Windthrows in the pine forests of the Tsagan-Daban ridge (the central part of the Selenga middle mountains)

V N Chernykh, Zh B Alymbaeva, S G Andreev, A A Ayurzhanaev, B Z Tsydypov

Baikal Institute of Nature Management SB RAS, Republic of Buryatia, Sakhyanovoy str., 6, Ulan-Ude, Russia

Abstract. This paper presents results of an analysis of damage to cedars growing on the slopes of the Tsagan-Daban Ridge (the central part of the Selenga middle mountain) caused by storm winds in 2018-2019. Based on a study of Landsat satellite data, the main areas of windthrows are determined, and their morphometric characteristics are calculated. The damaged areas of cedar forests on key sites in the Kunaleyka River basin are surveyed with UAV. The causes and consequences of windthrows in the Tsagan-Daban Ridge taiga are identified.

1. Introduction

Siberian pine (*Pinus sibirica* L.), or cedar, refers to especially valuable wood species. It is widely spread in Transbaikalia. *Pinus sibirica* is a significant part of the forest stands of the mountain dark coniferous taiga on the territory of Buryatia and Zabaikalsky Krai, forming areas with a continuous distribution - cedar forests. Cedar forests are spread on the ridges of Khamar-Daban, Eastern Sayan, Barguzin, and Ikat. Due to the specific microclimate of Lake Baikal, *Pinus sibirica* grows right on its coast, at an absolute height of only 456 m, although the largest areas occupied by cedar trees are located in the height range of 1100-1900 m. Cedar also grows in the taiga of the Ulan-Burgasi, Tsagan-Daban, Kurbinskiy, Khudanskiy, Malkhanskiy, and Yablonoviy ridges.

In Russia, cedar forests have been systematically studied for many years. This is due to their special value and commercial significance. Among the works there are forest [1] and forest pathological [2] studies, descriptions of taiga landscapes with forest stands, articles devoted to the problems of restoration and rational use of cedar forests [3]. Over the last years, more and more works are being carried out based on remote monitoring of cedar forests [4]. Such works are devoted to the impact of fires on cedar forests [5], and wind damage to forest stands [6]. The research area is limited to the areas of cedar distribution, i.e. Siberia and the Far East. In Buryatia and Transbaikalia, the study of cedar forests is usually focused on their condition and use [7]. Meanwhile, mountain taiga landscapes and forests with habitats of *Pinus sibirica* L. are currently experiencing increased anthropogenic impact and are being transformed under the influence of natural processes. One of such types of cedarwood degradation is large-scale wind damage to forest stands with the formation of extensive windthrows.

Despite the vast geographic coverage of cedar forests in Transbaikalia, their total area in forest stands is limited. Thus, according to the Republican Forestry Agency, on the territory of Buryatia the share of cedar forests in the total forest area is only 8.9%. This is explained, first of all, by the ecology of *Pinus sibirica* L. The conditions of moisture and physical and chemical properties of soils, the state of soils, and relief are limiting factors in the spread of cedar. In addition, the cedar forests in Siberia in general, and in Transbaikalia in particular, are subject to increased anthropogenic impact, as the mountain taiga is the area of commercial production of cedar nut. In recent years, cedar forests have been increasingly exposed to fires and logging. In some districts of Buryatia (Zakamensky, Severobaikalsky) the cedar forests are damaged by Siberian silkworm caterpillars. In 2018 - 2019 in some areas of Buryatia covered with mountain taiga with stands of *Pinus sibirica* L. the formation of windthrow areas was detected, which had not been previously recorded on such a scale in this area. The aim of this work is to estimate the windthrow distribution in cedar forests using, as an example, the mountain taiga of the Tsagan-Daban ridge.
2. Study area
The area of the study (Figure 1) is the Tsagan-Daban ridge, a medium-altitude mountain chain 200 km long. The main watershed of the ridge extends to the north-east from the Selenga River to the Kizhinga Basin. The southern macroslope of the ridge faces the Tugnui hollow; the northern slope has no distinct orientation, as this part is characterized by numerous spurs, which extend in the direction from the main watershed to the Uda River valley. The maximum height of the ridge is 1434 m. The highest point is located on the watershed of the Tugnui and Chelutai Rivers. The absolute height of the bottoms of the intermountain basins of small rivers ranges from 530 to 600 meters. The absolute interfluvial excesses over the valley bottoms and the relative height of the ridge is 800-850 m.

