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Summer and Autumn Distribution of Fish in Lake Glubokoe[1]

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Abstract—Seasonal (summer and autumn) and diurnal (day and night) distribution of fish in Lake Glubokoe (Moscow oblast) was analyzed using vertical and horizontal scanning research hydroacoustic systems. At the beginning of summer the distribution of the fish in lake is broad and homogeneous whereas in autumn it is more compact. Pelagic aggregations of the fish are aggregated mostly in the central part of this lake both in summer and autumn during the day. However, at night they scattered throughout its whole area. The pattern of the fish distribution depends on the cycles of the abiotic conditions and the concomitant pattern of trophic and defensive relationships.

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INTRODUCTION

Lake Glubokoe is situated in the Ruza district of Moscow oblast (55°45′ N 36°31′ E) and represents a mesotrophic water body with the total area 59.3 Ha with significant depth (up to 32 m in the central part of lake). Its littoral and sublittoral are densely vegetated by macrophytes, the sides are with forest and swamps. This ecosystem has been subjected to a rather low anthropogenic pressure until recently (Pavlov, 2002). The fish fauna of Lake Glubokoe includes 19 fish species, including the most abundant families: Cyprinidae: roach *Rutilus rutilus* and bream *Abramis brama*, Percidae: common perch *Perca fluviatilis* and ruffe *Gymnocephalus cernuus*, Esocidae: pike *Esox lucius* (Dgebuadze and Skomorokhov, 2002).

The first studies of the fish distribution in this lake usinf hydroacoustic systems have been conducted at the end of the 20s century (Pavlov et al., 1986, 1991; Presnyakov and Borisenko, 1993). However, the characteristics of that equipment had limited capabilities with respect to the recording of small juveniles, the size of the fish and their localization th the three-dimensional space. Therefore, additional studies of fish distribution in Lake Glubokoe using modern hydroacoustic devices is highly actual.

The aim of this work is to study the distribution of fish in the open part of Lake Glubokoe during summer and autumn and determine the most significant environmental factors that affect it. The main objectives of the study are to analyze the seasonal and diurnal dynamics of fish distribution in the open part of Lake Glubokoe, determine the size composition of the fish aggregations and patterns of environmental effects on their development.

[1] The article was translated by the authors.

MATERIALS AND METHODS

The hydroacoustic research was conducted using the research systems Askor and Pankor (Promgidroakustika, Russia). This equipment allowed to account for the abundance of fish, location and abundance of their aggregations, determine the body length of separate fish and identify them to the family using computer analysis of the reflected echo signals (Borisenko et al., 2006; Kudryavtsev and Borisenko, 2009; Pavlov et al., 2010). The body length of the fish was calculated from the values of the fish target strength TS (dB) obtained in situ using regression equations obtained for the most abundant species of temperate zones of Russia (Borisenko et al., 1989, 2006).

To study the distribution of fish in the epipelagial (from surface to 2 m depth) we used the Pankor hydroacoustic complex. Its working frequency is 455 kHz, maximum distance of horizontal scanning is 20 m. Analysis of the fish distribution at the depths exceeding 2 m was conducted with two-band vertical scanning complex Askor. Its working frequencies are 50 and 200 kHz, maximum operating distance is 100 m (Kudryavtsev et al., 2006; Pavlov et al., 2008; Borisenko et al., 2011). The use of the Askor system at the frequency 200 kHz also allowed to detect aggregations of zooplankton and determine their precise location. We used both Pankor and Askor simultaneously during our surveying, which allowed near-total recording of all fish throughout the whole water horizon, from the bottom to the surface.

