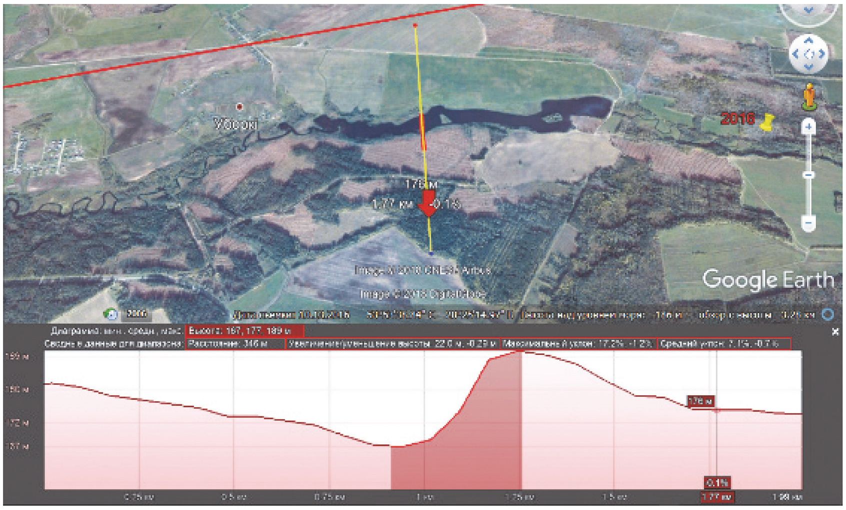
Figure 20. Direction of wind movement and terrain during the windblow of 2016: 1 – Minsk forestry; 2 – Borovlyany special forestry enterprise; 3 – Smolevichy forestry enterprise; 4 – Cherven forestry enterprise



The wind passed through areas of the forest from the south-west to the north-east with the approximate point of the compass of 70 NE. The windblow was observed on the stretch of more than 130 km length. The widest point of the stretch was in the territory of Smolevichy forestry where the maximum distance between the remaining forests stands was about 7 km.

The maximum damaged areas of the forest were mainly on elevated areas. This pattern was observed in almost all forest enterprises. Forest wetlands of a small area, which were located among the plantations on dry soils, were mostly not affected. Such sites were distinguished by a lower height of the stand, respectively, the surrounding plantations served as a protection for them. Plantations along the rivers also survived. However, at the end of the windblow line, in Cherven forestry there was a damage of stands (Figure 21) located on the southern and southeastern banks of the Usha River and having an elevation above the river level of 15–20 m (northern and northwestern exposure).

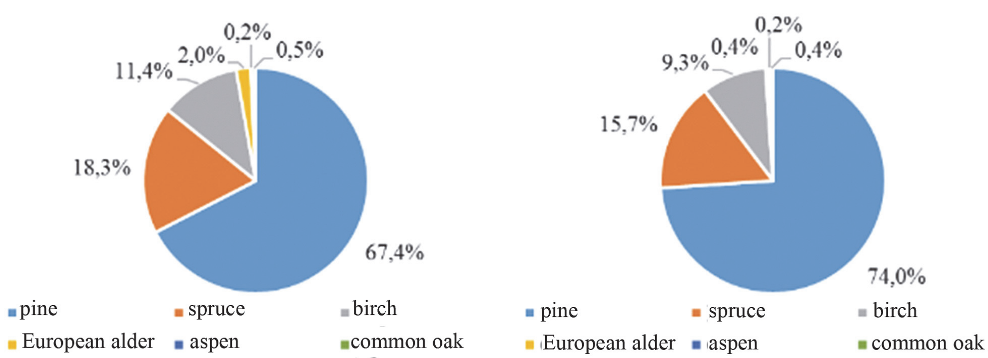
Figure 21. Location of damaged plantings relatively to the cardinal points and the slope exposure: the red line is the main wind direction



Forests of the slopes adjacent to the open terrains were mostly affected. And if at the beginning of the stretch of the large scale windblow the planting was damaged mainly on the slopes of the western and northwestern exposure, closer to the end of the stretch, there was a division of the wind into separate tongues, the direction of which was different from the general one. Probably, with a general weakening of the force of hurricane winds, there is a dispersal of wind currents along reduced relief features, but this assumption requires additional research.

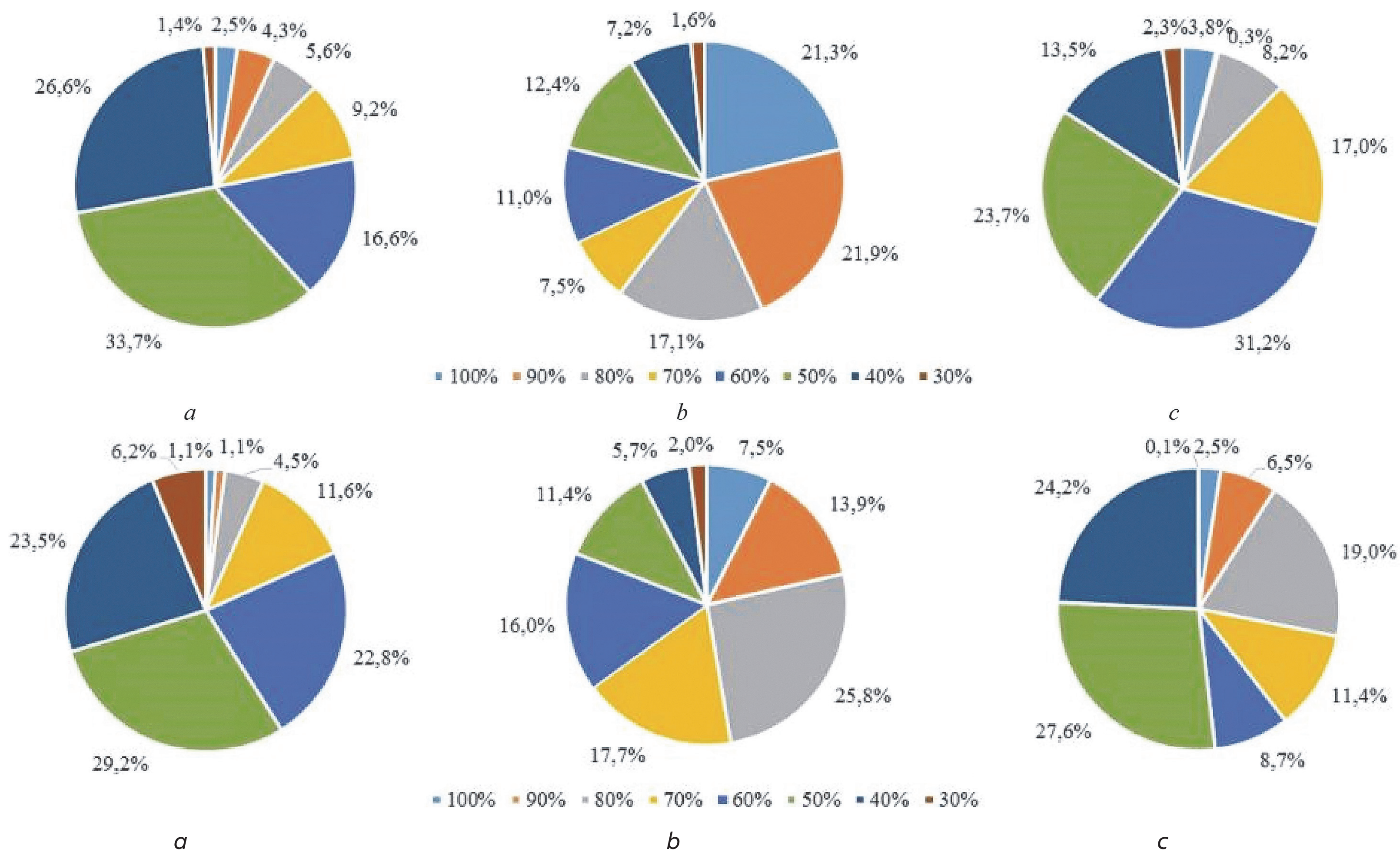
During the windblow of 2016, mainly coniferous plantations suffered. So in Cherven forestry enterprise the share of coniferous plantations, where clear sanitary fellings were carried out, accounted for 85.8% of the total area. Hardwoods were damaged in 14.2% of the territory. In Smolevichy forestry the share of coniferous plantations accounted for 89.7%, hardwood – 10.7%. The distribution of plantations by prevailing species is shown in Figure 22, and by the share of participation of the main species in Figure 23.

Figure 22. Distribution of damaged plantings by the prevailing species: a – Cherven forestry enterprise; b – Smolevichy forestry enterprise



a *b*

Figure 23. Distribution of damaged plantings by the share of the main species in the composition for the Cherveny and Smolevichy forestry enterprises: a – European spruce; b – common pine; c – silver birch



The distribution in the Figure 23 shows that the stands with any share of the main species, were damaged to the maximum extent, both pure and practically pure, and mixed with the participation of two, three or even four species.

