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Spatiotemporal Dynamics of Fish in Lake Pskov

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Abstract—The interannual and intraseasonal patterns of the spatiotemporal dynamics of the main commercial fishes from Lake Pskov, one of the most productive water bodies in northwestern Russia, are studied. The results of cartographic analysis of the summer–fall fish distributions in the lake are presented. The results of trawl surveys conducted in years that differed by the water level (2003, 2006, and 2008) were used as the input data. The initial data were aggregated into tables of attributes containing information on the trawling dates, trajectories, duration, average speed, water temperature, and the species and size composition of the catch. These tables were used to map the spatial distribution of seven fish species (bream, pikeperch, roach, perch, white bream, burbot, and ruff). Cartographic estimates of abundance are obtained for roach, pikeperch, bream, pike, and perch. An attempt is made to assess the reproduction efficiency of several fish species (pikeperch, perch, and pike) based on an analysis of their abundance variation from spring to autumn. Maps of the spatial distribution of the pikeperch that account for the size composition of the population are created. The discrepancy in the localization of different age groups in different seasons, along with their moving patterns, is ascertained. The patterns in the fish spatiotemporal dynamics are matched with the available hydrological characteristics.

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INTRODUCTION

Spatial heterogeneity plays an extremely important role in fishpopulation dynamics. In the framework of modern approaches, this factor must be taken into account in order to assess the speed and directions of fish migration, to study the demographic and ecosystem processes, to develop adequate models of biosystems, to solve a number of economic issues, etc. Unfortunately, even in reservoirs with a long history of fishing, information on the dynamics of fish distribution is extremely limited. They usually boil down to statements of more or less distinct seasonal movements of fish associated with spawning. Even though the necessary empirical data are available, there is usually no sense of the fish distributions in other seasons, which are important for an understanding of the processes occurring in the reservoir. This is usually due to the lack of attention paid to modern technologies focused on the obtainment of data for geoinformation analysis.

Until recently, the spatiotemporal dynamics of fish were mainly studied with hydroacoustic methods, the use of which has improved over several decades (Pavlov and Mochek, 2009; Pollom and Rose, 2016). However, since the end of the twentieth century, geoinformation technologies have become a top research tool. Their effectiveness is determined by the ability to generate visual representations of the behavior of macrobiological objects, thereby facilitating their study, as well as the cooperation of scientists and specialists in the management of aquatic biological resources.[1]

Lake Pskov—Peipsi occupies a special position in the system of commercial reservoirs. Its wide range of commercial species and high natural productivity make it one of the top-ranking fishery reservoirs in

[1] The GISFish portal was created in 2007 based on the website of the United Nations World Food and Agriculture Organization to exchange experience and promote this area. It is aimed at specialists in the field of fisheries, aquaculture, and geographic information systems ("Current issues, status, and applications of GIS to inland fisheries," W. Fisher, Cornell University, Ithaca, NY, United States, http://www.fao.org/tempref/FI/CDrom/T552/root/09.pdf).

Europe (Kangur et al., 2001; Kontsevaya, 2009; Saat et al., 2010; etc.).

Due to its position on the border, the biological resources of the lake fall into the sphere of interests of Russia and Estonia, which is reflected in the regulation of fishing activities and the implementation of environmental and fishery monitoring of the reservoir.

This paper presents the results of the use of the cartographic approach in relation to the analysis of the summer–autumn distribution of the main commercial fish species of Lake Pskov.

MATERIALS AND METHODS

Since 1999, regular trawl surveys have been carried out in the waters of Lake Pskov and Lake Peipsi. They present material on the composition and distribution of catches in the Russian part of the reservoir. Apart from some constructions of a qualitative nature, no cartographic analysis of the obtained data has been carried out to date.

In this study, we used data from the trawl surveys conducted in the water area of Lake Pskov. The data was taken from the archival materials of the Pskov branch of the Federal Research Institute of Fisheries and Oceanography (VNIRO). For Lake Pskov, the surveys cover the central part and were carried out two to four times per open water season. The survey dates usually do not coincide.

The most important feature of the surveys is the presence of a positional component in their materials: the coordinates of the starting and ending points of trawling. In addition, the data for each trawl include the date and time of the beginning and end of the trawling, the speed of the trawl, the water temperature during the trawling, and the catch composition distributed by the species and fish size. The following fish species are most fully represented in the materials of trawl surveys: the pike, pikeperch, burbot, and perch for predators and the bream, white bream, roach, and ruff for peaceful fish.

An important role in the formation of the living conditions of the fish of the Pskov–Peipsi Lake is played by the features of the hydrological regime of the reservoir, as well as the main rivers of its basin, primarily, Velikaya River, which accounts for 94% of the catchment area of Lake Pskov and almost half of the entire surface water runoff into the lake complex.

The hydrological station nearest Lake Pskov is located in the city of Pskov, in the lower reaches of the Velikaya River. Of the general list of hydrological characteristics recorded at this post, the water level is more strongly associated with the quantity of the discharge of suspended sediment. Based on data from the Information System on Water Resources and Water Management of the Russian River Basins (http://gis.vodinfo.ru) and a comparative analysis of the graphs of the course of the water level in Lake Pskov, all observation years (1999–2011) were divided into three groups according to the relative water content: low-water, medium-water, and high-water. The years with sufficiently informative results of trawl surveys were determined within each of the identified categories, i.e., those covering the beginning and end of the growing season and containing data on a large (seven or more) number of fish species. Based on these criteria, the following were selected as typical years in terms of water level and were the most informative: 2003, average water level; 2006, low water level; and 2008, high water level.

Six trawl surveys (two surveys per year) were carried out during these years. The survey materials formed the basis for the creation of cartographic models in the GIS environment: May 26–29 and October 28–30, 2003; May 22–25 and August 21–24, 2006; June 9–11 and October 25–26, 2008.

The trajectories were in the form of straight lines. These paths are represented as line features in the spatial database. In our case, these are segments with two peaks (the starting and ending points of trawling) containing attributive information about the corresponding trawling.

A unified system for the names of classes of spatial objects and a unified structure for the attribute tables of the corresponding classes were developed to formalize the selected data. These included the identifiers and names of the trawling lines, the coordinates of their start and end points, the duration of the trawl operation, its average speed, the water temperature at the start and the end of trawling, and the data on the composition of the catch, including information on the number of individuals of each species and their size.

The ArcMap application of the GIS package ArcGIS 10.2.1 was used as the geoinformation software.

Most geographic information software products, including ArcGIS, rely solely on the use of point features as input for interpolation methods. Therefore, the midpoints of these lines were chosen as the points that are most representative of the trawling lines and can act as input for interpolation.

A detailed description of the algorithm for the creation of maps that take into account the characteristics of the source material was presented earlier in the works of the authors (Vasiliev and Chistov, 2017; Vasiliev et al., 2018) and therefore is not presented here.

In addition to the total number of caught fish of each species, a relative index was calculated: the catch per unit of trawling area (ind./km^2). It is used in what follows as an interpolated density index.

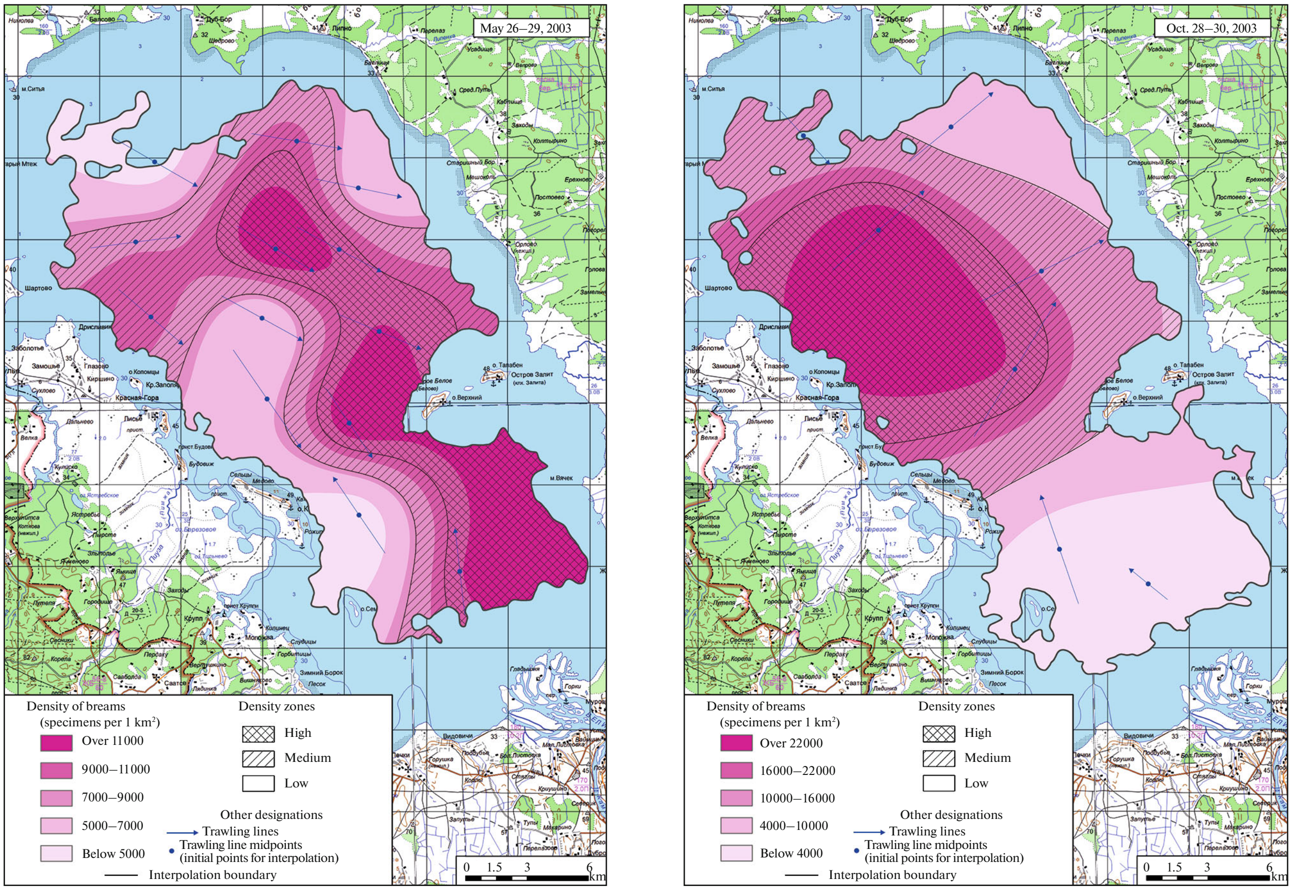


Fig. 1. Density distribution of bream in May (left) and October (right) 2003.