The basic conception of the fish distribution as a continual process (Pavlov and Mochek, 2009) determined the necessity of obtaining data on fish location in different time of the day and in different seasons of the year. Overall, we conducted four hydroacoustic

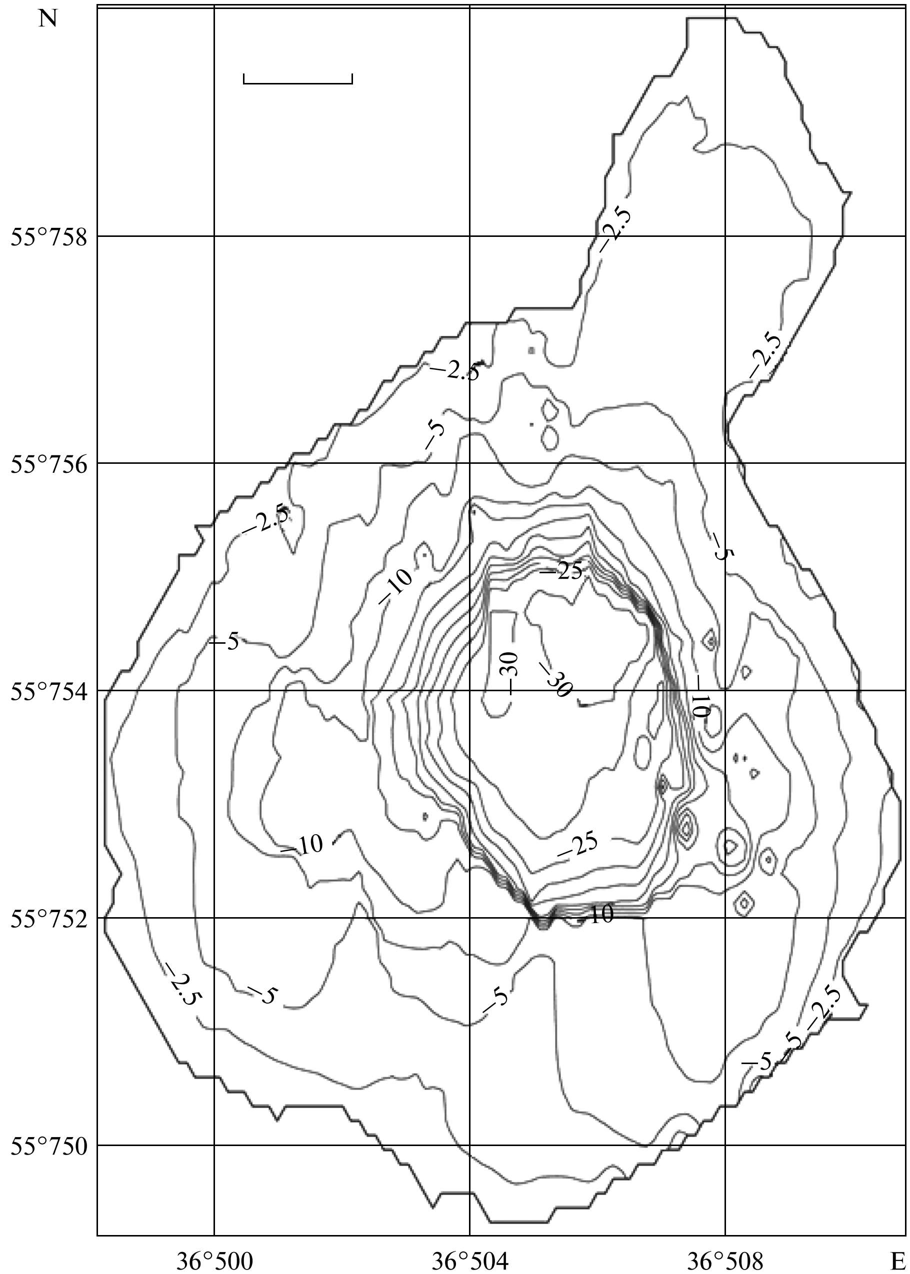


Fig. 1. Bathymetric map of Lake Glubokoe; (–)—isobath. Scale 100 m.

surveys in 2013: two in July (day and night) and two in October (day and night). The duration of each survey was approximately 2 hours. The surveys were conducted from a boat equipped with a low-noise electric engine. Hydroacoustic transponders were placed overboard using a specialized bracket. Hydroacoustic recording on the hard disk of the computer with visual control of its work was conducted by the operator onboard. The surveys were conducted on the open water area because echo-sounding equipment is possible only in absence of macrophytes and other large scale underwater obstacles.

