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The dynamics of overgrowing of spawning areas of Lake Pskov, using the example of Anokhovo Bay

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The dynamics of overgrowing of spawning grounds in the southern area of Peipsi-Pihkva Lake complex is considered, based on 28 years of observations from Anokhovo Bay. The history of the study of the water area is analyzed in detail, the species and syntaxonomic composition of plant associations in the littoral areas of the bay is described, and the dominant species are established. Over the entire observation period, the total number of macrophyte species increased by almost 2.5 times, and the number of plant associations increased approximately twofold. The area of the bay overgrown with macrophytes increased by 9.5%, with a simultaneous increase in the overgrowth density. The dominant species are common reed *Phragmites australis,* lakeshore bulrush *Schoenoplectus lacustris*, and yellow water-lily *Nuphar lutea*.

Keywords: helophytes, Peipsi-Pihkva Lake, *Phragmites australis, Schoenoplectus lacustris, Nuphar lutea*, spawning grounds, GIS, Earth remote sensing (ERS), ecological succession.

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Introduction

The Peipsi-Pihkva Lake complex is one of the largest transboundary water bodies in Europe in terms of its water surface area (3555 km²) and is the largest freshwater ecosystem in the Pskov Region. The basin consists of three connected areas (lakes), differing in a number of limnological indicators: northern, Lake Peipsi (area 2611 km²; average depth 8.3 m); southern, Lake Pihkva (708 km²; 3.8 m) and connecting Lämmi Lake (236 km²; 2.5 m) (Sokolov, 1983). Peipsi-Pihkva Lake is distinguished by high fish productivity, ranking first in commercial fish catch among other large lakes in the north-west of Russia, such as Ladoga, Lake Onega, Ilmen, Beloe, and Kubenskoe (Kozlov et al., 1993).

Most indicators of bioproductivity of a basin directly depend on the conditions and quality of habitats of aquatic organisms; therefore, to maintain the stability and high abundance of valuable species of aquatic organisms, it is necessary to ensure the stability of their existing habitats and reproduction (Lapointe et al., 2014; Rosenfeld and Hatfield, 2006). More than half of the 35–38 fish species inhabiting Peipsi-Pihkva Lake (Dorozhkina and Frantova, 1972; Timm et al., 2012) have phytophilic or nesting-phytophilic reproductive ecology (including those indifferent to the spawning substrate); these include commercially valuable fish: zander, bream, pike, perch, and roach. In this regard, an especially important role is played by littoral biotopes – protected from wind and waves, as well as open coastal areas of the lake with aquatic vegetation, acting both as reproductive sites for fish species coming here for spawning, and as stations for survival of their fry, especially in first year of life. Littoral zones are also permanent habitats for some fish species: crucian carp, tench, rudd, weather loach, spined loach and stickleback; in addition, in the coastal zone of the lake, in the channels and estuarine areas of numerous tributaries, where sandy-pebble soils prevail, there are spawning grounds for litho- and psammophilic fish species.

Lake Pihkva is almost entirely located on the territory of the Russian Federation and currently plays a leading role in the reproduction of the stocks of most fish species living here. This lake is characterized by a large littoral zone (approximately 15% of its water surface), a relatively large number of channels flowing into it (the largest of them is the Velikaya River) and the presence of bays and floodplain lakes, with favorable conditions for higher aquatic vegetation. In general, thickets of macrophytes occupy about 12% of the entire area of Lake Pihkva (Timm et al., 2012), which provide the conditions for the normal reproduction of phytophilic fish species (Gordeeva and Ilyina, 1978; Ilyina and Nebolsina, 1976; Kontsevaya and Dorozhkina, 1983; Kundiev, 1981; Poddubny and Malinin, 1988).

For the first time, the study of higher aquatic vegetation and the determination of the degree of overgrowing of the spawning grounds of Pihkva Lake was conducted 1988 by staff of the Pskov branch of "GosNIORKh" in order to develop a justification for land reclamation work. During the research, the species composition of macrophytes was studied and diagrams were prepared, showing the composition and distribution of plant communities in the main spawning grounds. According to their morphometry and degree of separation from the lake, bream spawning grounds can be divided into four groups (Otchet..., 1988):

1) open coastal areas;
2) bays;
3) floodplain lakes;
4) river spawning grounds.