The transformation of the initial data for each of the above surveys enabled the compilation of maps of the density distribution of various fish species in Lake Pskov. In addition to the dates and seasons of surveys, the resulting set of maps reflects the representativeness of various fish species in trawl catches, which is not always sufficient for a complete picture of the spatial and temporal dynamics of some species with low abundance, as well as species with a stable localization outside the trawl area.

RESULTS AND DISCUSSION

Spatiotemporal Features of the Distribution of Various Fish Species

Although the spring–summer surveys demonstrate a rather variegated picture of the distribution of various fish species, certain peculiarities can be traced in its dynamics.

In the spring–summer period (at the end of May), the densest bream (*Abramis brama*) aggregations are recorded in the southern part of the lake, south of the Talab Islands, and also east of the central part of the water area. From year to year, the density of these clusters varies from more than 37000 to 6000 ind./km^2.

In October, the main bream group moves to the northern part of the lake and forms extensive aggregations, the density of which reaches more than 20000 ind./km^2 (Fig. 1).[2]

It should be noted that the total bream number, which was determined cartographically, demonstrates a significant increase from May to October due to the breeding results of the current year. Table 1 shows that this growth was most pronounced in the medium-water year 2003 and, to a lesser extent, in the high-water year 2008.

Some similarities with bream are observed in seasonal distribution of the white bream (*Blicca bjoerkna*). In late May–June, this fish forms dense aggregations in the southern part of the lake, in the area adjacent to the delta of the Velikaya River (its maxi-

[2] Seasonal maps of the fish distribution were obtained for all selected observation years, which differ in the water level. For illustrative purposes, the used maps are those that most clearly convey the characteristic features of the spatial dynamics of the populations.

Table 1. Total number of common fish species of Lake Pskov in different years

View	Number of individuals by year and season					
	2003		2006		2008	
	May 26–29	October 28–30	May 22–25	August 21–24	June 9–11	October 25–26
Perch	192913	698780	658153	1042249	1092372	2502377
juveniles		505867		384096		1410005
proportion of juveniles		0.72		0.37		0.56
Bream	5139757	9025814	2470615	3186321	4696348	4396090
juveniles		3886057		715707		?
proportion of juveniles		0.43		0.22		?
Pikeperch	231540	1024850	723122	1058206	551253	430149
juveniles		793310		335084		?
proportion of juveniles		0.77		0.32		?
Pike	9412	292406	29803	74022	26577	96307
juveniles		282993		44219		69730
proportion of juveniles		0.97		0.60		0.72
Roach	2138007	1078584	3450232	3150558	4199560	32265968
juveniles		?		?		?
proportion of juveniles		?		?		?

mum density here exceeds 5700 ind./km^2). In autumn, the white bream moves to the north, creating compact clusters of high density by the end of October (more than 9500 ind./km^2) in the water area adjacent to Kolpin Island (Fig. 2).

Unlike bream, the densest aggregations of the early summer roach (*Rutilus rutilus*) form in the northern part of the reservoir. At this time, all roach form a single group, the density of which in some years varies from 6000 to 20000 ind./km^2. In June, the roach is dispersed throughout the central part of the lake, and several local zones of high density form; they gravitate towards the eastern and western parts. The August roach distribution is basically the same as in June. At the end of October in the average-water year of 2003, the roach formed an extensive aggregation (a density of more than 7500 ind./km^2) in the southern part of Lake Pskov. In the low-water 2008, almost the entire population was concentrated in a relatively small area located in the northwest, adjacent to the mouth of the Värska River. The fish density there exceeded 121000 ind./km^2 (Fig. 3).

At the end of May, the main clusters of ruff (*Gymnocephalus cernuus*) occupy the southern part of the lake (the area adjacent to the delta of the Velikaya River). The ruff density in this area varies from 4000 to 9600 ind./km^2. In June, the ruff occupies almost the entire center of the lake (Fig. 4), reaching its maximum density in its eastern part (more than 10000 ind./km^2). By the end of October, it moves north, closer to the strait connecting the Pskov and Teploe lakes.

The distribution of the perch (*Perca fluviatilis*) is variable. At the beginning of summer in some years, its dense aggregations are compactly located in the northernmost or southernmost parts of the lake (Fig. 5). In the south, the perch density reaches 2000 ind./km^2, in the north, three times lower. By the middle of summer, the perch moves closer to the center of the lake, forming rather extensive aggregations on the border of the southern and central parts of the reservoir, in the waters located east of Kamenets Island, and sometimes adjacent to the Talab Islands. The perch density here reaches 4500 ind./km^2.

In spring and early summer, the localization of dense pikeperch (*Sander lucioperca*) aggregations (up

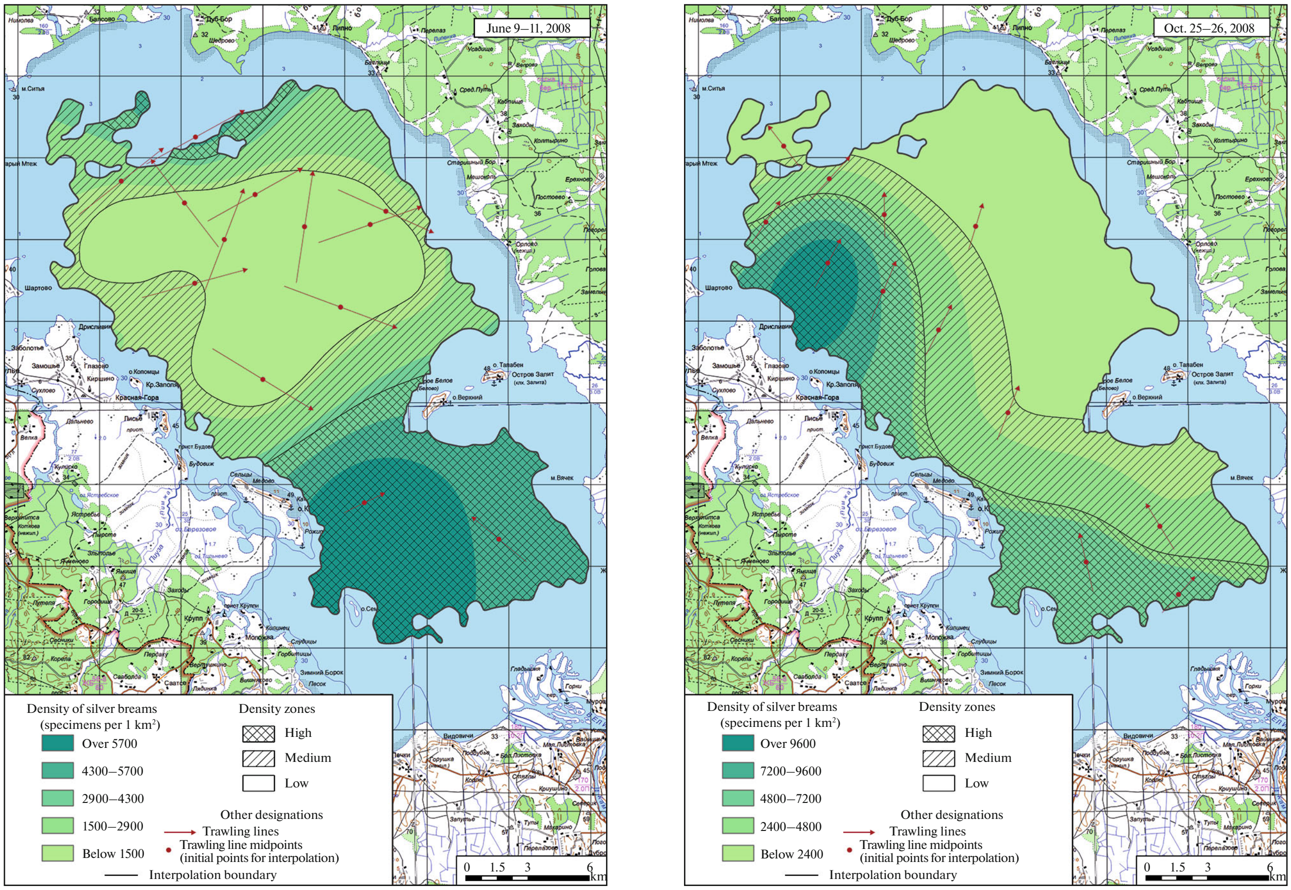


Fig. 2. Distribution of white bream in June (left) and October (right) 2008.

to 2000 specimens/km^2) is very similar to that of the perch (Fig. 6). In their position, they are also similar to the accumulation zones of bream and white bream. In late summer, the pikeperch is distributed throughout the eastern part of the lake; its maximum density in local areas reaches 3000 ind./km^2 or more. In autumn, almost all pikeperch move to the north, forming rather extensive zones with a homogeneous density of 1000 to 3000 ind./km^2 or more. The autumn aggregations of pikeperch almost coincide with the zones of the concentration of bream and white bream. As with the bream, the most noticeable increase in the abundance of pikeperch during the season took place in the average-water year of 2003.