To determine the relationship between the depth and fish density we conducted gridded bivariate linear interpolation of these measures on a grid using the Akima's algorithms (Akima, 1978) and subsequently calculated the correlation coefficients between the interpolated values.

RESULTS

Our hydroacoustic surveys of Lake Glubokoe allowed to obtain its current bathymetric map based on 12400 base points (Fig. 1). This map indicates that the perimeter of this lake is represented by shallow

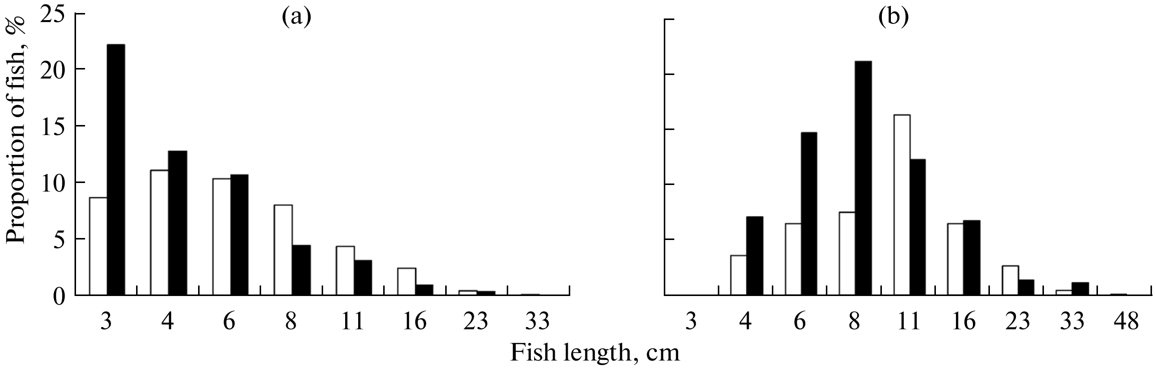


Fig. 2. Size composition of fish in the pelagial of Lake Glubokoe in July (a) and October (b), based on hydroacoustic surveys: (□)—day, (■)—night.

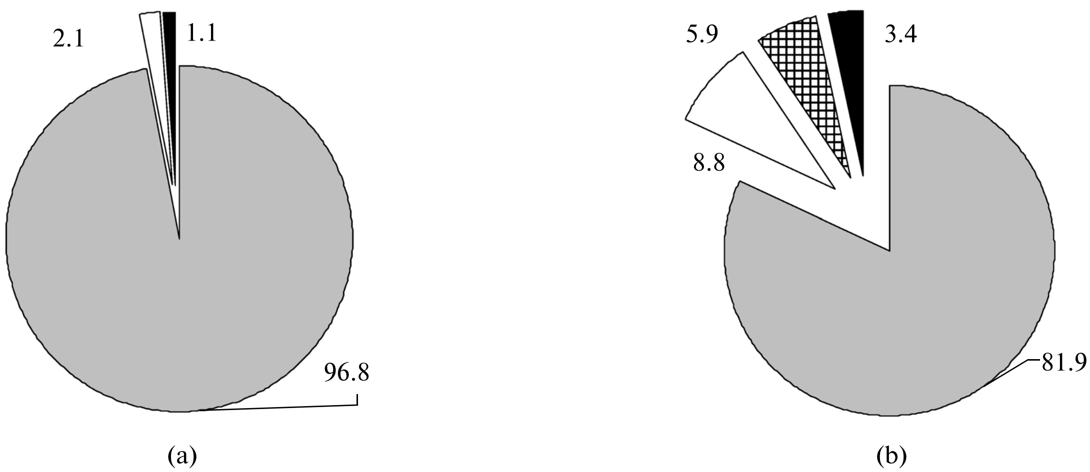


Fig. 3. Composition of the fish (families, %) in the pelagial of Lake Glubokoe in July (a) and October (b), based on hydroacoustic surveys; (▒)—Cyprinidae, (□)—Percidae, (⊞)—Esocidae, (■)—unrecognized.

