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Vyacheslav A. Melkiy[1], **Alexey A. Verkhoturov**[2]

MAPPING OF FOREST DISTURBANCE FROM WINDS OF EXTRATROPICAL CYCLONES IN THE SOUTHERN PART OF SAKHALIN BY REMOTE SENSING DATA

ABSTRACT

Deforestation was named one of the global environmental problems by the close of the 20th century. Tropical cyclones, which operate in the Northern-West Pacific during the summer and autumn and sometimes go far north, transforming into extratropical cyclones, are the main cause of damage for forest areas in Southern Sakhalin. In central parts of tropical cyclones, during their maximum development, pressure reaches 895 mbar, stable winds arising in atmospheric vortex can have speed up to 50 m/s, and gusts have speed up to 78 m/s. Storm winds with gusts have speed over 35 m/s, which are capable of knocking down free-standing trees, as well as causing significant damage to the forests. In October 2015, in the southern-west part of Sakhalin during the passage of typhoon Choi-wan, significantly forested areas were disrupted by winds. The purpose of the work was to investigate the extent and nature of damage to the forest, caused by winds during passage of extratropical cyclones over territory of the South-West of Sakhalin Island. Images of the research area were classified by "with training" method. The training sample was made up of a set of pixels representing images of sample plots, where geobotanical research was performed. It was revealed that total area of windthrows in the territory of Kholmsky and Nevelsky districts in south-west part of Sakhalin Island was 22 735 ha. To analyze character of windblow damages in researched area, the Normalized Difference Vegetation Index was calculated and areas with varying degrees of damage were identified in terms of content of phytomass, presented in form of green trees and clumps, as well as preserved underscrub and undergrowth. At the same time, it was revealed that among the affected stands, one can distinguish completely dead (occupy 19.85 % of the territory), partially damaged (41.85 %) and slightly damaged (38.29 %). Mapping forest disturbance from winds by remote sensing data after passing over territory of tropical cyclones makes it possible to quickly assess the disaster scale, as well as adjust reforestation plans for the coming few years. If using geoinformation technologies for processing data, time of work is significantly reduced.

KEYWORDS: satellite imagery, mapping of forest, deforestation, extratropical cyclones, Normalized Difference Vegetation Index, geoinformation analysis

INTRODUCTION

Forests cover 31 % of the land on Earth. Deforestation by the close of the 20th century was called one of the global environmental problems that the earth civilization has to solve for the sake of its survival[3]. In order to save the life of all the biodiversity of living beings on the planet, it is

1 Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian Academy of Sciences, Laboratory of Volcanology and volcano hazard, 1B, Nauki str., Yuzhno-Sakhalinsk, 693022, Russia, *e-mail:* **vamelkiy@mail.ru**

2 Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian Academy of Sciences, Laboratory of Geochemistry and Regional Geology, 1B, Nauki str., Yuzhno-Sakhalinsk, 693022, Russia, *e-mail:* **ussr-91@mail.ru**

3 Deforestation and Forest Degradation (2022). World Wildlife Fund. Web resource: https://www.worldwildlife.org/ threats/deforestation (accessed 25.02.2024)

necessary to move towards the implementation of a sustainable development strategy [*Ursul, Romanovich*, 2001; *Kasimov, Mazurov*, 2007; *Gosteva*, 2010]. In accordance with main principles of the strategy[1], the main provisions of sustainable forest management have been formed, aimed at following guidelines: conservation of forest cover with improved productivity of forest stands, ensuring the sanitary condition and viability of forests, preserving biodiversity, strengthening the role of forest vegetation in regulating the carbon balance of the territory, increasing the socio-economic significance of forest management[2].

Deforestation occurs as result of industrial felling without reforestation, burning-out of forest areas for farmland and natural causes, such as forest fires, windfalls during passing over territory of atmospheric vortices (hurricanes, typhoons), forest diseases, and climate change [*Shvidenko, Nilsson,* 2003]. In connection with the cessation of logging in industrial scale on Sakhalin, the disturbance of forests occurs mainly under the influence of forest fires and strong typhoons that come to the Island from South.