In 2012, the employees of the Pskov branch of the Federal State Budgetary Scientific Institution "GosNIORKh", within the framework of the state assignment, carried out studies of the main spawning areas of Lake Pskov to assess the habitat and spawning conditions of bream and other phytophilous fish species (Otchet..., 2013). Spawning grounds for bream in Lake Peipsi-Pihkva are located in shallow, calm areas of the reservoir rich in soft vegetation (Shirkova, 1974). In the course of the work, the species composition, dominant species and syntaxonomic composition of vegetation in shallow areas were determined. Charophyte algae (2.2%), vascular spore plants (2.3%), and angiosperms (95.6%) were found in the flora of the spawning grounds. *Phragmites australis* (Cav.) Trin. et Steud. is reported at all surveyed sites, and of submerged plants, *Nuphar lutea* (L.) Smith was found at 70% of the spawning grounds. Of the other most common species, *Schoenoplectus lacustris* (L.) Palla, *Stratiotes aloides* L., *Potamogeton perfoliatus* L., *Carex* spp. *P. australis, S. lacustris,* and *N. lutea* are the main components of cenoses (Mikhailova, 2013). According to Severin and Aleksandrov (1994), rooted stems and leaves of *P. australis, Carex* spp., *Caltha palustris, Equisetum* spp. and *Stratiotes aloides* served as the spawning substrate for phytophilous fish species. The densest clutches were recorded on the *Equisetum* and *Stratiotes*, and only in the upper third of the submerged substrate. Thus, the understanding of the overgrowth of spawning grounds makes it possible to assess their condition and suitability for spawning by the main commercial phytophilous fish species.

The purpose of this study is to identify long-term trends of overgrowing of the spawning areas of Lake Pihkva using the example of Anokhovo Bay, based on literature and archival data, materials of our own field studies and remote sensing (ERS) methods.

Materials ad methods

Anokhovo Bay is located in the southwestern part of Lake Pihkva (Fig. 1) and is connected to it by a wide strait. The small Obdekh river flows into the bay. The area of the bay is approximately 2.47 km² (246.2 ha); the length of the coastline is 2.13 km. The depth in the central estuarine part is 1.4–1.6 m, the transparency is 0.6–1.5 m. The bottom is covered with a layer of silt with a thickness of at least 1.5 m (Otchet..., 1988). Due to its physical, geographical and ecological characteristics, this bay is a natural littoral spawning ground in the southern part of the Peipsi-Pihkva Lake system, therefore it is appropriate to use it as a model site for tracking spatial and biotopic changes in other spawning areas of the lake complex.

The higher aquatic vegetation of the main spawning grounds of Lake Pihkva was studied in July 2012 and June 2016 during the planned monitoring works to study the macrophytes of the Peipsi-Pihkva Lake system, using the generally accepted methods of field geobotanical and floristic descriptions (Belavskaya, 1994; Katanskaya, 1981).

To study the vegetation dynamics in Anokhovo Bay, we use a linear trend coefficient (CT), which is calculated as the difference between the number of species that have appeared and the number of species that have disappeared from the reservoir, divided by the number of species that grew in the reservoir in all years of the study (Shipunov and Abramova, 2006).

The analysis of the syntaxonomic structure of communities was conducted to the level of associations on a dominant-determinant basis (Markov, 1955; Papchenkov, 2003).

