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Long-term dynamics of the area overgrown by helophytic vegetation in Lake Pskov

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This paper presents the results of a spatiotemporal analysis of the dynamics of the overgrowing of helophytes in the water area of Lake Pskov (Pikhva) for the period 1988 to 2017. Using the classification procedure for Landsat satellite images for different years, zones of overgrowing by helophytes in the coastal zone and islands of Lake Pskov were identified. During this period, no clear trend towards overgrowing of Lake Pskov by air and water vegetation was observed. Helophytes develop annually on the same sites. The positive dynamics of overgrowing of individual areas is local, as shown by the example of the Talabsk Islands, where the zone of overgrowth between 2007 and 2017 increased by 7.5 ha. The composition of the dominants of the main communities of the coastal aquatic vegetation did not change significantly over the years. The average value of the area occupied by helophytes is 4.14%. The results obtained are fundamental for determining the overgrowth of Lake Pskov within the framework of the ongoing environmental monitoring of the Peipsi-Pikhva Lake Complex.

Keywords: Lake Pskov, helophytes, overgrowing, geographic information system (GIS), satellite imagery, Landsat.

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Introduction

The study of the Peipsi-Pikhva Reservoir and Lake Pskov in particular has a history of more than 100 years (Mäemets, 1980). The first large work on the study of the higher aquatic vegetation of Lake Pskov was the PhD thesis of V.V. Ivanov, produced 1947–1949, which contains data on overgrowth dynamics, species composition and geobotanical structure of macrophytes of Lake Pskov. Lake Pskov and especially the delta of the Velikaya River showed the greatest diversity of species of typical aquatic (33 species) and helophyte (22 species) plants (Ivanov, 1949, 1966).

Tuvikene (1966) provided a brief analysis of the aquatic vegetation of the Peipsi-Pikhva Reservoir and published a list of macrophytes.

In 1966–1970 the aquatic vegetation of the Peipsi-Pikhva Complex Lake System was studied by the staff of the Botany Department of Pskov State Pedagogical Institute. In the course of the work, the species composition of macrophytes was refined, the phytocenoses were studied, the areas occupied by them were determined, and the mean biomass was assessed.

According to Nedospasova (1974), the overgrowth of Lake Pskov was 5% of the total area

of the basin. At the same time, 50.9% of the area of macrophyte overgrowth comprised submerged plants and 48.6% coastal plants or helophytes (Nedospasova, 1974; Papchenkov, 2001).

In the same period, Mäemets, an Estonian botanist, was studying the vegetation of Peipsi-Pikhva Lake System. She worked on the lake in 1970, 1971 and 1980, and on the main tributaries in 1986 and 1987. Her work presents the most comprehensive list of macrophytes (128 taxa), and indicates the frequency of occurrence of species in different parts of the Peipsi-Pikhva Lake Complex (Mäemets and Mäemets, 2001).

In 1988–1989, according to Sudnitsyna et al. (1990), the overgrowth of coastal plants in Lake Pskov was located in a continuous strip, the width of which ranged from 20 to 400 m. Coastal aquatic vegetation was absent only in small areas near some villages, but submerged aquatic plants were found everywhere. The total overgrowth of Lake Pskov was 7.9%.

In the summer of 2004, colleagues of the Pskov Branch (PO) of the State Research Institute on Lake and River Fisheries (GosNIORKh) began to study the higher aquatic vegetation of Lake Peipsi and Lake Pskov together with Estonian botanists.

The aim of the research was to study the composition of macrophytes and the nature of their distribution, as well as the structure and dynamics of the aquatic and helophyte plant communities.

In 2004–2006 GosNIORKh staff participated in the international project “Peipsi and IJsselmeer: mutual Reference for Long-term Management”, where they studied the structural indicators of the common reed, as well as the diversity of plant communities and their distribution throughout the basin (Sudnitsyna and Kozyrev, 2005a, b).

