GIS mapping of forest paludified landscape in the Great Vasuygan Mire marginal area (Western Siberia)

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Abstract. The aim of research is to estimate forest state within the Great Vasuygan mire marginal part using satellite and field data. Specifically, the objective of this study were to: 1) conduct field landscape studies and assessment of paludification intense to create training samples and asses the accuracy of satellite images interpretation; 2) distinguish paludification landscapes in mix forest surroundings raised bog massif by a semi-automatic landscape classification method and assessment mire influence zone; 3) create the classification of the raised bog massif spatial structure. The average length of mire influence zone is 3.9 km with fluctuations in the range of 0.6–8.4 km. Spatial structure is indicator of the development stage and the slope of the raised bog and, as a consequence, the intensity of surface runoff from mire into the surrounding areas. The length of mire influence zone differs between the selected classes of spatial structures and is mainly determined by the distribution of complex microlandscapes, the presence of which reflects the final stage of raised bog massif development.

Keywords: Landsat; mire classification; swamp forest; satellite image interpretation; GPR survey; peat deposit

1 Introduction

Mires are valuable natural resources that provide many environmental services to flora and fauna. Recently, wetlands have become a popular topic in climate change discussions as they include 12% of the global carbon pool [1]. Climate change and rapid land use change have turned mires into carbon source ecosystems. Peat mining, drainage, agriculture and potential negative feedback with warming environment are releasing the carbon stored in peat, and adding to atmosphere carbon dioxide [2]. Meanwhile, vast pristine wetland areas remain on the territory of Western Siberia and, in particular within the Great Vasyugan Mire, and the process of waterlogging continues [3]. The marginal parts of large raised bog massifs are most exposed to paludification. The process of paludification is mainly due to an increase in the water table level, leading to anaerobic conditions that in turn reduce microbiological activity and limit mineralization and nutrient uptake by plants [4]. The ambiguity of the paludification trend estimates within the mires marginal parts determines the need to obtain new data on the current carbon stocks here [5]. GIS mapping techniques can help generate accurate map of wetlands and get the spatial estimation paludification area. These maps can be used in climate models to assess the sensitivity and feedback to future climate change [2].

It is known that the length of the influence zone of the mire is mainly determined by geological and geomorphological factors, among which are the slope, horizontal and vertical surface defragmentation. The intensity of the paludification process development can be influenced by the change of the surface slope even by tenths of a degree. The marginal part of the Great Vasyugan Mire belongs to the territories with low values of the surface slope. Therefore, the dependence of the mire impact zone length and the surface slope is not always determined here by the medium-scale mapping due to the lack of detail and accuracy of topographic maps and SRTM data. The assessment of the relief morphometric parameters influence on the paludification process becomes possible only by detailed field studies in key sites [6]. Therefore, available indicators of the paludification process is necessary to search for the modeling of potential paludification zones which are convenient to use and allow to assess the hydromorphic transformation on large areas. One of these indicators is the characteristic of the spatial structures of the raised bog massifs, reflecting the stage of development of the mire, the shape of its surface and, as a consequence, the intensity of the surface flow to the surrounding areas.

The aim of research is to estimate forest state within the Great Vasuygan mire marginal part using satellite and field data. Specifically, the objective of this study were to: 1) conduct field landscape studies and assessment of paludification intense to create training samples and asses the accuracy of satellite images interpretation; 2) distinguish paludification landscapes in mix forest surroundings raised bog massif by a semi-automatic landscape classification method and assessment mire influence zone; 3) create the classification of the raised bog massif spatial structure.

2 Methods and data

2.1 Study area

The objects of study are the North-Eastern spurs of the Great Vasyugan Mire – Iksa and Bakchar raised bog massif (figure 1). The study area is located in the southeast West Siberian plain within Middle Ob River watershed. The territory belongs biogeographically to the south taiga zone. The fluviolacustrine loams and clays represent a quaternary deposit. The quaternary deposits thickness on the interfluve of the Bakchar River and the Iksa River reaches 40-60 m [7]. 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. Positive atmospheric water balances, flat relief, and weak drainage by rivers allows the formation and sustainable evolution of mires [8]. Large mire massifs are widely distributed within the study area. The study area includes typical Western Siberia pine-shrub-sphagnum, pine-shrub sedge-sphagnum ombrotrophic mires, and swamp forest with birch, aspen, Siberian cedar, and spruce in the margin part of the mire.

