Mapping post fire recovery in Bakchar bog with Landsat time series data

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Abstract. The aim of this research was to assess the pyrogenic load and recovery processes after the fire event of 2016 within the drained site of Bakchar bog. Satellite remote sensing data and field data were collected for this study. The specific objectives of this study were: 1) to conduct field studies in key sites with different pyrogenic load keys in order to assess projective cover and species composition of the vegetation cover and 2) to compare field data with satellite image data using the vegetation index and perform spatial assessment of vegetation post-pyroenic recovery in the first three years after the fire. The area of fire spread was 5.54 km², including 4.44 km² within the mire. The intensity and character of the vegetation recovery are differed between sites pyrogenic load classes. The first and second classes of the pyrogenic load are characteristic by the most intensive recovery process. These classes occupy 78 % of the burned area. NDVI values in three years after the fire become close and even exceed the values characteristic for drained pine-dwarf shrubs-sphagnum bogs mainly due to the intensive renewal of dwarf shrub layer. The emergence of deciduous trees will lead to a significant increase in the vegetation index in subsequent years.

1. Introduction
Large-scale works on drainage of bogs were carried out within the West Siberia taiga zone in 1970–1980. In particular, in the Eastern spurs of the Great Vasyugan mire areas, forest melioration is around 15 ha [1, 2]. At present, there is almost no data on their current state and recovery trends. Some of the drained mires were not used effectively, and since the early 1990s, the area of abandoned and previously drained lands have been growing [3].

Drainage of mires is the main cause of peat fires. Burning biomass is widely recognized as one of the critical factors affecting atmospheric chemistry because a significant amount of aerosols and greenhouse gas emissions are produced during burning. Fires also affect vegetation succession [4]. GIS mapping of anthropogenic-disturbed wetlands, including burned drained bogs, using satellite data is an effective method of long-term and seasonal monitoring of vegetation dynamics at different stages of recovery [5–7]. Out of the different techniques employed to assess post-fire recovery, the use of vegetation indices, especially the NDVI, are very popular [8]. For example, the study [9] shows that temporal anomalies in NDVI for burned and unburned areas display the impacts of fire and the recovery of the forest to pre-burn levels, and indicate changes in variability that might be associated with vegetative compositional changes consistent with early successional species.

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collected for this study. The specific objectives of this study were: 1) to conduct field studies in key sites with different pyrogenic load keys in order to assess projective cover and species composition of the vegetation cover and 2) to compare field data with satellite image data using the vegetation index and perform spatial assessment of vegetation post-pyrogenic recovery in the first three years after the fire.

2. Objects, data and methods

2.1 Study site
The study area is located within the southeast West Siberian plain in the interfluve of the Bakchar River and the Iksa River (the Middle Ob River watershed). The territory belongs biogeographically to the south taiga zone. The quaternary deposits are represented by fluvial-lacustrine loams and clays. The climate is continental with long, cold winters and short, hot summers; the average annual temperature is 0.23 °C. The annual amount of precipitation is 473 mm according to the meteorological station near the Bakchar village. The average annual evapotranspiration reaches 332 mm [10]. Large mire massifs are widely distributed within the study area, one of which is the Bakchar bog. The site in the central part of Bakchar bog was drained with the purpose of forest melioration in 1980. Pine-dwarf shrub-sphagnum bog dominates in the drained area. Currently, there is a decrease in the culvert capacity of the channels due to overgrowth and congestion. A more detailed description of the drained area of the Bakchar bog is presented in [11].

The object of this study is a site of drained bog and adjacent forest, burned out in the period of August–October 2016. The most intense burning occurred in the period of August 11–18, 2016 when 80% of the area was exposed to fire mainly within the drained pine-dwarf shrub-sphagnum bog. The burning of forest occurred in October 2016. The area of fire spread was 5.54 km², including 4.44 km² within the mire. The spread of fire in the eastern and northeastern parts was limited by the main channels, in the south by the boundary of the drainage network, and in the north by the road. The central part of the allocated area was not subject to pyrogenic load, the contour of which coincides with the boundary of moister hummock-hollow and grass-moss mire areas. Three classes of pyrogenic load differentiate soil damage and vegetation cover based on Landsat 8 satellite data and field research materials. Sites differ in the type of damage to the soil and vegetation cover: 1) areas with completely burnt vegetation (1.84 km²), 2) areas with partially burned vegetation (2.34 km²) and 3) sites of soil fire in forests and swamp (1.16 km²).

