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Hydroacoustic Investigation of Taxonomic Composition and of Vertical Distribution of Fish in the Riverbed Depression

D. S. Pavlov[a], A. D. Mochek[a], E. S. Borisenko[a], and A. I. Degtev[b]

[a] *Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Leninskii pr. 33, Moscow, 119071 Russia*
e-mail: amochek@yandex.ru

[b] *OOO PromGidroakustika, Petrozavodsk, Russia*

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Abstract—An original method of taxonomic identification of fish (at the family level) by means of hydroacoustic equipment is elaborated. The method is based on analysis of the form of instantaneous envelope of amplitudes of the acoustic signal reflected from fish. Analysis of distribution of mass fish of different size over horizons of the water column is made on the deep-water riverbed depression of the Irtysh and characteristics of their diurnal vertical migration are revealed.

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Key words: hydroacoustic investigations, fish distribution, vertical fish migrations, the Ob–Irtysh basin.

INTRODUCTION

Investigation of trends of distribution of fish in water bodies, including the traits of their distribution by the horizons of the water column, is a fundamental problem of ichthyology and an urgent practical task. The material characterizing distribution of fish is a base of modern theoretical hypotheses in fish ecology. In consideration of such data, practical measures used in the field of nature conservation and rational exploitation of biological resources of water bodies are implemented.

The set of methods of investigation of fish distribution comprising fishery and hydroacoustic methods has limitations in its application and is fraught with errors in the obtained data. One of most essential drawbacks of hydroacoustic methods, especially in investigation of multispecies fish associations, is the impossibility of distant determination of taxonomic position of the recorded targets. For this reason, fruitful investigations of the vertical distribution of fish in the water column of fresh water bodies demand a parallel application of hydroacoustic and fishery methods (Bazarov, 2007). However, under certain conditions, in particular, on deep-water stretches of water courses—riverbed depressions—application of fishing gear is not possible. Therefore, the sole source of data on the vertical distribution of fish is a hydroacoustic survey. The obligatory condition of efficient application of hydroacoustic methods under such conditions is a possibility of taxonomic identification of fish by the results of hydroacosutic surveys. Until now, technology of taxonomic identification of fish on the basis of analysis of the reflected signals was not elaborated.

It is known that in the principal water courses of West Siberia, the Ob and the Irtysh, there are large riverbed depressions which are important wintering habitats of many migratory and resident fish (Ioganzen, 1972), which play a polyfunctional biological role in their life (Pavlov et al., 2006, 2008, 2009). Fish aggregations in riverbed depressions are characterized by diverse dynamics; mosaic of densities of their concentrations in relation to the water surface depends much on depth differences. However, due to the aforementioned limitations of the hydroacoustic method, the traits of vertical distribution of fish (in different horizons of the water column in these deep-water sites) remain unknown.

The aim of the present study is elaboration of the method of taxonomic identification of fish by means of hydroacoustic equipment. The tasks were: (1) to elaborate the method of hydroacoustic identification of fish by means of hydroacoustic equipment at the family level, (2) to determine if mass fish prefer different horizons of the water column in a riverbed depression, (3) to reveal the kind of vertical distribution of fish population of a riverbed depression, and (4) to investigate the diurnal rhythm of vertical distribution of fish.

MATERIAL AND METHODS

According to previous investigations (Pavlov et al., 2008), the Lower Irtysh basin is populated by representatives of the following taxa: Acipenseridae—sterlet *Acipenser ruthenus*; Coregonidae—muksun *Coregonus muksun* and nelma *Stenodus leucichthys*; Cyprinidae—roach *Rutilus rutilus*, id *Leuciscus idus*, dace *L. leuciscus*, bream *Abramis brama, Carassius caras-*