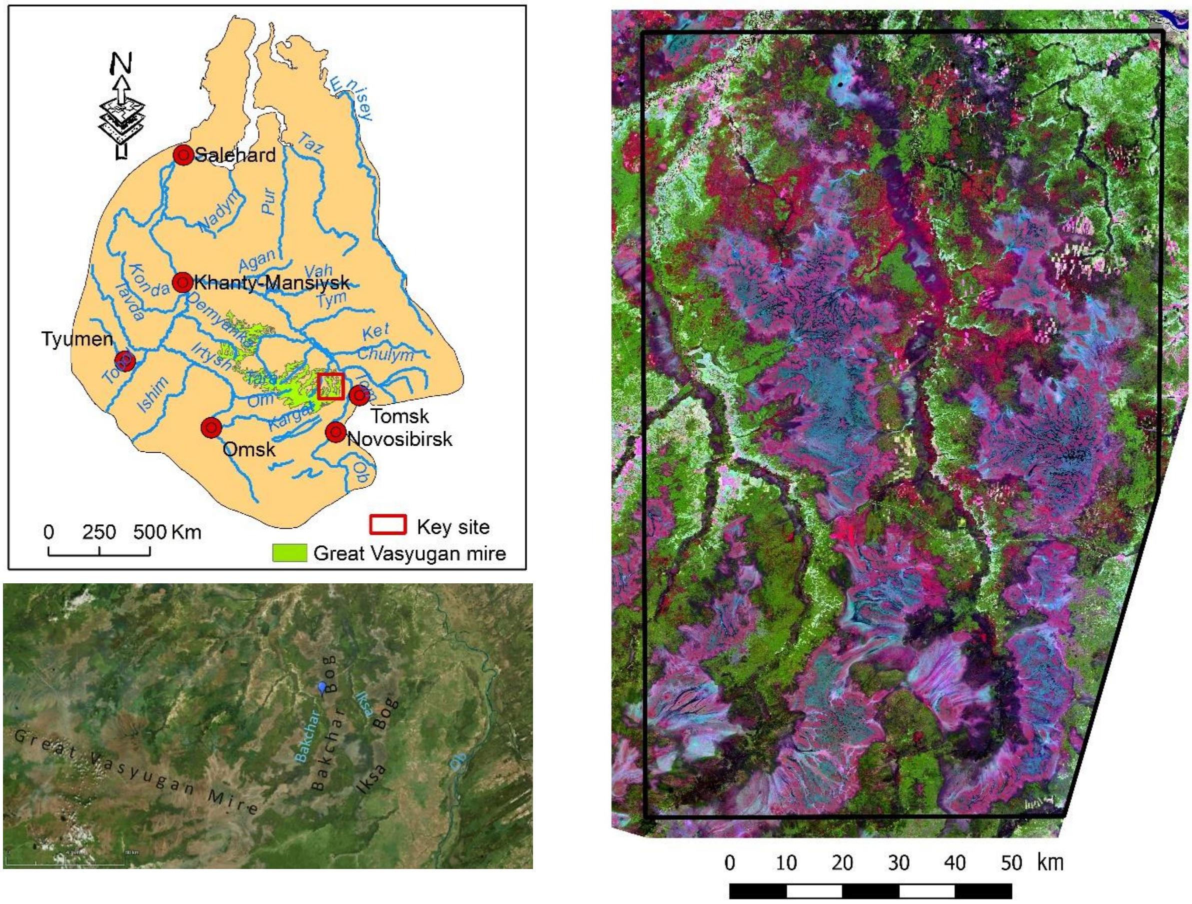

Figure 1. Study area **(**Landsat 8, July 17 2018)

2.2 Field study

The GPR surveys, which covered a total distance of 2.3 kilometers, were conducted in March 2017 and 2018. We employed a GPR system "OKO-2" ("Logical systems", Russia) with 250 MHz shielded antenna and displacement sensor. We placed marks as vertical lines on radiograms every 50-100 m during the GPR surveys to collect peat core and to binding high-altitude data in summer. The step size between the marks was determined by the peat deposits heterogeneity. The marks, the beginning and end of the GPR transect were located with GPS (accuracy: 5 m).

In accordance with the marks on the GPR profile in the summer of 2018 made contact sensing of peat deposits on 33 points, including definition of peat deposits depth, the allocation of stratigraphic layers by the types and degree of peat decomposition by the visual method [9, 10]. Geobotanical study are made, the height of the trees was determined using a laser rangefinder Nikon Forestry Pro. The mire water level is determined on 12 sites. Determination of the habitats soil moisture stages was carried out in accordance with [11] taking into account the specific weight of the plant species projective cover [5, 6]. The paludification intense assessment was carried out using the indicators: the stage of habitat moisture; the depth of peat deposits and the depth of the fibric peat; the groundwater level.

