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Acoustic-trawl studies of the *Coregonus migratorius* (Georgi,1775) in the Selenga shallow water zone of Lake Baikal, 2023

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ABSTRACT. Study of peculiarities of distribution of aggregations and size-age structure of the Baikal omul feeding stock in the Selenga shallow water zone of Lake Baikal were studied using the hydroacoustic method in combination with control trawls. Comparative analysis of the results of 2023 with the data of 2015-2022 showed significant changes in the general character of distribution of the Baikal omul aggregations in the water area and depth. Standard length of fish from different shallow water zones ranged from 10 to 39 cm with a sample median of 17 cm. In terms of weight, individuals of 18-26 cm in length were dominant. A "length-age" equation allows making an operational assessment of age class abundance correlation based on the probability of assigning individuals of a certain length to them. It is shown that 3-5 years old fish form the basis of the biomass of feeding stock in the Selenga fishing zone. A significant proportion of young fish indicates that there is sufficient recruitment to increase the biomass of the Baikal omul stock in 5 years perspective.

Keywords: *Coregonus migratorius*, hydroacoustic method, control trawls, size-age structure, "length-age" relationship, stock assessment, Lake Baikal

1. Introduction

The Baikal omul *Coregonus migratorius* (Georgi, 1775) habitats mainly to a depth of 350 m. The largest fish concentrations are formed in the zone of underwater slope in winter, in the coastal zone in the spring-summer season, and in the open pelagic zone in the summer-autumn warming of waters. The Selenga shallow water adjacent to the Selenga River delta is one of the main fishing areas of Lake Baikal, where, according to estimates obtained as a result of hydroacoustic studies (Melnik et al., 2009), a significant part (up to 50% and more) of the total stocks of this species is concentrated due to the extensive areas of the shallow water with depths favorable for its habitat. Areas with depths up to 300 m in Baikal are traditionally considered as "shallow water" in contrast to the deep water zone with depths up to 1600 m. The Selenga and Posolsky populations form the basis of the commercial stock here, spawning of these fish occurs in the Selenga River and the rivers of the Posolsky Sor, respectively.

The Selenga population of the Baikal omul migrates actively in the waters of southern and middle basins of the lake, and at certain years, fish entered wide-scale the Maloye More Strait are observed. Its stocks are intensively exploited by both industrial and recreational fisheries. The Posolsky Sor population of the Baikal omul is predominantly distributed in deeper waters. Until recently, individuals, which were in the period of spawning shoals and spawning migration, were the base of this population fishery. A significant share of the Posolsky omul is caught for artificial reproduction purposes determining its stock dynamics. Recently, recreational fishermen have mastered the catch of omul during the feeding period up to 200 m depth.

Developing and improving approaches to fisheries management in a changing environment (Anneville et al., 2015; DeVanna et al., 2016; Zhang et al., 2018) has received particular attention in many countries (Marchal et al., 2016; Jayasinghe et al., 2017). Relevance of reliable assessment of quantitative parameters of the state of populations of commercial hydrobionts is caused by increase of anthropogenic impact on the environment and need to ensure the restoration of bioresources. Fishery enterprises that provide employment of population are town-forming enterprises in many regions of the country. This is especially important for regions where fishing is the main source of the population life support. Since October

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2017, a ban on commercial and recreational fishing of the Baikal omul, the main commercial species of Lake Baikal, has been introduced (Order ..., 2014). Against this background, depressed reserves of the Baikal omul and restrictions on its catch, the amount of research work devoted to this problem is clearly insufficient. Under conditions of climatic changes, the migratory behavior of fish has been significantly transformed, which is probably caused by the established adaptive mechanisms. Changes in behavioral pattern have occurred periodically in the past, for example, changes in "resting" of the Baikal omul in the Maloye More Strait, which is the main fishing area of Lake Baikal in Irkutsk region. The dependence of fish migrations on climatic conditions is currently beyond doubt (Smirnov et al., 2012; Smirnov et al., 2013), but requires more detailed studies. Hydroacoustic surveys of the main fishing areas including the Selenga shallow water are carried out on a regular basis (Melnik et al., 2009; Makarov et al., 2012; Goncharov et al., 2022). The obtained data enable not only to conduct a comparative analysis of the peculiarities of distribution of aggregations and size-age structure of the Baikal omul feeding stock in this water zone, but also provide an opportunity to predict changes in biomass.

