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Hydroacoustic Characteristics of Mass Fishes of the Ob–Irtysh Basin

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Abstract—Hydroacoustic characteristics of mass fish species of the Ob-Irtysh Basin are investigated for elaboration of instrumental methods of fish identification by the results of hydroacoustic surveys. Linear-logarithmic regression equations of average values of the acoustic "target strength" are obtained, depending on the body length and weight of located objects. Instant values of the form of the echo signal envelope of amplitudes of echo signals from fish are analyzed. The numerical values of their statistical parameters are obtained. The characteristics of the backscattering from different species may be used for the solution of practical tasks of identification of fish and estimation of bioresources on inland water bodies.

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INTRODUCTION

Investigation of distribution and movements of hydrobionts is a fundamental task of aquatic ecology. Within the scope of these problems, main attention is paid traditionally to fish, a major commercial group of aquatic life. Methodical bases of such investigations are diverse. Among instrumental methods of fish registration in water bodies, the hydroacoustic surveys are especially efficient.

Hydroacoustic instruments provide data on the size of fish aggregations, their movements, and improve fishing techniques. The related devices are irreplaceable in investigations of fish migration, regularities of their distribution, and population dynamics. At the same time, today's methodology of acoustic surveys does not supply a reliable identification of the found fish species and a precise characteristic of their size and weight indices. This restrains a wide application of hydroacoustic devices in investigations of communities of hydrobionts.

The problem of the identification of fish species, determination of their size and weight directly from readings of the hydroacoustic devices, is traditionally a subject of special investigations (Yudanov, 1992). However, up to the present, the tasks of species and size classification remain urgent and acquire still greater significance due to the abrupt decline of fish resources, to the necessity of ichthyological monitoring and of instrumental supply of rational fisheries.

At present, the tasks of determination of the fish size by means of hydroacoustic devices are solved by analysis of the echo signals reflected from fish. For principal commercial marine fish, the characteristics of backscattering of echo signals are investigated, the numerical values, if the relationship of the values of "target strength" of various objects are obtained, and the proper techniques are devised for representation of the size distribution of fish "in situ" (Love, 1971; Nakken and Olsen, 1977; Foot, 1980; Gan'kov, 1980; Degtev and Ivanter, 2002; Gauthier and Home, 2002; Goncharov et al., 2002). The species identification of marine pelagic fish was made using methods and devices of treatment of reflected echo signals based on measurements of frequency relationships by the reverberation of the swimming bladder (Clay and Medwin, 1980; Simmonds and Amstrong, 1987; Conti and Demer, 2002), as well as analysis of spectral characteristics of wideband signals (Bondarenko et al., 1985, 1989; Bondarenko and Novikov, 1989; Kloser and Horne, 2002).

For now, the reflecting characteristics of freshwater fish are investigated but little (Bagenal et al., 1982; Lindem, 1983; Pushkin et al., 1984; Dahm et al., 1985; Borisenko et al., 1989; Rudstam et al., 2002; Kudryavtsev et al., 2005). Therefore, the biological interpretation of the results of hydroacoustic surveys made in rivers, lakes is difficult. And reservoirs are still difficult, the echograms cannot be reliably interpreted as to the species and size-weight composition of the fish population. By this reason it was necessary to make control catches in the water areas where the acoustic survey was made. This much complicated a wide implementation of hydroacoustic devices for research purposes.

For the solution of the problem of species and size-weight identification of freshwater fish directly by the results of hydroacoustic surveys, it is necessary to do the following: first, to elaborate principles of formaliza-