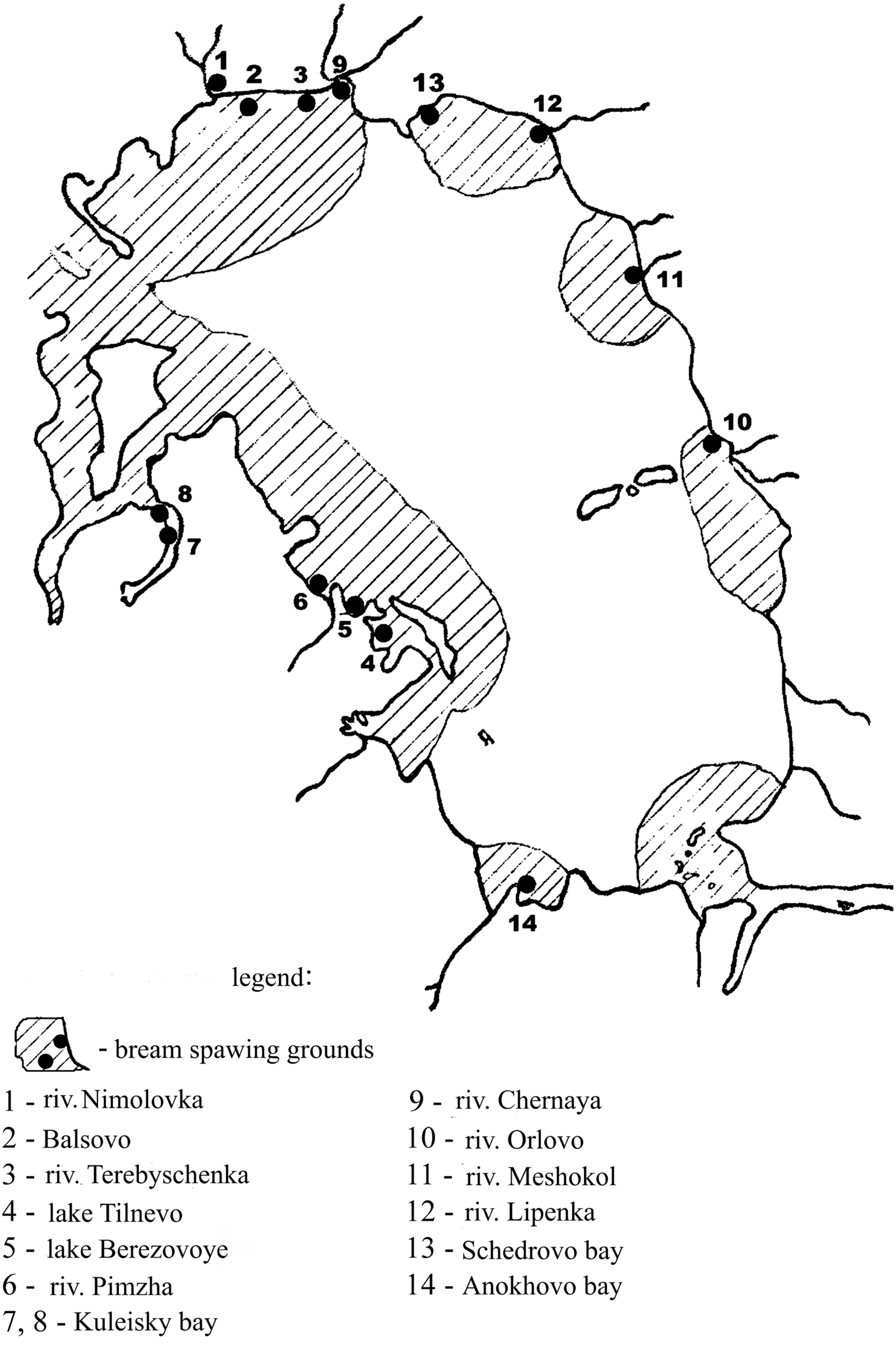

Fig. 1. Distribution of bream spawning grounds in Lake Pihkva.

The degree of overgrowth of the bay with higher aquatic vegetation was established visually, and the boundaries of overgrowth were determined by delineating the growing areas of dominant plant species using the GPS Garmin GPSMAP 62 navigator. The data were processed using QGIS 3.8 software. The files from the GPS-receiver in the GPX format obtained during the field research were converted into SHP formats and used in further analysis. To generalize the configurations of the obtained polygons, the standard “smoothing” QGIS tool was used. The accuracy of the configurations obtained was checked by comparing them with vegetation boundaries on Google Satellite images in the Google Earth application and data from the Sentinel-2 satellite for June 2016. After checking and correcting the polygons using the “field calculator” tool, the area occupied by dominant plant species was calculated.

The overgrowth of Anokhovo Bay in the summer of 1988 was determined by digitizing the overgrowth location map and its referencing in the WGS 84 coordinate system, as well as by classifying the Landsat LT04_L1TP_185020_19880821_20170206_01_T1 image for August 1988 using the QGIS program SCP module to determine the degree of overgrowth. This classification is discussed in detail in our previous study (Mikhailova and Mikhalap, 2019). The cartographic materials were built using the Layouts application of the QGIS 3.8 program.