To make a definite conclusion, it is necessary to know what distribution by share of the main species is typical for this region in general. Comparison of this distribution with the distribution presented in Figure 23 will make it possible to determine more accurately the role of the ratio of species in order to improve the wind resistance of the plantings and will help to assess the accuracy of the models work. However, such a work can be carried out only with the participation of specialists from the "Belgosles", who have the tools for the distributions set and an electronic database of forest plantations of Belarus.

The reforestation of the clear sanitary felling sites was carried out almost right after the completion of the development of the windblow sites in 2016. The Ministry of Forestry set the task of reforestation in the shortest period of time making the most of the weather in autumn 2016 and in spring 2017. Of course, the existing volumes of clear sanitary fellings could not be restored only by the forest enterprises on the territory of which there was a windblow. For example, in Cherven forestry enterprise the area of clear sanitary felling accounted for 4378 ha, in Smolevichy forestry enterprise the area of such fellings was 6111 ha with an annual reforestation volume up to 150-250 ha. To achieve this goal, it was decided to send the staff of forestry enterprises of the Republic to conduct the reforestation of those windblow sites in the development of which these enterprises took part. However, this decision was made after determining the scope of work, when the harvesting of a significant number of sites was already completed. Decision to delegate the workers of the forestry enterprises to log and restore windblow sites should be made immediately according to the complex of works such as the removal of windblow sites, clearing of felling areas, preparation of soil, reforestation. At the same time, it is necessary to provide a specific area for the whole complex of works. It will increase the degree of responsibility of employees for the quality of the concrete operation that in general will positively affect the overall quality of work.

At the same time, an active work on informing the media, organizations and citizens about the scale of natural disaster, the ongoing work and the necessity of comprehensive support was carried out. As a result of this work, not only forest workers, but also various segments of the population, from government officials to soldiers and students, participated in forest restoration (Figure 24). Since October 2016, the Republican campaign "Let's restore the forest together" was announced, in which thousands of people took part, including the officials of the Ministry of Forestry, departments and organizations of the Ministry of Internal Affairs, Ministry of Defense, Ministry of Education, hundreds of enterprises, university students. A significant amount of work was done by students of the Faculty of Forestry of the Belarusian State Technological University, who applied the knowledge they got on classes in practice. In spring 2017, work on reforestation was continued. In April, Prime Minister of the Republic of Belarus Andrei Kobyakov, as well as his Principal Deputy Vasily Matyushevsky and Deputy Prime Minister Mikhail Rusy took part in the creation of forest plantations at the windblow site in Smolevichy forestry enterprise. That event was widely covered in the media. In general, deliberate policies of the Ministry of Forestry has allowed many people, including children and young people, to be involved in the restoration of damaged forests, thereby having a positive impact on the image of the forester in the country.

Mobilization of efforts of a number of forestry institutions allowed to restore the windblow sites during the autumn 2016 and spring 2017. However, during such a short term reforestation works, some problem points appeared.

Firstly, reforestation was carried out by people with different levels of responsibility for their work. According to the workers of Smolevichy and Cherven forestry enterprises, survival index of plants was greatly influenced by the attitude of the engaged workers from other forestry enterprises to the process of planting.

Figure 24. Participation in the campaign "Let's restore the forests together" (according to the materials of the Belarusian forest newspaper)

In those sites where planting works were carried out without compliance with all the technology requirements with the aim of increasing the speed of work and the lack of proper control by the management of the forestry institution responsible for the particular site, the survival index could be 50 – 60%. At the same time, this rate could reach 90 – 95%.

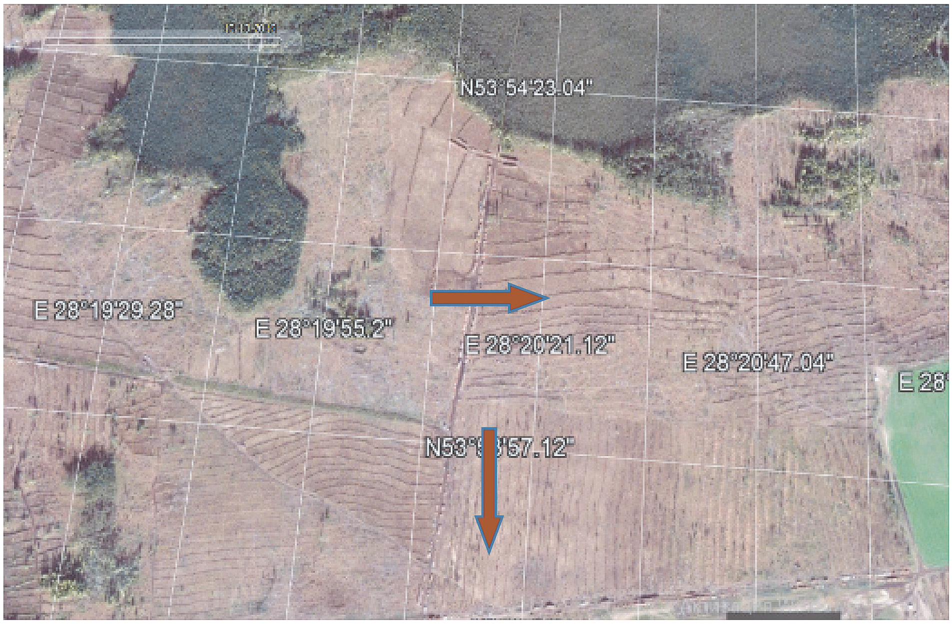
Secondly, the need to restore the forest in the shortest period of time led to the fact that the creation of forest plantations was considered as the only possible option. At the same time, a number of sites could be successfully restored during 2017 using the method of sowing or natural regeneration.

The issue of creating plantings resistant to windblows should be considered since the logging of damaged forests. During the harvesting of windblow of 2016, the issue of the spatial distribution of future plantings was not raised. Soil cultivation was carried out depending on the location of the rows of forest residues the direction of which depended on the convenience of the site development. Thus, the rows of forest residues and the rows of forest plantations could be located in different directions within the same site (Figure 25). Recommendations developed at the Forest Institute of the National Academy of Sciences of Belarus provide for the arrangement of rows perpendicularly to the windblow. However, considering non-permanent character of strong winds in Belarus and the lack of research that would show the correlation between wind resistance of plantings and the rows direction, it is not advisable to arrange all the rows of forest plantations in one direction at the moment.

Moreover, the sites where plantings of the same age and composition are located nearby, but with a different row direction can be the basis for further research on the assessment of forest resistance to wind.

However, in future, making a plan for the work on the windblow sites, for example, using unmanned aerial vehicles, it is advisable to give a plan for the work of harvesters with the aim of subsequent optimal placement of rows of forest residues and directions of future forest plantations along with the optimal plan for roads clearing and construction for timber transportation. With the active use of GIS technology in logging is not difficult.

Figure 25. The direction of the rows of forest residues and rows of forest plantations in windblow sites of 2016



During the development of windblow felling areas, rows of forest residues were located after 20 m. But in this case there is a significant area under the such rows which will mainly overgrow by deciduous species in 10–15 years only after wood rotting. To increase the area where it is possible to create forest plantations that are valuable from an economic point of view, the rows of forest residues were shifted by the tractor rakes at a distance of 40 m from each other.

Soil cultivation was carried out mainly by furrows that on poor soils led to the displacement of the fertile soil layer on the sides of a plants row.

However, as it was mentioned before, in Belarus there are no other technologies for soil cultivation except rototilling by FC-45 rotary plow that is characterized by low productivity of work and the presence of a compulsory period for mould soil firming.

In autumn 2016, 3.203.7 hectares were created in three most affected forestry enterprises (Smolevichy, Cherven and Borovlyany) that accounted for 80% of the planned volume of that year. Because of the desire to achieve values from the plan, plantings were carried out before the freezing period. It was late plantings that showed the lowest survival rate, and on fertile soils they were damaged by squeezing the seedlings. About 40% of the total number of forest plantations was created by workers of Minsk SPFA. The remaining areas of planting accounted for other production associations. On average, each association planted 300 – 350 hectares of forest plantations.

In 2017, the area of creation of forest plantations has increased significantly. Only in Smolevichy forestry enterprise 2827 hectares were created, where 159 hectares were created by the efforts of the forestry enterprise.

During reforestation of windblow areas, the same species that grew on these areas before the windblow were used. At the same time, preference was given to mixed forest plantations with the participation of deciduous species. In the Smolevichi forestry enterprise, the plantations were mainly created by 7-9 rows of Scots pine trees belt and 1-3 rows of silver birch. The scheme when after 7–8 rows of pine, 2–3 rows were left for natural regeneration was often used. Mixed plantations of spruce were created according to the scheme of 5 rows of spruce and 5 rows of pine, 5 rows of common oak and 5 rows of spruce. In general, mixed forest plantations of pine were created by

85.3%, spruce – by 11.8%, oak – 2.8%. On the area of 2.1 ha, small-leaved linden plantations were created. Survival rate of autumn plantations of European spruce was 81%, spring – 85%. Autumn plantations of Scots pine showed survival rate of 74%, spring 82.7%. For oak, the survival rate in the autumn and spring was 90%.