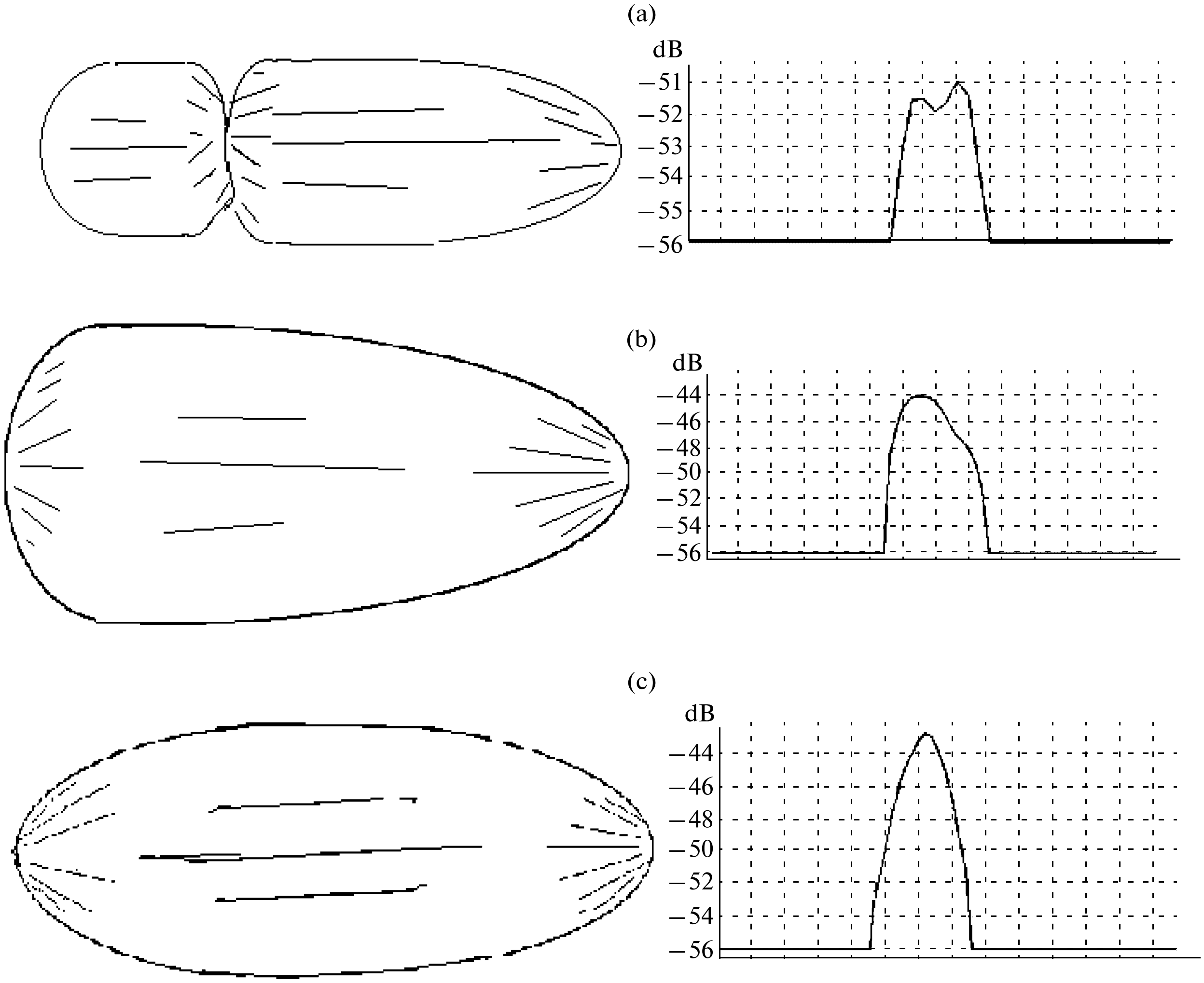

Fig. 1. Types of swimming bladders of fish (on the left) and oscillograms of instantaneous values of the amplitudes of reflected dispersion of fish (on the right) of families: (a) Cyprinidae, (b) Percidae, and (c) Coregonidae.

sius, and C. auratus; Percidae—perch *Perca fluviatilis*, ruffe *Gimnocephalus cernuus*, and pikeperch *Stizostedion lucioperca*; Esocidae—pike *Esox lucius*; and Gadidae—burbot *Lota lota*. In the area of investigations, the fish size was from 2 to 80 cm; juveniles and small-sized fish dominated in all cases.

Due to difficulties of seining of the water area of the Gornoslinkinskaya riverbed depression, it was not possible to reveal in detail the species composition of the fish population of this water area by means of traditional fishery methods. The sole method of investigation of distribution and of taxonomic identification of the fish population of the investigated water objects was special analysis of hydroacoustic signals recorded from single fish. As a result of methodical investigations, a method of determination of taxonomic composition of the fish population was elaborated on the level of families, by the results of analysis of the form of envelope of reflected signals of acoustic targets.