Since 2006, within the framework of the Agreement between Estonia and Russian Federation on the Protection and sustainable use of transboundary watercourses (1997), colleagues from GosNIORKh carried out environmental monitoring of Lake Peipsi. The subjects of their study are aquatic and coastal aquatic plants, among the most important components of the reservoir ecosystem. The purpose of the research is to study the composition of macrophytes, their distributional patterns, as well as the structure and dynamics of plant communities of aquatic and coastal-aquatic plants. Observations on the development of aquatic vegetation and overgrowing of the lake were conducted annually in the summer from 2007 to 2011 and from 2016 to the present. According to previous field studies at permanent stations, the overgrowth of Lake Pskov was 12% (Sudnitsyna and Kozyrev, 2005a, b). The above brief review shows that the information on the degree of overgrowth of Lake Pskov is ambiguous and contentious. This is primarily due to the local nature of the research and the lack of a system of continuous monitoring of the status of helophytes until 2007.

Overgrowing is a natural process of the ecosystem dynamics of any lentic reservoir. Moderate overgrowing (up to 20% of the area), according to some authors, has a positive effect on the development of coastal fauna, creating favorable habitats for various animals (Sadchikov and Kudryashov, 2004). The degree and rate of lake overgrowing are determined by a number of factors, two of which are particularly distinguished: shallow water and the trophic level of the reservoir (Gigevich, 1991; Nitsenko, 1967). Both hydrophyte and helophyte aquatic plants are involved in lake overgrowing (Papchenkov, 2001). Silting of the basin bottom and general climate warming contribute to the intensive spread of airborne plants in the coastal zone. In the overgrowing of the shores of Lake Pskov, the main role is played by the common reed *Phragmites australis* (Cav.) Trin. et Steud., 1840, followed by the lake reed *Schoenoplectus lacustris* (L.) Palla, 1888, and the sedges of *Carex* sp.

Estimation of the degree of development of communities of coastal aquatic vegetation in the water area allows assessment the ecological status of the reservoir as a whole, which is important for monitoring and integrated environmental studies. The purpose of this study is to trace the perennial trends in the process of overgrowing by coastal-aquatic vegetation of the coastal part of Lake Pskov using spatial analysis methods based on remote sensing data, enabling the monitoring of the entire area of Lake Pskov and the determination of the total area of its overgrowth in different years.

Materials and methods

Lake Pskov is the southern part of the Peipsi-Pihkva Lake Complex, belonging to the basin of the Gulf of Finland of the Baltic Sea and located on the border of two states, Russia and Estonia. Lake Pskov (area 708 km²) is almost completely located on the territory of the Russian Federation and is characterized by relative shallowness (average depth 3.8 m, maximum 5.3 m). The length of the lake from north to south is 41 km, the average width is 17 km (Sokolov, 1983). The bottom of the lake is mostly covered with lake silt. Sand is found in coastal areas. The average color index is 52º, the average water transparency is 0.6 m.

The concentration of total and mineral phosphorus in the surface layer of Lake Pskov in the ice-free period 1997–2006 amounted to 150 and 36 mg/m³, respectively; total nitrogen concentration to 1028 mg/m³ (Timm et al., 2012).

In terms of its chemical composition, the waters of Peipsi-Pikhva Lake Complex belong to the hydrocarbonate class, to the calcium group (Kostyuchenko et al., 1974; Kullus and Merila, 1966; Starast et al., 1999). In terms of its trophic content,

Lake Pskov is considered to be a hypereutrophic water body (Kondratiev et al., 2010).

Of the four methods of overgrowing reservoirs, recognized by A. Nitsenko (1967) in Lake Pskov, two are well expressed: (1) the gradual filling of a reservoir with sediments and the migration from the shore of the vegetation rooted in the basin substrate; (2) deposition of peat that goes into suspension in the water and eventually settles causing overgrowing. The latter process is characteristic only of the western shore of Lake Pskov. As the source material for the analysis of overgrowth of the Lake Pskov, satellite images of Landsat 5, 7, 8 from different years with minimal cloudiness were used, reflecting the state of coastal aquatic vegetation in the basin. To check the quality of image interpretation, data from our own field research were used, conducted by employees of the Pskov branch of GosNIORKh in the framework of the joint Russian-Estonian environmental monitoring of the Peipsi-Pikhva Lake Complex in 2007–2017.

For the monitoring of aquatic and coastal aquatic vegetation of Lake Pskov on the Russian side, 11 stationary stations (transects) have been established (Fig. 1).

A series of multispectral images of Landsat 5, 7, and 8 satellites was obtained from the US Geological Survey data catalog (USGS GloVis, https://glovis.usgs.gov/) for the period from 1988 to 2017 for the Peipsi-Pikhva Lake Complex.