In Cherven forestry enterprise forest plantations were created mainly according to the scheme of 7 rows of Scots pine and 3 rows of silver birch. According to a similar scheme with the participation of birch, the part of the plantations of European spruce was created. However, there were areas where plantings were created according to the scheme 4 rows of pine trees 4 rows of spruce and 2 rows of birch. In autumn 2016, in Cherven forestry enterprise forest plantations were created on an area of 1.550 hectares.

Unlike the previous two forestry enterprises, in Borovlyany special forestry enterprise the share of pure forest plantations of Scots pine and European spruce accounted for more than 60%. However, in Ratomka forest area, that has one of the richest soils in Belarus, mixed crops of 4 rows of oak and 6 rows of spruce was mainly used. This particular forestry enterprise doesn't have its own nursery, so for planting it was necessary to use planting material that was bought in other forest enterprises. Taking into account that the need for seedlings and saplings due to windblow in Minsk region was high, Borovlyany forestry enterprise had to use not suitable planting material according to the size. For example, forest plantations of European spruce according to the requirements of the Ministry of Forestry, are created by saplings with a biological age of 3-4 years. In Ratomka forestry enterprise unit two years seedlings sometimes were used. In the conditions of rich soils and strong competition of undesirable vegetation, such planting material was suppressed so it was necessary to implement a significant amount of tending. At the same time, forest plantations created by saplings or container seedlings exceeded by height the planting that were created by seedlings in 3-5 times. Next year such plantings will go beyond the negative effects of grassy vegetation that will allow for less tending. Thus, it is necessary to redistribute large-sized planting material or container planting material on the territory of windblow with rich soils to ensure maximum efficiency of artificial reforestation.

In general, autumn plantations showed a lower survival rate, primarily due to the late planting dates. The experience of forest plantations establishment requires additional study because when comparing with the climate characteristics it will be possible to determine the deadlines for planting forest crops that may be important if the need for reforestation on large areas in a short period of time arises.

Sowing in Smolevichy and Cherven forestry enterprises showed a very good result, though it was on relatively poor soils (Figure 26, 27).

Successful sprouting was obtained on 97% of the sites. In total, about 856 hectares in Smolevichy forestry enterprise and about 500 hectares in Cherven forestry enterprise were allocated for sowing. This experience can be widely used for sustainable plantings creation because after sowing the root system develops without damage to seedlings and saplings that are got after the planting. Compared with planting, sowing is less labor intensive. However, from 700 to 1000 g of seeds per hectare were used for sowing. Good germinating ability of seeds gives bushier forest plantations which subsequently require the removal of excess pine trees. Development of technology of rarer sowing will allow to reduce the cost of creating forest plantations by sowing.

Sowing was used in the spring of 2017, but in Cherven forestry enterprise there was a successful sowing experience in mid-June.

The summer planting of container pine seedlings was also successful. In the territory of the Cherven forestry enterprise, pine was planted with such planting material at the end of June 2017 (Figure 28a).

The survival rate of plantaitions was 97%, and the plants were characterized by a good development of anchor root (Figure 28b) that is very important from the point of the wind-resistant plantations formation. Plantations were created by seedlings with an actual age of 1.5 years. Currently, plant height exceeds 50 cm, and stem diameter is 1 cm.

Figure 26. Sowing of Scots pine in Smolevichy forestry enterprise

Figure 27. Sowing of Scots pine in Cherven forestry enterprise

Figure 28. Plantations of Scots pine, created by container seedlings

a *b*

However, the question of the density of created forest plantations arises. Planting was carried out with a step of 0.75 m and a row spacing of about 2.5 meters. This planting scheme gives a minimum density of 5.3 thousand plants per hectare that is a lot. As a result, while tending it will be necessary to remove pine plants, on the cultivation of which in the nursery a considerable amount of money was spent.

One of the problems that arise when creating coniferous plantations in areas of large-scale windblows is the increased fire danger that is created not only by the young plants but also by the dried rows of forest residues (Figure 29).

Figure 29. Dried rows of forest residues (at the right)

Sites with stored rows of forest residues are located throughout the windblow area and occupy more than 4.000 hectares. In time of drought and strong wind, a fire that has already occurred can cover most of this territory. Increased fire danger will remain permanently in this area. The introduction of 2 – 3 rows of deciduous species into the coniferous plantings will not have a significant effect on the fire situation.

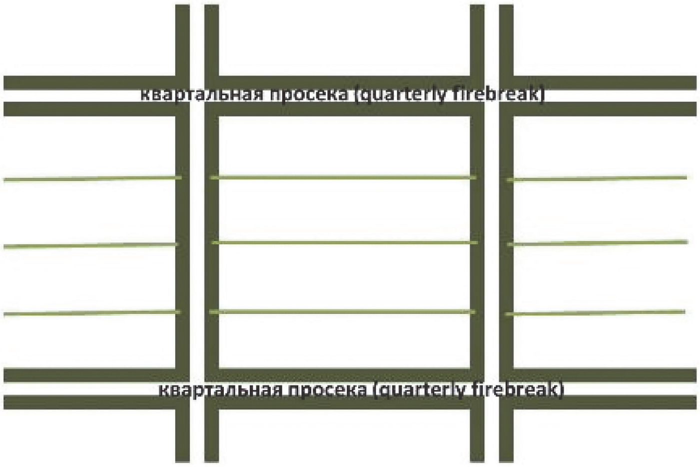
To increase wind resistance and reduce fire danger on large areas of windblows, it is necessary to form a line of deciduous species along quarterly firebreaks and existing roads (Figure 30).

Existing rows of forest residues after a few years of storage can be grind with forest mulcher and be used for creation of fireproof and windproof lines from deciduous species. If there is a demand for chip fuel it is possible to grind the rows of forest residues on the sites where logging residues can be brought in with special equipment, the prototype of which is currently being developed at the Belarusian State Technological University.

When carrying out reforestation works on the windblow sites in 2016 and 2017, the creation of lines of deciduous species was not designed. Currently, for the creation of such lines it is necessary to reorganize the composition of the created forest plantations, increasing the share of participation of deciduous species by preserving their natural regeneration.

During the windblow of 2016, almost all species were damaged. However, individual trees of common oak not more than 30 cm thick remained on the sites. Larger trees were broken or damaged to a large extent (Figure 31). Due to the deep root system and tough wood, this species can serve as the basis for windbreak belts. Employees of the Forest Institute of the National Academy of Sciences of Belarus at one time proposed a scheme for creating a windbreak border that consisted of two rows of common oak, one row of soil-improving shrub and of seven or eight rows of Scots pine. Such a scheme should be repeated two or three times. This is one of the possible options for creating a windbreak belt. As an option, thinned or gradual forest edge can be applied. However, the final choice should be made on the basis of additional studies, including aerodynamic, or computer simulation results.

Figure 30. Layout of deciduous species lines



Oak can be introduced into the composition of forest plantations to increase their wind resistance over a wide range of soil conditions. In adverse conditions where the oak cannot reach the upper story of the forest, it can form a protective lower story or can be used gradual forest edge creation.

Figure 31. Surviving trees of common oak in Borovlyany special forestry enterprise

The stability of oak, like other species, is affected by the presence, in the composition of plantings, of trees with large crown and low wind resistance, for example, aspen trees. In Smolevichy forestry enterprise, the site where the aspen was removed from the oak planting wasn't affected, while in the plot where the aspen was present, the vast majority of oak trees were broken or significantly damaged.

Natural regeneration during reforestation of windblows in 2016 was used silver birch and Scots pine. The share of natural renewal accounted for about 15%. Successful renewal of pine was observed only directly at the forest edge at a distance of up to 50 m, and the size of naturally renewed plants was 2-3 times smaller than the plantings. However, the potential for natural regeneration of pine must be taken into account when performing reforestation work of windblows. For example, it is possible to select the lines with the width of 50 ± 10 m along the remaining plantings for natural regeneration. And forest plantations, clear or partial can be created there in 3 years if it will be necessary. Such a technique will help to redirect the part of the workers to more problematic areas. However, it can be used only in poor or relatively poor soil conditions, where there will be no intensive development of undesirable vegetation.

The renewal of silver birch was successful approximately at a distance of up to 1 km. (Figure 32) And in some places it drowned out the plants of Scots pine. At a distance of more than 1 km, natural regeneration of both birch and other species is practically absent.

Figure 32. Continuous natural regeneration of silver birch

The problem of the natural regeneration of unwanted woody plants, along with the intensive development of grass and shrub vegetation, is very relevant for open felling area from under the windblows. The problem is especially acute in rich soil conditions. Aspen, for example, in such areas can grow up to 1.5 m per year. Grassy vegetation is actively growing. If not to take any measures, there will be an undesirable change of species from coniferous or hardwood to low-value species.

As a result of the development of unwanted vegetation, the planting material occurs under thick cover and cannot develop normally (Figure 33).

It becomes necessary each year to carry out two or three thinning during the first few years after reforestation. The natural renewal of coniferous species under this cover also practically does not appear.

Figure 33. Forest plantations of European spruce under the canopy of unwanted vegetation

The formation of coniferous plantings will begin only after reducing the number of birch or aspen due to competition with each other, which will take about 10-15 years.