Typhoons are atmospheric eddies, a type of tropical cyclones, passing from May to November (other months are not excluded) over the North-West part of the Pacific Ocean [*Prokh*, 1983]. The pressure drops in the central part of some cyclones reached 895 mbar. The passage of typhoons over the coasts and islands of the eastern margin of Eurasia is accompanied by strong gusty winds and a large amount of precipitation. When cyclones move to latitudes of 30–45°, they turn from tropical to extratropical cyclones, which are characterized by a decrease in wind speed and precipitation, which is well studied on the example of North Atlantic hurricanes [*Hart, Evans,* 2001; *Leonardo, Colle*, 2020]. Extratropical cyclones with hurricane winds pass over the territory of Far Eastern outskirts of Russia and adjacent islands: Emma in September 1956, Nancy in September 1961, Irving in August 1979, Phyllis in August 1981, Judy in July 1989, Melissa in September 1994, Talas in September 2011, Bolaven in August–September 2012, Halong in July 2014, Lionrock in August–September 2016 [3,4,5] (Table 1).

Often, under the influence of strong winds, not only individual trees, but also entire forests are damaged or even die [*Grace*, 1988; *Everham*, *Brokaw*, 1996; *Mitchell*, 2013]. Large-scale windfalls in boreal forests under the influence of extratropical cyclones occur much less frequently than in tropical ones [*Korznikov* et al., 2019; *Vozmishcheva* et al., 2019]. There is evidence of medium-scale forest disturbance on Sakhalin caused by high winds in past decades [*Bratkov* et al., 2020; *Sabirov* et al., 2021].

In the first ten days of October 2015, forests of southern-west part of Sakhalin Island (Kholmsky and Nevelsky districts) were disturbed on large area by strong winds during passage of Typhoon Choi-van. The purpose of this work was to research the degree and character of forest damages under exposure of strong winds.

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[3] Worldwide Tropical Cyclone Centers. National Hurricane Center and Central Pacific Hurricane Center National Oceanic and Atmospheric Administration. Web resource: https://www.nhc.noaa.gov/aboutrsmc.shtml (accessed 25.02.2024)

[4] Digital Typhoon. Website National Institute of Informatics (NII). Web resource: http://agora.ex.nii.ac.jp/digital-typhoon/summary/wnp/s/202122.html.en (accessed 25.02.2024)

[5] Tropical cyclones in 2015. Website360wiki.ru Web resource: https://360wiki.ru/wiki/Tropical_cyclones_in_2015# October (accessed 25.02.2024)

Table 1. Main characteristics of strong Pacific tropical cyclones that passed over Russian Far East territory

Typhoon name	Dates	Category SSHWS*	Pressure in center, GPa (mbar)	Steady wind speed, m/s	Wind gust speed, m/s (km/h)
Kitty	27.08–02.09.1949	3	952	35–40	57 (205)
Emma	01–11.09.1956	4	930	35–40	69 (248)
Nancy (Muroto)	07–22.09.1961	5	882	55–65	95 (345)
Elsie (Narsing)	16–28.09.1969	5	895	45–50	78 (280)
Irving	07–18.08.1979	2	955	25–30	42 (150)
Phyllis	02–05.08.1981	Tropical storm	975	25–30	38 (136)
Judy	21–26.07.1989	4	910	35–43	57 (205)
Melissa	11–19.09.1994	4	910	35–43	57 (205)
Talas	23.08–07.09.2011	Tropical storm	970	22–27	40 (144)
Bolaven	19.08–01.09.2012	4	910	45–51	63 (230)
Halong	28.07–15.08.2014	5	915	45–55	72 (260)
Choi-wan	01–10.10.2015	Tropical storm	965	25–31	36 (130)
Lionrock	16–31.08.2016	4	940	35–46	60 (215)
Talim	08–22.09.2017	4	935	45–49	61 (230)

*SSHWS — Saffir–Simpson hurricane wind scale

RESEARCH MATERIALS AND METHODS

Available images from the Sentinel-2 spacecraft taken in period from 2016 to 2017 were used as materials for identifying windfall glades[1]. We selected images that were taken in the summer (July–August) and with a minimum number of clouds after atmospheric corrections [*Moravec* et al., 2021].