The autumn distribution of pike (*Esox lucius*) bears some resemblance to the distribution of pikeperch. At this time, aggregations of this species are characterized by the highest density (more than 900 ind./km^2). In the spring–summer period, the pike assimilates the entire water area of the lake, and its distribution is more or less uniform. In the middle of summer, it is represented by a set of local aggregations of low density that gravitate towards coastal areas or are evenly distributed over the entire lake-water area (Fig. 7).

The spatial distribution maps for the burbot (*Lota lota*), the representativeness of which in trawl catches is low, indicate that its preferred habitat is the northern part of Lake Pskov (Fig. 8). It is there, in zones adjacent to the northwestern or northeastern parts of the water area, that its main aggregations are located. Their density is low and varies within 30–40 ind./km^2.

A common feature of the fish distribution in Lake Pskov is the more or less pronounced intraseasonal dynamics, which is clearly manifested in species such as the bream, perch, pikeperch, and roach and, to a lesser extent, the pike, ruff, and burbot. The similarity in the spatial position of species in the years of different water levels (which is especially characteristic of the autumn fish distribution) indicates that the movement of species within the Lake Pskov is regular.

One of the important features of the obtained picture of the fish distribution in Lake Pskov is the conjugation in the spatial position of some species of predatory and peaceful fish. It is most pronounced in the pair pikeperch–bream and partly in the pair pikeperch–perch. Since this conjugation manifests itself independently of changes in the hydrological (ecological) regime of the reservoir, it may be caused by

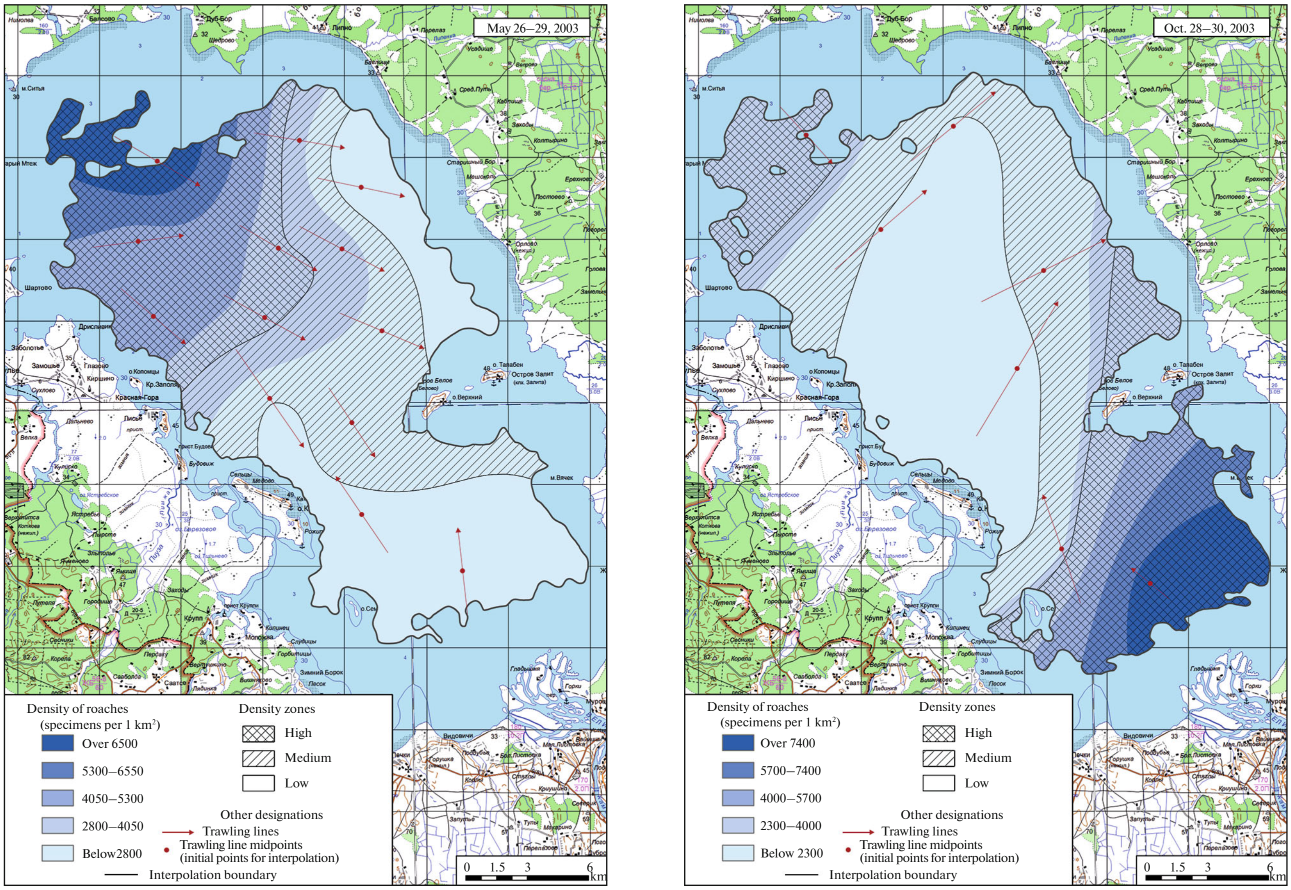


Fig. 3. Roach distribution in May (left) and October (right) 2003.

behavioral mechanisms (e.g., the tendency to maintain constant contact with species of potential prey, which is characteristic of pelagic predators) or similarities in reactions that ensure the choice of preferred habitats.

The relationship between the spatial dynamics of pike and that of roach, white bream, and perch is less pronounced. This is likely due to the absence of any strict food specialization in this predator or the peculiarities of the feeding behavior of the pike, which prefers to hunt along the prey migration routes in habitats providing maximum secrecy.

Fish Abundance and Changes during the Season

It should be noted that the hatching of different zones on the maps (Figs. 1–8) reflects the density ratios of certain species typical for a particular period of trawl survey. This representation does not take into account the interannual dynamics of the fish abundance, which can also affect the dynamics of their spatial position. Leaving the question of the relationship between population dynamics and distribution for the future, let us consider the results of a cartographic assessment of the abundance of individual species and its changes during the season.

In the simplest case, the total abundance can be estimated via integration of the density over the area of the trawling zone. The lake estimate as a whole requires additional information to allow extrapolation. In this case, it is based on the relationship between the fish density and depth.

Table 1 shows the calculated estimates of the abundance of five fish species in different seasons of the growing season.

As can be seen from the Table 1, the roach is first in abundance among the mass species. It is followed by the bream and then, with a lag, the pikeperch, perch, and pike. The ruff is also a species with high abundance, but it was not assessed due to the insufficient representativeness of this species in the trawl catches.

It is noteworthy that the obtained characteristics of the abundance at the beginning of the season, at least for pikeperch and bream, are in good agreement with the estimates obtained earlier via virtual population analysis (Danilov et al., 2018, 2020).