Special attention should be paid to the natural seed renewal of oak. Around the remaining oak plants, sprouts of fallen acorns can appear. They need particular tending, since later they can serve as the centers of increased stability of plantings against the wind. If there is no natural regeneration of oak, an oak biogroup should be created by sowing or planting seedlings with a closed root system. However, the existing regulatory framework for reforestation in Belarus does not take into account the possibility of forming biogroups of less than 0.5 ha.

As with the artificial and natural reforestation of wind sites, it is necessary to carry out multiple thinnings on the areas where valuable species is competitive with less valuable that are not the main ones in these conditions. Annually, there should be one to three thinnings depending on the soil fertility. Considerable amounts of reforestation do not allow to carry out independent tendings to the most affected forestry enterprises of Smolevichi and Cherven. The forces of other forestry enterprises were engaged to assist. Involvement of the independent workers was complicated because of the low wages. However, in a number of Cherven forestry enterprise units, some brigades were formed that carried out works on tending at a level that provides decent wages. This experience should be studied appropriately because in future Belarus will need to form a service market in forestry production, such as planting, agrotechnical and silvicultural tending.

The main method of tendings is the removal of unwanted vegetation by brush cutter. This method has considerable complexity and low productivity that leads to the need to attract a large number of workers when processing large areas. The use of mechanisms in conjunction with tractors will significantly increase the speed of tending. Good results on sandy soils in the Cherven forestry enterprise showed good tending with the use of the Krakovski shaft, produced in Poland (Figure 34).

A double passage along a number of forest cultures effectively destroys grass and raspberries. However, this mechanism has low efficiency on rich soils due to the strong development of the natural renewal of deciduous species.

Figure 34. A tool for the care for forest plantations by Krakowski shaft (www.innovatech.by)

6. International experience of restoration of windblow sites and assessment of the possibility of its use within the territory of Belarus.

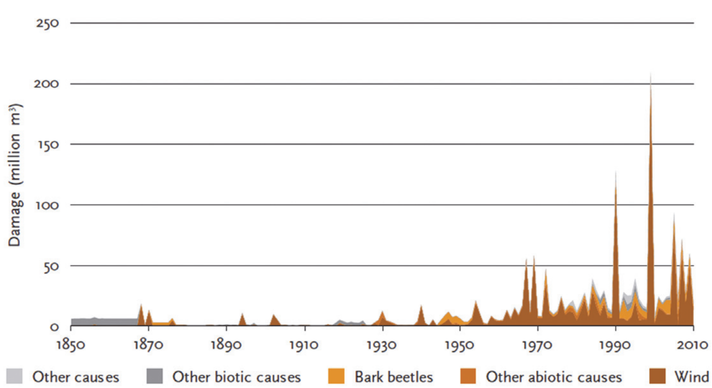
Wind damage is the major cause of forest damage in Europe resulting in more than 50% of all losses (Schelhaas et al., 2003). There are increasing concerns that damage will increase in the changing climate and that areas such as Eastern Europe that were little affected in the past will become increasingly at risk (Lindner and Rummukainen, 2013).

Scientific investigations estimate that about 0.12% of the standing volume of European forests is damaged annually (1950–2010 average) being equivalent to about 38 million m3/year. This represents approximately the annual fellings of Poland. The damage to forests is due to a multitude of disturbances. For abiotic damage, wind is the most prominent. It is responsible for about 51% of all recorded damage. Wildfires follow with 16%, snow 4% and other abiotic damage with 6%. Biotic damage adds 17% and is mainly caused by bark beetles. The remaining 6% are either combinations of damage or cannot be directly accounted for.

When looking at the total forest area in Europe affected by biotic and abiotic damages, recent published data estimates it to be at about 7.3 million hectares or 5.8%. In terms of forest area the most prominent damaging agents are insects and diseases, wind, and wildlife and grazing.

Observations across Europe show that disturbance damage to forest has increased markedly in the last few decades (Figure 35). Recent changes in climate are frequently stated as a major driving force behind such increases. However, especially for storms it is very difficult to statistically prove trends in frequency and severity, because data series are relatively short, usually inhomogeneous, and storms are highly stochastic. Scientific literature therefore gives a diverse picture for storms: some results indicate an increase of maximum gust wind speeds at local level while others show a decrease in cyclone frequency over the last few decades. However there is evidence that the actual severity of storms in the wake of climatic changes may increase during the next decades.

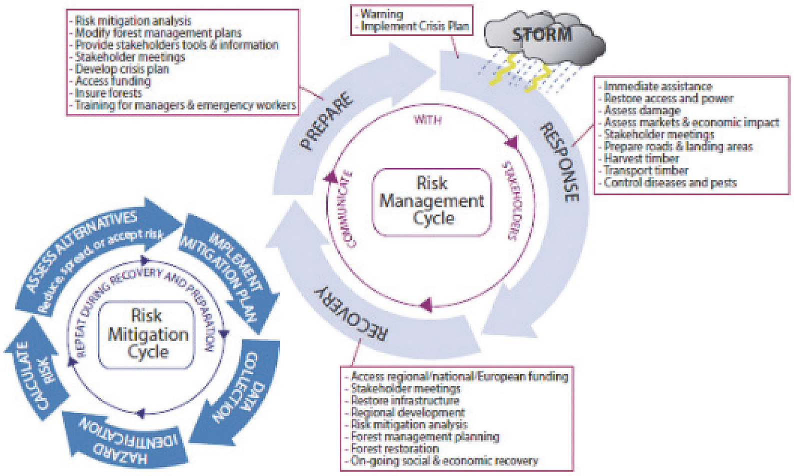
Figure 35. Total damage occurring in European forests (million m3) due to different disturbances. The category "other causes" includes anthropogenic damage, unidentified causes and mixed causes.



The management of the risk of wind damage to forests requires an integrated approach that follows the classic risk management cycle of immediate response to a situation leading to damage (in this case a storm), followed by a recovery period when the forest is restored and a preparation period ahead of the next event (see Figure 36).

The response period takes place over a period of up to a year. In the immediate aftermath of a storm the priorities are to reestablish services, in particular electricity supplies and communications (telephone systems, roads and railways). The other critical requirement is to as quickly as possible

Figure 36. Risk management cycle and risk mitigation cycle



make an assessment of the levels of damage by satellite, aerial photography and ground surveys. Such information is vital to the ability to make informed decisions on the best way to manage the immediate response to the storm and the subsequent recovery.

In Belarus, we tried to get this information as soon as possible. The next day after the windblow, the flight around the damaged Smolevichy and Cherven forestry enterprises was made by the authorities of the Ministry of Forestry. An attempt to estimate the damage with the help of drones was made, but the existing programs made it possible to assess the damaged forest in a relatively small area. Systems for automatic interpretation of aeronautical or satellite imaginaries are under development.

The other key requirement is to establish a method for efficiently sharing information with key organisations (e.g. government agencies, forest associations, forest owner groups, contractors associations, etc). This initial response occurs over the period of days to approximately one or two months.

In Belarus, a clear interaction between government agencies that are involved in the mitigation of natural disasters is organized. After the hurricane of 2016, first of all, the Ministry of Forestry, the Ministry of Emergency Situations, the Ministry of the Interior, and road services worked together to clear transport routes and search for affected people.

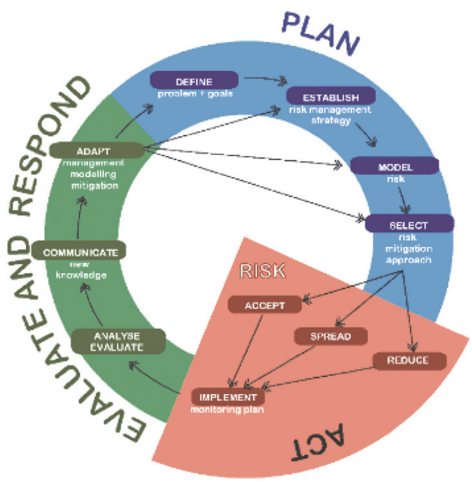
The second part of the response period is the organisation of timber removals, sanitary felling, timber transport, and timber storage. It depends on the availability of information on the location and extent of any damage, on the impact of the storm on timber prices, the availability of machinery and the availability of storage areas for storing timber over the short and long term. It also often requires deregulation of a number of regulations regarding the movement of timber and equipment across borders.

In the recovery phase the forest is restored. The nature of the restoration depends on multiple factors including decisions about the future roles for the forest (desired ecosystem services) and experience from the storm. Decisions on species choice, silvicultural methods, plant material, seed source, etc. Depended on detailed planning with all responsible bodies and stakeholders. It requires access to regional, national and even international funding. It requires detailed plans of both the forest restoration and forest management but societal and environmental recovery. The recovery period usually starts while the response stage is in operation but can last for many years (at least 10 years).

In Belarus, decisions on reforestation of damaged plantings were made on the basis of existing legal documents and the current situation, taking into account the availability of mechanisms, human resources and planting material. The question of planning measures to improve the wind resistance of plantings was not raised.

