ASSESSING WIND-CAUSED PINE STAND DISTURBANCE

IN THE SOUTHERN PART OF CENTRAL SIBERIA

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Abstract

Estimates are given of levels of the south Central Siberian pine stand disturbance by the November 1994 hurricane. Major factors accounting for decrease in stand resistance to wind are determined. These are such as: - specific environmental conditions (complex relief patterns, ground structure, and light soil structure), infestation by fungi (Heterobasidion annosum (Fr.) Bref.) and disturbance of natural conditions by human economic activity. Measures are suggested to optimize wind resistant pine stand formation.

Key words: windthrow, resistance, disturbance, site conditions, partial logging.

Ribbon-shaped pine stands in the south of Central Siberian are unique natural objects. They grow along the southern boundary of the forest vegetation area and cover some 65,000 hectares. These pine stands are considered to be particularly valuable and fall in Group I of the Forest Value Classification System. They protect soil and water bodies, and perform sanitary and recreational functions. In the anthropogenically stressed landscapes of the Siberian agricultural zone, ribbon-shaped pine stands are the biggest source of genetic, species, and ecosystem biodiversity.

Over recent decades, the tendency of ecological pine stand state worsening has become stronger. They are periodically damaged by dendrophilous insects, wild animals, cutting, and hurricanes. Windfalls are a very remarkable feature of the present look of the pine stands. Due to the light mechanical composition of soils, tree infestation by fungi (Heterobasidion annosum (Fr.) Bref.), the dune/hilly relief, and high density of woody vegetation at some sites, the pine stands are regularly disturbed by strong winds which results in considerable economic and environmental damage. In November 1994, strong winds (more than 30m/s) made about 300,000 cubic m of wood to fall in an area exceeding 2.5 million ha. Wind-caused tree root disturbance had led to weakening of the pine stands in big sites. This makes the understanding of pine stand resistance to wind a very serious and important research problem and also confirms an urgent need to improve existing forest management guidelines in order to maintain forest sustainability.

Looking through literature, one can find many research papers addressing effects of strong winds for forestry in terms of their influence on stands differing in composition, structure and site conditions. It was reported (Rozkov and Kozak 1989; Mitchell 1995) that windfalls occur due to complex interaction between topographic, climatic, soil, hydrological, ceonotic, and economic factors. The role of each of these factors and their level of interaction vary depending on local conditions. Different combinations of relief, soil properties, and forest stand parameters, which are influenced by climatic factors and man activities, refer to different classes of windfall hazard (Mitchell 1995).

Inside the forest, wind has a stratified structure. Wind speed at different levels depends on overstory composition, stand structure, height and density, and the presence of regrowth and understory vegetation. Wind speed is also controlled by mesorelief, logged areas, glades, cuttings, fire breaks. Mass windfalls are the result of long-term wind impact combined with topographic conditions, high soil moisture, tree infestation by root sponge, and intensive forest exploitation activities (Valendik 1968; Bush 1970; Kiselevsky-Babinin, 1972; Belov 1976). Open mature and old stands with one-species overstory and growing in overwetted sites or on shallow soils, causing surface root system development, are least resistant to strong winds.

There are different opinions among scientists as to the relationship between stand density and wind resistance of trees. Some authors (Valendik 1968; Belov 1976) consider that at high canopy closure the wind slides over rounded crowns and can hardly penetrate into the stand through openings (gaps). In dense stands, however, wind resistance of each individual is lower than in open stands, because high density prevents good tree root system development (Rozkov and Kozak; 1989). Disturbances of continuously closed dense stand canopy by partial cuts result in a dramatic decrease in the resistance of trees to wind, because their morphological parameters, characteristic of high density of stands, cease to fit the altered ecological situation.

Wind speed, tree crown size and shape, as well as the trunk's center of gravity are the factors which determine how the wind influences a tree. As for mature stands, high crown situations, strong tree trunks and relatively small root systems promote windthrow over branch snapping (Bush; 1970). The problem of improving forest resistance to windthrow should thus be approached based on full account of all environmental factors, as well as thorough study of forest soils, site conditions, stand composition, structure and productivity specific to geomorphological situations, and analyses of forest planting methods.

Our investigation scooped the following interrelated aims:

- determine the scale of pine stand disturbance caused by the November 1994 hurricane;
- estimate factors that influence forest resistance to wind in relation to local environmental conditions;
- make some instructions on how to improve methods of wind resistant plantation establishment.

Over many years, scientists of the Institute of Forest, Siberian Branch, Russian Academy of Sciences, have performed complex studies in pine stands in the south of Central Siberia dealing with soils, site conditions, forest productivity, and the current ecosystem state. The work involves representative sites, transects, landscape profiles, permanent sample sites, and the use of 1:12000 - 1:200000 aerial images.