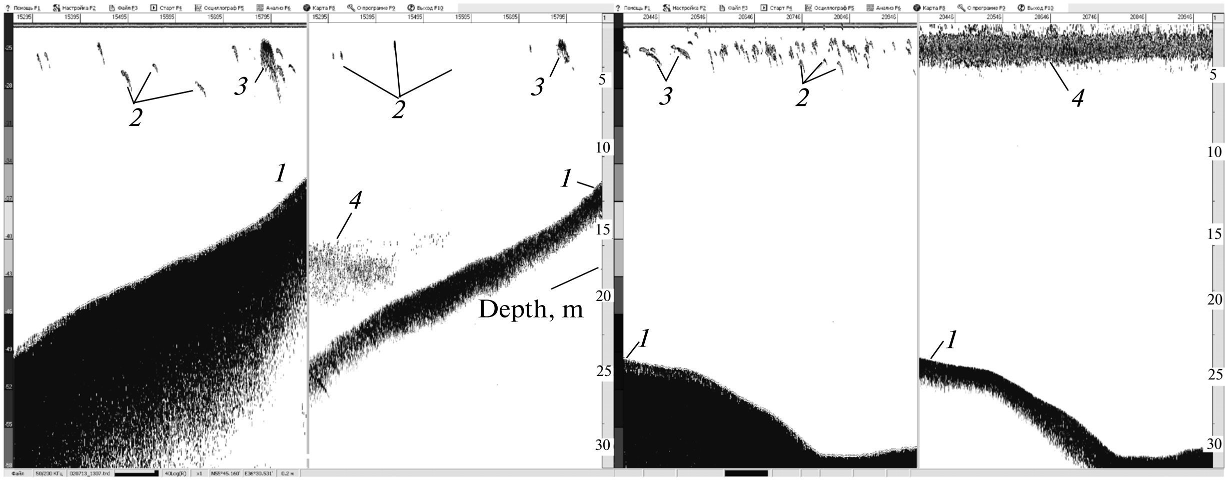
plain with the depth to 2.5 m. From the sides to the center, the depth increases, the bottom topography is relatively complex up to 12 m. A sharp slope is recorded in the central part of the lake, here the depth reaches the 20-m level. The maximum depth in Lake Glubokoe is 32 m.

Due to significant maximum depth and almost complete absence of effluent discharge, Lake Glubokoe has a characteristic thermal regimen. A stable thermocline has developed at the depth 4.0–4.5 m at the beginning of July. The water temperature in the near-surface water of the epilimnion reached 25°C, did not exceed 21.5°C at 3.5 m, and abruptly reduced at 4 m to 13°C. The metalimnion zone with water temperature 10–12°C was observed up to the depth 6.5 m. Hypolimnion begun from the depth of 7 m. The minimum water temperature in summer (7°C) was recorded in Lake Glubokoe at the depth exceeding 20 m (E.A. Mnatsakanova, personal communication). Thermocline disappears at the beginning of September and temperature becomes homological throughout the whole water column to the middle of October (Shcherbakov, 1967).