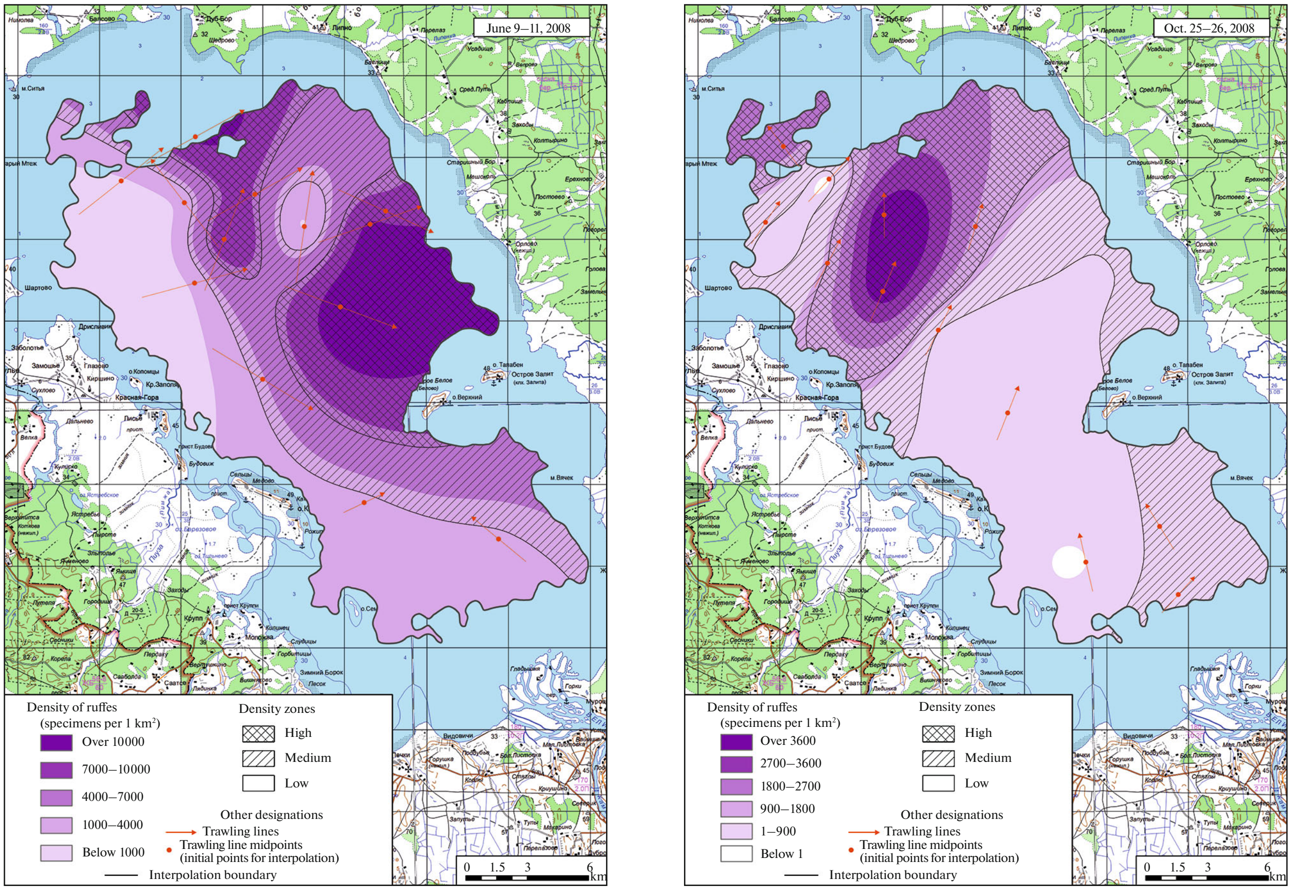


Fig. 4. Ruff distribution in early June (left) and October (right) 2008.

These Table 1 make it possible to trace the seasonal changes in the number of certain species, which, as a rule, increases from spring to autumn. There is no information about the movements of fish from Lake Peipsi to Lake Pskov in late summer or early autumn. Therefore, we can assume that the corresponding changes are due to reproduction. The difference between the abundance of the species at the beginning and the end of the feeding season is reflected in the table in the rows labeled "juveniles." Obviously, the estimates obtained in this way rather roughly reflect the abundance of juveniles, since they take into account only those in the trawling zone that are big enough for the trawl to keep. Nevertheless, these estimates can be used to judge the efficiency of the reproduction of species in different years. It can be measured by the proportion of juveniles in the total species number at the end of the season. This indicator turned out to be higher for the bream, pikeperch, perch, and pike in the average-water year 2003 than that recorded in the low-water 2006. The pike is first in terms of breeding efficiency. The perch and pikeperch follow. It is noteworthy that the pike is characterized not only by high rates of breeding efficiency but also by its fairly high stability. It turned out that the abundance of young roach cannot be estimated, which is apparently due to the fact that its feeding takes place in shallow waters, where trawl surveys are not carried out.

Age Features of the Spatial Distribution of Pikeperch in Lake Pskov

Information on the composition of populations of certain fish species provides additional information on their spatial organization, in particular, to identify the distinctions (if any) between the feeding areas of adult fish and their juveniles and thereby obtain more accurate information on the dynamics of the distribution of the population as a whole. Let us consider this issue using the example of pikeperch.

During the trawl survey, the size composition of some fish species, primarily, the pikeperch, which is the most abundant of the lake's biological resources, is assessed. As seen from Fig. 9, the histograms of the size distributions of pikeperch are distinctly divided into groups that unite fish of different ages. Their affiliation is easily established based on the available data

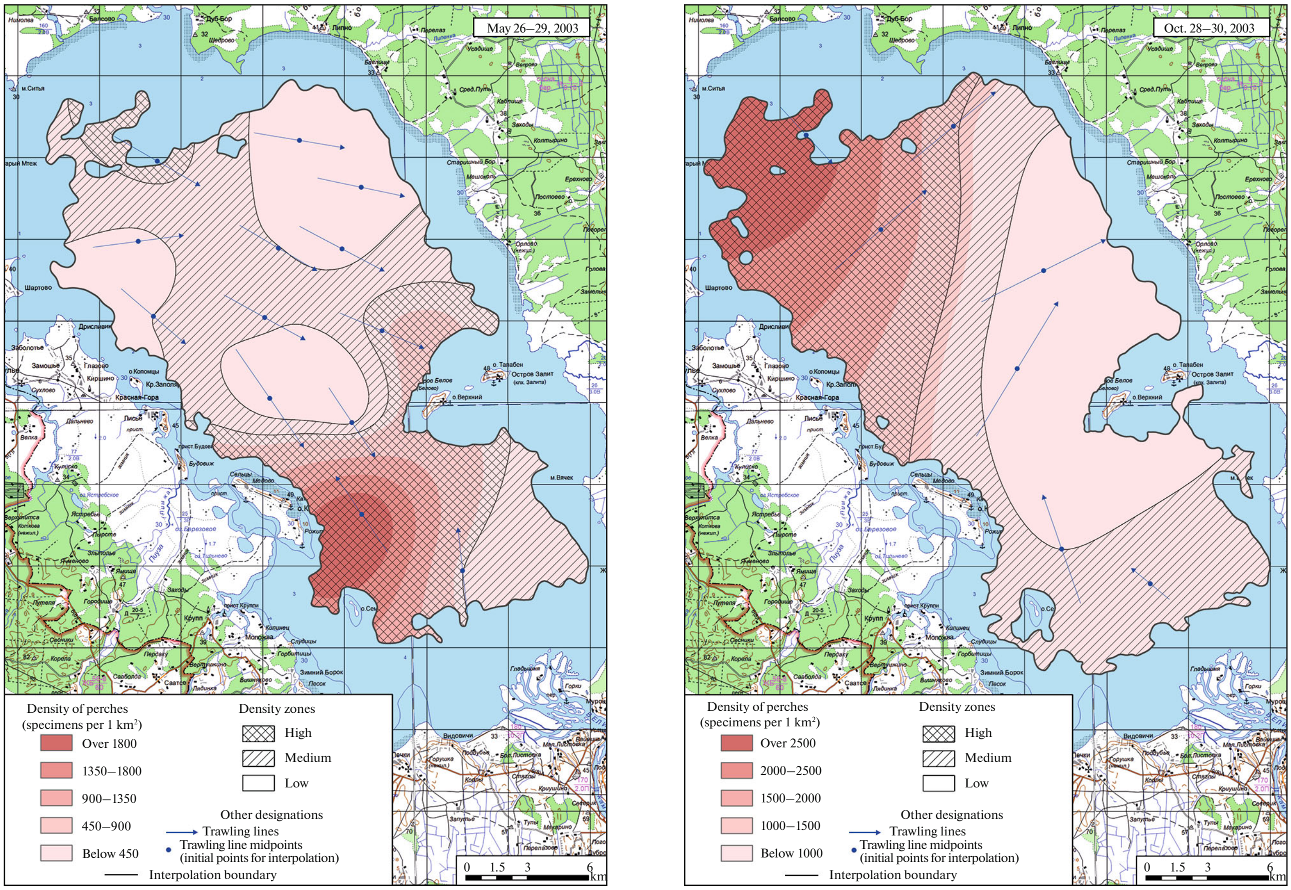


Fig. 5. Perch distribution in May (left) and October (right) 2003.

on the rate of pikeperch growth in size (Danilov et al., 2018).

The corresponding groups can be combined with the division of the population, for example, into "adult" fish, "fingerlings," and "yearlings" and the obtainment of estimates of the abundance of each of these categories. This technique makes it possible to specify the spatial distribution of the population with allowance for its internal heterogeneity. Unfortunately, the representativeness of the identified age categories in the experimental catches was sufficient only for some of the surveys carried out in the second half of summer and autumn of 2006 and 2008. Figure 10 presents maps that reflect the localization of juveniles and adult pikeperch in these years.

In August 2006, adult pikeperch were found throughout the entire water area of Lake Pskov; they formed dense aggregations in its southeastern part. In this period fingerlings were located to the north, in the shallow waters of the eastern part of the reservoir. Their distribution is presented in the form of local aggregations in a small area. The yearling distribution practically mirrored the distribution of adult pikeperch.

In 2008, fingerlings were found in the June and October samples. In June, the distribution of juveniles practically repeated the distribution of adult fish. In October, the main fingerling aggregations were in the northeastern part of the lake, in the same place as those of adults, but did not coincide with them. They preferred the shallow waters located to the west.

Differences in the localization of fish of different ages were manifested to the greatest extent in the distributions of adult fish and fingerlings, which, as a rule, keep apart and generally gravitate towards the shallower coastal zone. The data for 2006 and 2008 make it possible, as a first approximation, to determine the characteristic features of the pikeperch seasonal dynamics. In the spring months, the adult pikeperch move to the southern part of the lake en masse and feed on the spawning accumulations of many fish species (roach, white bream, bream, smelt, etc.). Yearlings at this time remain in the central part of the reservoir. There are no fingerlings in trawling areas.