As a result of several years of investigations, it has been established, that, in the geomorphological respect, today's ribbon-like pine stands occurred in the places of ancient valleys of past Yenisei river tributaries (Soil Factors Controlling Pine Stand Productivity 1976). After the hydrological system had changed, exposed sands experienced wind-induced redeposition which was accompanied by the development of dune/hilly relief. Loamy sand soils of different maturity are predominant here. In the forest-steppe zone, sand deposits are underlaid at the edges by light loess-like loams some 20-100 cm deep. One can observe loam layers at different levels of sand thickness. Many deposits are covered by dark-gray forest soil, leached black soil, and meadow black soil. In most of the area, ground water is situated deeply, and so it has no direct influence over the soil development process. Annual air temperature averages 0.5C, and annual average precipitation is 402 mm.

Pine, being the major overstory species, comprises more than 9 percent of the total forest land.

As for the methods used, we collected information from variety of sources, ranging from space imagery to ground observations, to result in different scales of geographic detail outworking. This involved use of available forest inventory data, ecological maps, and information on the current forest state. When working on the representative sites and transects, we plotted the boundaries of disturbed pine stands on maps and aerial images. In addition, we used data from observation routes covering the whole of the area of interest. Tree trunk wind-induced snapping and windfall structure was studied at permanent sample sites.

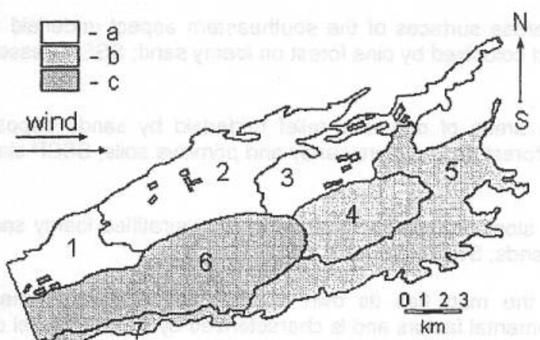

Fig.1. A map of disturbances in a forest management area (pine forest belts in the south of Central Siberia) caused by a hurricane in November 1994.

 - boundaries of site types.

▭ - places of continuous windfall (wind-fallen trees are 80- 90 %).

Disturbance levels: a - heavy, b - medium, c - light. 1-7 - types of site conditions (see text for explanation).

The results of our investigation show that, in the south of Central Siberia, the level of wind-caused pine stand disturbance is determined by topographic (relief, soil-ground thickness structure), biological (soil richness and stand age, density, productivity, and horizontal structure), and economic activity factors. In Fig.1, an ecological information-based map is presented of one of the studied pine stands. Each contour in the map represents a certain type of site conditions, which are relatively uniform with respect to the complex of environmental factors, such as mesorelief type, general slope aspect, lithologic parameters, soil, and vegetation pattern.

Below is a brief description of the contours:

1. Situation of soft slopes and bald hills of the northwest aspect underlaid by sandy and loamy deposits and colonized by pine stands on well-developed loamy sand soils; site-specific stand productivity (SSSP) of classes II and III.

2. Areas of relatively flat and undulating relief mostly of the northwestern aspect underlaid by three-strata deposits (loam/sand/loam) and colonized by pine forest on loamy soils; SSSP classes Ia, I, and II.

3. Areas of small hills and bald mountains of the northwestern aspect underlaid by two-strata deposits (loam and sand) and colonized by pine and birch stands on loamy soils; SSSP classes I and II.

4. Areas characterized by soft bald hills of the southeastern aspect and colonized loamy soils; SSSP classes I and II by pine and mixed birch/pine stands on light loams; SSSP classes I and II.

5. Softly sloping erose surfaces of the southeastern aspect underlaid by two-strata deposits and colonized by pine forest on loamy sand; SSSP classes II and III.

6. Heavily broken areas of dune-like relief underlaid by sandy deposits and colonized by pine forest on immature sandy and primitive soils; SSSP classes IV and V.

7. Flat and softly sloping surfaces characterized by stratified loamy sand soils supporting pine stands; SSSP classes II and III.

Each contour in the map has its own specific combination of the above mentioned environmental factors and is characterized by a certain level of forest disturbance due to wind. The highest disturbance is observed in the sites of mostly northwest aspect with relatively flat, slightly undulating or soft-sloping/small bald hilly relief (contours 1,2, and 3), which were directly affected by the hurricane. In these areas, relatively rich soil and site conditions of classes I and II promote highly productive mature pine stands. Wind-fallen trees account for 30-50 percent of their total number. The sites that suffered most (wind fell up to 90 percent of trees) are shown in the map as areas of continuous windthrow.