2.2 GIS mapping and spatial structure classification

The paludification zone definition was conducted on the basis of Landsat 8 data classification using Semi-Automatic classification plugin. The training sample was compiled using the data of field landscape studies and included 4 classes of sites indicating the development of paludification processes within forest: 1) swamp forest areas characterized by mass felling of trees; 2) pine-shrub grass-sphagnum bogs outside the raised bog massif main contour, 3) cedar-birch swamp forest; 4) pine-birch swamp forest. Assessment of the mire influence zone length is determined by the method of landscape profiling. We laid 40 profiles crossing the border of raised bog massifs parallel to the drain lines. We measured. the bog massif length, the distance from the watershed to the marginal part of the mire, the extent of the mire influence zone, the surface slope within the influence zone, a set and the length of the main microlandscapes (hummock-hollow and hummock-pool complexes, pine-dwarf shrubs-sphagnum bogs, grass-moss mires). The length of mire influence zone was measured in accordance with the distribution of plots allocated by the results of Landsat image interpretation on each profile. The surface slope map is drawed by the method of raster interpolation Topo to Raster based on the elevation of topographic maps with correction on the lines of the hydrographic network.

We used the method of cluster analysis to classify spatial structures of raised bog massifs. The comparison of values paludification zone length differences between the classes was conducted using tests of Mann-Whitney and Kruskal-Wallis. The dependence of the paludification zone length, the characteristics of the spatial structure and the surface slope was determined using the principal components method.

3 Result and discussion

3.1 Paludification landscape within the mire influence zone

Swamp forests with a predominance of *Betula pubescens* are widespread within the key area. Subdominants of the tree layer are *Pinus sibirica*, *Pinus sylvestris*, *Picea obovata*, *Populus tremula*. The tree layer height varies from 15 to 22 m with a cover of 20-60 %. Typical representatives of the shrub layer are *Ribes nigrum*, *Rosa acicularis*, *Sorbus sibirica*, *Rubus idaeus*. The layer projective cover usually does not exceed 5-10 %. Various species of sedges (*Carex acuta, C. Elongata, etc.*), horsetails (*Equisetum palustre, E. Sylvaticum, etc.*), reed grasses (*Calamagrostis canescens, C. neglecta, etc.*), ferns (*Gymnocarpium dryopteris, Athyrium filix-femina*, *etc*.) are widely distributed in the grass layer. *Bryidae* occupying a fallen rotten trunks and tree trunks hummock dominate in the moss layer often [6]. The stage of habitat moisture is characterized as wet-forest, wet-forest and wet-forest [11].

Shallow peat soils with a peat layer depth 0,7–1 m and peat-gley soil with a peat layer less 0,7 dominate within the mire influence zone. The peat deposits depth within the key area reaches 1.75 m, the average value is 0.4 m. Sapric wood and wood-grass peat with a high degree of decomposition dominate in the stratigraphy of swamp forest peat deposits.

3.2 GIS mapping result of raised bog massif and it influence zone

Spatial structure of large raised bog massif within the Great Vasyugan Mire spruces is characterized by a change of plant communities in the following sequence: 1) pine grass-sphagnum bogs, stretching a narrow strip along the mire border, 2) the pine-shrub-sphagnum bog, occupying a large area within the raised bog massifs slopes, 3) ridge-hollows and ridge-pool complex pine-shrub grass-sphagnum bogs in the central part of the raised bog massifs. The large raised bog massif northern parts and smaller raised bog massif are characterized by a lack of complex bogs and a simpler spatial structure. The averages width of the raised bog massifs in parallel to the direction of flow is around 11 km, in some areas up to 24 km. The surface slope within the mires ranges 0-0,2°, but for the most part it does not exceed 0.05°. The surface slope does not exceed 0.3° and an average of about 0.1° within the watershed plains occupied by forests and swamp forest (figure 2).

According to principle component analysis the mire influence zone length is largely determined by the raised bog massif width (0.92), a length of ridge-hollow (0,64) and ridge-pool (0,63) complex bog. The surface slope of the areas adjacent to the mire have less influence (0.30) due to the low variation of the values with almost flat relief within the area under study (figure 3).