The aim of this work is to analyze the structure of the Baikal omul feeding stock in the Selenga shallow water zone based on 2023 data.

2. Materials and methods

The hydroacoustic survey in the Selenga fishing area of Lake Baikal was conducted during the spring warm-up period from May 21- 27, 2023. The R/V "G.Yu.Vereshchagin" moved according to a standard tack grid (Fig. 1) with depth ranges from 50 to 400 m. The total length of tacks was more than 230 km. The survey was carried out with hydroacoustic complex "Echo-Baikal" representing software and hardware combination of modernized echo sounder Furuno FCV-1100 (Japan) and author's software. The complex operated in dual-frequency mode with the following parameters: probing signal frequency 28 and 200 kHz, pulse duration 1.0 ms, single-target selection threshold -52dB. Calibration of the hydroacoustic complex was carried out according to the standard method (Simrad, 2001) using a copper sphere with a diameter of 60 mm with calculated value of target strength (*TS*) equal to -33.61 dB. Control trawls were conducted using a multi-depth trawl (vertical opening up to 10 m, 17.5 m bottom opening) after 4-5 tacks and detection of fish aggregations.

Control of trawl operation (opening, trajectory of movement relative to the bottom and fish aggregations) was carried out using synchronized depth recording sensors placed on the upper and lower picks. Sensors were calibrated before trawling using the cross-calibration method with a two channel submersible temperature and depth logger RBR*duet*^{3} T.D. (Canada). After lifting the trawl on board, data were read via BlueTooth wireless interface.

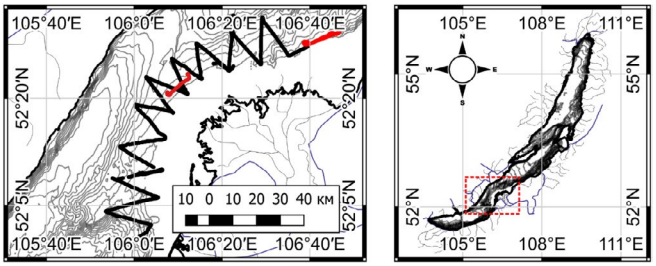

Fig.1. Standard tack grid (in black) of the acoustic survey. Sites of productive trawls (in red)

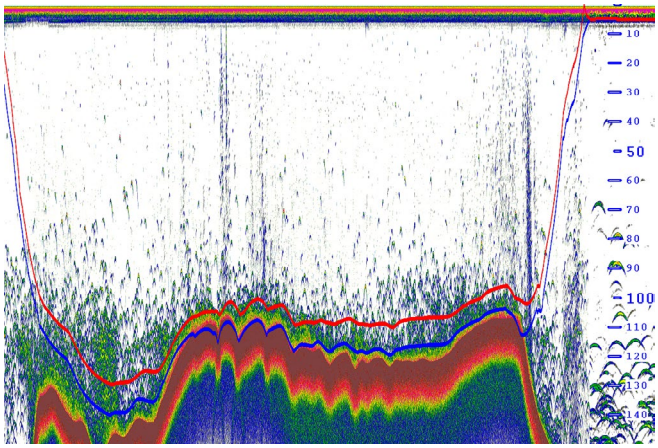

Fig.2. Echogram of the bottom trawling mode (trawl №4). Trajectory of the lower (in blue) and upper (in red) wings

Four bottom trawls were conducted by bottom trawling (Fig. 2). The size composition of fish in the Baikal omul feeding stock was studied based on the data of successful trawl catches (Nos. 2 and 4), measurements of fish from trawls Nos. 1 and 3 were additionally used to estimate biomass (Table). Fish length measurements were taken accurate within 1 cm. Sampled fish weights were obtained using the "length-weight" relationship $Wg = 10.9(SL_{dm})^{3.02}$, where *Wg* is weight in grams, SL_{dm} is standard length in decimeters (Anoshko et al., 2022). A total of 1258 specimens of the Baikal omul were included in the analysis.