2.2 Field study methods
Field studies were carried out in the northeastern part of the key site in accordance with the pyrogenic load classes and on two background sites within the drained pine-dwarf shrub-sphagnum bog outside the spread of the fire. Assessment of long-term dynamics of vegetation cover was carried out at the sites of the first and second pyrogenic load classes. Geobotanical studies at post-pyrogenic sites included an assessment of the intensity and area of fire damage to each vegetation tier. Total station surveys of model sites of 25 m² with a step of 0.5 m were carried out to assess the proportion of burnout surface and transformation of the microtopography. We employed a ground penetrate radar system “OKO-2” (“Logical systems,” Russia) with 250 MHz shielded antenna and displacement sensor in March 2018 to study peat deposit properties and justification of the identity of the initial state after fire and background sites. According to the GPR, the depth of peat deposits varies from 2.8 to 3.5 m. The peat deposit structure along a profile line is homogeneous. There is a layer of sphagnum peat with a low degree of decomposition (5–10%) with a depth of 1.6–1.9 m, followed by grass-moss and wood-grass-moss peat with a degree of decomposition up to 40%.

2.3 GIS mapping
GIS mapping of the site was carried out using a QGIS 3.4.3 package based on Landsat 8 satellite data and field geobotanical research materials. Mapping of geosystems at the key site before the pyrogenic
load was done by classification of Landsat 8 imagery for the period prior to the fire (shooting date 16/07/29, channels 2–7). The training sample included 45 polygons belonging to eight classes. Drawing the boundaries of the fire area and its classification according to the degree of pyrogenic load was carried out with the use of Landsat 8 data (shooting date 17/06/05, channels 2–7). The date of the satellite data was selected in accordance with the period of maximum differences in spectral brightness between the classes to begin the recovery process. The training sample was made using data from field studies and included 23 polygons. The site was divided into three pyrogenic load classes, depending on the nature of damage to the soil and vegetation cover as a result of the classification. NDVI values were determined using Landsat 8 data satellites (figure 1). Shooting dates (16/07/29, 17/08/01, 18/07/17, 19/07/13) were selected in accordance with the timing of field geobotanical research in the second half of the growing season. The definition of average NDVI values for drained bogs was conducted according to Landsat 8 over the period 2013–2018. The choice of images to analysis was carried out according to the criterion of clouds, choosing one over a vegetation period (June–August) with minimum cloudiness. The data were averaged over 13 key sites within the drained pine-dwarf shrub-sphagnum bog in the vicinity of the pyrogenic site.

3. Results and discussion

3.1 Field study result
The site in question was a pine-dwarf shrub-sphagnum bog before the fire. The height of the tree layer of pine was 2–3 m with a projective cover of about 40%. The dwarf shrub layer consisted of typical representatives of taiga zone bogs: *Ledum palustre*, *Chamaedaphne calyculata*, *Vaccinium uliginosum*, *Andromeda polifolia*, etc. with a total projective cover of 90%. The moss cover was formed by sphagnum mosses with a predominance of *Sphagnum fuscum* with a projective cover of 80–90%; green mosses were found only occasionally. The microtopography of drained bogs was formed by moss pillows and vast, flat depressions. The microtopography amplitude ranged from 40 to 50 cm.
The first pyrogenic load class was characterized by complete burning of moss and grass-dwarf shrub layer on all forms of microtopography. Complete burn of the moss pillows led to the positive alignment of microtopography forms. The formation of depressions due to burnout he moss and upper peat layer with a depth of approximately 5 cm, which is most pronounced around the trunks of charred trees. Trees trunks and crowns of trees are completely charred. The appearance of the grass-dwarf shrub layer had a total projective cover of no more than 10%. V. uliginosum, C. calyculata, Rubus chamaemorus, A. polifolia, L. palustris and Eriophorum vaginatum were observed the year following the fire due to vegetative regeneration of the surviving shoots buried underground in the peat. The projective cover of grass-dwarf shrub layer increased to 30% two years after the fire. In the third year, shrubs occupied almost 40% of the site. A year after the fire, a single appearance of Polytrichum strictum and liver mosses were noted, two years later their projective cover reached 10%, the third year it increased to 20%. Renewal of the tree layer (Betula pubescense and Populus tremula) was noted by the end of the second growing season, and in the third year reached 5%.

Partial burnout of the surface within 40–60% is characteristic for the area corresponding to the second pyrogenic load class. Trees burned on all forms of microtopography and living specimens were not preserved. The depression of microtopography and slopes of moss pillows were the most exposed to the burning of the moss and grass-dwarf shrub layer; the share of burning within which was 60%. Burnout within positive forms was 13% of the surface. Recovery of the grass-dwarf shrub layer a year after the fire in the depressions was noted. V. uliginosum, C. calyculata and E. vaginatum occurred as single specimens with a total projective cover of 10% and hepatic mosses were present. Positive forms of microtopography covered by charred heads of Sphagnum fuscum appeared one year after fire. The regrowth of new heads and the appearance of Polytrichum strictum with a total projective cover of not more than 5% were noted. The projective cover of the dwarf shrub layer on positive microtopography form was 30% (V. uliginosum, L. palustris, A. polifolia, C. calyculata, R. chamaemorus). Dwarf shrubs grow at the expense of surviving underground shoots. Two years after the fire, there was an increase in the total projective cover of the dwarf shrub layer of 50%; the positive forms preserved after the fire reached 80%. This corresponds to values characteristic of the background areas. In the third year, the total projective cover of dwarf shrubs was 60% and the projective cover of mosses increased to 60%. Recovery of the tree layer was marked and the projective cover was 5%.