Our method of taxonomic identification of fish on the basis of the data of acoustic surveys is based on the results of investigations of characteristics of dispersion of reflected acoustic signals obtained for freshwater fish. Special measurements and calculations yielded linear–logarithmic equations of regression of target strength of fish depending on their length and the generalized equations for the fish of families Cyprinidae, Percidae, and Coregonidae. Representatives of these families make a bulk of the fish population in water bodies of the Lower Irtysh. The fish belonging to different families have significant differences in statistical characteristics of dispersion of reflected acoustic signals (Borisenko et al., 1989, 2006). Differences in characteristics of acoustic dispersion in fish are determined by specificity of the form of their swimming bladder—the major diffuser of acoustic energy. The amplitude and form of the envelope of the reflected signal significantly depend on the size and configuration of the swimming bladder (Clay and Medwin, 1977; Andreeva and Samovol'kin, 1986). Schematic drawings of the types of swimming bladder of the fish from three families (Cyprinidae, Percidae, and Coregonidae) and instantaneous values of the amplitudes of their reflected signals are shown in Fig. 1. Due to absence of a special bank of acoustic data, the acoustic identification of Acipenseridae, Esocidae, and Gadidae is not made and remains a task for further investigations.

The form of the envelope of the instantaneous amplitude of echo signals of Percidae is characterized by a clear asymmetry (at the right or at the left) in relation to the central axis, while the central part of the envelope of the amplitude is bell-shaped (Fig. 1b). The form of the envelope of the amplitude of the reflected signal of Coregonidae is mainly symmetrical (Fig. 1c). The reflected signal of Cyprinidae is characterized by two maximums in the main lobe of the envelope of the echo signal (Fig. 1a).

On the basis of differences in form of the envelope of amplitudes of echo signals in representatives of different families of background fish of the Lower Irtysh, a computer program was elaborated for analysis of acoustic signals for their taxonomic identification at the level of families. The program allows for the possibility to solve the following tasks: recognition of a single fish with consideration of duration of the signal and of its from; determination of the target strength of a fish using the direct method of "double ray"; analysis of the form of the envelope of the echo signal by criteria of symmetry/asymmetry within limits of its duration; calculation of coefficients of asymmetry/symmetry, excess, and of their variations; construction of schemes of fish distribution and plots of the size composition of fish by the identified taxa; visualization of the treatment process at the background of moving echogram and of the board of the performed survey; and saving of the results of treatment on the hard disk or on the external carrier.

Identification of fish may be made both generally, over the whole water column of the investigated water area, and in the prescribed horizon. The beginning of analysis and its termination are prescribed by the operator in any point along the movement of the echogram. In the present study, the analysis of hydroacoustic material with determination of abundance, size, and taxonomic position of the recorded fish was made both for the whole water column of the river and at different horizons of the water column, at every 5 m. Taxonomic identification of fish species was made by this program at the frequency 50 kHz.

Identification of fish families was made simultaneously with echometric surveys for estimation of their abundance. For these aims, the AsCor hydroacoustic complex was applied, modified with consideration of the present task. The AsCor complex comprised: two-frequency research echo sounder with the working frequency 50/200 kHz and direction diagrams at the level of 3 dB, 46°, and 14°, respectively; electric power on antenna 300 W, duration of a pulse 0.1–1.0 ms; frequency of samples 10–0.5 Hz; external outfit of input–output of data E-440 with frequency of analog to digital conversion from 40 to 400 kHz and digit conversion of 14 bit; built-in satellite navigational GPS detector; software for control of the system and data collection compatible with OS Windows XP; specialized mathematical software of the system for assessment of abundance and size composition of fish; mathematical software for taxonomic identification and identification of fish families; and a serial notebook.

The size of fish was determined by the method of "double ray" based on application of two coaxial antennas working at frequencies 50 and 200 kHz, with directionality discerning of two and more times by the angular width. In real time scale, the vessel route was reflected on an electron chart composed with application of the system of GPS satellite navigation. Ecometric surveys of the water area of the Gornoslinskinslaya riverbed depression was made by tacks using standard techniques, the coverage level of the water area was $d \geq 4$, and the coefficient of variation $CV = \frac{0.5}{\sqrt{d}} = 0.25$. Interpolation of the values of spatially distributed recorded densities by the network of tacks was made by one of the methods realized in Surfer-8 software. Construction of the boards of distribution of fish aggregations was made using MapViewer-7 software.

RESULTS

Type of vertical distribution of fish from different families. The taxonomic composition and numerical ratio of the fish population of the water area of the riverbed depression determined on the basis of hydroacoustic surveys is shown in Fig. 2. The materials of the diagram indicate a definite domination, in the quantitative aspect, of representatives of the family Cyprinidae. According to results of catches made in previous investigations, this group comprises roach, dace, id, and bream. Percidae are represented mainly by perch, ruffe, and small quantities of pikeperch. Coregonidae living in the investigated area comprise nelma and muksun. Starlet, pike, and burbot living in the area of the present study are not at present identified by the form of the envelope and, thus, they are combined into the "unidentified fish" category. The category of small-sized fish comprises specimens up to 10 cm in length. The fish with large linear size are termed large.