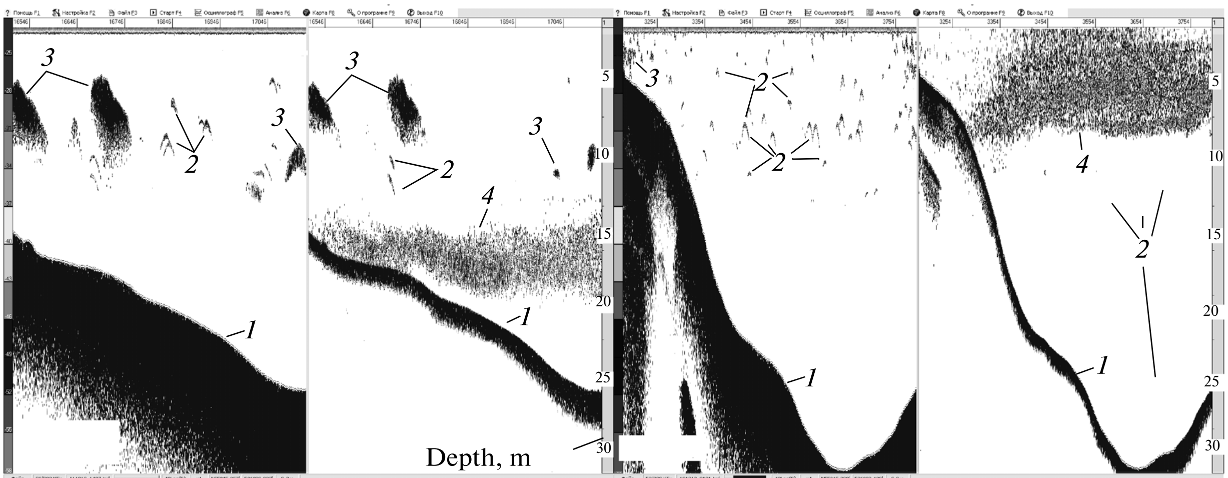
Summer distribution of the fish is characterized by aggregation of most of them in the epilimnion, the water layer above the thermocline. Indeed, most fish are located close to the surface up to the depth of 2 m: about 250000 fish are concentrated in this narrow near-surface horizon during the day and more than 500000 at night. Slightly more than 200000 fish were recorded at the depth exceeding 2 m during the day and more than 300000 at night.

In July, the pelagial was dominated (Figs. 2a and 3) by the fish with the length not exceeding 4 cm (Fig. 2a). Juvenile cyprinids (96.8%) significantly dominated whereas the share of perches was only 2.1% (Fig. 3a). Our echograms (Fig. 4) point to spatial association of fish (frequency 50 kHz) and plankton (frequency 200 kHz) aggregations (Figs. 4a and 4b).

At night the fish occupy almost the whole open area of Lake Glubokoe (Fig. 5), whereas during the day their aggregations occur predominantly in its central



(a) (b)



(c) (d)

Fig. 4. Echograms of fish aggregations recorded with Askor (working frequency 50 kHz), fish and zooplankton (working frequency 200 kHz) in the pelagial of Lake Glubokoe in July (a, b) and October (c, d) during the day (a, c) and night (b, d): *1*—bottom, *2*—fish recorded separately, *3*—fish aggregations (including juveniles), *4*—zooplankton.

part above significant depth (Figs. 5a and 5b). Our statistical analysis revealed a significant positive correlation between the fish density and the depth during the day ($r = 0.58$, $p < 0.001$), but such a relationship is not significant at night. Fish concentration in the pelagial of Lake Glubokoe reaches the maximum values at night (Fig. 6), but in the morning most fish leave the open areas and probably hide in the nearshore macrophytes (Figs. 6a and 6b). This accounts for the significantly lower assessment of the fish numbers obtained during the day surveys: 480000 versus 864000. It is interesting that the highest concentrations of the fish weer observed in proximity of water vegetation.

Autumn characterized by pre-winter homothermy, and the fish tend to exploit the whole water column below the 2-m near-surface, where only individual fish occur sporadically. The grown juveniles is usually found in lower horizons of water in autumn. Interestingly, the tendency of extended occurrence of the fish in the pelagial at night as compared with the day is retained during the autumn (Figs. 5c and 5d). The density of the fish aggregations during the day was not much linked with the depth in autumn ($r = 0.31$, $p < 0.001$).

In October, the assessments of the total numbers of the fish during the day and at night are approximately the same, 330000 and 360000. However, the night aggregations of the fish are 2.4 times smaller than those in summer whereas the day aggregations do not much differ between July and October.