Immensity of windblows was determined by synthesized images in combination of channels 11-8-4 with the use of classification procedure "with training" [*Buchnev, Pyatkin*, 2017]. The training sample was composed of a set of pixels representing the image of reference areas where geobotanical descriptions were performed.

To analyze the nature of windfall damage in the study area, the Normalized Difference Vegetation Index (NDVI) was calculated and areas with varying degrees of damage were identified [*Cherepanov*, *Druzhinina*, 2009; *Cherepanov*, 2011]:

$$NDVI = (NIR - RED) / (NIR + RED) \qquad (1).$$

RESEARCH RESULTS AND DISCUSSION

Field work research of windblow sites in Nevelsk and Kholmsk districts revealed large disturbances mainly in dark coniferous forests, where forest stands are formed mainly by Sakhalin fir (*Abies sachalinensis* (F. Schmidt) Mast.) and Jezo spruce (*Picea jezoensis* (Siebold & Zucc.) Satyoge). Significantly less damage was observed in forests, formed by deciduous trees (*Betula ermanii*, Mongolian oak (*Quercus mongolica*), Mayra maple (*Acer mayrii*)) [*Melkiy* et al., 2023].

The difference between forest-covered and unforested territories has pronounced character, so their separation during satellite image interpretation does not cause any difficulties. Windblows, as well as burned and felled forest areas, are displayed on images in reddish and bluish color. At the same time, clearings are distinguished by more or less geometrically regular boundaries,

[1] Sentinel Missions. Website ESA (European Space Agency). Web resource: https://sentinel.esa.int/web/sentinel/ missions/sentinel-2 (accessed 25.02.2024)

indicating their artificial origin. On the images of cuttings, clumps are clearly visible, and on high-resolution images there are also individual trees and their small groups left during cuttings. In the burnt areas, in most cases, single trees and curtains are also dispersed in disorder over the territory. Dead trees are clearly visible on the windblows in the form of strokes oriented in one direction, which stand out well on high-resolution images.

During the interpretation of space images, it was revealed that the total area of windblows is 22 735 ha (6.29 % of the study area). In analyzing data of the training sample on the scatter diagrams, the sections of windblows were quite well separated from other classes in terms of spectral characteristics. However, it should be noted that spectral characteristics of windblows show great similarity with territories, which have open soils, as well as residential areas. In this respect, they were previously identified and excluded from consideration.

An analysis of the results of interpretation of windblows showed that the transformation of forests in damaged areas can be of a different nature. The forest on the periphery of windbreak spots, in areas with local relief depressions, can be damaged less: surviving trees and curtains are clearly visible. Around the other groups of trees, as a rule, there is undergrowth, which, soon after being damaged by a cyclone, begins to actively grow and distribute seeds, contributing to the rapid overgrowth of the site. However, often in the southwestern part of Sakhalin, areas with destroyed forest vegetation were inhabited by bamboo.

The research of the spatial distribution of NDVI values within the areas with the development of windblows made it possible to identify the difference in the spectral characteristics in RED and NIR, reflecting the different nature of damage to forest stands. The results of geoinformation analysis of forest damage are summarized in the table 2 below.

Table 2. The character disturbance of timber standing in southern-west part of Sakhalin Island

Character of damage to piece of forest	**NDVI value**	**Share of occupied area, ha**	**Share of occupied area, %**
Completely damaged (> 70 % of trees)	< 0.5	4 513.6	19.85
Partially damaged (70–30 % of trees)	0.5–0.6	9 515.29	41.85
Slightly damaged (< 30 % of trees)	> 0.6	8 705.95	38.29

Windfall-disturbance areas in the southwestern part of Sakhalin Island are highlighted on the map (Fig. 1).