All stages of the preparation of remote sensing data and their subsequent processing were carried out in the QGIS 2.18 geo-information environment. Landsat satellite scenes have a pixel resolution of 30 × 30 m.

The data were analyzed using various combinations of Landsat channels, selected for the best visualization of helophyte overgrowth. As a result, five scenes were selected for June 1988, July 1999, July 2007, July 2013 and June 2017. At the first stage, radiometric and atmospheric data correction was performed using the Semi-Automatic Classification Plugin (SCP) for QGIS.

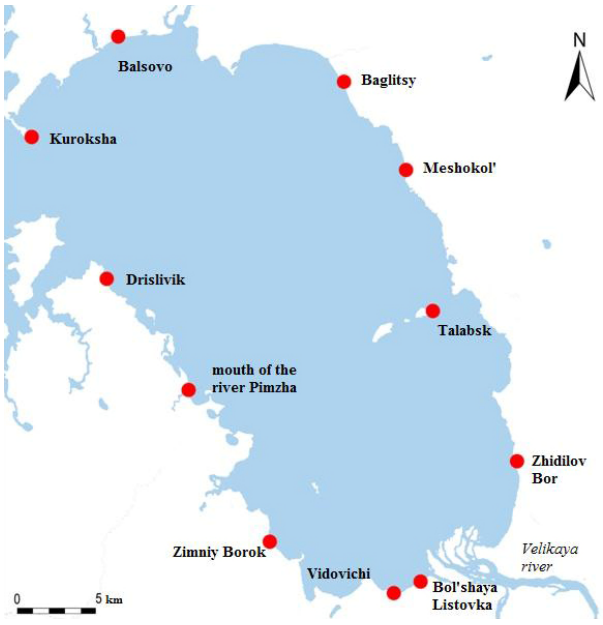

Fig. 1. Map of the location of stationary monitoring stations on Lake Pskov.

Then, the single-channel Landsat images were combined into a single multichannel image for each year of observation using the Union tool in the QGIS program.

Next, the images were decrypted in order to identify the configuration of the overgrowth of coastal water plants in Lake Pskov. Since completely immersed plants are almost not identifiable by the classification procedure, only helophytes that are well recognized during decryption were included in the analysis. Plants of this group occupy coastal shallow waters with a depth of 1–2 m (Papchenkov et al., 2003). As a basic tool for decryption, the classification procedure with training included in the SCP module was used. After selecting the most successful classification and correction option, all the images were translated into a vector format, and using the field calculator tool in QGIS, we calculated the area of overgrowth by helophytes in square kilometers.

Results

The analysis of the results showed the fluctuation of the proportion of the area occupied by helophytes, within 3.6%–4.7% of the total area of Lake Pskov (Table 1).

The largest areas occupied by helophytes in the basin were recorded in 2013 and 2017. Helophyte overgrowth developed uniformly along the entire coastline with an increase in the area in the estuaries of rivers and around numerous islands. Large groups of helophyte vegetation are located in the southern part of Lake Pskov and along the northeast coast up to the Talabsk Islands. The most extensive overgrowths of helophytes are found in the delta of the Velikaya River.

The occupation by helophytes of Lake Pskov based on the example of 2017 is presented in Fig. 2. As can be seen, the largest area of overgrowth with helophytes was recorded in the southern part of the lake, in the delta of the Velikaya River represented by a system of lowland, mostly marshy islands separated by channels. The ecosystem of the delta of the Velikaya River provides favorable conditions for the development of coastal and aquatic vegetation, due to the suitable relief, hydrological regime and climate.

The area of the Velikaya River is characterized by maximum diversity of macrophyte associations. The distributional pattern of the helophyte vegetation in the coastal part of the water bodies is uneven and is determined by the presence of low marshy shores, the nature of soils and fluctuations in water level. During the observation period, no clear trend

Table 1. Area of overgrowth by helophytes of Lake Pskov using Landsat imagery.