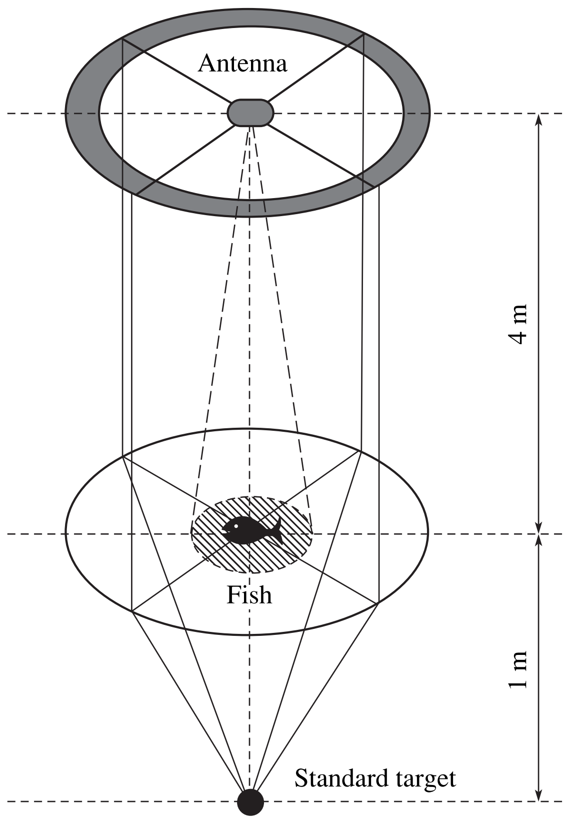

Fig. 1. Scheme of the field device for measurements of acoustic characteristics of the backscattering of sound by fish.

tion of the revealed properties of echo signals from different fish species which can be expressed quantitatively in the methods of computer recognition of images; and, secondly, to start formation of the data bank of returned signals of the background fish species.

The present study is made for determination of the values of the acoustic "target strength" and for analysis of the form of the echo signal envelope for some fish species of Western Siberia. The authors consider this investigation to be a first step towards formation of the data bank of principal biological objects for hydroacoustic investigations in this region.

MATERIAL AND METHODS

The field investigations were carried out at the Irtysh River (its tributary, the Varpak) in the area of "Missiya" station of the Tobolsk Biological Station RAS (the Tymen region) in June to July 2005. Hydroacoustic measurements were made on living specimens of mass fish: bream *Abramis brama*, roach *Rutikus rutilus*, id *Leuciscus idus*, goldfish *Carassius auratus*, perch *Perca fluviatilis*, pikeperch *Stizostedion lucioperca*, and sterlet *Acipenser ruthenus.* For experiments, fish with different size and weight parameters were selected: body length 10–40 cm, body weight 16–1300 g.

Reflecting acoustic characteristics of fish were measured by means of a research hydroacoustic complex "ASKOR" (Degtev and Ivanter, 2002). The apparatus part of the complex comprises: a modified research echo sounder Furuno LS 6000 (working frequency 200 kHz, antenna beam width 14° at the level—3 dB), 14 discharge analog-to-digital converter E14-140 (frequency of conversion of the sample 100 kHz); notebook (processor PC-4, 3000 mHz, DDR 512 MB, HDD 80 GB); a standard copper sphere (45 mm in diameter with the target strength for frequency 200 kHz TS = –39.6 dB). The value of amplitudes and the form of the echo signal envelope was controlled in conditions of the window of an oscillograph incorporated in the program. Electroacoustic parameters of the complex with high metrological characteristics ensured measurement of the amplitudes of echo signal envelope within the range not less than 85 dB. The values of amplitudes of echo signals from fish and from the standard sphere were recorded as numbers on the hard disk of the notebook for subsequent processing in the laboratory.

The standard sphere and the investigated fish were brought to the axis of the acoustic antenna by means of a special stiff suspension device previously described in detail (Borisenko et al., 1989). This scheme of the suspension device (Fig. 1) and the independent movement of targets in two planes ensured their bringing to the acoustic axis of the antenna with accuracy of 1 mm. Moving the target, in turn, in two planes the maximum amplitude of echo signals from the targets was determined and then the cycle of measurements was performed consisting not less than of 500 errands.

The throughout graduation of the complex of devices was also made using the standard copper sphere suspended instead of a fish to the prescribed depth (4 m). In the course of the subsequent processing in the laboratory, the value of the graduated signal was a measure for the relative calculation of the target strength of the investigated fish. The precision of graduation, within the dynamic range and with consideration of the TVG law, was +/–0.3 dB. Principally, all measurements were made at the dorsal exposure. To reveal traits of scattering of the echo signal by fish specimens of different species, some specimens were investigated in a lateral position.