Results

According to the literature data (Otchet..., 1988) and the results of our field studies, for the period from 1988 to 2016, 35 species of higher aquatic plants belonging to 4 divisions, 18 families and 29 genera were recorded in Anokhovo Bay (Table 1). The flora of the bay contains two species of cryptogamous macrophytes (Bobrov and Chemeris, 2003) – charophyte green algae *Chara* sp. and the green alga *Cladophora glomerata* (L.) Kützing, the rest of the species belong to the angiosperm division. Among them, 56.2% are monocotyledonous plants, 43.8% are dicotyledons. *Chara* algae were only found in the bay in 1988 (Otchet..., 1988) and not in subsequent years.

The alga *Cladophora glomerata* in 2012 and 2016 was abundant: the stems of almost all helophytes and hydrophytes, especially in July, were covered with threads of these algae, and in the absence of higher aquatic plants, filamentous algae were attached to stones of different sizes. The abundance of filamentous algae in spawning grounds has both positive (thickets are inhabited by numerous invertebrate species which provide food for fish) and negative effects (*Cladophora* filaments clog the gills of fry, and when abundant cause secondary pollution) (Velichko, 1982).

The ecological structure of the flora of Anokhovo Bay is represented by six ecological groups, which are combined into four ecotypes, according to Papchenkov’s classification (2001).

In Anokhovo Bay, hydrophytes, or true aquatic plants, prevail, accounting for 40% of the total number of species (Fig. 2). This ecotype includes 4 ecological groups (Papchenkov, 2001):

1) hydrophytes, freely floating in the water column;

2) submerged rooted hydrophytes;

3) rooted hydrophytes with leaves floating on the water;

4) hydrophytes, freely floating on the water surface.

The flora of the bay is dominated by submerged rooted hydrophytes: *Potamogeton* spp., *Elodea canadensis, Batrachium circinatum*. The smallest ecological group among real aquatic plants was those that are free floating on the water surface, represented by a single species, *Staurogeton trisulcus*.

Helophytes, or aerial-aquatic plants (26%), are equally represented by tall grasses (average height of shoots 180–300 cm), *Phragmites australis, Schoenoplectus lacustris, Glyceria maxima*, *Typha angustifolia*, and low grass (average height of shoots 60–100 cm) represented by *Butomus umbellatus, Sagittaria sagittifolia*, etc.

Hygrohelophytes (waterline plants) make up 20% of the entire flora of the bay. These include species such as *Rumex aquaticus, Caltha palustris, Sium latifolium*, etc.

Plants of damp habitats (hygrophytes) are the smallest ecological group in the flora of the bay, which account for 14% of the total number of species (Fig. 2).

It should be noted that, according to literature data, 10 species of macrophytes were found in Anokhovo Bay in 1988, while we recorded 29 species in 2012 and 25 in 2016 (Table 1). Thus, for the period from 1988 to 2016. In the flora of the bay, the number of macrophyte species increased almost 2.5 times. At the same time, charophytes disappeared from the spawning ground flora. *Chara* algae are known to be indicators of clean, nutrient-poor water, as well as the background undisturbed state of some types of aquatic ecosystems (Krause, 1981).

The dynamics of the flora of Anokhova Bay has a positive trend (CT = 0.7). During the period under consideration, the flora was enriched by 26 species, among which were noted species that are indicators of water pollution (Gigevich et al., 2001): *Hydrocharis morsus-ranae, Glyceria maxima, Potamogeton natans, Staurogeton trisulcus*, etc. In addition, it is known that local intensive development of duckweed, *Lemna*, indicates the input of nutrients into the reservoir (Kutyavina et al., 2013). Anthropogenic impact on aquatic ecosystems is also suggested by the presence of *Elodea* and *Stratiotes* (Sadchikov and Kudryashov, 2004).

In total, during the period under consideration, 16 macrophyte associations were identified, of which six were found regularly (Table 2).

Table 1. Species composition of macrophytes in Anokhovo Bay (1988–2016). Ecotypes: I — hydrophytes, II – helophytes, III – hygrohelophytes, IV – hygrophytes.