Year	1988	1999	2007	2013	2017
Area, km²	29.54	25.92	25.85	32.99	31.67
Proportion of basin area, %	4.2	3.6	3.7	4.7	4.5

towards an increase in the area of the area occupied by helophytes was revealed. On average, the area of lake overgrowing on the basis of the Landsat imagery analysis was 4.1%, which differs from the earlier published data and is closest to the estimate published by Nedospasova (1974). The standard deviation for the thirty-year period is 3.3 km^2, or 0.46% of the total area of Pskov Lake. Such results make it possible to say with confidence that the process of overgrowing of the coastal part of Lake Pskov is fluctuating, with a weakly pronounced positive trend component. Similar results are recorded by other authors who have studied the processes of overgrowing of water bodies using satellite images (Filonenko and Komarova, 2015; Peterson and Liira, 2016). Despite the oscillatory nature of the general process of the overgrowing of Lake Pskov, some of its sections demonstrate an increase in the area of macrophyte overgrowth, which can be promoted by such factors as a decrease in the water level, an increase in the area of sandy sediments and coastal silting processes.

The greatest variability in overgrowing was recorded at the Talabsk station (Fig. 3, Table 2), located on the island of the same name, which is part of the Talabsk Archipelago near the eastern coast of Lake Pskov. Marginal glacial formations are developed near the islands, which is associated with a small thickness of loose sediments of the coastal slope (0.2–0.5 m). At high water level, the coast is strongly eroded, and at a low level, the area of beaches, shoals and sandbars is increased (Karpukhina, 2012). A study of the higher aquatic vegetation of the Talabsk Islands was carried out for the first time in 1998–2000 (Sudnitsyna and Grigorieva, 1998; Sudnitsyna and Tarasova, 2002). These years were water-rich; the average annual water levels ranged from 222 to 238 cm (Table 3). During this period, according to satellite imagery, there is a slight decrease in the area of overgrowth compared to 1988.

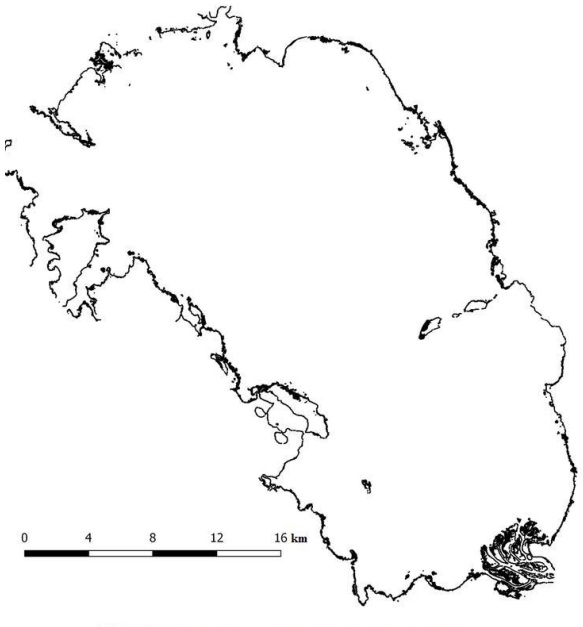

Fig. 2. The distribution of helophytes on Lake Pskov in 2017.

In 2007, the water level dropped to 175 cm. Extensive beaches arose in the vicinity of the islands; sand bars connecting the islands and the eastern shore of Lake Pskov were exposed, which contributed to the beginning of the process of intensive overgrowing. In subsequent years, they were periodically flooded with water and were again exposed, but the process of overgrowing of this zone with helophytes had a steady positive trend (Sudnitsyna and Mikhailova, 2016). This is confirmed by the results obtained on the basis of the decoding of satellite images, according to which the area of overgrowing from 2007 to 2017 increased by 7.5 hectares.

Discussion

According to data from previous studies of the higher aquatic vegetation of Lake Pskov, the area of overgrowing of this basin was 55.93 km² (7.9% of the water area) (Sudnitsyna et al., 1990).

Among the remote sensing data analyzed, the closest to this time period is an image from 1988. According to the classification results, the area of overgrowth by helophytes was 29.54 km² (4.2%).

The differences in the data obtained can be explained by the choice of the study object, since completely submerged aquatic vegetation is practically not identifiable when classifying satellite images, or by research methods. In 1988–1989 the extent of lake overgrowth was estimated visually without strict reference to any coordinate system. In subsequent years, the total area of overgrowing of the lake's water area was not measured, so there are only rough estimates that are difficult to objectively compare with the results of the remote sensing decoding.