Treatment of the obtained data was made in three ways:

(1) Direct calculation of the target strength (TS, dB) in relation to a known target strength of the standard sphere by the equation:

$$TS = 10\lg M_{\rm p} - 10\lg M_{\rm sph} + TS_{\rm sph} - C, \qquad (1)$$

where $TS_{\rm sph}$ is the target strength of the standard sphere, dB; $M_{\rm p}$, $M_{\rm sph}$ are values of intensity of the signal of the fish and of the sphere, respectively, volt; C is the electroacoustic constant of the measurement system determined by the throughout graduation of the system by the standard sphere, dB.

(2) Restoration of the distribution of the target strength of solitary fish in the layer beyond the lag of 100 errands by the Craig–Forbes method in its modification with calculation of errors (Craig and Forbes, 1969; Ehrenberg, 1984). In measurements for each fish, the histograms of distribution of the amplitudes of solitary signals were constructed for all cycle of measurements and the obtained average values of the amplitudes were used for the subsequent calculation of the average values of the target strength of fish.

(3) By analysis of statistic characteristics of instant values of the envelope of the echo signal from fish, square of their envelope, energy, and duration. The sample of instant values of the echo signal envelope was taken in the process of treatment of each series of measurements for all fish, for the subsequent analysis of the form of the envelope using the numerical characteristics: coefficient of variation K_v, skewness K_{sk}, and excess K_{ex}.

For hydroacoustic measurements, the fish were caught with nets and kept in a tank for a day, to reveal traumatized specimens. Then the experiment was started. The fish were fixed in a frame in water, minimizing the getting of air bubbles in the gills and entrails. Having submersed the fish to the depth of 4 m, the investigated specimen was brought to the acoustic axis of the antenna and kept at this depth for not less than 10 min prior to measurements. The echo signals were registered only at stable amplitudes of the echo signals from the fish and from the standard sphere suspended at the distance of 1 m below the fish at the same axis.

By the obtained values of the target strength from individual fish, the equations of logarithmic regression were calculated for each fish species using polynomials, by the least squares method.

RESULTS

On the basis of the performed measurements and calculations, the linear-logarithmic regression equations of average values of the target strength of fish were obtained, depending on their length and weight, as well as generalized equations for representatives of

Results of measurements of target strength of fish

Fish species	*n*	Length (*L*), cm	Weight (*W*), g	Regression equation
Fam. Cyprinidae				
Bream *Abramis brama*	15	7.5–34.0	10–1150	$21.16\log L - 65.63$
				$7.60\log W - 54.61$
Roach *Rutilus rutilus*	11	6.0–26.0	10–360	$24.51\log L - 69.08$
				$5.52\log W - 49.7$
Id *Leuciscus idus*	7	12.0–33.0	25–940	$23.14\log L - 67.92$
				$5.20\log W - 49.2$
Goldfish *Carassius auratus*	6	15.0–36.0	76–980	$22.93\log L - 67.23$
				$5.22\log W - 48.7$
General	39	6.0–36.0	10–1150	$23.00\log L - 67.5$
				$5.90\log W - 50.6$
Fam. Percidae				
Perch *Perca fluviatilus*	12	17.5–36.0	155–1080	$23.60\log L - 66.34$
				$8.10\log W - 54.3$
Pikeperch *Stizostedion lucioperca*	7	12.0–39.0	120–1350	$23.80\log L - 65.9$
				$8.05\log W - 54.88$
General	19	12.0–39.0	120–1350	$23.70\log L - 66.1$
Fam. Coregonidae				
Cisco *Coregonus lavaretus**	13	20.0–39.0	100–1300	$20.97\log L - 66.0$
				$5.50\log W - 50.0$
Omul *Coregonus autumnalus migratorius***		13.0–38.0		$28.70\log L - 76.4$
Fam. Acipenseridae				
Sterlet *Acipenser ruthenus*	7	18.0–33.0	42–247	$31.37\log L - 84.51$
				$7.80\log W - 57.02$

Note. By the data of: * Borienko et al., 1989; ** Kudryavtseva et al., 2005.