Significant changes occur in the size distribution: dominance of early juveniles with the length less than 4 cm in October changes to the dominance of grow-up fish with the length 8–11 cm (Fig. 2). Cyprinidae still dominate in the autumn fish aggregations, however their share is reduced to 81.9% whereas the proportion

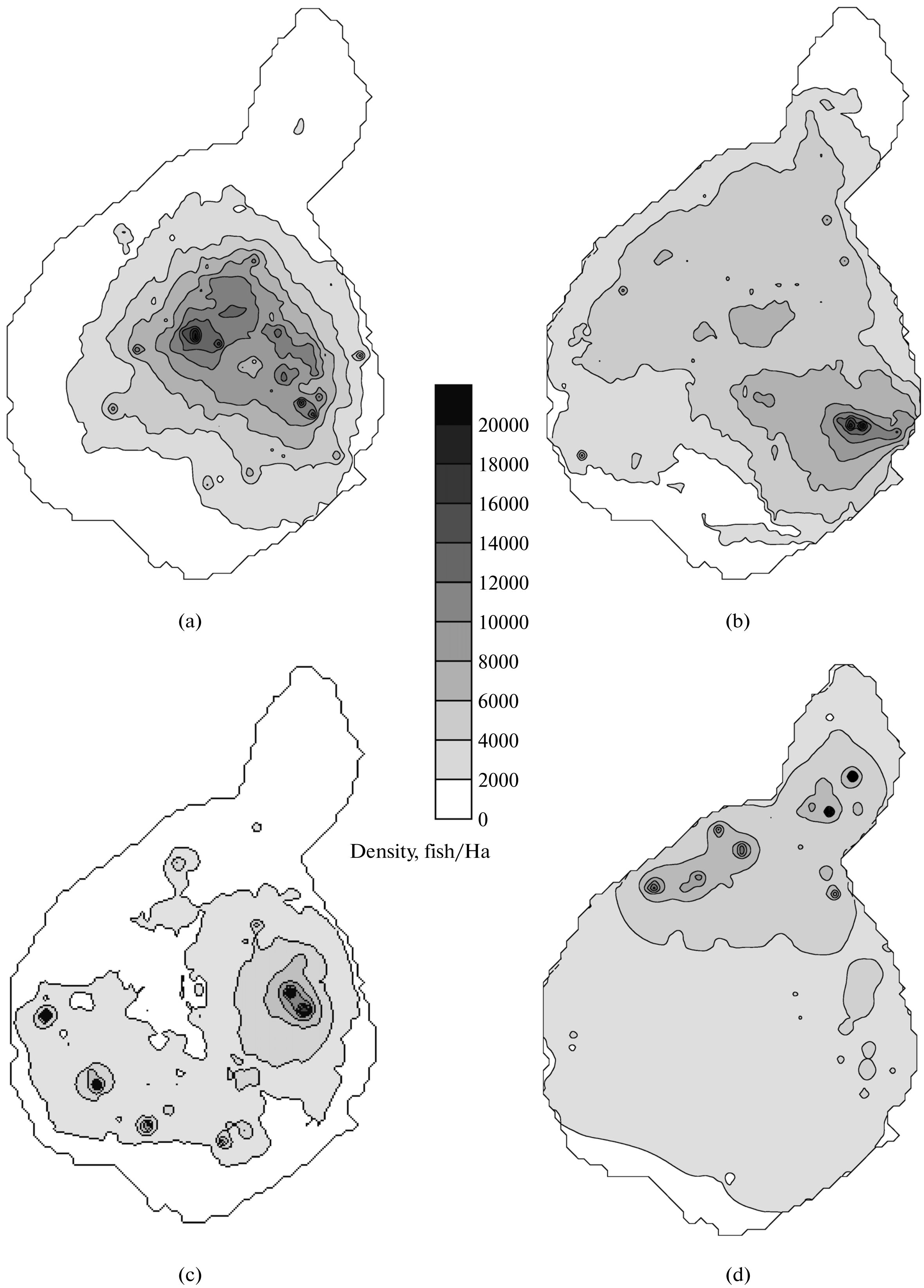
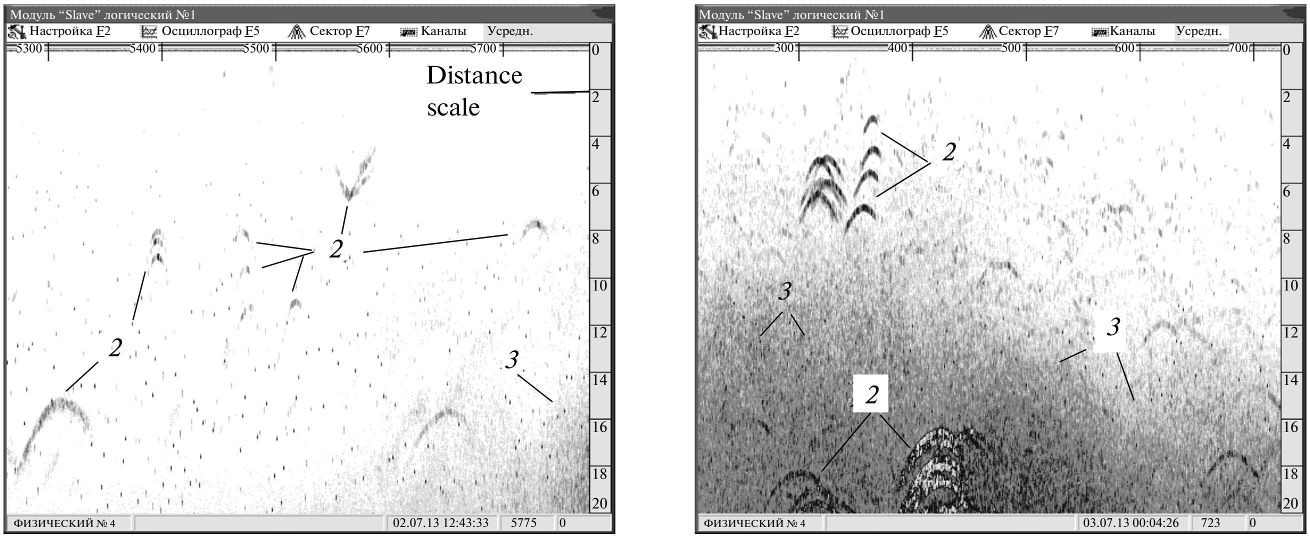