Thus, the revealed regularities of the combustion process propagation, limited by negative forms of microtopography, are explained by the low mire-water level during the fire, which is also noted in the study [12]. The surface of drained pine-dwarf shrub-sphagnum bogs has higher values of dismemberment in comparison with pristine bogs, which explains the significant heterogeneity of the combustion process of the mire surface. As a result, for the most part, post-fire area, pertinent to the second class of the pyrogenic load is characterized by almost complete combustion of the depressions. Positive forms of burnout were exposed to predominantly tree layer, partially damaged dwarf shrubs. Processes of recovery also differ between microtopography forms. Depressions are overgrown with green mosses and positive forms represent intense growth by the dwarf shrub.

3.2 Assessment of vegetation recovery using NDVI
The average long-term NDVI values calculated for drained pine-dwarf shrub-sphagnum bogs unaffected by fire is 0.30 and varies between 0.29–0.34 with a standard deviation of 0.03. The value of NDVI corresponds to the average projective cover of tree layer 50%, shrub 70% and moss 70–90%. According to Landsat8 satellite data on 29 July 2016, before the fire, the value of the average NDVI for pine-dwarf shrub-sphagnum bogs amounted to 0.27–0.28; forested mire and swamp had higher values, reaching 0.36 (figure 2, 3).

NDVI values differ between the pyrogenic load classes according to 2017 as a result of the spatial inhomogeneity of vegetation burnout. The largest decrease in the index is typical for the first and third classes in which the value of NDVI decreased by 1.5 times compared to 2016. The second class is characterised by an NDVI decrease of 1.3 times.
Figure 2. NDVI dynamics within by classes pyrogenic load: 1–3 classes pyrogenic load, Mean – the Mean value for drained pine-dwarf shrub-sphagnum bogs (date 29.07.2016, 01.08.2017, 17.07.2018, 13.07.2019).

Figure 3. Change in NDVI values as a result of fire and post-pyrogenic recovery in 2016-2019.
NDVI values of the first and second classes reached and slightly exceeded the values in 2016 and are about the average value characteristic of drained pine-dwarf shrub-sphagnum bogs despite the almost complete absence of a tree layer in both classes in the third year after the fire. The significant NDVI increase is associated with the intensive overgrowing shrub layer and a settlement on open areas of green moss. For the third class, the projective shrub coverage had reached 80% by 2019 and the NDVI value exceeded the first and second classes, but was still below the initial value of 2016. This is due to the large contribution of the tree layer to the NDVI value of forested mire and swamp compared to pine-dwarf shrubs-sphagnum bogs with highly-oppressed tree layers. Here, the largest contribution to the value of NDVI is the projective cover of the dwarf shrub layer (figure 2 and 3).

The analysis of satellite and field data for the period 2016–2019 within the points of geobotanical study within the background site and different pyrogenic load classes at burnt sites showed that the NDVI is, to a great extent, determined by the values in the projective cover of dwarf shrub layer less the total projective cover of all vegetation layers. The dependence of NDVI and projective tree layer coating is not significant (figure 4).

Thus, GIS mapping of post-fire recovery processes within Bakchar bog are conducted using the vegetation index. The highest rate of overgrowth is characterized by areas belonging to the first class of pyrogenic load, where NDVI values three years after the fire already exceed the initial values of 2016 on the date before the combustion process. In subsequent years, the NDVI values of the first and second class of pyrogenic load are likely to exceed those of drained bogs untouched by fire due to overgrowth by more productive species compared to typical bog vegetation.

Figure 4. Distribution of NDVI values according to total projective cover (orange), dwarf shrub layer projective cover (blue) and tree layer projective cover (gray)

4. Conclusion
This study, using the method of GIS modelling and field geobotanical studies, performed spatial evaluation of the pyrogenic load intensity and recovery processes of the drained bog area in the first three years after the fire. It is noted that the intensity and nature of vegetation recovery vary between sites of different pyrogenic load classes. The most intensive vegetation recovery is typical for the first and second classes of pyrogenic load, occupying 78% of the area of the pyrogenic site. Here, an increase in NDVI to the level of 2016 (before the combustion process) was marked three years after the fire. The main factor of the NDVI increase is an intensive post-fire plot overgrown with dwarf shrubs and herbs. The emergence of deciduous trees in subsequent years of post-pyrogenic overgrowth will lead to a significant increase in the vegetation index, which will exceed the values characteristic of the pine-dwarf shrub-sphagnum bogs.
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