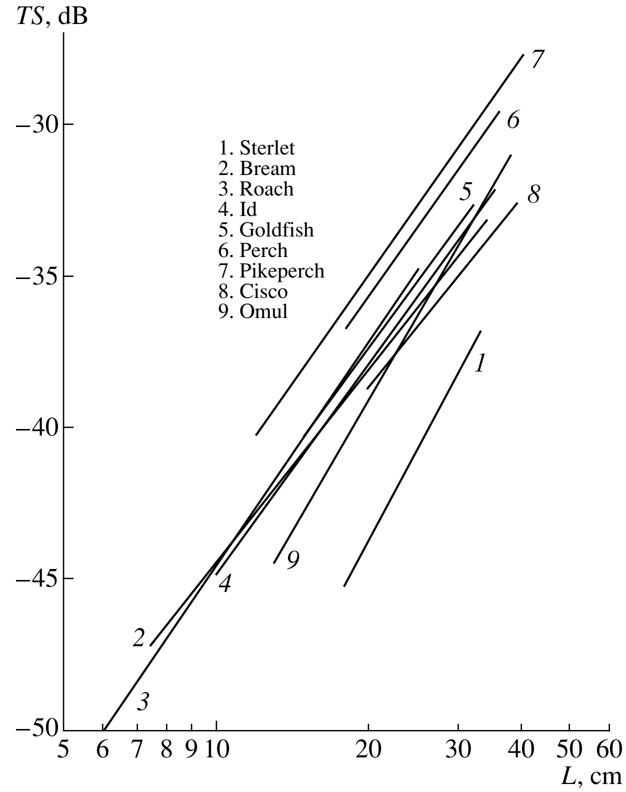

Fig. 2. Plots of linear-logarithmic relationship of the target strength (*TS*, dB) and length (*L*, cm) for different fish species.

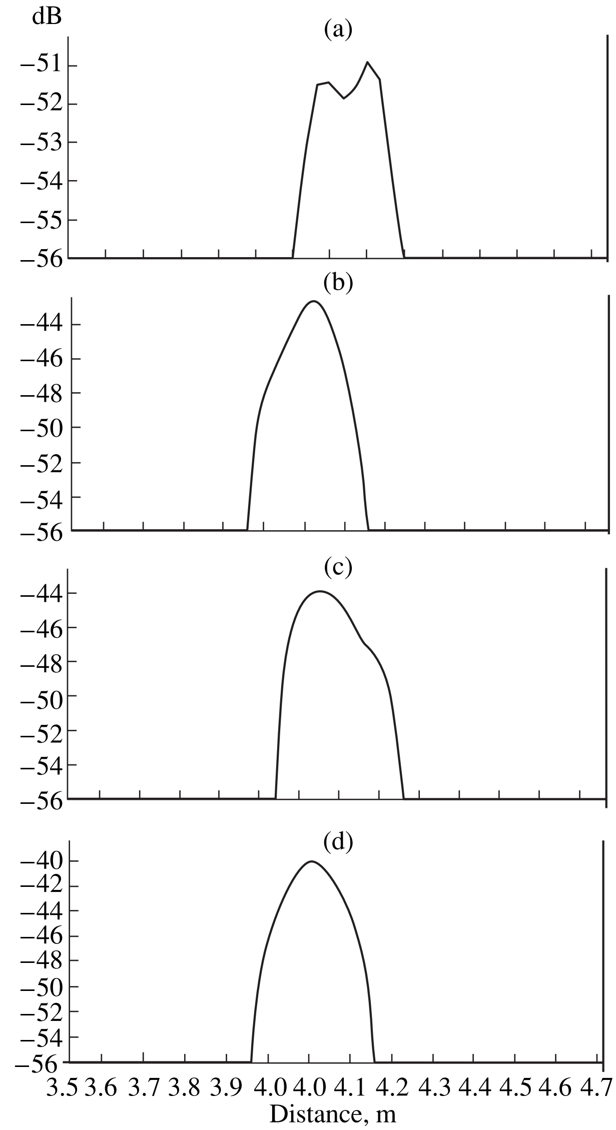

Fig. 3. Oscillograms of instant values of the amplitude of backscattering of some fish species and of the standard sphere: (a) fam. Cyprinidae, (b) fam. Coregonidae, (c) fam. Percidae, and (d) the standard sphere.

families Cyprinidae and Percidae (table, Fig. 2). These relationships are usually represented as the equation

$$TS = A\lg L + B, \quad (2)$$

where *TS* is the target strength of the fish *L* cm long, dB; *A*, *B* are experimental regression species-specific coefficients.