Species	Ecotype	1988	2012	2016
Phylum Chlorophyta				
Family Cladophoraceae				
Cladophora glomerata (L.) Kütz.	I	–	+	+
Phylum Charophyta				
Family Characeae				
Chara sp.	I	+	–	–
Phylum Magnoliophyta				
Class Magnoliopsida				
Family Nymphaeaceae				
Nuphar lutea (L.) Smith	I	+	+	+
Nymphaea candida J.C. Presl	I	–	–	+
Family Ranunculaceae				
Batrachium circinatum (Sibth.) Spach (= *Ranunculus circinatus* Sibth.)	I	+	+	–
Caltha palustris L.	III	+	–	+
Ranunculus reptans L.	IV	–	+	–
Family Polygonaceae				
Persicaria amphibia (L.) S.F. Gray	I	–	+	–
Rumex aquaticus L.	III	–	+	–
Family Primulaceae				
Lysimachia vulgaris L.	IV	–	+	+
Family Lythraceae				
Lythrum salicaria L.	III	–	+	+
Family Apiaceae				
Cicuta virosa L.	III	–	+	+
Oenanthe aquatica (L.) Poir.	III	–	–	+
Sium latifolium L.	III	–	+	–
Family Lamiaceae				
Menhta aquatica L.	IV	–	+	+
Stachys palustris L.	IV	–	+	+
Class Liliopsida				
Family Butomaceae				
Butomus umbellatus L.	II	+	+	+
Family Alismataceae				
Alisma gramineum Lej.	II	–	+	+
A. plantago-aquatica L.	II	+	+	+
Sagittaria sagittifolia L.	II	+	+	+
Family Hydrocharitaceae				
Elodea canadensis Michx.	I	–	+	–
Hydrocharis morsus-ranae L.	I	–	+	–
Stratiotes aloides L.	I	–	+	–

Species	Ecotype	1988 г.	2012	2016
Family Potamogetonaceae				
Potamogeton compressus L. (= *P. zosterifolius* Schum.)	I	–	+	–
P. lucens L.	I	–	+	+
P. natans L.	I	–	–	+
P. perfoliatus L.	I	+	+	+
Family Cyperaceae				
Carex spp.	–	–	+	+
Eleocharis palustris (L.) Roem. et Schult	III	–	+	+
Schoenoplectus lacustris (L.) Palla	II	+	+	+
Family Poaceae				
Glyceria maxima (Hartm.) Holmb.	II	–	+	+
Phalaroides arundinacea L.	IV	–	+	–
Phragmites australis (Cav.) Trin. et Steud.	II	+	+	+
Family Lemnaceae				
Staurogeton trisulcus (L.) Schur) (= *Lemna trisulca* L.)	I	–	–	+
Family Sparganiaceae				
Sparganium erectum L.	II	–	–	+
Family Typhaceae				
Typha angustifolia L.	II	–	+	+
Total		**10**	**29**	**25**