The distribution pattern of Cyprinidae over horizons indicated predominant colonization by this fish group of the upper horizons of the water column to the depth 2.5 m. Among Cyprinidae, juveniles up to 6 cm long prevailed. Distribution by horizons of the water column of the fish of family Cyprinidae noticeably

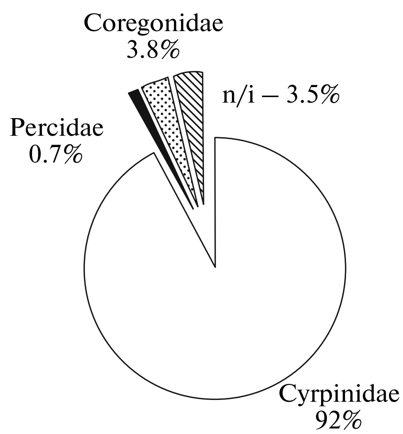

Fig. 2. Taxonomic composition of the fish population (families) of the water area of the Gornoslinkinslkaya riverbed depression (n/i—nonidentified fish objects).

changed in the light and dark part of the day (Figs. 3a, 3b). Our data demonstrate that at night Cyprinidae raise to upper horizons of the water column. Evident preference of cyprinid juveniles of the surface layer of the water column is retained at all periods of the day. However, at night their abundance in the upper horizons increases more than two times. Relatively large specimens of Cyprinidae (over 10 cm long) occur predominantly at depths over 12–17 m and noticeably rise to the surface at night.

In contrast to Cyprinidae, Percidae are distributed on the water area of the depression almost all over the water column and fish 3–6 cm long prevail (Figs. 4a, 4b). The diurnal rhythm of vertical movement of Percidae is characterized by the rise at night of specimens of all size groups to the upper horizons of the water column. At this time, the bulk of fish up to 6 cm long is concentrated immediately at the water surface.

Vertical distribution of Coregonidae (Figs. 5a, 5b) is rather similar to the vertical distribution of Percidae. Coregonieae are represented mainly by juveniles up to 3 cm long. The fish of this size group prefer the upper horizons of the water column (to depth 10–12 cm). Large specimens whose length exceeds 30 cm live predominantly in the middle horizons and at larger depth. Coregonidae on the water area of the depression are characterized by diurnal vertical movements. At night,