Application of the average values of the measured amplitudes of signals from fish only is related to the fact that the acoustic section of the backscattering of the object in the action zone of the antenna of the echo sounder acquires a certain value depending on occasional factors (fish position in space, individual physiological condition, behavior, etc.). That is, the acoustic section of the backscattering of fish is a random variable and is described by one of principal characteristics of the statistical distribution—the mathematical expectation. This parameter is a certain average value and all possible values of the considered values are concentrated around it.

It should be noted that application in the quantitative estimation of the target strength of fish of the maximum values (TS_{max}) only lead to significant errors. It is determined experimentally (Nakken and Olsen, 1977; Foot, 1980; Halldorsson and Reynissen. 1982; Ermolchev and Pokhilyuk, 1986; Artemov and Krasilnikov, 1989) that the average target strength of fish is smaller by 6–10 dB than TS_{max}. The frequency of acoustic vibration increasing, the scattering of values of TS_{max} decreases. As at present it is not possible to establish the analytic relationship between the maximum and average values of *TS* taking into consideration all factors influencing the reflecting capacity of the object, the recalculation of the *TS* values with consideration of any factors may lead to considerable errors.

Thus in hydroacoustic measurements of the size distribution of fish in water bodies and quantitative estimation of their aggregations, it is preferable to apply average values of the target strength.

In analysis of the reflected echo signals from different fish and from the standard sphere, the histograms of the amplitude-temporal distribution of instant values of