In June, both adult fish and juveniles begin to move to the central part of the lake. By August, the pikeperch is distributed throughout the entire water area of the reservoir. The densest aggregations of adult pike-

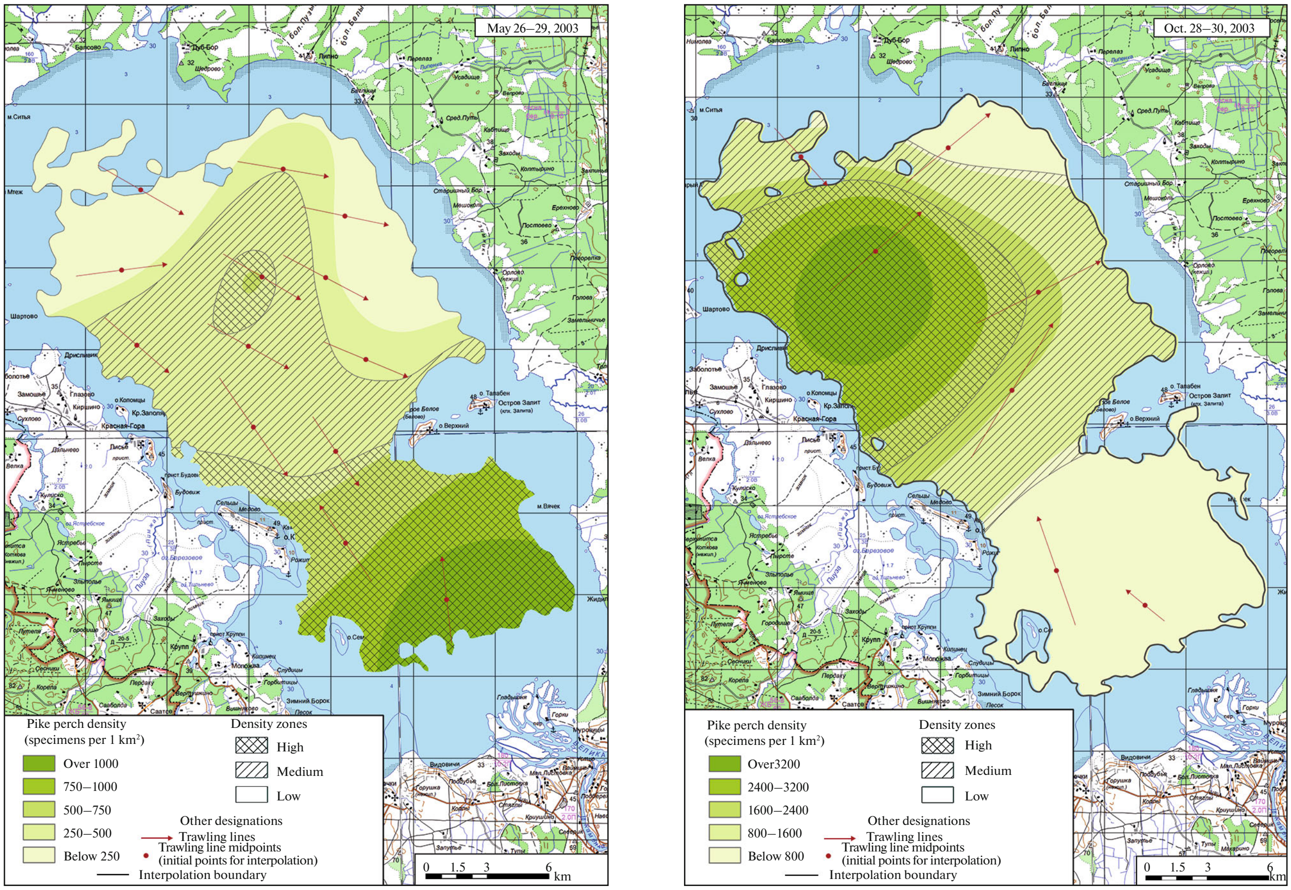


Fig. 6. Pikeperch distribution in May (left) and October (right) 2003.

perch at this time are located within the areas adjacent to the eastern coast, which coincide with the zones of accumulations of such species as bream, roach, white bream, ruff. In October, many species, including the pikeperch, move to the northern part of the lake and prepare for wintering in areas of the nearby Lake Teploe.

In general, the results indicate that the number and total area of dense fish concentrations are positively related to water level. The prevailing depths at which clusters form are 4.1–4.6 m. With an increase in lake-water levels (in comparison with the values typical for the considered year), the zones of high fish density shift to a region of greater depth with a surface-water temperature that corresponds to the average values and is below the average values for the water area. This is illustrated by the diagram of changes in the density of roach aggregations with respect to the depth and water temperature in May 2003 (Fig. 11).

As noted above, the comparison of fish-distribution maps are indicative of the spatial conjugation of individual species. The developed system makes it possible to carry out a detailed analysis of the spatial relationships between the occurrence of such species and to analyze their dependence on the considered environmental factors. As an example, let us consider maps of aggregations of pikeperch and bream at the end of May 2003 (Fig. 12) with the profile A–B, which crosses areas from north to south with different densities of both types.

Along the profile in the direction from north to south, the values of density, temperature and depth were taken and then transferred to graphs; the distances from A to B are given along the horizontal axes (Fig. 13).

It should first be noted that the curves of changes in the density of bream and pikeperch are similar at a given orientation of the profile, which confirms the similarity of their spatial position noted above. At the same time, the ratio of the species number remains practically constant and independent of the density: there are always 2.5–3 times more bream. An almost synchronous jump in the density of both species is also noticeable (from 2000 to 7000 ind./km^2 for bream and from 500 to almost 3000 ind./km^2 for pikeperch) following a 1° increase in the surface-water temperature.

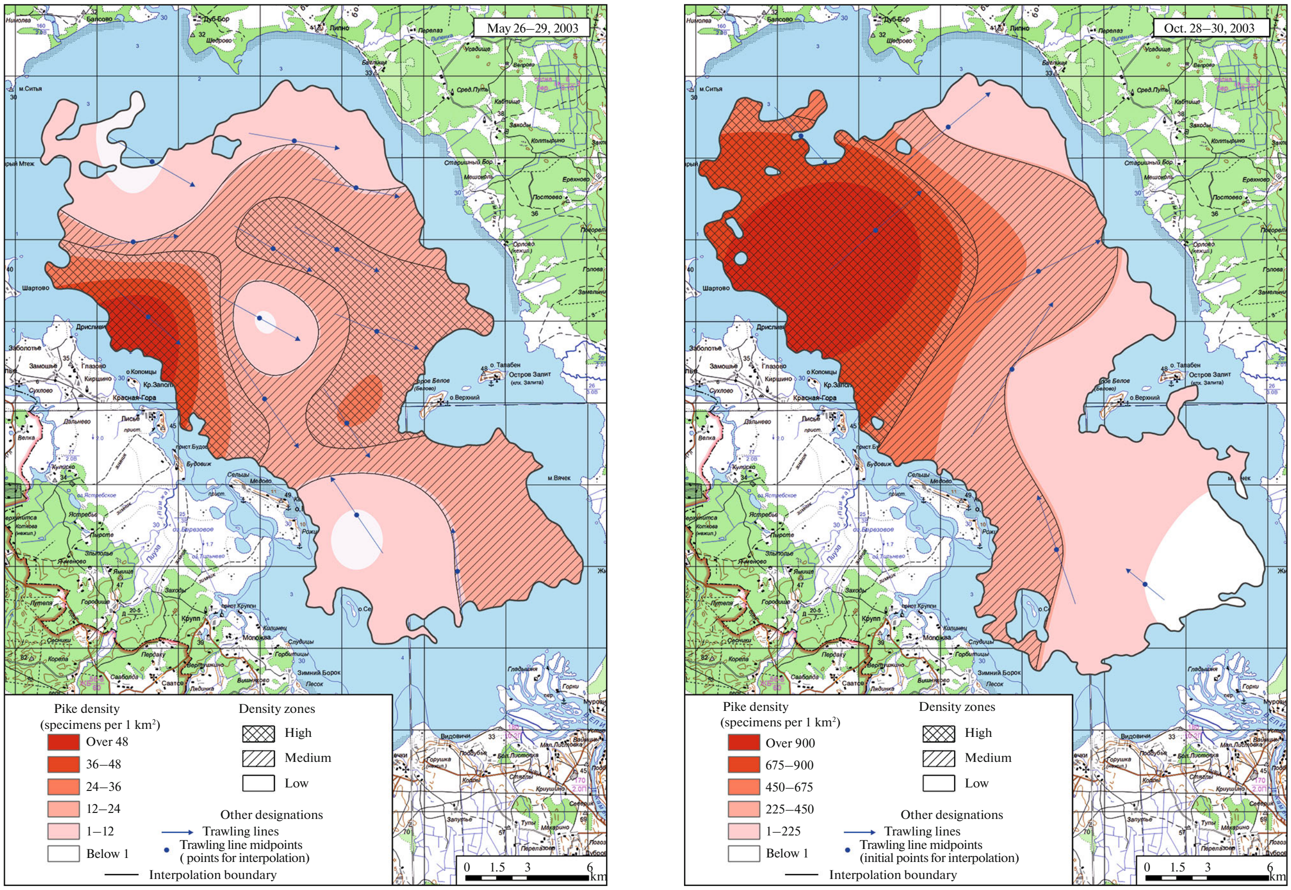


Fig. 7. Pike distribution in late May (left) and October (right) 2003.

We noted above that the similarity of the spatiotemporal dynamics of the considered species can be generated by both trophic relationships and similarities in the responses that ensure the choice of preferred habitats. The results obtained with the use of profiles provide clear evidence in favor of the latter. This indicates that there is a positive relationship between species and temperature, which is typical for representatives of the Ponto-Caspian faunal complex.

It is noteworthy that the surface temperature increases as one moves towards the areas experiencing the greatest influence of Velikaya River runoff. It is recorded on the depth profile from 11 to 16 km, where a channel probably forms. The relatively warm waters from the Velikaya River flow along it.

SUMMARY

Despite the long history of research on the biota of Lake Pskov (Kangur et al., 2001), the scientific publications on these studies contain little information on the spatial characteristics of individual fish populations and their intraseasonal and long-term dynamics.