A key component of the recovery phase is the requirement for conducting a risk mitigation assessment (see Figure 1). This assessment identifies the hazard and calculates the risk to the forest. Depending on the risk there are three alternative responses; accept the level of risk (do nothing), modify the risk (e.g. harvest at risk stands, improve drainage, change the order of stand felling, etc.), share the risk (normally through some sort of insurance scheme or by combining different forest areas into the management portfolio). The risk mitigation cycle can be seen as part of an adaptive management system in which there is regular evaluation of the level of risk and management plans are adapted and modified in response (Figure 37).

Figure 37. Adaptive forest management of risk



Risk mitigation is a key part of risk management (see Figure 33). In particular it allows an assessment to be made about the level of risk faced and whether that risk can or should be mitigated. The first part of risk mitigation is to identify the hazard of interest, which is clearly wind damage in this case. The second part is to calculate the level of risk. Risk is the multiplication of the vulnerability of the forest, the level of exposure to the forest to which the forest is being subjected and the value at stake (what would be lost if the forest was damaged).

The vulnerability is a measure of the inherent level of resistance of the forest and depends on numerous factors including tree size, spacing, species, soil type, time since the last thinning, etc. There are a number of methods for calculating the vulnerability and these include statistical and hybrid mechanistic models. The level of exposure is calculated from the local wind climate and is a measure of the probability that the critical wind speed required to damage the forest will occur. It is usually calculated by converting the wind climate data into either a Weibull or a Gumbel distribution. Finally, the value of stake has to be calculated based on what would be lost if the forest was damaged. This is normally a financial calculation and will be dependent on the age of the forest and what end products are expected. However, other ecosystem services such as biodiversity, water quality, recreational value, etc. can be included if they can be converted into a financial value.

Based on the calculation of the level of risk it is possible to make 3 choices.

1. Accept the level of risk. If the forest enterprise believes that the level of risk is acceptable or that undertaking mitigation in the forest would not be justified then the risk can just be accepted. However, it is important to ensure that there is repeated calculation of the level of risk because this changes with time.
2. Reduce the risk. If the level of risk is too high or it is not regarded as too expensive to reduce the risk then mitigating actions can be undertaken. At its most simple this would be too cut the forest but it might involve thinning, maintenance of drains, replacing certain species. However, to make decisions on the best course of action it is absolutely necessary to have a method for calculating the immediate impact of any action and the impact on risk in the future.

3. Spread the risk. Generally this is through some sort of insurance scheme but it might be by ensuring that the level of risk over a whole enterprise is acceptable by having some parts of the forest at low risk to compensate for those at high risk.

In Belarus, the assessment of the risk of windblows was not carried out and was not considered for the design of measures for reforestation of both fellings and windblows. The lack of a comprehensive economic assessment of damage from windblows did not allow to fully understand the importance of planning measures to improve wind resistance of plantings.

A key component of the risk mitigation is the need to be able to calculate the level of risk and how the risk changes with time and with different management operations. For wind damage risk there are a number of mechanistic wind risk models and statistical models. Statistical models are normally developed directly from damage data and usually cannot be transferred from one region to another. Mechanistic models (Gardiner et al., 2008) are more flexible but need to be parameterised for the species and conditions of interest.

The ForestGALES mechanistic model was originally developed in the UK (Hale and Gardiner, 2015) but has been adapted for use in many countries in Europe (France, Spain, Denmark, Sweden) and elsewhere in the world (Japan, Canada, New Zealand, United States). The model is available in stand-alone form for use on personal computers (Figure 3) or as part of an Excel spreadsheet or coded within the R statistical package (FG_R) to allow integration with GIS packages.

Since Belarus lacks experience in modeling the effects of wind on plantings, it is very important to adapt existing models to the conditions of Belarus using local models of growth of stands and the formation of individual parameters of trees.

The prepare stage is actually a permanent stage that needs to be constantly evaluating the risk, adapting management and making contingency plans. Contingency plans are the key component of the preparation stage along with regular (at least annual) assessment of the level of risk. Contingency plans need to be developed based on experience of previous storms either in the country of interest or from other countries with similar forest types. These contingency plans are based on an evaluation of which measures worked and were helpful in a previous storm and which were not helpful. The contingency plans need to be discussed and agreed with all the key stakeholders (government and regional forest agencies, emergency services, forest owners, forest associations, etc.).

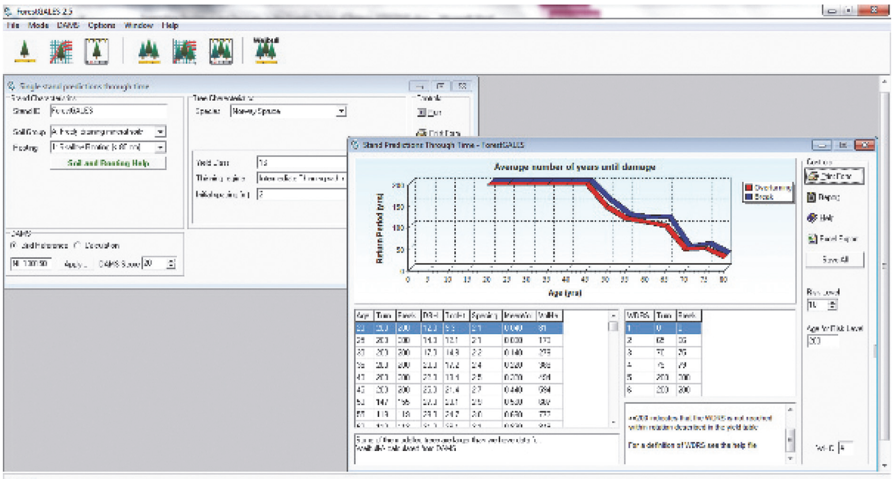
In Belarus, it is necessary to develop an action plan for the occurrence of large-scale windblows, built on the basis of the 2016 windblow experience. A plan of action in case of emergencies of a general nature exists in each enterprise, but windblows are an emergency situation specifically for forestry enterprises. Such a plan is needed due to the unpredictability of windblows, as well as a natural change of specialists who may not have relevant work experience.

Another important aspect of the preparation stage is training. This involves all those likely to be engaged in the immediate response to a storm event from regional authorities, emergency services, foresters required to clear roads, etc. Training can be both directly focussed such as chainsaw courses for clearing wind blown timber to taking part in simulation exercises that replicate a storm to determine how well the contingency plan is likely to work.

In different parts of Europe different approaches have been taken to reduce the risk of wind damage and the impact of wind damage by use of different silvicultural strategies (Mason and Valinger, 2013).

Atlantic forestry. This is typified by even-aged stands managed on short rotations (< 45 years) and is associated with patch clear felling. In the maritime pine plantations of south-west France, this is based on planting at comparatively wide spacing, the development of individual tree stability through early thinning (including thinning to waste) and in the past pruning of final crop trees. In the Sitka spruce plantations of the British Isles, a closer spacing is used to maintain timber quality, but little or no thinning takes place, and greater reliance is placed on maintaining within stand stability for as long as possible. The short rotation forestry systems used for eucalyptus in the Iberian peninsula would also fall into this category.

Figure 38. ForestGALES computer-based mechanistic wind damage risk model



Traditional even-aged forestry. Much of the high forest area of Europe has been managed the same way for over a century or more, with the main silvicultural systems used being patch clear felling, seed tree, and uniform, strip and group shelterwood systems. Trees are grown on rotations of at least 50 to 150 years, depending upon the species being grown and the timber products envisaged. Stands are established at close spacing, pre-commercial thinning may be carried out in the thicket stage, and this is followed by regular thinning after canopy closure to develop quality stems. In the early part of the rotation, the resistance to wind depends upon maintaining within stand stability, but the emphasis gradually changes to favour individual tree stability as a result of thinning. The vulnerability of stands managed in this way is often a function of their thinning history. In parts of Europe, respacing and/or early thinning was often delayed for marketing reasons with consequent risks when dense stands were eventually opened up. In regions where wind and wet snow can destabilise trees, a policy of heavy early thinning to favour more stable trees has been implemented, sometimes followed by a period of no thinning until the period of rapid height growth has passed.

In the Baltic states traditionally to reduce wind induced damages, eastward stands are cut in clear felling before those situated in western part of the "block of compartments", in this way reducing stand edge exposure to wind. Thinning late in rotation (20 years before final felling for coniferous or 10 years for deciduous was avoided.

Close-to-nature forestry. This approach (also termed continuous cover forestry) is generally identified with the single and group selection systems developed in the more mountainous regions of central Europe. These systems are characterised by irregular stand structures with a range of tree sizes present in close proximity and a more open canopy structure. Thinning seeks to foster individual tree stability. In many countries of Europe, there are aspirations to increase the proportion of forests managed in this way. However, transformation of even-aged stands into irregular structures can take several decades, and there can be increased risks of windthrow if the trees are slow to respond to the changed wind loading as a result of heavier thinning. In such situations, it may be more practical to seek to develop irregular structures in the successor stand.

Mixed species stands. There is increasing evidence from forests in Central Europe and Scandinavia that forest stands with an admixture of more stable species (Griess and Knoke, 2011; Valinger and Fridman, 2011). In Norway spruce stands with beech, pine or birch there was found to be a reduce level of damage.