The main type of landscape of the territory is mountain taiga. Most of the slopes and peaks of the ridge are covered with forest vegetation. Coniferous and coniferous small-leaved forests with common pine, larch, birch, and aspen prevail in the lower part of the slopes. The light coniferous trees are mostly replaced by dark coniferous, spruce, fir, and cedar trees above 800 - 900 meters in Tsagan-Daban. This part of the territory is characterized by the prevalence of cedar in the forest stand.

3. Materials and methods
During the study of the windthrows in the cedar forests of the Tsagan-Daban Ridge, a comprehensive approach based on the use of Landsat 8 data, UAV imagery, and field route description materials was applied. Landsat 8 images were selected to detect the extent of stand damage and windthrow localization areas. Summer scenes for 2017 and 2019 were uploaded from the servers of the U.S. National Geological Survey (glovis.usgs.gov). A forest mask was created based on ENVI images using the IsoData uncontrolled classification method. To detect windthrows, the images were processed in ArcGIS by using NBR and SWVI indices, by the difference of which windthrows were separated from other objects in the area (burnt areas, fellings, rock outcrops, stone runs, etc.). Clarification of the windthrow contours obtained as a result of analysis of remote sensing data, was carried out on the terrain using UAVs and ground route field observations.

4. Results and discussion
The presence of windthrows in the cedar forests of the Tsagan-Daban Ridge was discovered in the autumn of 2018. In June 2019, an inspection of some parts of the damaged stand at the top of the watershed between the basins of Kuitunka and Bryanka was carried out. As a result of the inspection of an area of about 4 km2, significant damage to cedar forests as a result of wind impact was
identified. In some places, cedar forests were completely destroyed. There were no such damages to the stand in the taiga of the Tsagan-Daban Ridge during the historical period. In this area, which has been a place of pine nut mining for many years, there are no traces of windthrows, fallen trees are occasional and rare. At the same time, the age of the stand does not reach the limit for Pinus sibirica L., it fluctuates within 150-200 years, which excludes natural successional processes and makes factors of climatic nature the main causes of the stand damage. Windthrows in the Tsagan-Daban ridge taiga have not been studied before.

As a result of these studies, maps of windthrows location (Figure 2) were obtained and their areas were calculated. Based on an inspection of different parts of the taiga, a discreteness in the stand damage was observed. Some parts of the damaged cedar forests are substituted with parts of the undamaged coniferous and small-leaved vegetation (Table 1). In the study area, 6 centers of windthrows have been established, which are confined to the highest axial parts of the Tsagan-Daban ridge and have a total area of 405 ha.

| Site | 1  | 2  | 3  | 4  | 5  | 6  |
|------|----|----|----|----|----|----|
| Windthrow area, ha | 31.7 | 136.5 | 28.7 | 23.8 | 60.6 | 123.7 |

The character of the damage to the stand shows that the reason for the windthrows was a northeastern squally wind, whose destructive effect appeared at heights of 1300 m. No damage to the stand was found below this orographic mark. At the nearest weather station in the village Tarbagatai in September 2018, no squall was recorded, which indicates its local manifestation.

Figure 2. Map of windthrow distribution in the Tsagan-Daban Ridge (localization areas are marked with numbers).
The damage to the stands in cedar forests was caused by a combination of factors. Along with the storm wind, prolonged drought and anthropogenic impact on the cedar forests during nut harvesting played their role.