It is obvious that the biotic environment of any large water body is heterogeneous. In the Lake Pskov (the water area of which is more than 700 km^2), the expression of this heterogeneity was confirmed by monitoring of the organisms that form the primary links of the community, as well as the benthos organisms. This is shown, for example, by studies of the nature of the distribution of macrophytes, phytoplankton, and macrozoobenthos (Laugaste et al., 1996; Timm et al., 1996; Sudnitsyna et al., 2009; Mikhailova and Mikhalap, 2019; etc.) It can be expected that similar features are inherent in other groups of organisms, including fish, which lead a mobile lifestyle and occupy the upper trophic levels in the lake community. The results indicate that the heterogeneity of distribution is inherent in almost all of the species of fish considered above, which indicates that the spatial factor must be taken into account during the assessment of the nature of their biotic relationships, in the planning of economic activities, and, ultimately, in the prediction of the overall course of the formation of the biological production of the reservoir.

Unfortunately, the limited number of hydrological measurements carried out on the lake does not allow a

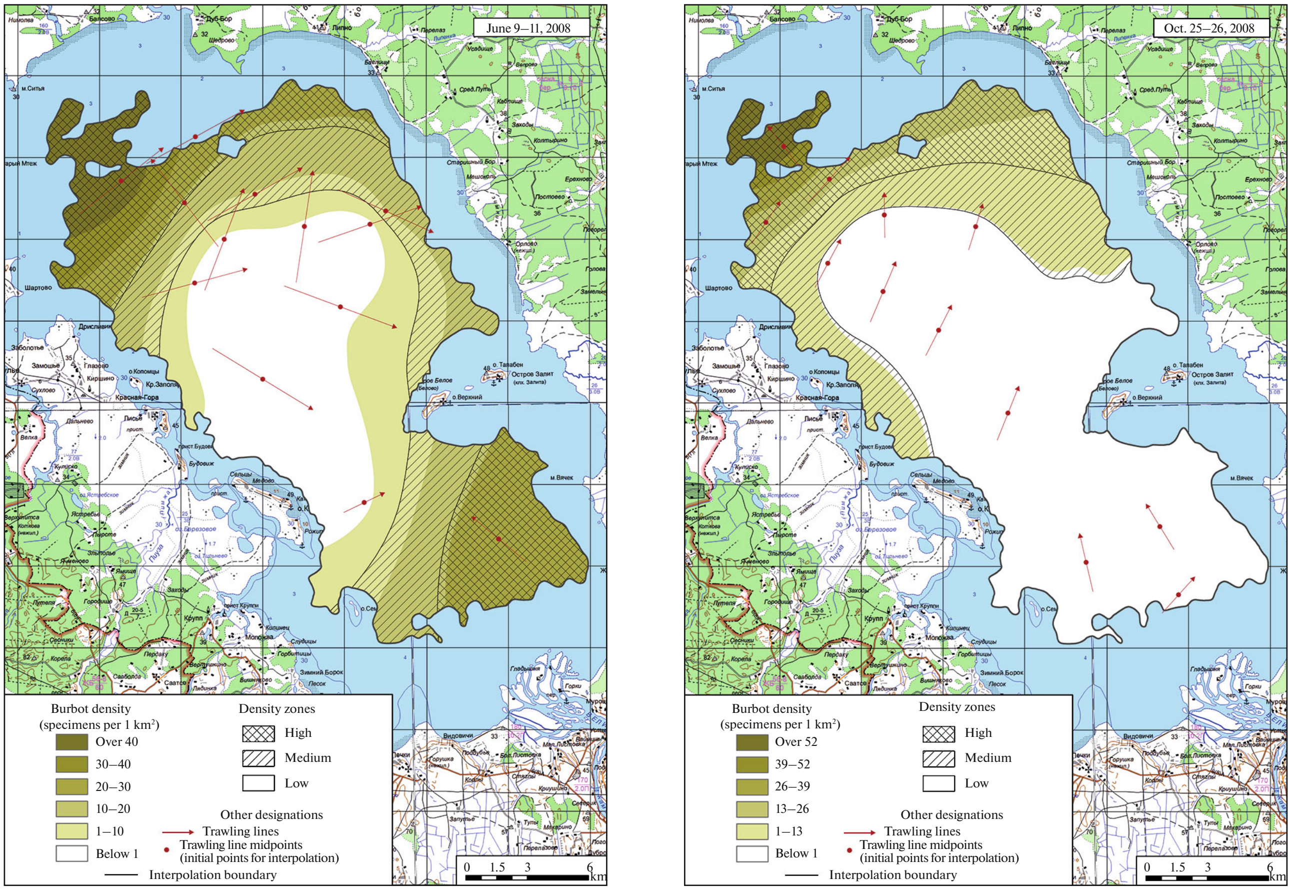


Fig. 8. Burbot distribution in early June (left) and in October (right) 2008.

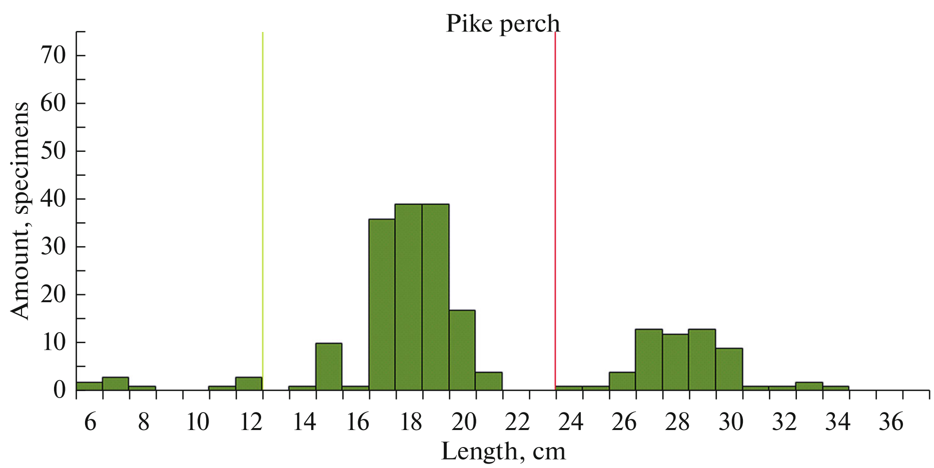


Fig. 9. Example of the pikeperch size distribution (trawl no. 6, August 2006).

full study of the role of external factors that ensure the formation of aggregations of various fish species. It is not excluded that the answer to these questions can be provided by indirect measurements, e.g., those based on the interpretation of satellite images synchronized in time with trawl counts. Leaving this task for the future, we note that the developed GIS makes it possible to carry out a variety of comparisons that are useful to clarify the nature of and to assess the intensity of relationships between individual species. The previ-

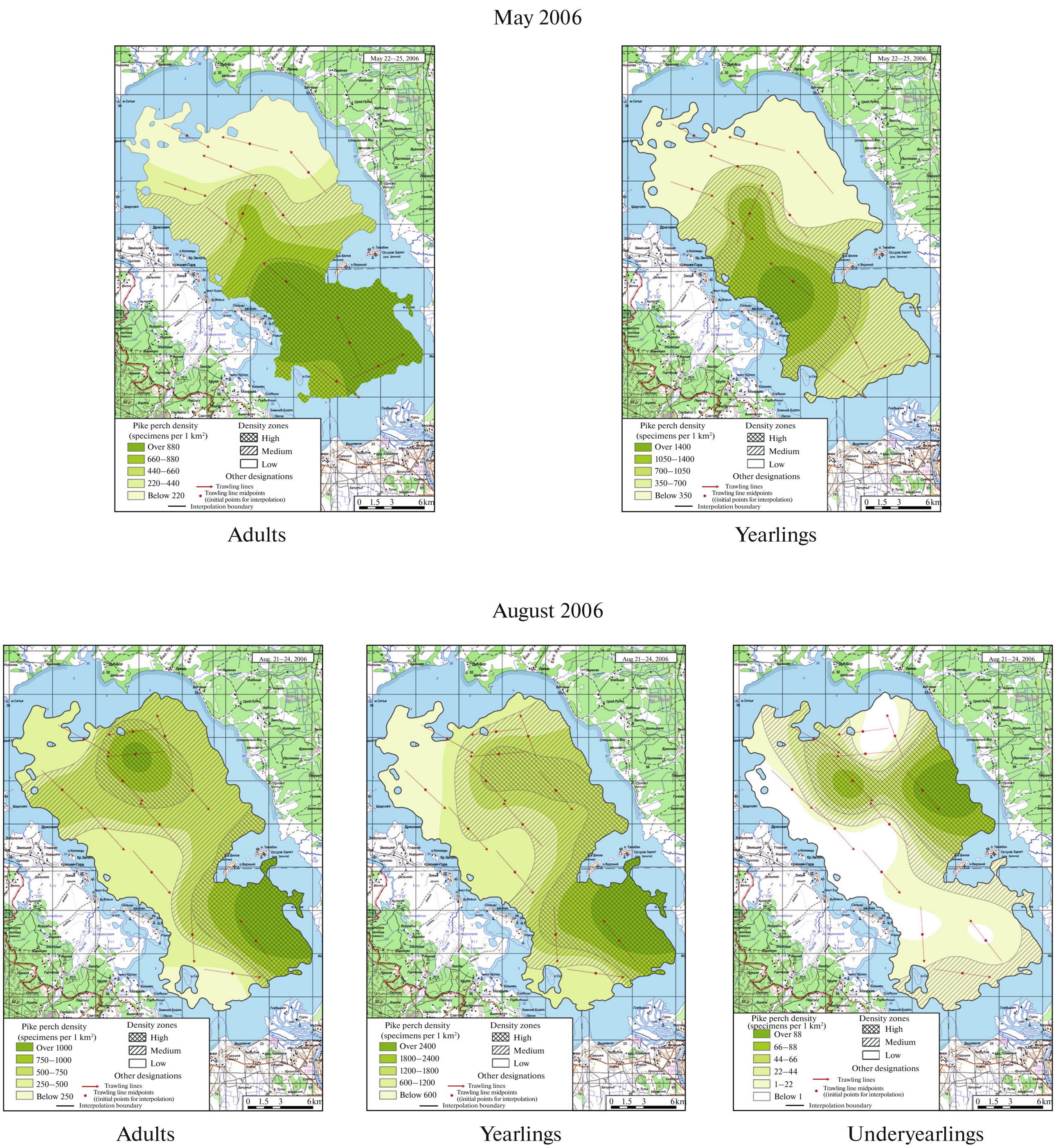
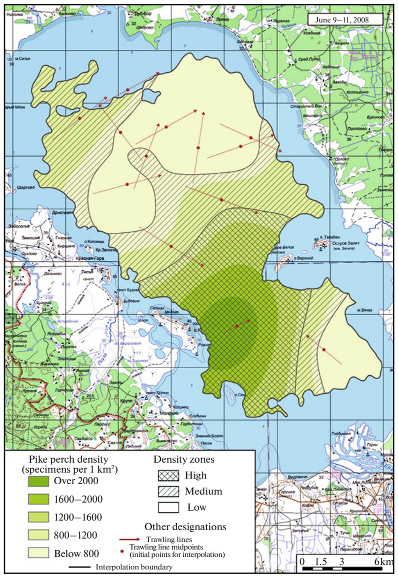