One of the ways to change the wind resistance of plantings in Belarus is to reduce the initial density of forest cultures or naturally renewed plantings with a simultaneous change in the mode of clarification and thinning. However, this work can be carried out only on the basis of computer modeling of the wind effect on plantings of various species composition.

Many factors can affect forest stability. In Figure 39 there is a simplified summary of all the factors that affect tree stability and need to be considered in any management strategy.

Tree species vary in characteristics such as crown characteristics, root anchorage and wood density and strength, which will all influence resistance to wind forces. Evergreen conifers are generally perceived to be more vulnerable to wind than broadleaves, which may also reflect the deciduous habit of the latter during the winter storm season and the tendency for conifers to be the taller trees in a forest. In addition, both spruce and pine species have been widely planted on wetter soils with shallower rooting and reduced anchorage, and such stands will therefore be highly vulnerable to strong winds. Table 3 below summarises existing classifications of species vulnerability based on observational data derived from previous storm events in different parts of Europe.

Table 3. A ranking of the vulnerability of important tree species of European forests to wind damage (Mason and Valinger, 2013). Adapted from Table 13.4 in (Colin et al., 2009).

Vulnerable	Intermediate	Resistant
Picea abies	*Pinus nigra*	*Larix decidua*
Picea sitchensis	*Pinus nigra ssp laricio*	*Abies alba*
Pinus pinaster	*Pinus sylvestris*	*Cedrus atlantica*
Pseudotsuga menziesii	*Fagus sylvatica*	*Quercus robur*
Pinus contorta	*Prunus avium*	*Quercus petraea*
Populus nigra, P. trichocarpa, and hybrids	*Betula pendula*	*Tilia cordata*
Populus tremula	*Betula pubescens*	*Carpinus betulus*
Pinus radiata	*Castanea sativa*	*Fraxinus excelsior*
Eucalyptus globulus		*Acer pseudoplatanus*

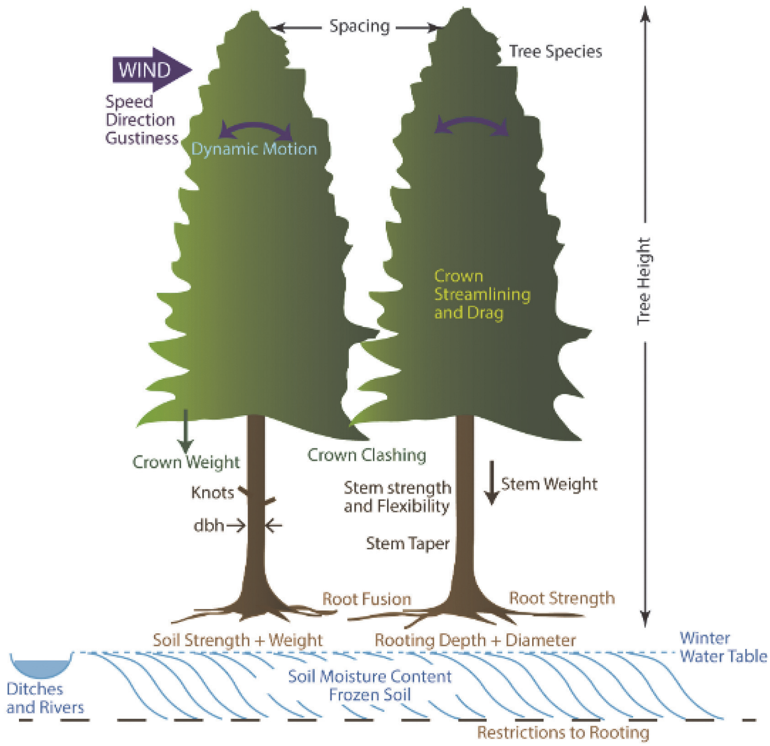
However, such classifications should only be considered as a rough guide to species vulnerability since the evidence for difference between species is often confounded by soil and past management. For example, when planted on deep rooting soils supposedly vulnerable species such as Norway spruce show much better root development and stronger anchorage.

Similarly provenances within a species may show differing vulnerability to wind, as exemplified by lodgepole pine, where south coastal provenances have heavier crowns and a greater instability compared to material from Alaska.

The most critical aspect is to ensure that a particular species is suited to the soil and climatic conditions, before worrying about relative vulnerability to wind damage.

The soils information should identify those sites in the forest where the presence of an indurated layer or soil wetness is likely to restrict tree rooting depth and anchorage. Field inspection may show that it is possible to ameliorate these conditions through appropriate cultivation, for instance by breaking an ironpan through the use of a ripper and so allowing tree roots access to freely drained soil below the pan. Similarly, carefully located drains may channel away water from wet hollows and improve soil aeration. The scale of these operations needs to be considered since experience shows that extensive drainage networks can be difficult and costly to maintain in the long-term. Small wet areas are often better left unplanted rather than becoming a pocket of early windthrow as a result of neglected drains. The potential impact of the cultivation method on subsequent root architecture and long-term tree stability also needs to be considered. For example, the use of single furrow ploughing provided excellent planting sites on wet gley soils in north-west Europe, but root development tended to be mainly along the line of the furrows, making the planted forests more vulnerable to strong winds. One aim of any cultivation method should be to encourage deeper rooting and the development of symmetrical root systems. For example, the creation of spaced mounds can be used to facilitate regular root development on problematic soil types.

Figure 39. Components of tree stability



The choice of planting stock combined with poor planting technique can have a negative effect on root development and subsequent stability. This aspect is too often overlooked and managers should remember that root architecture of a mature tree is determined in the early years of establishment. Bare-root plants that have distorted (J-rooted) root systems or containerised plants where root spiralling has occurred can develop into mature trees with unstable root architecture. While in some species (e.g. spruces) the development of adventitious roots can compensate for poor nursery roots, in general any seedlings with misshapen roots should be discarded and not be planted. Naturally regenerated seedlings normally have a more symmetrical root system than planted trees. The planting operation can also harm the future architecture of the root system, for instance when roots are forced into a narrow spade slit and surrounded by compacted soil. The planting technique should provide a zone of cultivated and aerated soil around the planted seedling to allow ready root-soil contact.

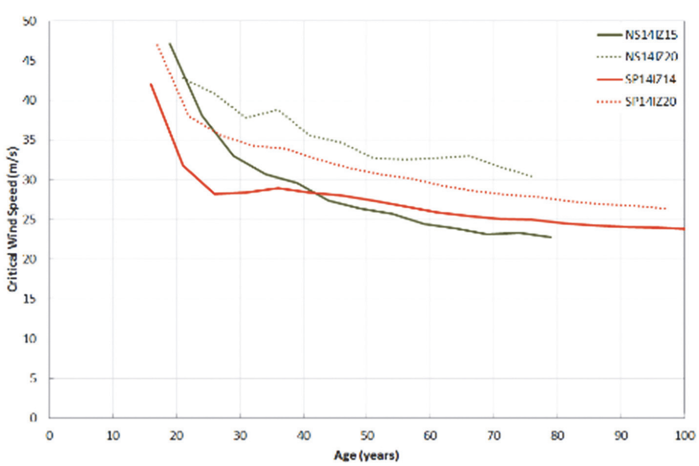
The critical wind speeds needed to cause uprooting or stem breakage of trees are predicted to decrease as tree height, the ratio of tree height to breast height diameter, or between tree spacing increases. In addition, the trees at newly created upwind edges of a stand are expected to be much more vulnerable to damage than trees well inside a stand or at permanent or long established edges. At the same time, trees inside stands with long established edges are more vulnerable than trees at the edge. Lower critical wind speeds are also needed to cause damage at the downwind edges of large clear cuts compared to small openings because of the higher wind speeds and loading that occurs on the far side of a wide opening in the forest.

A wide range of initial planting densities are used in European forestry, ranging from around 200 stems ha-1 for poplar plantations in lowland Europe and 1100 stems ha-1 for maritime pine and Douglas fir in France through 2000 to 3000 stems ha-1 for spruce and pines in the UK and Scandinavia and reaching 4000 to 5000 stems ha-1 for oak and beech in parts of central Europe. Stocking in areas of successful natural regeneration can be even higher. Wider spacing will tend to result in larger diameter and more stable individual trees but these will generally require pruning to prevent loss of timber quality. Close spacing will encourage earlier canopy closure and natural self-pruning of the valuable lower part of the stems, but the risk is that individual tree stability is reduced and the trees can be more vulnerable to strong winds immediately following thinning, especially in the more exposed regions of Western Europe. In Northern Europe an increased vulnerability to damage from snow and wind has been detected in high density stands and in stands of high density where respacing and thinning has been performed recently.

The interaction between thinning and wind damage is complex and is influenced by several factors such as the timing of thinning in relation to stand age and tree height, the pattern and intensity of thinning (i.e. the proportion of trees that are removed and their spatial distribution) and the risks due to permanent features such as climate and soil (figure 40). The critical point to recognise is that all thinning will increase the potential risk of wind damage in the short-term (i.e. up to five years) because the stand is opened up and individual trees will absorb greater wind loading before their stems and root systems have adapted to the new wind climate and the crowns have grown back into the canopy gaps. This increase in risk after thinning is the major reason why late thinning in older stands can result in major wind damage. However, in the long-term, a series of careful thinning operations begun early in the life of a stand can result in a lesser vulnerability to wind damage because the individual trees are then should grow become sturdier and have develop better root anchorage than those in unthinned stands. One issue is that the increasing use of mechanised thinning harvesters in European forests plus feller-selection of trees for removal can result in poor patterns of thinning that do not foster the development of the stability of the stand. Better training of operators is desirable to ensure that mechanised harvesting operations do not compromise long-term tree and stand stability.