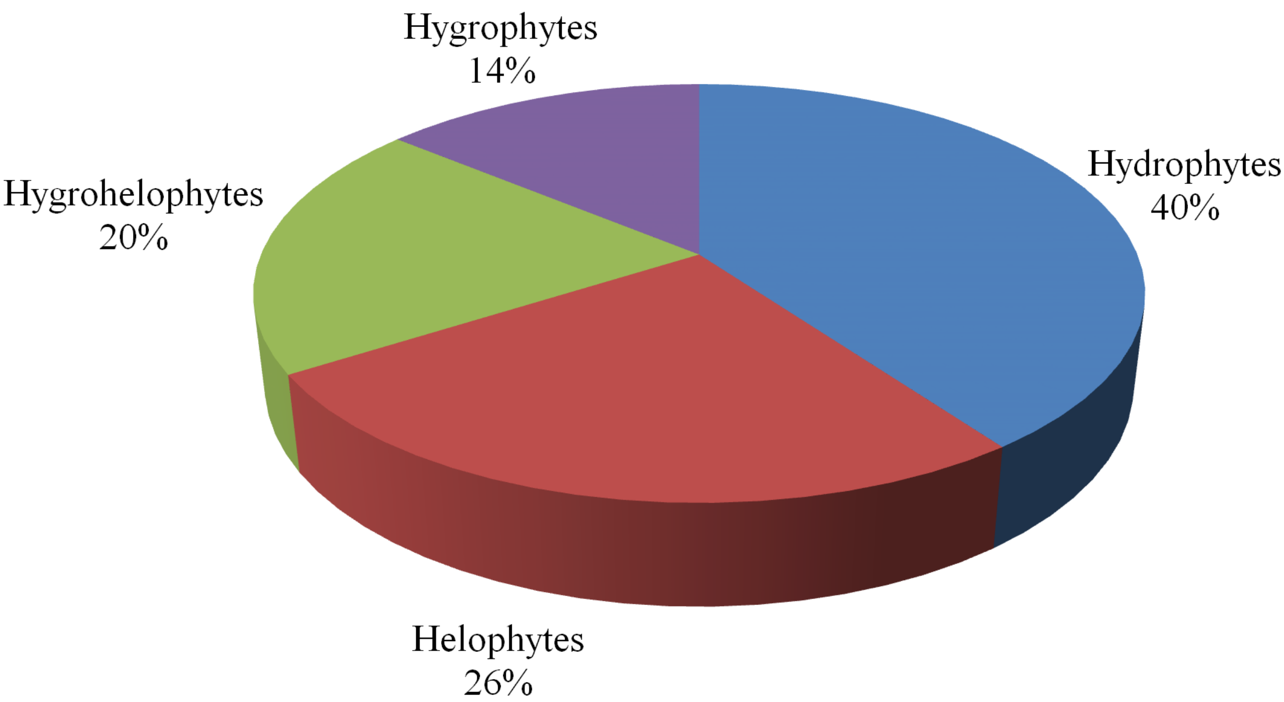

Fig. 2. Ecological structure of the flora of the Anokhovo Bay.

In 1988, the leading role in the overgrowing of the bay belonged to four main cenosis-forming species: *Phragmites australis, Schoenoplectus lacustris, Potamogeton perfoliatus,* and *Nuphar lutea*. The common reed association formed the marginal areas of overgrowth almost along the entire coastline of the bay and especially in the estuarine area. Lakeshore bulrush thickets were located mainly in small islands along the reed line and occupied a relatively small area; further into the bay stretched sparse phytocenoses of perfoliate pondweed, among which the thickets of yellow water-lily were located in separate "spots" of various sizes.

With a significant change in the spatial configuration of overgrowth in Anokhovo Bay for the period from 1988 to 2016 (Fig. 3) there was also an increase in the syntaxonomic diversity of the plant communities of the spawning ground (Table 2).

In 2012, we discovered vast areas of *Potamogeton lucens*, which formed single-species thickets everywhere, and was also part of the communities of the **Potameto lucentis – Nupharetum luteae** association (the projective cover of *Nuphar lutea* is 50–80%, *Potamogeton lucens* is 20–60%). The greatest diversity of plant communities was noted at the mouth of the Obdekh River entering the Anokhovo Bay. Here, at a depth of 1.2 m, two species communities of **Stratioto – Nupharetum luteae** were located in a continuous cover (total projective cover 90–100%). The average projective cover of the *Nuphar lutea* was 70–80%, and of *Stratiotes*, 30%. *Nuphar lutea* dominated in the phytocenoses **Schoenoplecto – Nupharetum luteae** (total projective cover 90%). Fragments of the *Persicaria amphibia* association were recorded; single-component communities of this species formed small spots (2×3 m).

During the 2016 fieldwork, the emergence of phytocenoses of *Nymphaea candida*, forming large one- or two-part associations with a predominance of *Nuphar lutea*, was recorded. In the eastern and western parts of Anokhovo Bay, monodominant communities of **Typhetum angustifoliae** were found, the thickets of which were located behind the reed on the water side at a depth of 0.7 m, forming a strip up to 2 m wide. Phytocenoses of the low-grass helophyte *Sagittaria sagittifolia* were also described. Together

Table 2. Characteristics of macrophyte communities (at the level of associations) in Anokhovo Bay (1988–2016).