Fig. 10. Spatial distribution of different age groups of pikeperch.

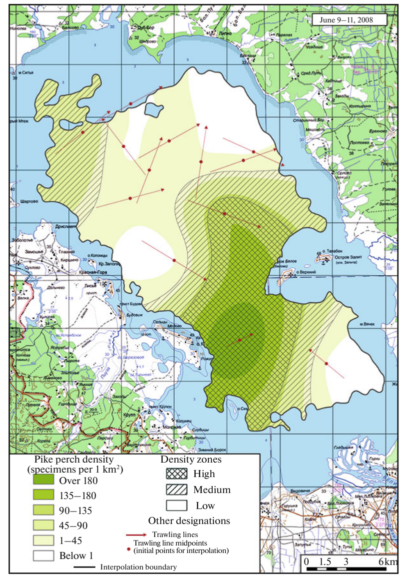
ously studied mass-balance model of the Lake Pskov–Peipsi community (Bobyrev et al., 2013) provided only the most general view of its functioning, reducing the internal diversity of the ecosystem and its main elements to spatially averaged indicators. The results of cartographic analysis make it possible to adjust the model parameters, e.g., based on areal estimates of zones that are common for various species of aquatic organisms connected by competitive relations or relations of the "consumer-resource" type. At the same time, they make it possible to move to the analysis of an extended, more powerful version of the model that takes into account the spatial factor.

In this work, using the clarity inherent in cartographic methods, we restrict ourselves to a description of the general picture of the spatiotemporal dynamics

June 2008

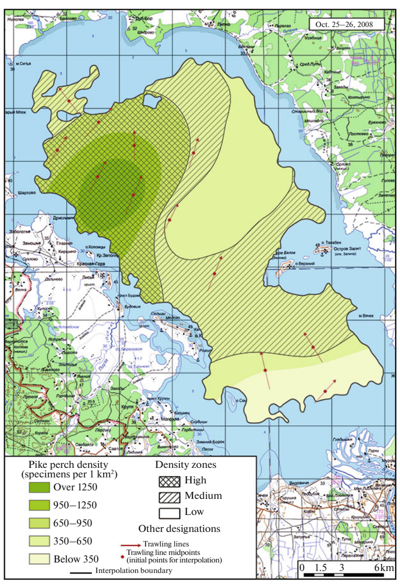


Adults and yearlings

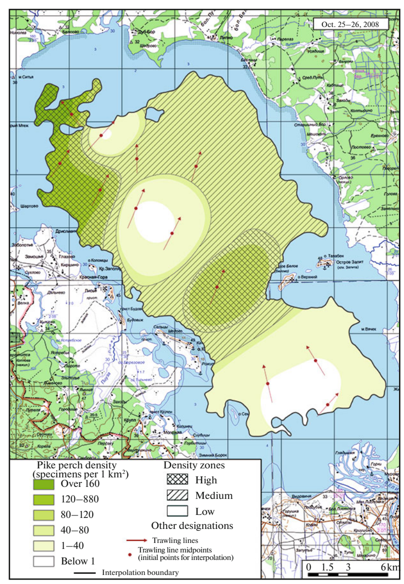


Underyearlings

October 2008



Adults and underyearlings



Underyearlings

Fig. 10. (Contd.)

of the fish population of Lake Pskov. Less attention is paid to their analytical tools, which can reveal the role of factors that are commonly considered responsible for the deterioration of the ecological state of the reservoir and the decrease in its production characteristics. According to the general opinion, these include organic pollution of the lake (Nõges et al., 2003; Kondratyev et al., 2014; Sudnitsyna and Cherevichko, 2015; Lozovik and Frumin, 2017; etc.). The publications on this contain direct or indirect estimates characterizing the concentration of compounds of nitrogen, phosphorus, and other elements. Unfortunately, data on their distribution over the water area are extremely limited. Note that the interpretation of the

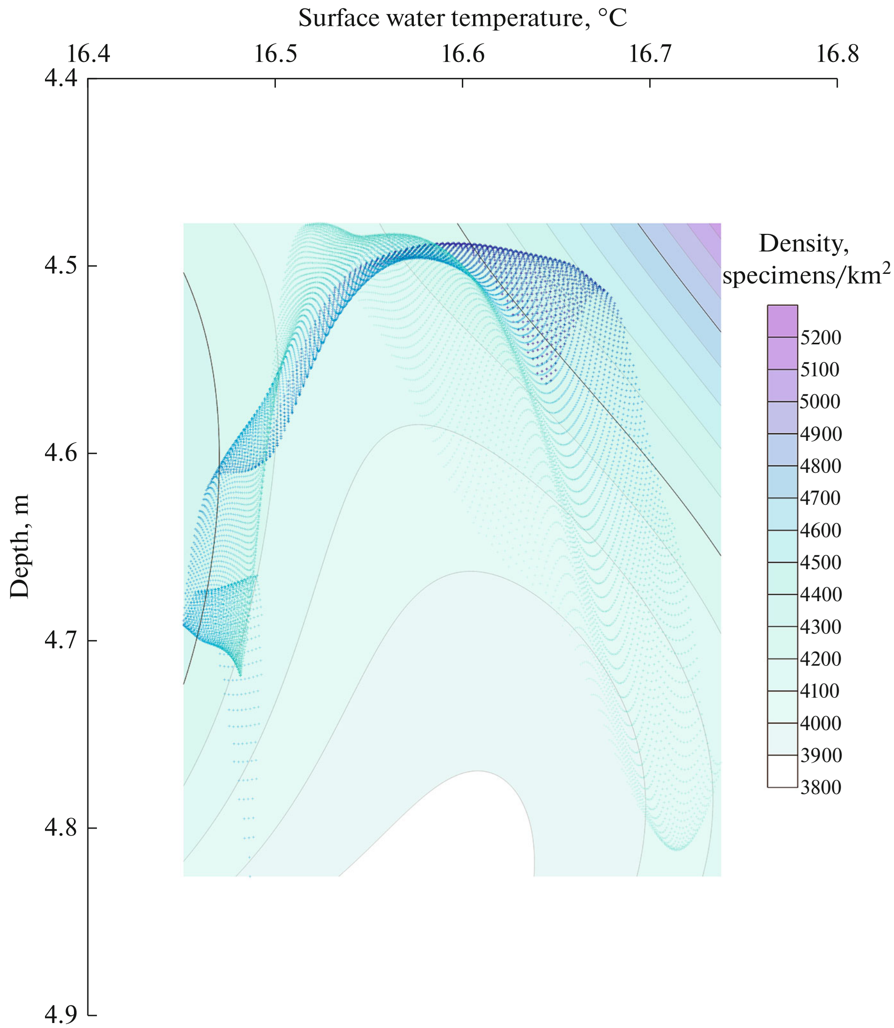


Fig. 11. Relationship between the roach-cluster density and the temperature and depth of Lake Pskov.

role of pollutants in itself is currently based on general ideas and lacks specific content. The created GIS can be used to integrate and accumulate relevant information, to make it available for comparison and analysis, and to reveal the importance of the pollution factor in the formation of the ecological regime of the lake.

Fishing plays an important role in the maintenance of the fishery status of Lake Pskov. It should be noted that fishing activity, based on its inherent empirical experience, partly takes into account seasonal changes in the formation of fish aggregations, concentrating efforts for a short time on relatively small areas located mainly in the spawning area. It is quite obvious that it can be extremely useful to take into account the spatial distribution of biological resources in other seasons of the fishing period in order to optimize the placement of various fishing gear, to predict the results of fishing for effective management of fishery activities, to protect biological resources, and lastly, to solve social problems for the placement of recreational facilities or the justification of fishing-ground boundaries.