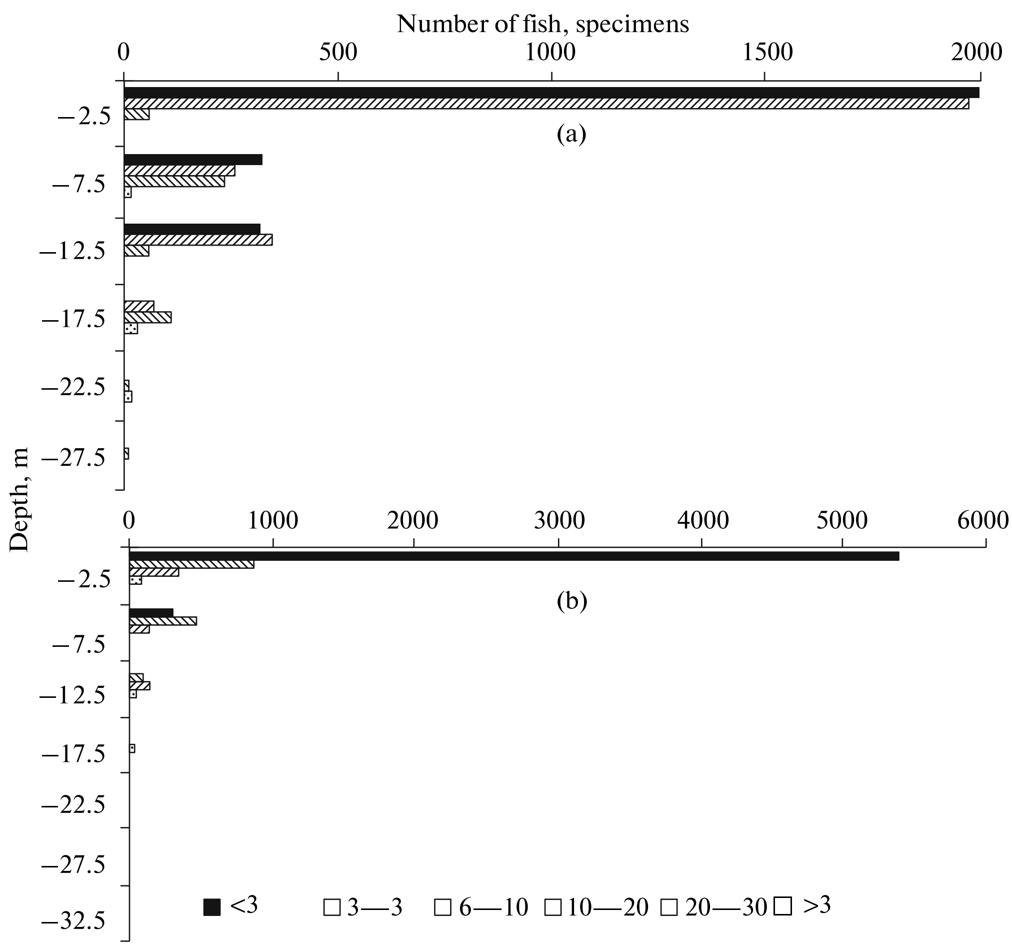

Fig. 3. Distribution of Cyprinidae in different horizons in the (a) daytime and (b) at night.

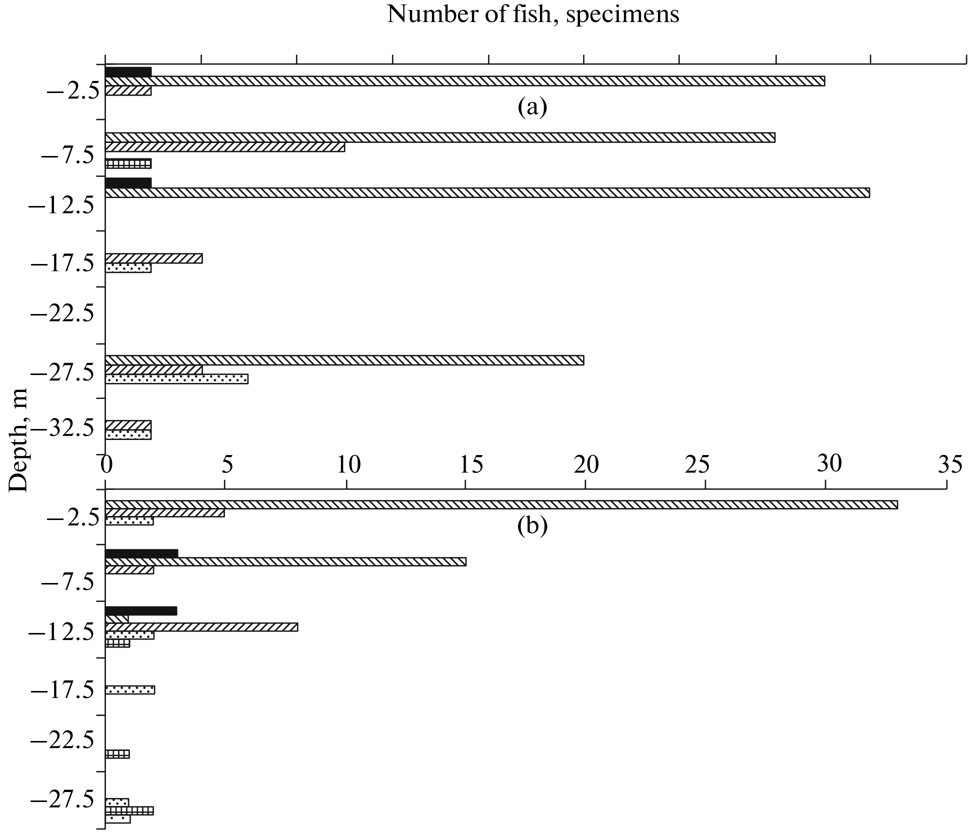

Fig. 4. Distribution of Percidae in different horizons in the (a) daytime and (b) at night.

most small fish up to 6 cm long rise to the water surface. Specimens 6–20 cm long also rise at night to upper water layers—to depths from 12 m to the surface. At night, motor activity of large Coregonidae (over 30 cm) seems to increase and they are recorded by the hydroacoustic equipment only in the dark period of the day.

Distribution of the fish population by horizons. From the kind of colonization by the fish population generally of different horizons of the water column of the water area of the Gornoslinkinskaya riverbed depression, it follows that the trends of diurnal rhythm of vertical distribution of fish should be analyzed in detail, by each 5 m horizons.