3. Results and discussion

Distribution. The distribution of the Baikal omul in the Selenga shallow water area generally corresponded to the winter-spring distribution, the main aggregations were concentrated at depths of 100-300 m. Denser fish aggregations were observed in the underwater slope zone. During the daytime, sparse aggregations were recorded at depths of about 200-250 m. In the upper layers from 100 to 150 m, fish formed small dense (unresolved) aggregations that dispersed at night (Fig. 3).

Comparative analysis of the hydroacoustic survey results of the Selenga shallow waters with similar data from 2015-2022 showed that the general character of the distribution of the Baikal omul aggregations in the water area and depth has significantly changed in 2023. The omul accumulations were more active in comparison with the previous research years. Their redistribution from south to north was recorded,

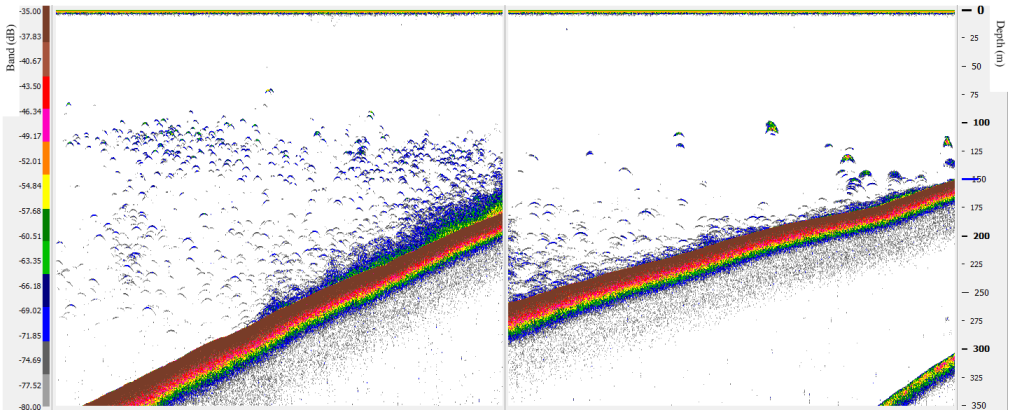

Fig.3. Echograms of the Baikal omul aggregations according to the night survey (from the left) and the day survey (from the right) on May 25-26, 2023

caused probably by the peculiarities of the coastal zone warming due to the arrival of the warmer Selenga River waters in the spring-summer period of 2023.

Size composition. Based on trawl catches in different shallow water zones, the standard length of fish from the feeding stock ranged from 10 to 39 cm with the sample median of a size equal to 17 cm. Representative samples (Fig. 4) had a similar distribution of individuals by size class. Sample from the northern part of the zone was characterized by a large number of small (10-13 cm) and largest (more than 25 cm) individuals. Sample from the middle part was dominated by fish 14-24 cm in length.

Weight composition. Analysis of weight characteristics of fish from all trawl fisheries obtained using "length-weight" relationship (Anoshko et al., 2022) showed that size classes dominant by weight were individuals of 18-26 cm in length (Fig. 5). The sample median was 102 g with fish length corresponding to a size class of 21 cm.

Age composition. The local modes (abundance peaks) of 11, 14, 18, and 21 cm that can be identified in the frequency histograms (Fig. 4), in our opinion, correspond to the age classes of 1-4 years old. To confirm this we used the "length-age" regression relationships (Fig. 6) based on the trawl catch data of 2023 and the TACs data (Materials ..., 2017). The following relations are obtained: $T = 0.0071SL^{2.1}$ and $T = 0.0079SL^{2.0}$, where T – is the age in years, SL – is fish length in cm. Age in years for the Baikal omul is proportional to length SL close to 2, i.e. to the square of length.