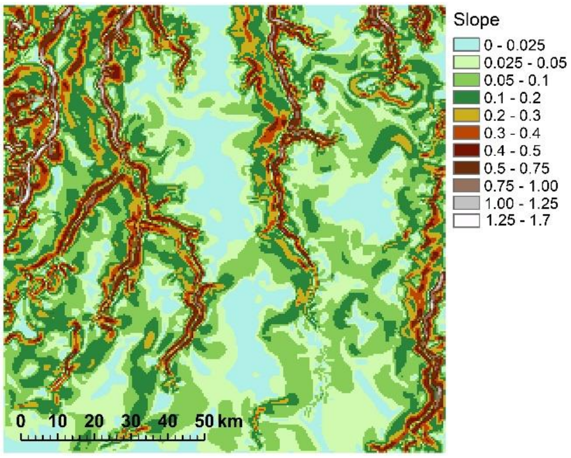

Figure 2. Surface slope map of key site

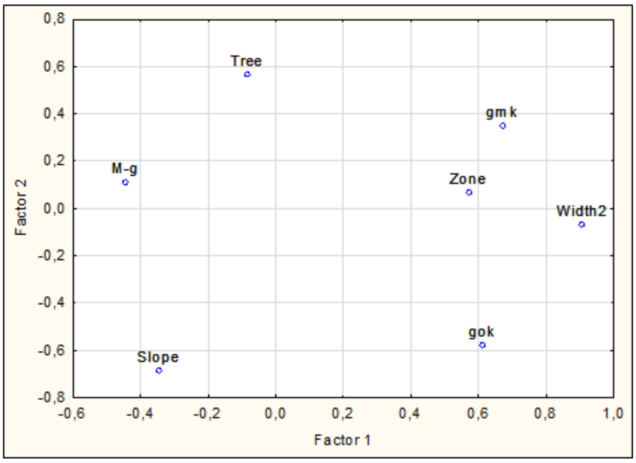

Figure 3. Principle component analysis result: *Zone* – mire influence zone; *Width2* – distance from the watershed to the marginal part of the mire; *Slope* – surface slope; microlandscapes length: *M-g* – moss-grass; *Tree* – wood and wood-moss; *gmk* – ridge-hollows complex; gok – ridge-pool complex.

3.3 Classification of raised bog spatial structure

The raised bog massif spatial structures are combined to four classes as a result cluster analysis of bog microlandscapes length data array.

The first class of spatial structures is characterized by a wide spread of complex bogs, including ridge-pool microlandscapes. The length of ridge-pool microlandscapes reaches its maximum value within the considered area of 15 km, with an average value of 8.7 km (figure 4, 6). Unlike the first, the second class is characterized by a large distribution of ridge-hollow complex, with absence ridge-pool complex. The raised bog massif marginal parts are occupied by wood and wood moss microlandscapes. The mire influence zone length values are maximum in the first and second spatial structures class within the key area. The length reach to 8.4 km from the border of the raised bog massif with an average value of 4.6 km.

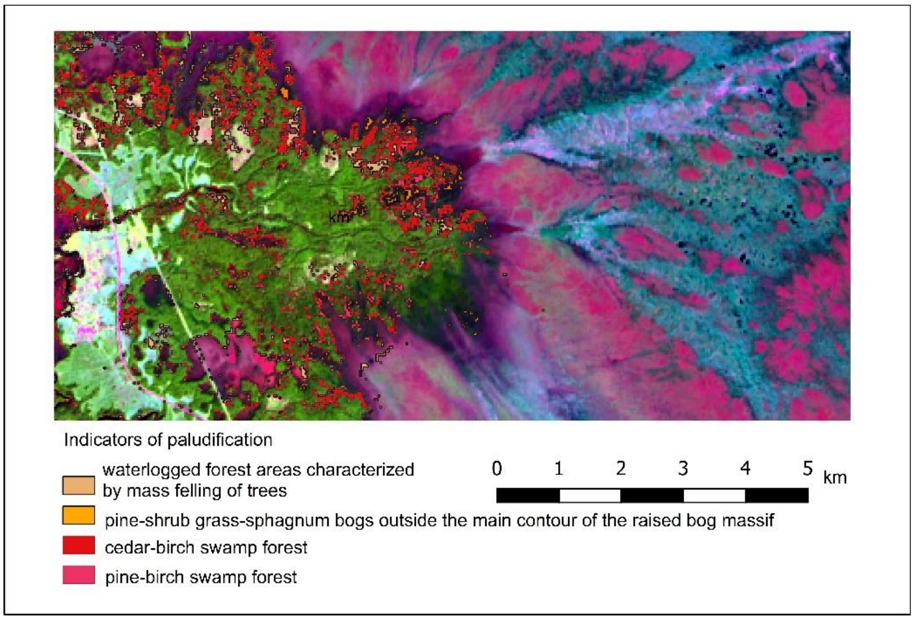

Figure 4. Mire influence zone with first class spatial structure (Landsat 8, July 17 2018)

The third spatial structure class is characterized by a wide distribution of the grass-moss microlandscapes. The average length of ridge-hollow complex does not exceed 1 km, ridge-pool complexes are absent in most cases. The average length of the mire influence zone is 3.5 km. The fourth spatial structures class is characterized by a lack of a complex and wide distribution of wood and wood moss micro-landscapes. The values of mire influence zone are minimum length in the fourth class within the site under study which average made 1,7 km (figure 5,6).