The materials of our investigation demonstrate that the fish colonize predominantly the surface horizon of the water column (Figs. 3–5). Within the range of depth 0–5 m (Fig. 6a) strong aggregations of the maximally mass component of the fish population of the depression—juveniles of Cyprinidae—are present all round 24 h. Percidae and Coregonidae are present insignificantly. At depths from 5 to 25 m (Figs. 6b, 6c, 6d, 6e) Cyprinidae also prevail but the part of Pericidae and Coregonidae somewhat increases. At greater depth—from 25 to 35 m (Figs. 6f, 6g)—abundance of Cyprinidae, dominant in the above horizons, abruptly decreases, while the part of Coregonidae and Percidae noticeably increases.

Maximum depths on the water areas of the riverbed depression attaining 35–40 m are populated 50% with Coregonidae; the part of these fish in the total abundance of specimens recorded here remained permanent both in the daytime and at night. Unfortunately, we did not manage to identify the taxonomic position of 50% of fish present at this depth.

DISCUSSION

Vertical distribution of fish in rivers was investigated most of all in the course of studies of fish migrations (Pavlov, 1979). Investigations of spawning migrations of spawners and downstream migration of juveniles revealed the composition of migrants and rhythm, rate, and pathways of their movements, as well as preferred horizons of a water course. Selection by migrants of horizons of movement in the principal channel depends on their age, physiological state, and biological traits of the species. In large riverbed depressions where the depth of the water column is tens of meters and the hydraulic conditions is different in comparison with the transit channel of the river, the vertical distribution of fish has specific traits, as the present study revealed.

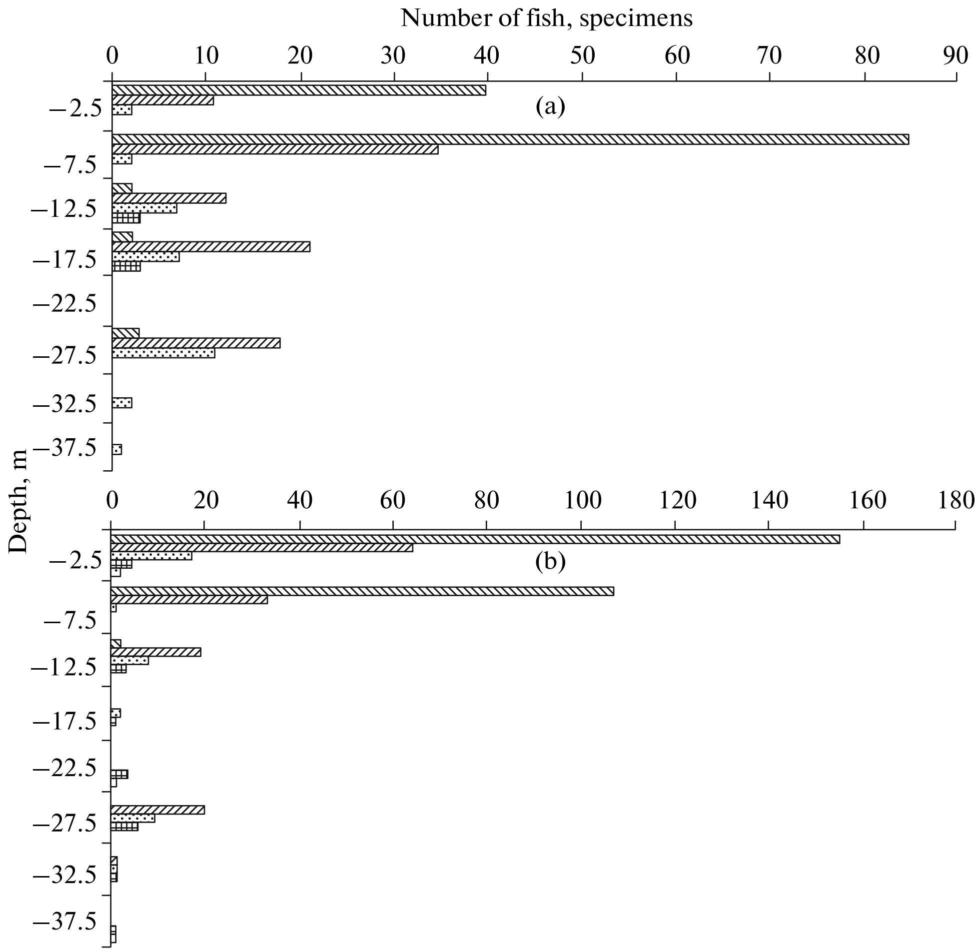

Fig. 5. Distribution of Coregonidae in different horizons in the (a) daytime and (b) at night.