CONCLUSIONS

1. A common feature of the distribution of fish in Lake Pskov is their pronounced intraseasonal dynamics, which is regular and clearly manifested in species such as the bream, perch, pikeperch, and white bream and, to a lesser extent, the pike, roach, ruff, and burbot. Spring accumulations of fish of the first group tend to be found mainly in the southern part of the lake, and those of the second are found in the eastern and western parts. From August, dense aggregations of most species begin to move northward, to the central part of the lake. In October, almost all of them are

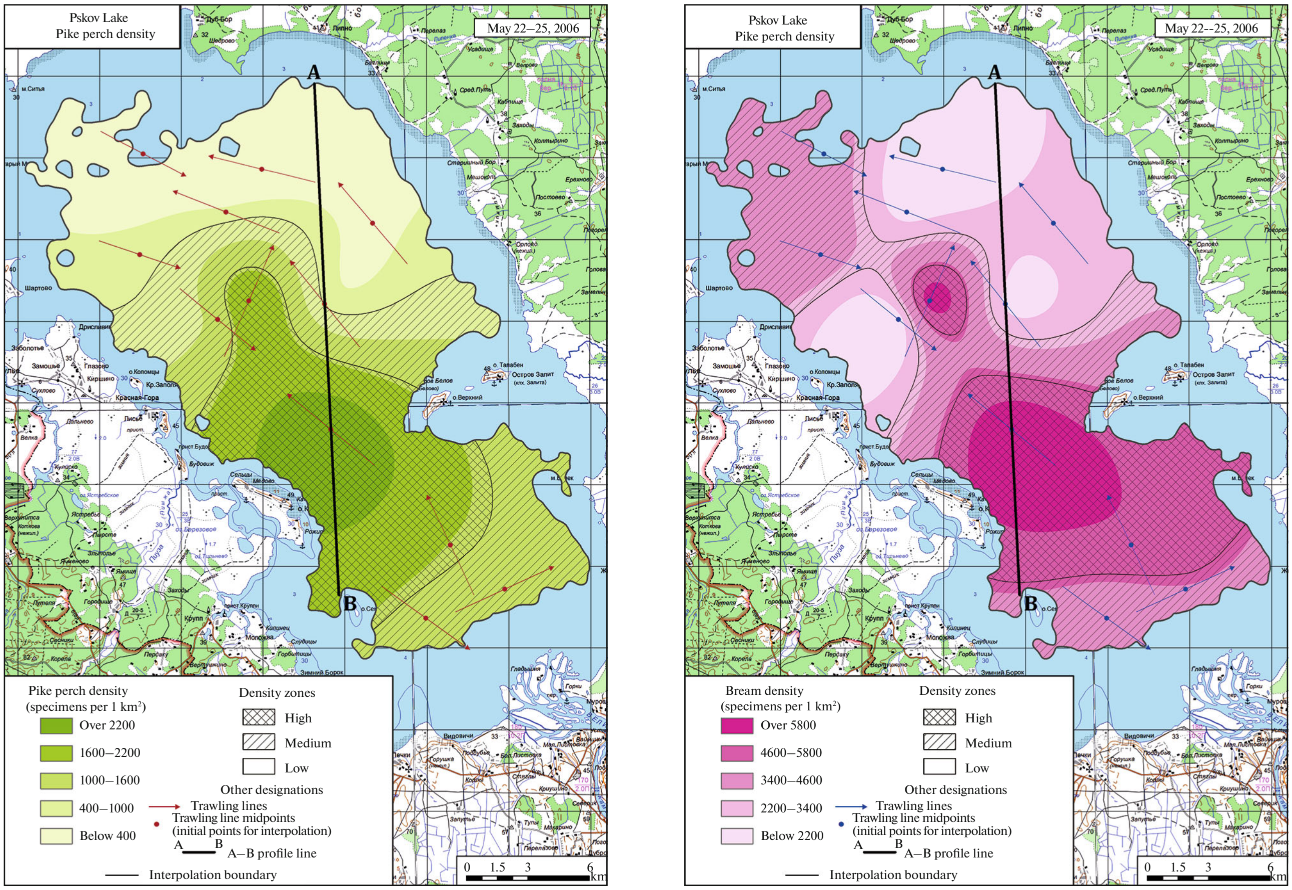


Fig. 12. Densities of pikeperch (left) and bream (right) clusters at the end of May 2003 and profile position A–B.

concentrated in the water area located in the deepest part of the reservoir adjacent to Lake Teploe.

2. One of the important features of the fish distribution in Lake Pskov is the conjugation in the spatial position of a number of species. It is most pronounced in the pair pikeperch–bream and partly in the pair pikeperch–perch. This conjugation is likely due to the similarity of their responses to hydrological conditions, which ensures the choice of preferred habitats.

3. Cartographic estimates rank the roach as the most abundant of the fish species. Its representativeness in the fish population of Lake Pskov is adequately reflected in the composition of trawl catches. It is followed by the bream, pikeperch, perch, and pike. The cartographic estimates of the abundance of pikeperch and bream are consistent with independent estimates obtained via virtual population analysis. A quick assessment of the efficiency of species reproduction in different years can be obtained based on geoinformation analysis according to data on the ratio of the population size at the beginning and end of the open-water period.

4. Differences are observed in the distribution of pikeperch individuals of different ages, which are manifested in the isolated localization of adult fish and fingerlings. The adult pikeperch move en masse to the southern part of the lake in the spring months; they feed on many of the accumulations of fish species (roach, white bream, bream, smelt, etc.) that spawn there. Yearlings at this time remain in the central part of the reservoir. Subsequently, the distribution of yearlings repeats the distribution of adult fish.

5. Geographic information analysis based on cartographic profiles indicates that there is a positive relationship between the seasonal distribution of the pikeperch and bream density with the surface-water temperature. This connection can be considered a factor that indirectly ensures the conjugation of the spatiotemporal dynamics of these species.

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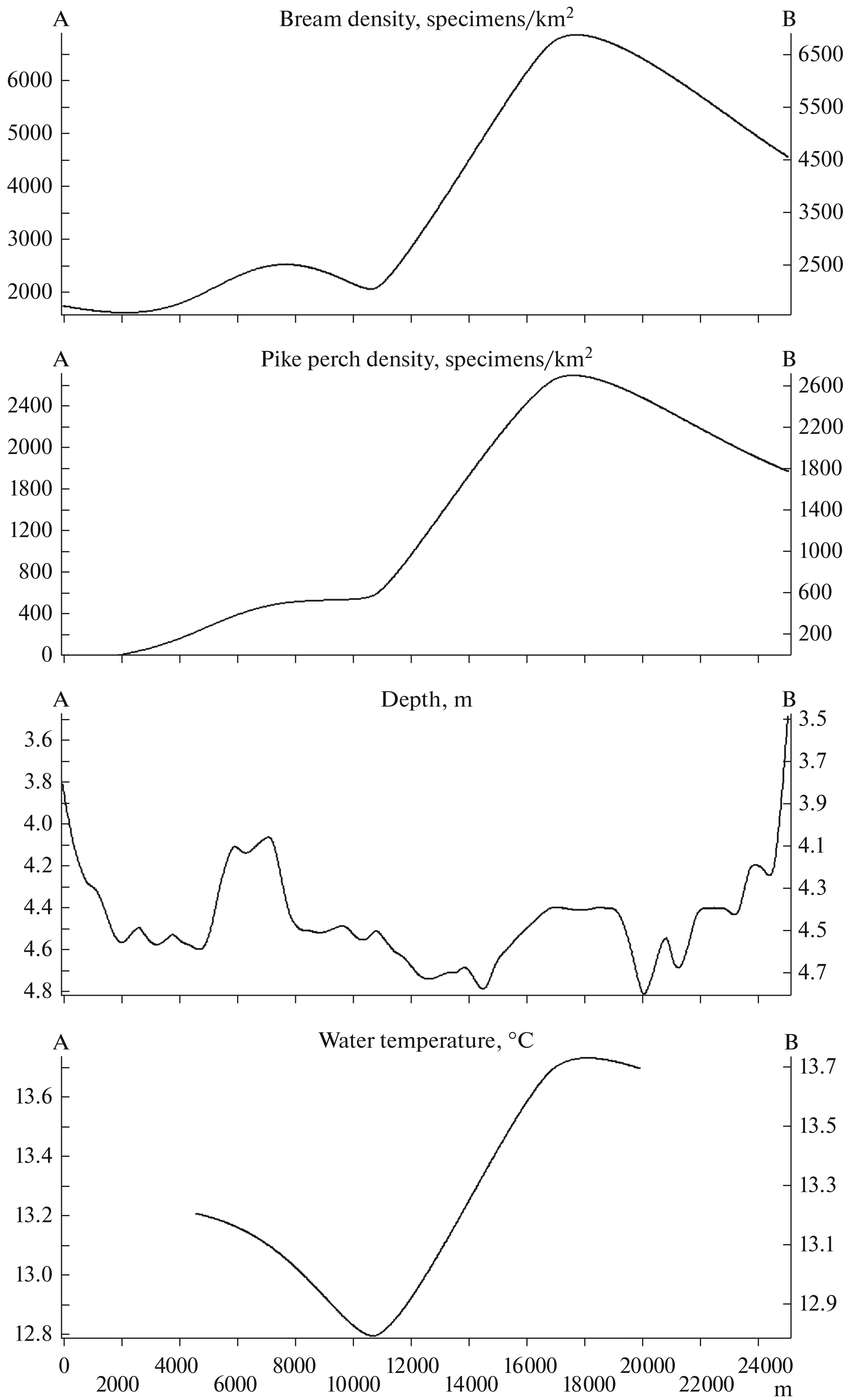

Fig. 13. Diagram of the correspondence between the density of pikeperch and bream clusters with allowance for the temperatures of the water surface and depths along the profile A–B.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflicts of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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