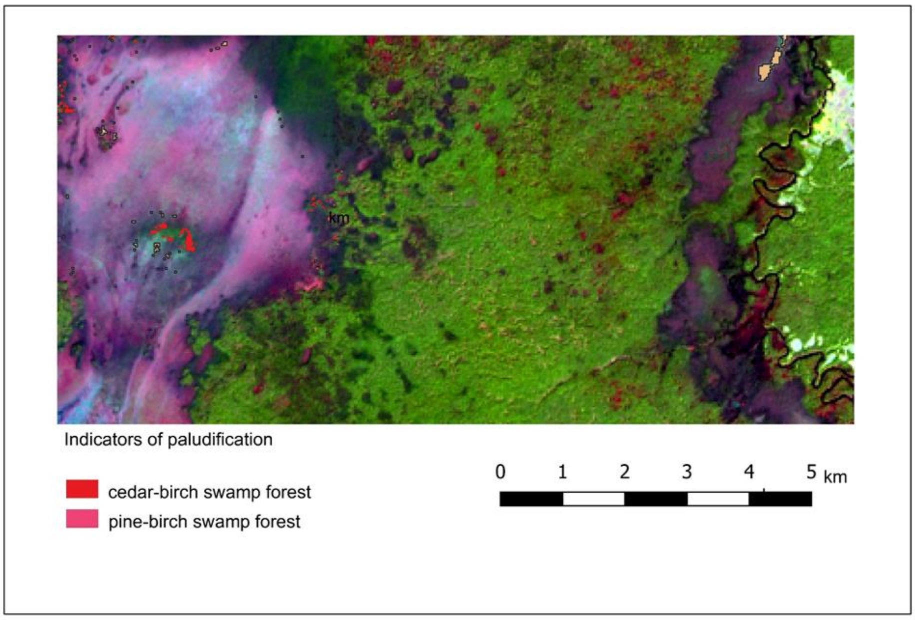

Figure 5. Mire influence zone with fourth class spatial structure (Landsat 8, July 17 2018)

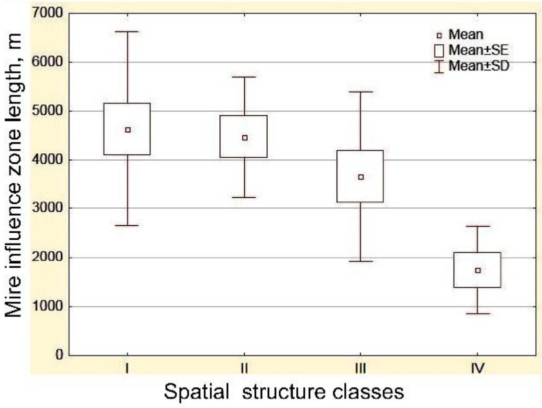

Figure 6. Comparison of the mire influence zone length of the spatial structure classes (I–IV – class numbers)

Thus, the study result is assessment of the mire influence zone and forest state within the marginal part of the Great Vasyugan Mire North-Eastern spurs. The average zone length is 3.9 km with fluctuations in the range of 0.6–8.4 km. The dependence of the mire influence zone length from the characteristics of the spatial structure is statistically confirmed. Spatial structure is indicator of the development stage and the slope of the raised bog surface and, as a consequence, the intensity of surface runoff from mire into the surrounding areas. The length of mire influence zone differs between the selected classes of spatial structures and is mainly determined by the distribution of complex microlandscapes, the presence of which reflects the final stage of development of the raised bog massif.

4 Conclusion

The use of modern research methods based on the analysis of satellite data and GIS mapping allowed to obtain qualitatively new scientific data on the spatial differentiation of adjacent areas to the mires and to assess the length of the influence zone of large raised bog massif. The developed algorithms for modeling the hydromorphic transformation of ecosystems will be universal for the taiga zone of Western Siberia and can be used to assess the paludification processes in large areas.

Acknowledgments

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