Selective colonization by representatives of different families of the water column and the diurnal dynamics of this process on the deep water area of the Gornoslinkinslkaya riverbed depression indicates that this phenomenon depends on biological factors. The fish mostly occupy the upper horizons of the water column. Here, aggregations of juveniles of enormous abundance are formed, predominantly of Cyprinidae. Juveniles of other families—Percidae and Coregonidae—are represented much less.

The fish juveniles make vertical movements within the upper horizons of the water column. With onset of night, the small-sized fish rise to upper water layers and to the surface and with onset of the day make the reverse translocation. This decreases their availability to predatory fish and birds. The diurnal vertical movements are characteristic also for large-sized fish which present a potential danger to juveniles. Vertical migrations of fish observed in the sea, lakes, and reservoirs are a universal adaptation in the predator–prey system (Manteifel', 1980). Under conditions of a riverbed depression, diurnal vertical migrations of small-sized cyprinids are also adaptive.

Large fish of all families prefer middle and bottom horizons of the water column. Vertical distribution of percids of all size groups is confined to middle horizons. The middle-sized and large coregonids remain predominantly at larger depths.

At maximum depths, immediately at the bottom, large coregonids and probably acipenserids (sterlet) make the bulk of the fish population. Burbot and large specimens of pike are also present here. At present, for some families of fish, taxonomic identification by analysis of the amplitude of the envelope of the reflected acoustic signal cannot be made as there is no base of primary data. At the same time, a crucial condition of remote taxonomic identification of fish is accumulation of statistically sufficient quantity of hydroacoustic signals of various fish. Formation of the data bank of hydroacostic signals of various fish is a foremost task for practical development of the suggested method.

The inhabitants of medium and lower horizons of the water column make vertical diurnal movements. According to our data, with onset of the night most fish rise to upper water layers. It seems that large fish