The use of Earth remote sensing data in mapping disturbance to forest tracts by winds during the passage of tropical cyclones makes it possible to quickly assess the scale of a disaster using geoinformation technologies [*Verkhoturov, Melkiy,* 2020].

Reforestation work on the island is planned by the Ministry of Forestry and Hunting of Sakhalin Region. The work is carried out by forest ranger stations, which are branches of the Sakhalin Forestry State Institution, established by order of Government of the Sakhalin Region No. 956-p., dated December 23, 2010. A significant contribution to reforestation activities is made by tenants of forest plots who harvest timber[1].

Information about forest areas disturbance by tropical winds should be used in planning reforestation, it is necessary to adjust the plans drawn up taking into account changes in areas exposed to strong winds.

1 Reforestation. Official website of the Agency for Forestry and Hunting of the Sakhalin Region. Web resource: https://hcvf.ru/ru/maps/hcvf-sakhalin (accessed 25.02.2024)

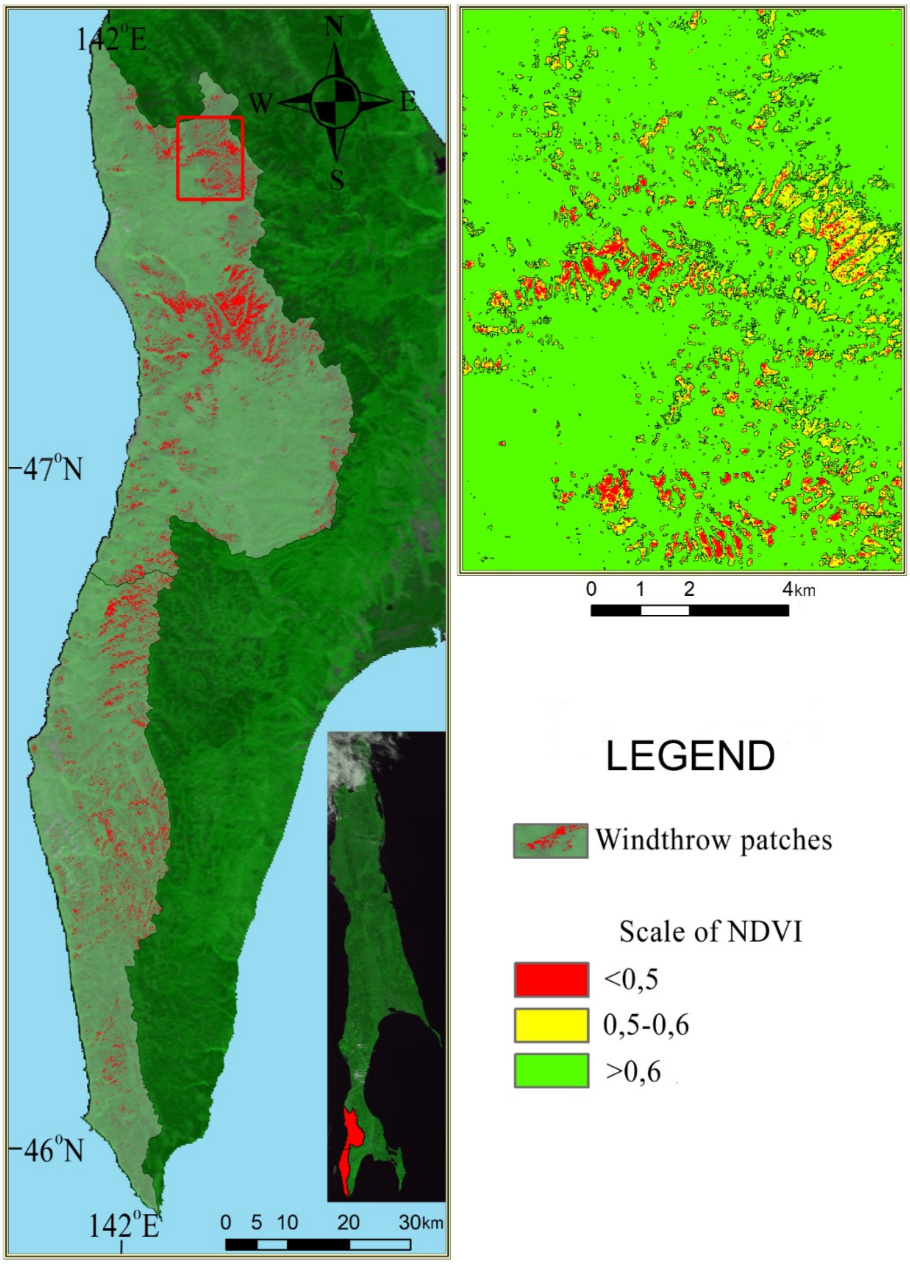

Fig. 1. Damage to a stand in southwestern Sakhalin Island (a) as identified by a "trained" classification (b) and according to NDVI values (c)

The research of windblows formed as a result of the passage such as Typhoon Choi-van in 2015, was carried out earlier by other researchers [*Everham, Brokaw*, 1996; *Korznikov* et al., 2019; *Vozmishcheva* et al., 2019]. Based on remote sensing data, areas of disturbance forests were identified. In an article published on the basis of the research, it was indicated that violation of forest vegetation on Sakhalin on such a large scale was described for the first time. However, we found that large windfall phenomena had been observed on the island earlier. Thus, as a result of the passage of Typhoon Nancy in 1961 on the southwestern slopes of the East Sakhalin Range, significant disturbance to forests was recorded on an area of 8 909 ha.

During 1964–1966, timber was harvested by logging station "Vetrovalny" of the Pervomaisky timber industry enterprise. In 1966, after the loss of commercial quality of wood, caused by the development of saprophytic fungi, the harvesting was stopped. It should be noted that using windblown timber was a positive example of the rational use of forest resources, which, unfortunately, has not found application at the present time. Thousands of hectares of fallen forest not only are not used, but also serve as a source of insect pests.