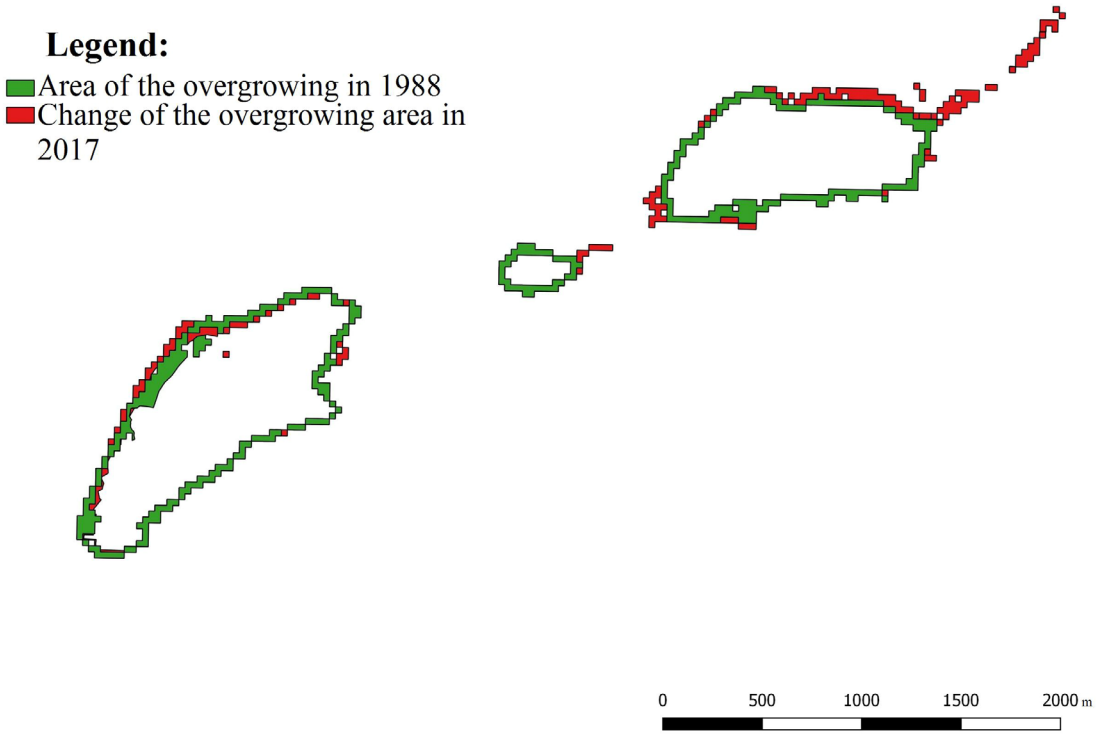

Fig. 3. The dynamics of the helophyte overgrowth of the Talab Islands for the period from 1988 to 2017, according to the ERS data.

Conclusion

Analysis of the data obtained using satellite images for the period from 1988 to 2017, revealed the spread of helophyte vegetation overgrowths along the entire coastline, as well as around the numerous islands of Lake Pskov (Talabsk Islands, Kolpin Island, Semsky Island).

The overgrowth of Lake Pskov for the period 1988–2017 fluctuated in intensity. Helophyte vegetation developed most in the delta of the Velikaya River, and also around islands and on sandbanks. No clear trend towards an increase in the area of lake overgrowing by helophyte vegetation was observed. According to the results of processing satellite images for the period indicated above, the average area occupied by helophytes is 4.14%.

The advantage of using remote sensing images of small spatial resolution is a wide viewing area and good decoding capabilities due to the combinations of spectral channels, permitting a choice of the most contrasting display of plant communities of interest (Filonenko and Komarova, 2015). The undoubted advantage of Landsat satellite images is that they are available free of charge, and that captured scenes are archived long-term (since 1972), which allows them to be used to study the long-term dynamics of plant communities. The presence of spectral channels allows the identification and analysis of natural phenomena that are not available with standard aerial or land photography.

Table 3. Interannual changes in average annual water levels in Lake Pskov in the ice-free periods of 1988–2017.

Year	Water level May–October, cm
1988	235
1999	222
2007	175
2013	203
2017	219

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Table 2. The long-term dynamics of the area of overgrowth of the Talabsk Islands according to the data obtained from Landsat images.

Year	1988	1999	2007	2013	2017
Area of overgrowth, km²	0.333	0.293	0.324	0.356	0.399

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