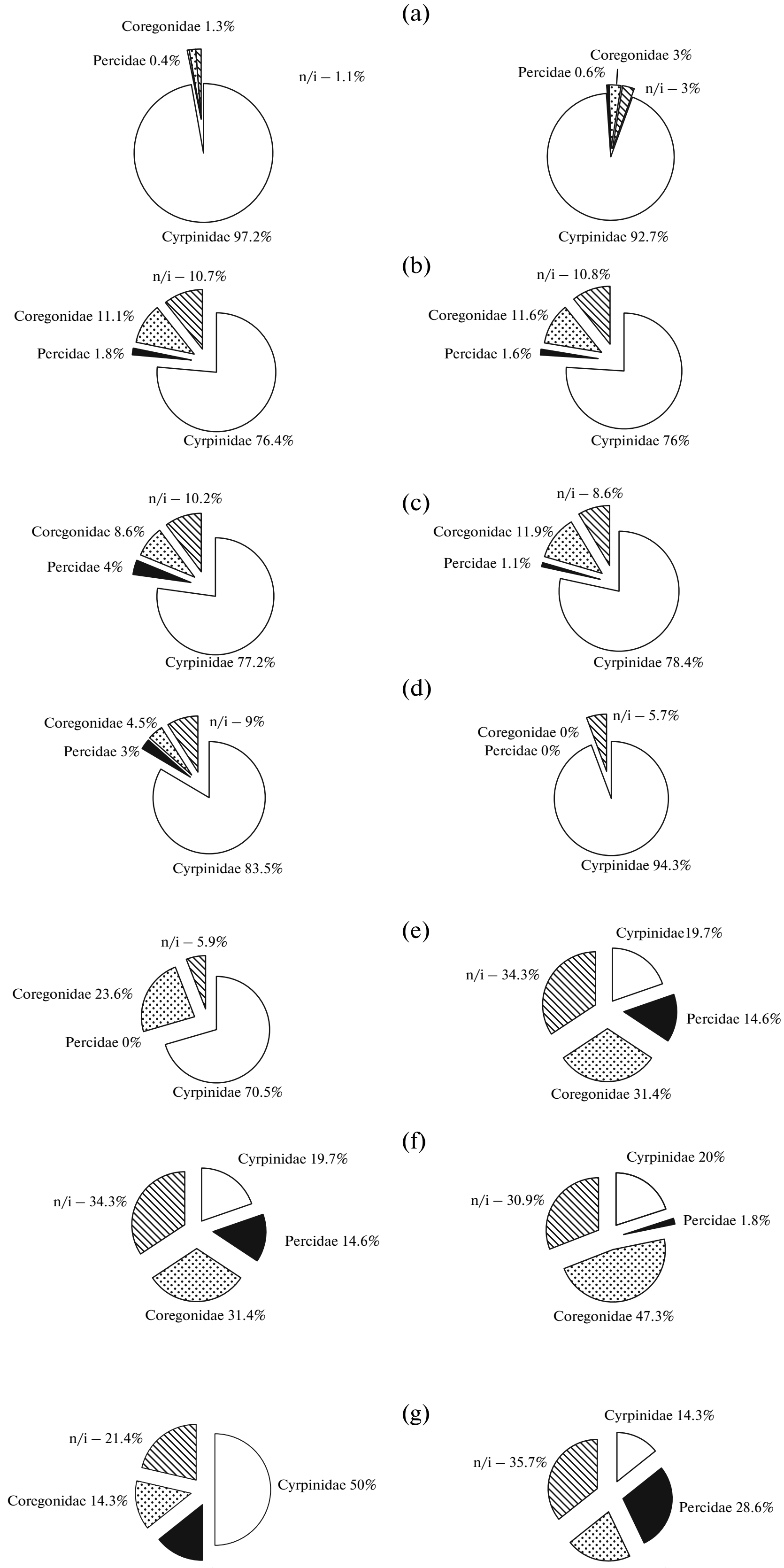

Fig. 6. Distribution of fish of the families Cyprinidae (☐), Percidae (■), Coregonidae (⚃), and of nonidentified fish objects (n/i, ▨) by depth in the daytime (left) and at night (right), m: (a) 0–5, (b) 5–10, (c) 10–15, (d) 15–20, (e) 20–25, (f) 25–30, and (g) 30–35.

rise synchronously with vertical movement of their potential food organisms, including juveniles. Thus, diurnal vertical migrations are characteristic of the fish of all size and taxonomic groups and indicate that this ecological phenomenon is universal.

CONCLUSIONS

(1) The taxonomic composition of the fish population of a water body at the level of families may be identified by the hydroacoustic method on the basis of analysis of instantaneous envelope of the reflected signal.

(2) The absolute majority of fish, first of all juveniles of cyprinids, are distributed at the surface and in the subsurface water layers. Percids and coregonids are distributed principally in the middle horizons and at the maximum depth.

(3) Vertical distribution of fish is a cyclic process—most fish on the water area of the riverbed depression make diurnal vertical movements.

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REFERENCES

1. I. B. Andreeva and V. G. Samovol'kin, *Scattering of Acoustic Waves on Marine Organisms* (VO "Agropromizdat", Moscow, 1986) [in Russian].
2. M. I. Bazarov, Candidate's Dissertation in Biology (IBVV RAN, Borok, 2007).
3. E. S. Borisenko, A. G. Gusar, and S. M. Goncharov, "The Target Strength Dependence of Some Freshwater Species on Their Length-Weight Characteristics," in *Proceedings of the Institute of Acoustics. Progress in Fisheries Acoustics and Underwater Acoustics, Lowestoft, England*, Proc.I.O.A. **11**, Part 3, p. 27–34 (2006).
4. E. S. Borisenko, A. D. Mochek, A. I. Degtev, and D. S. Pavlov, "Hydroacoustic Characteristics of Mass Fishes of Ob-Irtish basin," J. Ichthyol. **46** Suppl. 2, S227–S234 (2006).
5. C. S. Clay and H. Medwin, "Acoustical Oceanography: Principles and Applications" (Wiley-Interscience Publication, NY, 1977).
6. B. G. Ioganzen, "Zonal and Biotopic Distribution of Fish in the Ob Valley," in *Biological Resources of the Ob Floodplain* (Nauka, Novosibirsk, 1972), pp. 270–291.
7. B. P. Manteifel', *Ecological and Evolutionary Aspects of Animal Behavior* (Nauka, Moscow, 1980) [in Russian].
8. D. S. Pavlov, *Biological Foundations of Control of Fish Behavior in a Water Stream* (Nauka, Moscow, 1979) [in Russian].
9. D. S. Pavlov, A. D. Mochek, E. S. Borisenko, et al., "Biological Significance of the Gornoslinkinskaya Riverbed Depression in the Irtysh," J. Ichthyol. **46** Suppl. 2, S125–S133 (2006).
10. D. S. Pavlov, A. D. Mochek, E. S. Borisenko, et al., "Comparative Analysis of Fish Aggregation in Channel Depression of the Irtish," J. Ichthyol. **48** (11), 919–936 (2008).
11. D. S. Pavlov, A. D. Mochek, E. S. Borisenko, et al., "Distribution of Fish in the Complex of Floodplain-Riverbed Biotopes of the Irtysh," J. Ichthyol. **49** (11), 1021–1031 (2009).