As a result of the research, we found that damage to the forest cover may be of a different nature: completely disturbance, partially disturbance and slightly disturbance. The degree of damage affects the value of the vegetation index.

As a successful example of the implementation of a geographic information system that allows integrating data on the state of forest cover from various sources and using them in assessing the extent of forest disturbance and planning reforestation activities, one can name the system developed by WWF Russia in partnership with FSC Russia.

The information system given as an example contains information on forests of high conservation value, however, when searching for disturbance in the forests of southern Sakhalin, inaccuracies were found on the site, in particular, the species composition of forest stands was determined incorrectly over most of the territory, and the locations of deforested areas were incorrectly indicated.

The management of the forestry sector can be focused on forest management in accordance with the best world standards. At the same time, in order to organize appropriate management and monitoring, it is necessary to use the information obtained from the interpretation of medium and high-resolution images, and, if necessary, for research forests in detail, take surveys from unmanned aerial vehicles.

CONCLUSIONS

The study showed that forest vegetation in the Kholmsky and Nevelsky districts in the southwestern part of Sakhalin Island was severely damaged by storm winds during the passage of Typhoon Choi-van in the first decade of October 2015. The area of windblows was 22 735 ha. When studying the spectral characteristics of the surface in satellite images, areas with different content of phytomass, reflected by NDVI values, were identified by degree of damage, presented in form of green trees and clumps, as well as preserved undergrowth and undergrowth. At the same time, it was found that among the affected stands, one can single out completely dead (occupy 19.85 % of the territory), partially damaged (41.85 %) and slightly damaged (38.29 %).

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