Associations	1988	2012	2016
Submerged rooted hydrophytes			
Potametum perfoliati	+	+	+
Potametum lucentis	–	+	+
Rooted hydrophytes with leaves floating on the water			
Persicarietum amphibii	–	+	–
Nupharetum luteae	+	+	+
Potameto perfoliati – Nupharetum luteae	+	+	+
Potameto lucentis – Nupharetum luteae	–	+	+
Nyphaeto – Nupharetum luteae	–	–	+
Stratioto – Nupharetum luteae	–	+	–
Schoenoplecto – Nupharetum luteae	–	+	+
Nymphaeetum candidae	–	–	+
Low-grass helophytes			
Lemno – Sagittarietum sagittifoliae	–	–	+
Tall grass helophytes			
Phragmitetum australis	+	+	+
Schoenoplecto – Phragmitetum australis	+	+	+
Schoenoplectetum lacustris	+	+	+
Nyphaeto – Schoenoplectetum lacustris	–	+	+
Typhetum angustifoliae	–	–	+
Total number of associations	**6**	**12**	**14**
Number of dominant species	**4**	**6**	**8**

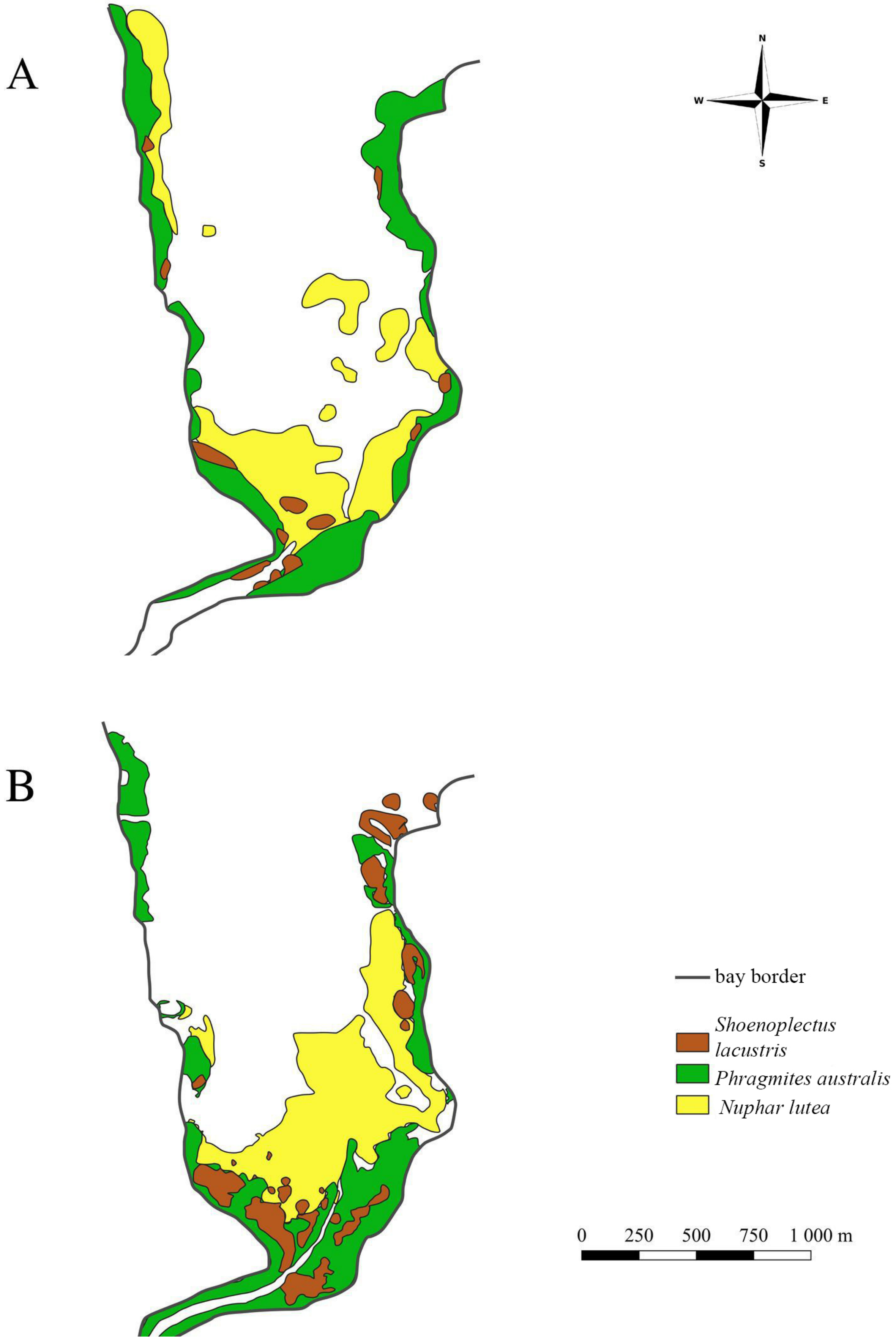

Fig. 3. Dynamics of change in the spatial configuration of the three dominant species of higher plants (common reed, lakeshore bulrush and yellow water-lily) in Anokhovo Bay in 1988 (**A**) and 2016 (**B**).