Fig. 5. Fish location at the open area of Lake Glubokoe in July (a, b) and October (c, d) during the day (a, c) and night (b, d).



(a) (b)

Fig. 6. Echograms recorded using Pankor in near-surface water layers of Lake Glubokoe in July: a—day, b—night; other legends as in Fig. 4.

of predatory fish increases: perches to 8.8% and pikes to 5.9% (Fig. 3b)

DISCUSSION

The distribution of fish in lake Glubokoe reflects a universal pattern for many inland water bodies. Spatio-temporal characteristics of fish distribution reflect main environmental factors, life-history strategy and the motivation condition of the fish (Pavlov and Mochek, 2009). Depending on the species, age, phase of the life history, the fish use specific zones of Lake Glubokoe, and their habitat preference changes across the diurnal cycle and the season. Diurnal dynamics of fish distribution can be traced in summer and in autumn, whereas the fish movements include both horizontal and vertical components.

In response to the diurnal changes of the illumination, juvenile roach, which is the dominant species, moves horizontally between the open central part of lake to its periphery covered with macrophytes. Both in summer and autumn the area of the nocturnal distribution of the fish is significantly larger than diurnal (Fig. 5). Thus, these fish predominantly occupy the pelagial at night, whereas during the day most of them probably are located in littoral. Thus, the previously documented in Lake Glubokoe differentiation of the fish into two groups, littoral and pelagic (Boikova, 1987), is not obvious according to our data. We suppose that these two groups converge spatially not only as a consequence of daily migrations littoral—pelagial—littoral, but also due to increased proportion of zooplankton (up to 90%) in feeding of the so called littoral fish (Boikova, 1986).

It is known that fish aggregations are attached to the upper layers of the pelagial in European lakes (Malinin and Poddubnyi, 1983; Strelnikov and Permitin, 1983). Lake Glubokoe is not different from such a pattern. According to the results of our hydroacoustic surveys, during the summer and autumn most fish in the pelagial are concentrated in the epilimnion and only partially in metalimnion.