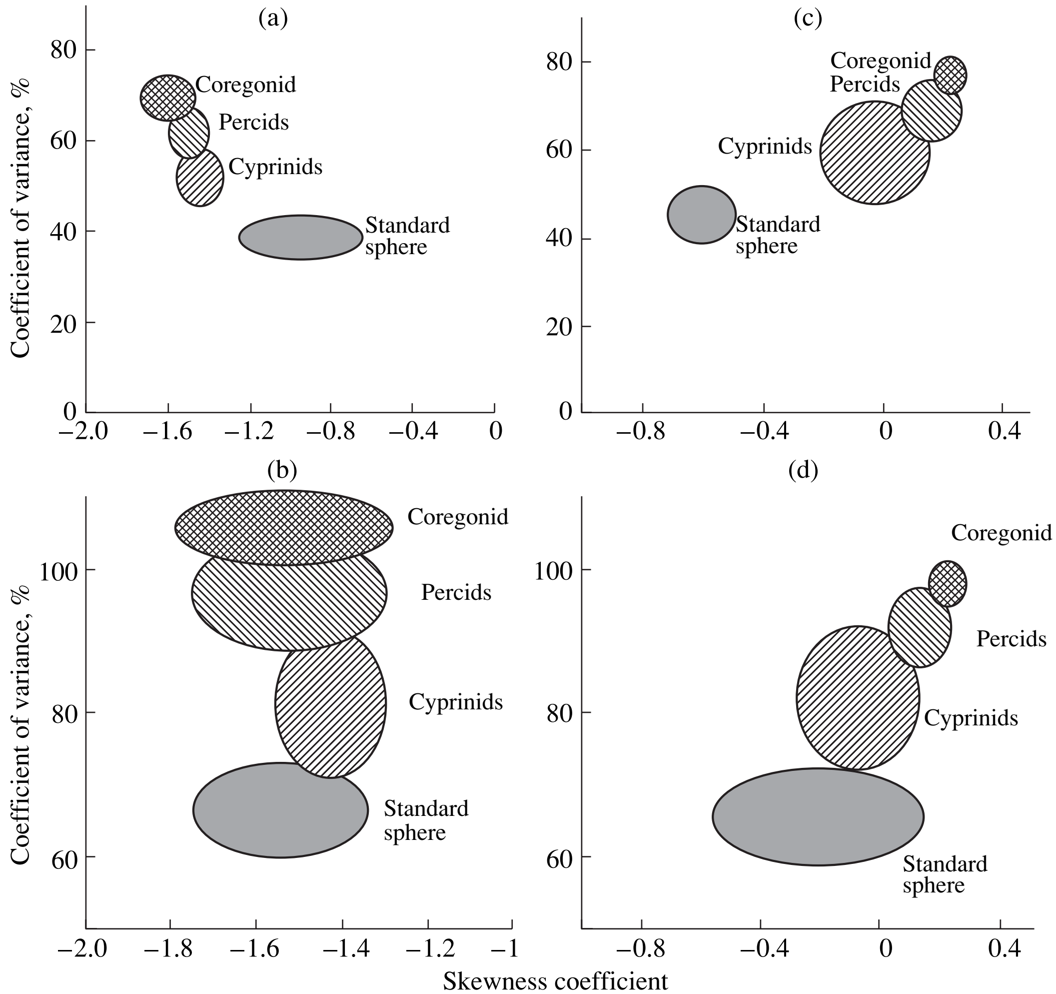

Fig. 4. Areas of values of coefficients of variance, skewness, and excess of envelopes of signals of backscattering of sound (a, c) and their squares (b, d) of some fish species and of the standard sphere.

signal envelope and of their intensity were constructed (Fig. 3). Not less than 500 values of such echo signal envelopes were obtained for each fish (for the later calculation of numerical statistical characteristics). The investigations revealed that for different fish species and for the standard sphere there are significant differences in the polar diagrams of backscattering and in statistical characteristics. Figure 4 shows the areas of values of statistical coefficients of variance, skewness, excess, and the square of the echo signal envelopes characterizing the sound scattering properties of fish of different taxonomic position and their differences in comparison with the reflection power of the standard sphere.

DISCUSSION

The experiments demonstrated that the acoustic characteristics of backscattering of the investigated fish significantly differ from each other. In the plots shown in Fig. 2, it is seen that the maximum values are characteristic of the family Percidae—pikeperch and perch, the minimum values are typical for the family Acipenseridae—sterlet. The differences of values exceed 8 dB.

The differences in the values of target strength in the fish belonging to the same family are not high. For representatives of the family Cyprinidae (bream, id, goldfish) the interspecies differences make not more than 0.9 dB; for the family Percidae (perch and pikeperch)—not more than 1 dB. If the values of target strength are compared in the representatives of different families, e.g., in percids and cyprinids, the differences range from +2.2 to +3.2 dB. These values are important for determination of the individual size in the echometric restoration of the size distribution of the surveyed fish aggregations.

Comparing the values of *TS* in the fish of the families Coregonidae and Percidae, the values make from –3 to –4 dB, between the families Coregonidae and Cyprinidae they range from –0.5 to –1.5 dB. They are still greater between Acipenseridae and Coregonidae—from –5.0 to –4.5 dB, between Acipenseridae and Cyprinidae—from –5.5 to –6.5 dB.

Thus the obtained equations of TS regression for different fish species demonstrate that, by the numerical values and by slopes of the regression line angles, four taxonomic groups may be discerned: Percidae (perch and pikeperch), Cyprinidae (bream, roach, id, and goldfish), Coregonidae (cisco and omul), Acipenseridae (sterlet).

The construction of the generalized linear-logarithmic relationships of the target strength of fish on their length, which may be used for investigation of mixed fish aggregations, is possible only for two combinations of fish groups: percids and cyprinids, cyprinids and coregonids. In this case the result of construction of the fish size series by the data of echometric surveys may be quite representative. In addition, applying the proper equations for determination of the fish size series, one should take into consideration special traits of behavior and distribution of fish and their types of diurnal and seasonal activity. This will provide reliable results and estimation of the principal contribution of the species dominating in a certain water area and staying at a certain depth. If echometric surveys are applied for estimation of biomass of commercial aggregations, the linear-logarithmic relationships of the fish target strength on the weight, indicated in the table.