Contours 4, 5, and 7 represent a macroslope of the southeast aspect. Forest disturbance is considerably less here (disturbance of 10-20 percent on the average). However, single thrown trees are found everywhere. The factors accounting for a lower disturbance level might include not only an opposite aspect, but also lower pine density and productivity, as well as the presence of mixed birch-pine stands with grass ground cover and young pine stands.

The areas largely represented by 50-60 year-old and young pine stands (6), where site conditions are poor and relief is heavily broken (dunes and hills), appeared to be the most resistant to wind.

To sum up, the highest disturbance occurs in mature pine stands (SSSP classes I and II) covering northwestern slopes (more than 15 deg.) easily affected by wind, and relatively flat softly sloping/hilly surfaces.

Based on an ecological map previously created by our specialists (Ryzkova V.A., Pleshikov F.I., Tcherkashin V.P. 1992) we could perform a more detailed investigation of areas with continuous windthrow. Fragments of a large-scale ecological map and a vegetation map were entered into a computer, overlaid, and analyzed using a forest inventory data base. (Integral indicators of the quality of site conditions are as follows: actual and potential productivity, and the percentage of realization of site conditions potential by vegetation.)

Fig.2 shows fragments of large-scale maps of forest sites disturbed by wind and represented by different types of site conditions.

Site A (site conditions type 2; Fig.1) is characterized by rich soils and stands of high productivity. Sites where windthrow is the highest, have been subject to partial logging over the last 10-15 years; this has decreased the wood biomass amount and disturbed the natural stand structure. For these areas, average realization of site potential by vegetation is 45-65 percent. Man-caused changes of the natural structure of these pine stands resulted in their low resistance to negative environmental factors including wind.

Site B is situated at the boundary between site conditions of types 1 and 6. In the upper part of the site, mature stands prevail (SSSP classes II and II), which have also experienced selective logging. The coefficient of site potential realization by vegetation is 40-50 percent. This is where the windthrow was extremely high.

The lower part of the site is very different from the upper part in terms of site conditions type (shallow sandy soil, dune/small hill relief), SSSP class (IV and V), and stand age structure. Here, a considerable area is covered by natural young pine stands. The coefficient of realization of site potential by vegetation is 90-100 percent. That means that the natural forest cover structure is only slightly disturbed here. Single thrown trees can be found in saddles between dunes (where site SSSP class increases to III). In general, this part of the pine forest was left practically unaffected by the windthrow. One of the factors that contributed to the high wind resistance of this area is that it had not been disturbed by logging because of low productivity of the stands.

Analysis of the vegetation inventory data obtained from the permanent sample sites allowed us to determine the reasons and identify the mechanisms of decreasing stand resistance to wind after partial logging. Since there are ecological constraints for forest thinning operations in the foreststeppe zone, these stands remain very dense up to the age of 50-60. For example, comparison of local tables of pine stand growth built by V.V. Kuzmichev (Soil Factors Controlling Pine Stand Productivity 1976) with more general ones compiled by

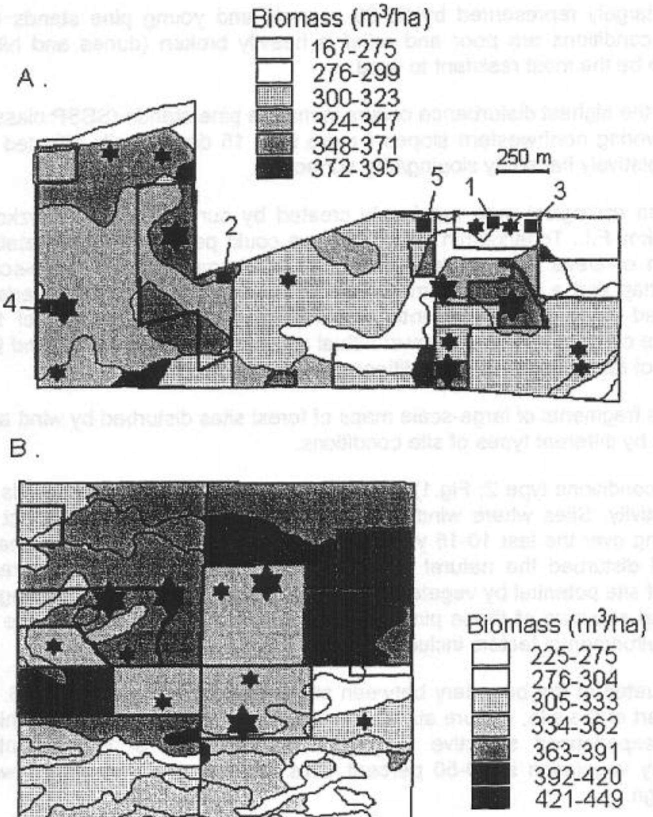

Fig.2. Disturbance of forest sites (A and B) by 1981-1989 partial cuts and 1994 windfall.