The choice of the horizon by the fish significantly depend on the time of the day: the fish aggregate in the near-surface layers whereas during the day move deeper. This pattern of fish distribution was documented both in July and October, but is most clear in summer. Early juveniles, which is the most abundant part of the fish inhabitants, rise to the surface in huge amounts in July. Most probably, intense use of the upper water layers is an important condition of the fish survival at early stages of their ontogeny. Here these fish find the most optimal temperature conditions (Golovanov, 2013), sufficient oxygenation (Pavlov et al., 1986), and, as our surveys show, high concentration of zooplankton. Our echograms indicate (Fig. 4) that zooplankton organisms concentrate as a thin layer directly at the surface in summer at night, whereas in autumn these organisms form characteristic “clouds” in deeper horizons. Thus the distribution of the fish significantly correlate with the distribution of zooplankton.

Generally, one of the most important cause of both horizontal and vertical migrations of the fish is circadian dynamics of interactions in the triotrophe system (Manteifel, 1980). Diurnal migrations of the fish are the result of the interactions between non-predatory species, their food organisms and predators at a higher trophic levels. The direction and rhythm of fish diurnal migrations depend on their reception and behavioral strategies. Stereotypes of horizontal and vertical migrations are characteristic of fish of different species in different natural conditions and geographic position (Bazarov et al., 1988; Mochek et al., 1993; Bazarov, 2007; Borisenko et al., 2013). It should be noted that the vertical and horizontal migrations of the fish are not related with each other. For example, diurnal horizontal migrations are documented in shallow lakes, when vertical ones are impossible (Pavlov et al., 2010).

The seasonal dynamics of the fish distribution over the area of Lake Glubokoe is highly characteristic (Figs. 4 and 5). The maximally broad use of the pelagial by the fish is observed at the beginning of summer whereas in autumn the fish are located more compactly. Results of winter distribution of fish in Lake Glubokoe (Pavlov et al., 1991) indicate that the fish aggregations reach even higher values under the ice in the deepest areas of this water body. Importantly, the development of dense aggregations of the fish is characteristic not only of lakes but also rivers in places of deep riverbed hollows (Pavlov and Mochek, 2005).

Obviously, seasonal changes of the temperature of various layers of water significantly affects the vertical distribution of the fish. For example, the near-surface pattern of fish distribution in summer is determined by warm waters near the water surface, whereas the deep layers below the thermocline are unfavorable for both fish and zooplankton. Our hydroacoustic surveys did not record fish or zooplankton below 6 m in summer. In autumn and in winter, when the thermocline is absent, active organisms, fish and zooplankton use the whole water column, displaying no preference to the near-surface layers (Pavlov et al., 1991).

Our investigation revealed seasonal changes not only in the pattern of fish distribution, but also their abundance. The documented reduction of the total abundance in pelagic aggregations of fish in autumn as compared to summer agrees with the standard values of mortality in roach during the first year of life (Slyn'ko E.E. and Slyn'ko Yu.V., 2010). Additionally, the numbers of roach and its seasonal dynamics remain almost constant from the end of the 80s (Pavlov et al., 1986).

CONCLUSION

The distribution of fish in Lake Glubokoe is characterized by universal patterns typical of most limnic water bodies in general. The basic factors affecting fish distribution in lakes are overall illumination, water temperature, depth, zooplankton concentrations, macrophytes. Fish distribution is determined by the diurnal and seasonal dynamics of the environment and the concomitant changes of the defensive and feeding relationships of aquatic organisms. The main characteristics of fish distribution is their vertical and horizontal migrations. Spatial vectors of the migrations are not related and their characteristics depend on the water body. In summer and autumn during the day, pelagic fish are located compactly predominantly in the central part of lake. At night, homogeneous distribution of the fish throughout the open area is observed. Night vertical migrations of juvenile fish are synchronized with the rise of zooplankton organisms to epipelagial. The clear preference of the near-surface horizons by aquatic organisms is caused by the stratification of the water body with respect to temperature. In autumn and winter, fish use the whole column of lake due to homothermy. The fish tend to concentrate in limited areas in autumn as compared to the beginning of summer, which may be accounted for by significant reduction of the abundance of cyprinid fish. The density of fish aggregations and the depth are linked.

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