Considering the form of the envelope and the amplitudes of signals from different fish, their significant differences are seen (Fig. 3). Analysis of the form of the envelope of the echo signal amplitudes revealed that fish with a one-chambered swimming bladder (Percidae and Coregonidae) are characterized by clear main antenna directional lobes in the polar directional diagram corresponding to irradiation of fish by the normal to the longitudinal axis of its swimming bladder (Fig. 3b, 3c). In case of lateral irradiation of these fish, the value of amplitude changed insignificantly, at the applied frequency of acoustic vibration (200 kHz)

A different pattern (Fig. 3a) was observed in the case of acoustic irradiation of fish with a two-chambered swimming bladder (the family Cyprinidae). In the main lobe of the polar diagram of the dorsal irradiation aspect, several maximums appear whose number varies depending on the fish size and its species (probably, on its physiological conditions too). This phenomenon may depend on interference of sound waves scattered by two chambers of the swimming bladder. In addition, at lateral irradiation of the fish belonging to the family Cyprinidae, the envelope line of the main lobe of the amplitude abounds in bursts, as was previously noted in investigations of the fish with two-chambered swimming bladders. In this case the values of the amplitude of the returned signal significantly exceed the average values of the echo signals obtained in case of dorsal irradiation. The latter is explained by the presence in the inner organs of numerous small bubbles and gas cavities which are screened by the swimming bladder in the case of the dorsal irradiation (Samovolkin, 1976; Andreeva and Samovolkin, 1986).

Experimental investigation of the reflecting properties of fish demonstrate that the value and kind of scattering much depend on the internal structure and biometric parameters of the fish body. The precise measurements made under basic (fully controlled) conditions revealed that for commercial fish of small and average size the major part of the value of acoustic section results from the swimming bladder. At higher parameters characterizing principal conditions of scattering (the frequency of acoustic vibration and the fish size), the sum echo signal is summed up of the echo signals from the swimming bladder, soft tissues, bones, and other acoustically heterogeneous parts of the fish body (Andreeva and Samovolkin, 1986). In this case the influence of the swimming bladder on the amplitude of the returned signal decreases and, having attained a certain boundary conditions, it becomes comparable with reflecting properties of soft tissues and bones.

Besides, the reflecting capacity of fish much depends on their orientation in relation to the direction of irradiation. For each species there is a certain dependence of the directed backscattering of sound on the fish length (Samovolkin, 1974; Love, 1977). At a greater fish size, there is a tendency to narrowing of the diagram of backscattering by the fish, and, in different fish species, differences appear in the form of the envelope of echo signal amplitude. The difference in the form of backscattering diagrams and in the envelope form of the echo signal amplitude of different species may be explained by the body form, special traits of the volume, and shape of the swimming bladder (Samovolkin, 1976). These differences are incorporated in the statistical distribution of the amplitude of echo signals, the form of their envelope, and in the indicatrixes of backscattering of sound by fish, which may be expressed quantitatively by parameters of these distributions (Fig. 4).

The relationships of statistic coefficients of variance, skewness, the excess of envelopes of echo signals, and squares of envelopes (Fig. 4) clearly demonstrate the differences in reflecting properties of fish of different species and of the standard sphere. The values of numerical characteristics of these coefficients most clearly define the areas of their interaction. Thus a conclusion may be made on quite satisfactory prospects of classification of particular fish groups.

Analysis of all obtained angular relationships revealed that the polar diagrams of scattering and the forms of amplitudes of the envelope are much more complicated for the fish of the family Cyprinidae (with two-chambered swimming bladders) than for the fish possessing the swimming bladders of a more simple form. For the fish of the families Percidae and Coregonidae (with the one-chambered swimming bladder), the similar measurements did not reveal differences in the level of backscattering in case of dorsal or lateral irradiation (Andreeva and Samovolkin, 1986).

With consideration of the performed measurements, it may be noted that the fish of the families Cyprinidae and Coregonidae are commensurate by the values of target strength (Fig. 2), but the areas of values of their statistical coefficients of the envelopes of echo signals significantly differ (Fig. 4). For the fish of the families Cyprinidae and Percidae the difference in characteristics of the envelope of echo signals is more important.

CONCLUSIONS

(1) At the level of families, a reliable parameter of fish size is the acoustic section of fish backscattering—target strength. This characteristic differs in representatives of different families in numerical coefficients of the equations of linear-logarithmic regression.

(2) For identification at the species level it is advisable to make analysis of the form of echo signal envelope with calculation of statistical parameters—coefficients of variance, skewness, and excess.

(3) Special treatment of the entity of hydroacoustic characteristics of signals returned from fish—target strength and statistical parameters of the form of envelope amplitude—permits if the necessary databank is available to approach practical solution of tasks of the quantitative and qualitative identification of fish by readings of hydroacoustic devices.

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