Issues of the influence of the characteristics of plantings and individual trees on their wind resistance require additional study in Belarus, as the applied forest management approaches either do not take into account the effects of winds or are based on a limited study of existing windblows. They do not take into account the local features of the wind regime, especially the wind resistance of various species on different soils, the interaction of various species with each other in the same plantation, the effects of various measures on the resistance of trees to wind. A separate issue, which is being discussed now and in Europe, is the design of the windbreak borders based on their aerodynamic properties.

Figure 40. Change in critical wind speed for Norway spruce (NS) planted at 1.5m and 2.0m and Scots pine (SP) planted at 1.4m and 2.0m with intermediate thinning. Mineral soil with shallow rooting



7. Recommendations for restoring windblow sites, taking into account international experience.

The Belarus authorities should immediately develop a crisis management plan for dealing with wind damage to Belarussian forests. Such a plan would synthesise all the knowledge gained from dealing with the storm of July 2016; those things that worked well and those things that did not work so well. Such a document would make it much easier after a second storm for all responsible parties to know what they are expected to do. Examples of such documents for Scotland and France have been attached as appendices.

Such a plan will be the basis for action for forestry workers, it will help professionals without experience in restoring windblows to choose the right actions and immediately react to large-scale forest damage by wind. One of the components of such a plan should be the possibility of rapid damage assessment and mapping of damaged areas. It is necessary to optimize and develop software for processing visual information obtained using drones, airplanes or satellites. It is important to establish parameters for assessing damaged forests and detailing images in order to be able, with a sufficient level of accuracy, to quickly process information over large areas and submit to forestry enterprises not only maps of damaged plantings, but also schemes for road clearing and organization, storage area directions for harvesters and reforestation project with indication of possible options for both species composition and methods of forest restoration.

For this purpose it is necessary to use the resources of the state institution “Belgosles”, which has at its disposal digital maps of plantings, soil maps and the ability to link them with the images obtained. This organization together with the Belarusian State Technological University is working on the development of methods for automated decoding of damaged vegetation.

A practical guide for the overcoming of hurricane consequences can become a complementary to the crisis phenomena management plan that is connected with the wind. In this guide, it is advisable to introduce the international experience to the Belarusian forestry workers and bring all possible options for their development and reforestation, indicating the positive and negative sides of each option.

The possibility of a reasonable choice of options for carrying out activities is a key point when working at windblow sites, because, as experience has shown in reforestation of plantings damaged by hurricane 2016, tight deadlines have led to their quality decrease and to a significant predominance of planting of forest cultures over sowing and natural regeneration. However, the correlation of these methods and their applicability should be further studied, especially since the vast territories of the windblow of 2016 are good research objects. On a territory of several thousand hectares there are areas with different distances from the intact forest edges with different soil conditions, on which various reforestation methods and tree species were used. In addition, the rows of forest cultures in these areas have a different direction that will allow to evaluate the spatial arrangement of the rows on the growth and development of forest cultures.

Moreover, the plan should take into account the high fire hazard of windblow rehabilitated by conifers and the measures to reduce the risk of fires, such as firebreak devices, hardwood lines, road networks, and remote monitoring systems for forest fires should be scheduled.

Along with the plan development and practical guidance, it is necessary to work on assessing the risk of windblows in Belarus. For that it is necessary to study the features of the past years windblows. It will make it possible not only to identify the conditions of damage to plantings but also to identify patterns in the spread of windblows both throughout the Republic and for regions. However, for forest management measures planning aimed at increasing the wind resistance of plantings it is necessary to adapt methods of computer modeling of the wind effect on forest.

For example, modify the existing ForestGALES wind damage risk model for Belarussian conditions. Parameterisation already exists for Scots pine, Norway spruce and birch in the model and this could be improved with local parameterisations for allometric relationships based on Belarussian data.

These include equations for crown width, crown depth and stem volume. Relevant information is available at BSTU and Belgosles. However, the work on adaptation should be conducted under the guidance of foreign experts who are closely acquainted with the work of this program.

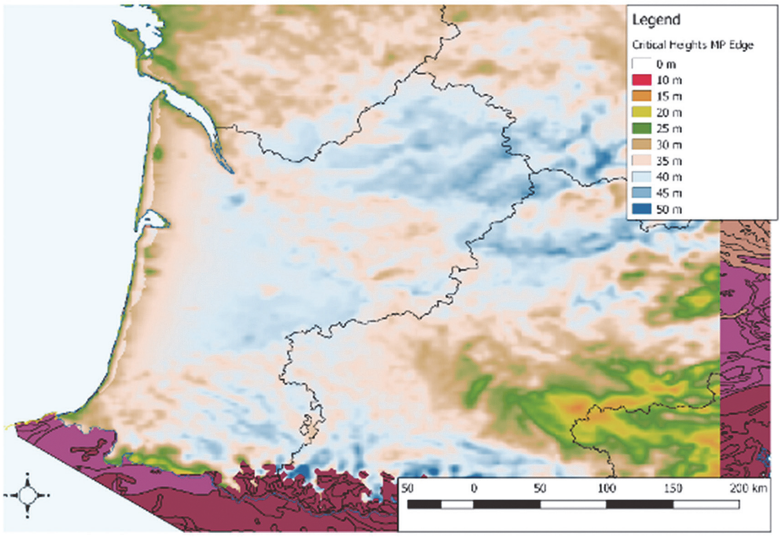
Adaptation of the existing ForestGALES program will make it possible to develop approaches to improving wind resistance when creating new plantings and conducting forest management measures, such as clarification, cleaning, and felling. The information obtained can be correlated with the database of forest plantings and be used in the future by the Belgosles experts in developing forest management projects. However, it should be borne in mind that the dependencies on which the models were built were obtained in other countries and in slightly different conditions. For the initial hazard assessment and modeling of the model of damage to plantings these dependencies can be used. However, in future when developing research in the area of increasing wind resistance of forests in Belarus, it is necessary to clarify the parameters for windblow and windbreak of common oak on various soils, clarify critical winds for Scots pine and European spruce, study the interaction of hardwood impurity in coniferous plantings, etc.

In addition to damage risk model it will be necessary to map the wind climate across Belarus in order to calculate the level of exposure to wind. This information may already be available, for example from analysis of wind power potential in Belarus, or could be constructed from data from meteorological stations, digital terrain data and use of the airflow model WAsP (Mortensen et al., 1993 The work to determine the wind energy potential in Belarus was carried out, however, according to Belhydromet, due to the uncertainty of wind energy in Belarus, it was not fully completed. It is necessary to adapt the wind motion models used by Belhydromet for the damage risk model needs. Also, the critical wind directions over the years can be identified on the basis of surveys of existing windblows.

The risk model can be made available as an add-on to any GIS system (figure 41) that is used by the Ministry of Forestry in order to provide maps of wind risk across Belarus.

In future, these maps can be applied to the least resistant windblow plantations, determined on the basis of computer modeling, which will allow forestry workers to monitor their condition in strong winds and initially assign measures to improve their wind resistance.

Figure 41 – Risk map for Maritime pine in Aquitaine using FG_R and QGIS



In future, these maps can be applied to the least resistant stands, determined on the basis of computer modeling, which will allow forestry workers to monitor their condition in strong winds and initially assign measures to improve their wind resistance.

It may be interesting to develop a wind damage map for stands with a colour scale. And Belhidromet will give “color” information for the Ministry of Forestry. For example, the level of wind danger for forest is “orange”. This means that all orange coloured plantings and less resistant are at risk. And the forester can send workers the next day to assess these stands.

Recommended steps:

1. Prepare a storm damage contingency plan based on the experience of the 2016 storm (Ministry of Forestry, Belarusian State Technological University, 2019).
2. Develop rapid assessment methods for storm damage area based on satellites/aircraft/ drones (Belarusian State Technological University, Belgosles, 2019-2020).
3. Develop a wind damage risk model for Belarus based on existing models (Belarusian State Technological University, Belgosles, Forest Institute of the National Academy of Sciences of Belarus, 2019-2020).
4. Map the wind damage risk level for the whole of Belarus using risk model and wind climate data (Belarusian State Technological University, Belgosles, Belhidromet, 2021).
5. Develop a forest management guide book focussed on conditions in Belarus (Ministry of Forestry, Belarusian State Technological University, Forest Institute of the National Academy of Sciences of Belarus, 2022).
6. Set-up online site to provide information on management to mitigate storm damage and to provide a resource on how to respond following wind damage (Ministry of Forestry, Belarusian State Technological University, 2022).
7. Encourage Belarussian scientists to engage directly in international conferences and workshops and to begin engagement with the European Forest Risk Network (Belarusian State Technological University, Forest Institute of the National Academy of Sciences of Belarus, since 2019).
8. Organize training courses on forest management to mitigate storm damage for foresters in the Republic of Belarus (Ministry of Forestry, Belarusian State Technological University, 2022-2023).