"Length-age" ratio ($T = 0.0071SL^{2.1}$) enables to conduct rapid estimation of age class abundance ratio based on the probability of assigning individuals of a certain length to them (Fig. 7). The histogram

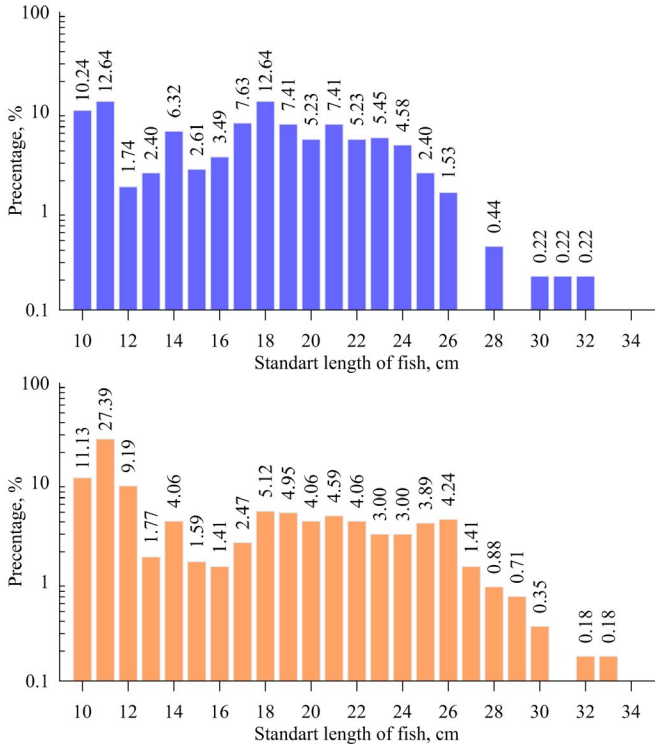

Fig.4. Size composition of catch based on data from trawl №2 (upper) and trawl №4 (bottom).

Table. Trawl parameters and material structure

Trawl no.	Trawling coordinates		Time of trawling		Depth of trawling, m	Sampling volume, spec.
	Beginning, Lat°N/Lon°E	Ending, Lat°N/Lon°E	Beginning	Ending		
1	52.16228/105.96628	52.16231/105.96627	12:20	13:50	145	112
2	52.38949/106.20513	52.34594/106.12876	10:10	12:10	150	461
3	52.48270/106.76392	52.46015/106.6544	22:50	00:50	140	119
4	52.48481/106.77041	52.46027/106.6444	02:10	04:20	140	566
Total, spec.						1258

is constructed only up to 7 years of age due to low representation of fish with sizes corresponding to older ages. It should be noted that it is the younger age groups of fish that are more important for predicting stock biomass. The dependence demonstrates a trend of exponential decrease in abundance of fish proportion with its age. The degree coefficient of 0.33 is analogous to instantaneous mortality coefficient. However, in this case it reflects the trend caused by total mortality (natural and by-catch), the level of recruitment in different years and migration patterns of older individuals. The share of the two-year-olds in catches showed a sharply deviating value from the obtained trend. It can be assumed that the hatching generation of 2021 gave a relatively low recruitment to population. However, other reasons cannot be excluded, such as heterogeneous distribution of fish size classes in the water area, as well as conditions that facilitated the migration of fish of this generation to other areas.

The biomass peak of each generation occurs in fish of 7-8 years age (Sokolov and Peterfeld, 2011) with 25-35 cm in length. However, their weight proportion in our catches was relatively low, indicating a period of low recruitment in the respective generations. Weight of fish with 18-26 cm in length may triple for three years, but, according to the natural mortality rates, (Materials ..., 2023) fish abundance will decrease by half. Consequently, a 1.5-fold increase in reserves of the Selenga region can be expected in the medium term from 3 to 5 years.

Against the background of extremely high estimates of the annual reproduction rate in 2001-2010, there was a decline in the Baikal omul stocks in 2007-2019, totally 3.24 milliard larvae in Baikal (Materials ..., 2017). Downstream migration of larvae in the Selenga River and rivers of the Posolsky Sor averaged 1.729 milliard in 2008-2013, and decreased to 0.640 milliard in 2018-2020 (Materials ..., 2023). At the same time, the basis of the biomass of the Baikal omul in the Selenga shallow water in May-June 2023 contained individuals aged 3-5 years, i.e. the hatching generation of 2018-2020. This indicates the recruitment sufficient to increase the biomass of the stock in the future. Probably, low reproductive rates are not catastrophic for the Baikal omul stocks, and level of fish mortality in the first year of life is of greater importance.