★ - forest site completely killed by wind (80-90% of wind-fallen trees).

- places where wind-fallen trees account for 30 to 50 %.

- contours on the ecological map.

- boundaries of sites subject to partial cutting.

- permanent sample sites.

A.V. Tyurin (Forest Inventory Guide 1980) has revealed that ribbon-like pine stands up to 50-60 years old growing under similar conditions are characterized by a bigger d.b.h. (tree diameter at breast height - 1,3 m) stand area, higher tree number and greater biomass amount per hectare. For older pine stands, these parameters are of lower values in comparison with A.V.Tyurin's table. This difference is attributed to intensive thinning activity in close-to-mature stands (aging about 70-80).

High density of stands disturbs the normal structural arrangement, the balance among above- and underground tree parts, and promotes root fungi (Heterobasidion annosum (Fr.) Bref.).

As a rule, pine stands are intensively thinned during partial logging operations. According to our data , some 11-38 percent of the total stand wood biomass amount are removed by partial logging.

Since the remaining mature trees grow slower, they slowly adapt themselves to the altered ecological situation and become very sensitive to wind. Investigation of the last windthrow in the pine stands under consideration showed that some 90 percent of disturbed stands had been subject to partial thinning of different extents in the preceding years.

Table 1. Characteristics of Pine Stands Disturbed by Wind on Permanent Sample

		Average Inventory/Morphological Tree Parameters									
¹	A	Wind-thrown Trees					Surviving Trees				
		N	G	d	h1	h2	N	G	d	h1	h2
1	101	256	21.4	32.6	26.6	15.7	201	17.2	33.0	26.6	14.7
2	90	260	13.2	23.2	22.1	13.2	412	21.5	23.8	22.1	13.8
3	101	72	8.2	29.4	23.7	13.7	616	35.1	27.0	23.0	14.3
4	72	88	3.4	22.8	19.6	10.9	114	25.9	17.3	17.9	10.8
5	77	17	1.0	42.8	26.7	10.4	205	25.1	38.5	25.6	11.3
6	98	12	0.1	-	-	-	134	35.0	18.3	19.4	13.4

¹ - Sample Site Number; A - Stand age; N is number of trees per ha; G is d.b.h. stand area, sq.m/ha; d is d.b.h. tree diameter, cm; h1 tree height, m; h2 is height to crown bottom, m.

In table 1, inventory data are summarized on trees in permanent sample sites that managed to survive the hurricane. The windthrow was assessed the highest (10.5-56.0%) in the first three sample sites, 20 m away from a medium-size forest inventory unit boundary. (This boundary is a man-made cutting 10 m wide separating one forest inventory unit from another.) The hurricane appeared to go the same direction as the boundary. Practically, morphological and inventory parameters do not differ between the wind-thrown and the remaining trees in this area. The rate of local canopy closure was probably critical for survival of trees, when the wind blew in powerful gusts along the cutting. In the rest of the sample sites (4, 5, and 6), established in closed stands, the windthrow accounts for 0.9 to 6.7% of all trees. It is noteworthy that heights and trunk and crown diameters of the surviving trees are slightly less than those of wind-fallen individuals. A close relationship, identified between vertical growth of a tree and its crown (cross-section) area, appears to primarily determine tree resistance to wind influence (Kiselevsky-Babinin; 1972). In lightly disturbed sites, cross-section crown areas of surviving trees are 17 to 27% smaller than those of wind-fallen individuals.

Conclusion

We failed to identify any relationship between the room (space) available for a tree to grow and its resistance to wind. We can only mention one thing: the biggest number of wind-thrown trees occur in less dense stands, with other parameters being the same.

We can say in conclusion that pine stands of the southern part of Central Siberia are remarkable for generally low resistance to strong wind influence. The two major factors accounting for that are a specific character of the environmental conditions and disturbance of natural vegetation communities by human economic activities. Least wind resistant are the mature high-productivity pine stands with discontinuous horizontal canopy closure growing on pure loamy sand deposits which result in only surface root system development. Underlying loamy sand which is reachable by tree roots improves tree resistance to wind significantly due to better development of main roots. Infestation of the pine stands, which grow densely up to the age of 50-60, by fungi (Heterobasidion annosum (Fr.) Bref.), and following intensive thinning of the stands, during partial logging operations, also contributes to pine wind resistance decrease.

Pine stand resistance to wind can be improved through optimizing forest maintenance on the basis of well-planned thinning activities. The latter should be aimed at promotion of strong root systems and long crowns of trees (Stoyko; 1965). When planning forestry activities dealing with increasing stand resistance to wind, one should take into account site conditions, ground thickness structure, topography, forest land structure, and the inventory/morphological characteristics of the future vegetation communities that will in time replace disturbed forests.

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