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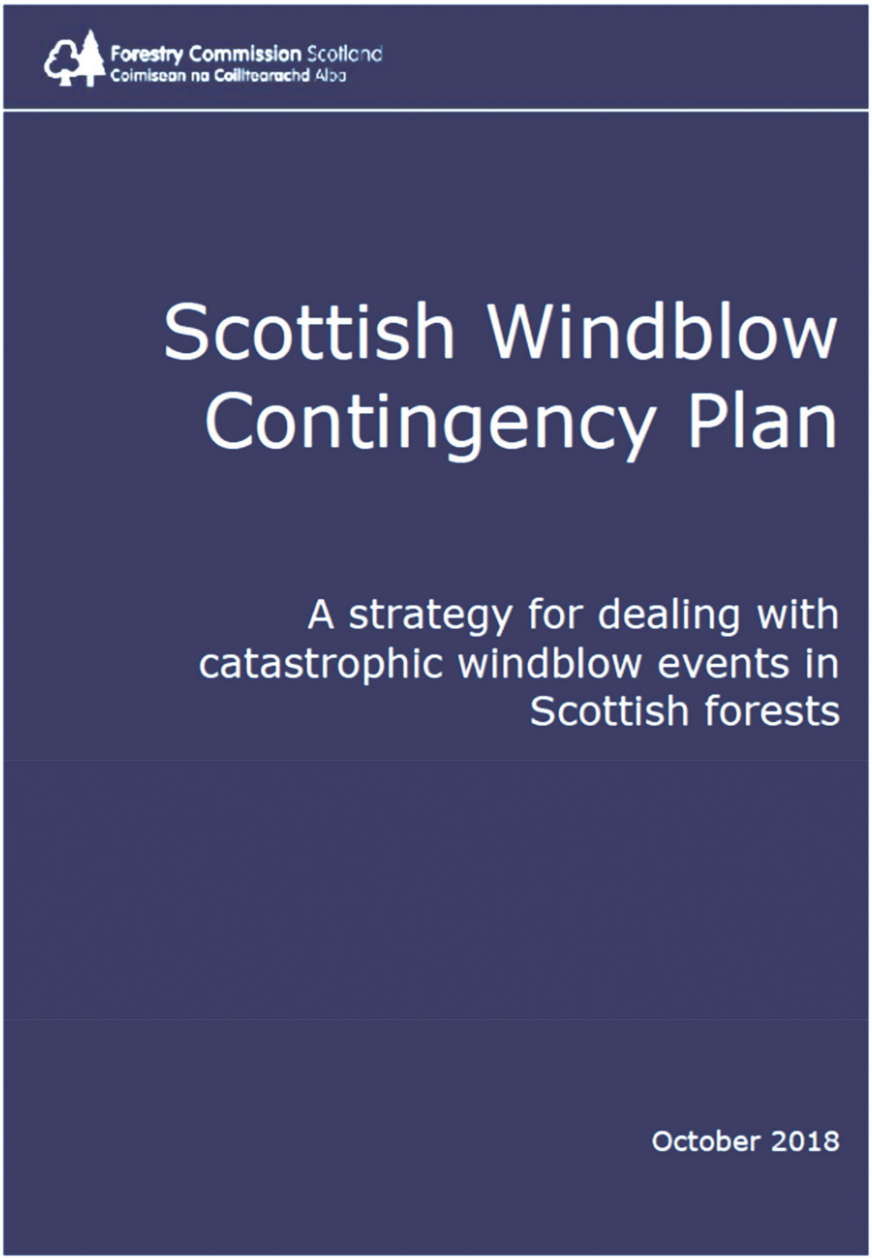
Appendices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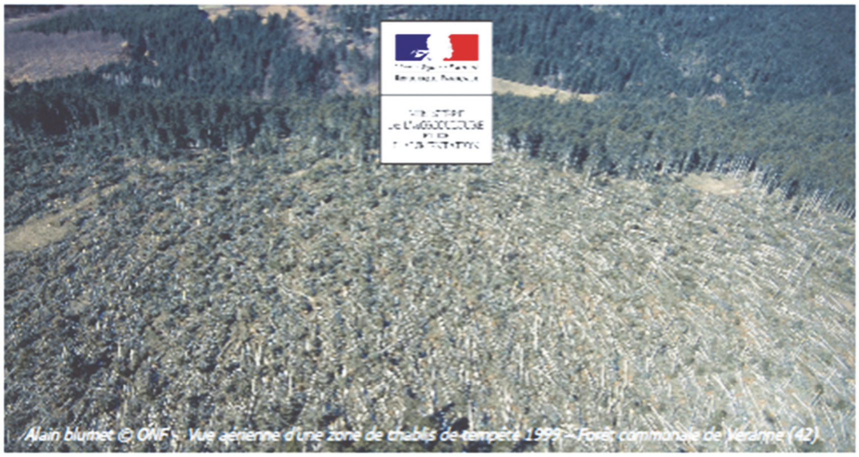
Scottish Windblow Contingency Plan

A strategy for dealing with catastrophic windblow events in Scottish forests

October 2018



Alain blumet © ONF – Vue aérienne d'une zone de chablis de tempête 1999 – Forêt commonale de Véranne (42)

Plan national de gestion de crise tempête pour la filière forêt-bois

Dominique Merzeau – IDF © CNPF – Tempête Klaus du 24 janvier 2009 : volis de pins maritimes

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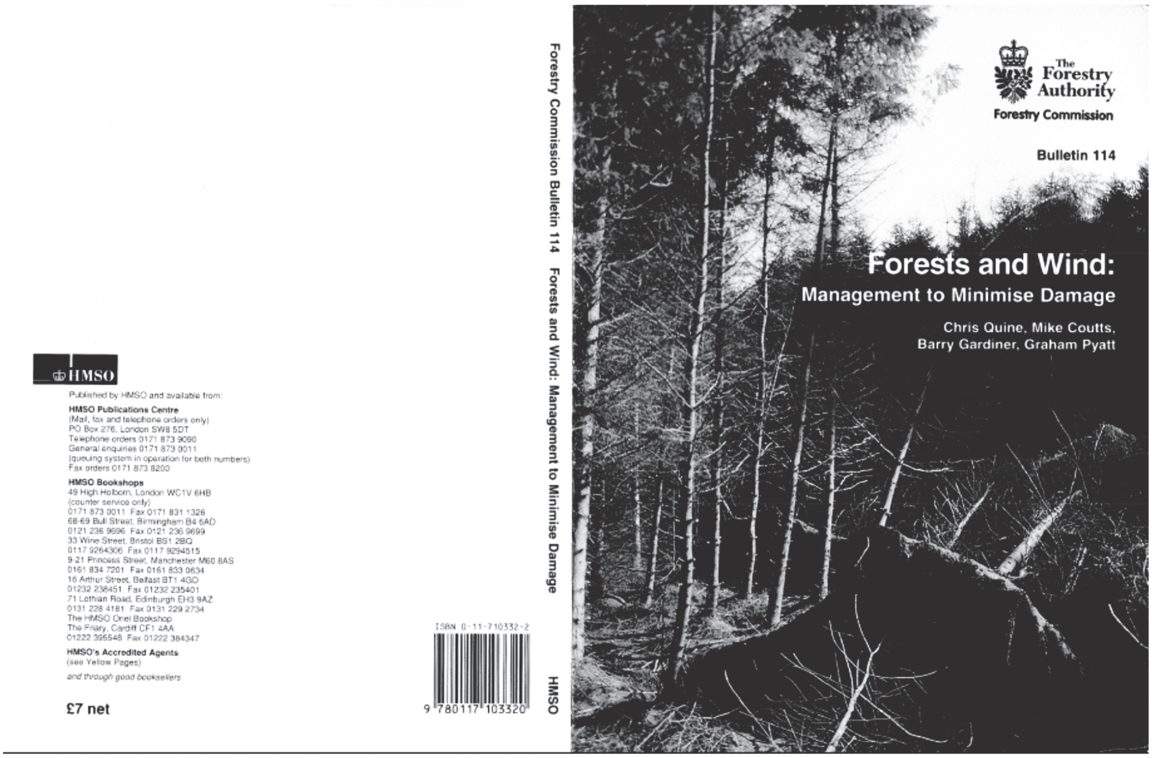
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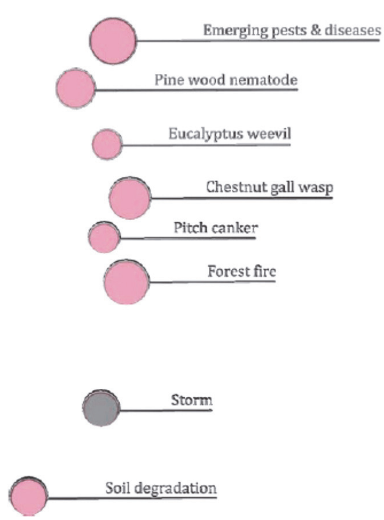

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