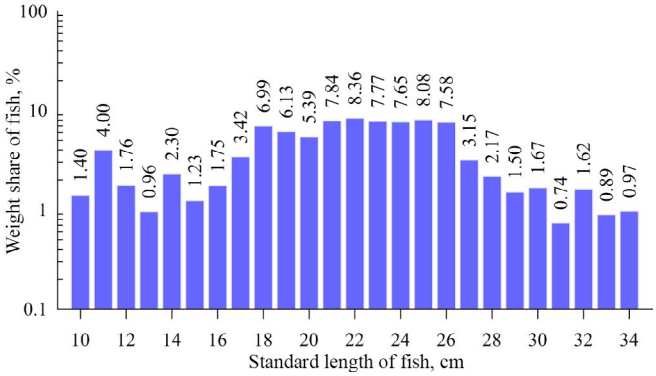

Fig.5. Weight composition based on data of trawls Nos. 2 and 4.

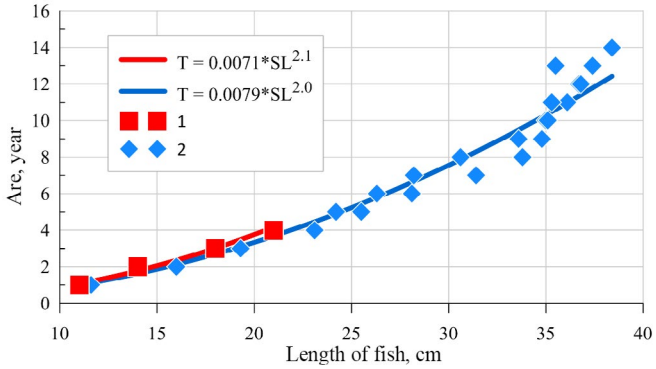

Fig.6. "Length-age" correlation of fish of the Selenga population obtained from: 1 - abundance peaks, our data and 2 - age determination by scale (Materials ..., 2017).

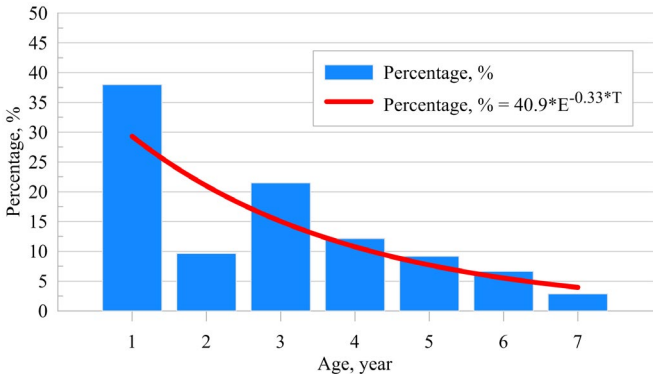

Fig.7. Correlation of age classes of the Baikal omul according to trawl catches data.

4. Conclusion

Comparative analysis of the results of 2023 with the data of 2015-2022 showed significant changes in the general character of distribution of the Baikal omul aggregations in the water area and depths of the Selenga shallow water. Analysis of mass measurements using "length-weight" and "length-age" correlation enables to make an operational assessment of ratio of age class abundance and to formulate middle-term forecast. The standard length of fish ranged from 10 to 39 cm, individuals with 18-26 cm were dominant in terms of weight. Thus, the feeding stock of the Baikal omul was characterized by a significant share of juveniles despite the low level of natural reproduction. This indicates that there is sufficient recruitment to increase the biomass of the Baikal omul stock in 1.5 times in a 5-year period.

The size of reproduction is an important condition for stock recovery, but not a determinant. In the previous period high level of reproduction did not allow ensuring stable stock indices against the background of the traditional Baikal structure. Low reproduction rate of 0.73 milliard larvae in 2016-2020 provides positive dynamics of increase in the Baikal omul stocks, but does not allow quickly restoring them to the level of ecological capacity of Lake Baikal. Therefore, it is an urgent issue to study the factors determining the level of mortality of the Baikal omul in the first year of life, which further will allow correct regulation of its stocks.

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Conflict of interest

The authors declare that they have no competing interests.

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