with the duckweed, it formed the communities of **Lemno – Sagittarietum sagittifoliae**, which were 3×2 and 4×5 m in size and arranged in a mosaic pattern at a depth of 0.5 m in the southern and southeastern parts of the bay.

The association **Nymphaeetum candidae** was the most widespread in Anokhovo Bay in 2016, which belongs to the group of formations of rooted hydrophytes with floating leaves. This community was ubiquitous, located at a depth of 0.5 to 2.2 m. In the group of tall-grass helophytes, the main role in overgrowth was played by common reeds and lakeshore bulrush. According to a number of researchers, reed thickets reduce the quality of spawning grounds (Podolyako and Vasilyeva, 2013) and worsen the hydrochemical regime in the thickets, since oxygen is spent on decomposition of last year's plant remains, especially in warm springs and autumns (Ivlev, 1950; Korsak and Myakushko, 1981; Velner and Loigu, 1975; Zhuravleva, 1973).

In total, for the period from 1988 to 2016, the number of plant communities in Anokhovo Bay approximately doubled. The ratio of communities of submerged vegetation (hydrophytes) and aboveground vegetation (helophytes) in 1988 was one to one (50% each), over the subsequent period it did not change significantly and amounted to 60% and 40%, respectively.

In general, the number of dominant species in the plant communities of Anokhovo Bay for the period from 1988 to 2016 increased from 4 to 8 (Table 2). At the same time, from 1989 to 2012, the density of dominant macrophyte species increased (Table 3).

Analysis of the data obtained by contouring thickets of dominant species using a GPS receiver, as well as by decoding satellite images, showed an increase in the areas occupied by macrophytes in Anokhovo Bay (Table 4). Note, that when decoding satellite images, we were unable to isolate the areas of communities in which *Potamogeton perfoliatus, Potamogeton lucens, Nymphaea candida, Typha angustifolia*, and *Sagittaria sagittifolia* became the dominant species. This is because thickets including only these of these cenoses do not form large enough areas, and merge with thickets formed by the mixed main distinguishable dominant species.

Thus, by 2016 the area overgrown with macrophytes in Anokhovo Bay increased by 9.5% compared to 1988. The growth of lakeshore bulrush was shown to be especially significant, which significantly expanded its area of growth in the southern part of the bay, forming extensive thickets on its eastern side, which in the 1980s was not observed.

Conclusions

The total area of overgrowing of Anokhovo Bay with macrophytic vegetation, and the biodiversity of phytocenoses have increased over the past decades, and this is reflected both in an increase in the total number of species and in their relative proportions. At the same time, we recorded an increase in the

Table 3. Dynamics of average density values of dominant macrophyte species in Anokhovo Bay (Pihkva Lake) (1988, 2012).

Species	Density, specimen/m^2	
	1988	2012
Phragmites australis	43	71
Schoenoplectus lacustris	105	212
Nuphar lutea	13	28

Table 4. Area overgrown with macrophytes in Anokhovo Bay according to Landsat images (1988, 2012).

Species	Overgrown area, ha	
	1988	2016
Phragmites australis	42.34	52.61
Schoenoplectus lacustris	5.2	16.85
Nuphar lutea	44.37	45.93
Overgrowth (% of the total bay area)	37.33	46.87

number of dominant species in the community, which somewhat reduced its overall uniformity. An increase in the proportion of common reeds and lakeshore bulrush in the phytocenosis indicates an increase in the accumulation of organic matter in silt deposits and a general decrease in the water level in the bay, which created favorable conditions for the formation of beds of the above species. In the long term, such dynamics can negatively affect the quality of the spawning grounds, since dense reedbeds with a high biomass are inaccessible for spawning and feeding of juveniles, which, according to some authors (Chavychalova and Kushnarenko, 2008), can contribute to a sharp decrease in fish productivity.

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