The analysis of changes in the river runoff in the basin of Lake Baikal, the amount and nature of precipitation, the long-term course of air temperatures gives reason to believe that the drought recorded in Transbaikalia in the last 20 years is most extensive both in depth and duration for the latest period of instrumental observations [8]. Thus, the long-term trend of precipitation according to the data of the Ulan-Ude weather station in the period from 1997 to 2018 is negative. The same situation is with the precipitation of the warm period of the year. At the same time, the trend of air temperature is positive. Against this background, there is a lack of moisture, which is destructive to mountain-taiga landscapes. Low precipitation and increased evaporation lead to a decrease in moisture reserves in the soil. An analysis of the dynamics of ice areas on small rivers and streams with origin in the spurs of the Daban-Daban Ridge, based on the study of multi-temporal Landsat satellite data for the period from 1997 to 2018, shows a total reduction in the areas from 40 to 6 km², which indicates a decrease in the underground groundwater reserves. According to the Tarbagatai weather station, the runoff of the Kuitunka River, whose formation takes place in the mountains of Tsgan-Daban, decreased in this period from 0.018 to 0.005 km³. These climatic processes have led to a decrease in the water saturation of near-surface soils and soils in the taiga. As is known, the root system of cedar is shallow and holds the tree well even on steep slopes, but only if the soil is sufficiently moistened. Loosened sediments, which form soils with a shortened profile, have a depth of 15-20 cm in the taiga on the Daban-Daban ridges. Indigenous granites with increased jointing features are found under the soil and colluvium, which is formed by a fragmentary material. The poor thickness of sediments and soils in arid climatic conditions leads to a rapid loss of moisture in the surface soils, reducing their binding. As a result, the root system of cedar cannot hold the tree, and in strong storm winds the cedar falls. The character of a cedar forest stand, its density, increases the scale, creating a "domino effect". This is the main reason for the formation of windthrows in the taiga of the Tsagan-Daban ridge.

However, the natural factors of the taiga damage are intensified by anthropogenic impact. The cedar forests of the Tsagan-Daban Ridge, as well as the whole Transbaikalia, are areas of active harvesting. Pine nut harvesting has been carried out in these forests for ages, mostly by hitting tree trunks using a kind of a big wooden hammer "oko lot". As a result of this method of harvesting, dents are formed in the cedar trunks, and the damage affects the entire morphological structure of the tree. The droughts of recent years coincided with an increase in pine nut harvesting due to economic reasons, which in 2018 led to fatal consequences for the Tsagan-Daban cedar forests.

The problem of degradation of cedar forests in the taiga of the Tsagan-Daban ridge, the occurrence of windthrows in place of cedar stands may become important for other areas of growth of this valuable tree species in the Trans-Baikal region, although at present there is no stand damage of such magnitude to cedar forests of the other similar surveyed territories (the taiga of the Ulan-Burgasi ridge).

Acknowledgements
This study was supported by the Russian Foundation for Basic Research (project no. 19-55-53026 and 17-29-05083) and under BINM SB RAS State assignment.

References
[1] Zakharov A 2007 Formation of cedar forests of the Chita region Vestnik KrasGAU (Krasnoyarsk: KrasGAU) No 3 pp 131 – 34
[2] Pak L 2007 Renewal of cedar under the forest canopy in Eastern Transbaikalia Forestry (Moscow: Science) No 2 pp 63 – 5
[3] Debkov N and Ilyintsev A 2018 The structure and dynamics of forest regeneration in the burn-out areas of the middle taiga of Western Siberia Forestry Bulletin 22 6 31 – 9
[4] Ismailova D, Baboi A, Gosteva D and Nazimova D 2011 Application of GIS for the analysis of the relationship between forest vegetation and mountain relief on the example of rain-barrier landscapes of the Western Sayan Geoinformatics (Moscow: VNIGNI) No 3 pp 29 – 35

[5] Debkov N, Zalesov S and Opletaev A 2016 Walnut-fishing zones and their current state (on the example of the Tomsk region) Forestry Bulletin 3 21 – 3

[6] Bondarchuk S, Vozmtishcheva A, Gromyko M and Pimenova E 2018 Changes in the structure of the cedar forest cover caused by typhoon Lionrock Scientific Conference Plants in the monsoon climate: anthropogenic and climatogenic transformation of flora and vegetation (Blagoveshchensk: Far Eastern State Agrarian University) pp 21 – 6

[7] Kuzakova Z 2018 Transformation of the geosystems of the Barguzin biosphere reserve (on the example of the influence of pyrogenic activity in the Shumilikha river basin) Proc of Conference on Modern landscape and ecological condition and problems of optimization of the natural environment of regions (Voronezh: Istoki) pp 370 – 72

[8] Frolova N, Belyakova P, Grigoriev V, Sazonov A and Zotov L 2017 Long-term fluctuations in river flow in the Selenga basin Water Resources 44 (3) 243 – 55