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Seasonal Distribution and Size Composition of the Black Edged Sculpin *Gymnocanthus herzensteini* (Cottidae) off the Mainland Coast of Russian Waters in the Sea of Japan

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Abstract—Off the mainland coast of the Russian waters of the Sea of Japan, the Black Edged sculpin *Gymnocanthus herzensteini* occurs at depths from 10 to 424 m at temperatures from −0.7 to +17°C. The main aggregations throughout the year are formed in the southern part of the region. It does not enter the continental waters of the Tatar Strait above 48°40′ N. The area bordering the waters of the strait is inhabited mainly by adult fish and to a greater extent during the cold season than during the warm season. Seasonal migrations are predominantly bathymetric in nature. Juveniles in all seasons adhere to the shelf zone, being more eurythermal than adults. As the Black Edged sculpin grows, it becomes more stenothermic and eurybatic.

Keywords: Black Edged sculpin *Gymnocanthus herzensteini*, distribution, density, migrations, temperature, depth, dimensions, Sea of Japan

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INTRODUCTION

Sculpins of the genus Gymnocanthus are mass representatives of the family Cottidae, which are promising fishery objects in the Far Eastern seas (Borets, 1997; Matveev and Terentiev, 2016; Dansky, 2017; Tokranov, 2017). The Black Edged sculpin *G. herzensteini* is a low boreal Cis-Asiatic species that lives in the Sea of Japan, in the southern part of the Sea of Okhotsk, along the Pacific coast of Japan and the Kuril Islands (Lindberg and Krasyukova, 1987; Amaoka et al., 1995; Novikov et al., 2002; Sokolovsky et al., 2007; Parin et al., 2014).

In most of the range, targeted studies of the distribution of the Black Edged sculpin have not been carried out. Some results of the analysis of the distribution of sculpins in certain seasons, which also affect this species, are presented for the central and southern regions of the Russian inland waters of the Sea of Japan (Kalchugin, 1998; Panchenko and Zuenko, 2009). The regularities of the seasonal distribution of the Black Edged sculpin (without taking into account the winter period) are considered only for a relatively small area—Peter the Great Bay (Panchenko and Antonenko, 2004), which occupies ~15% of the area of the continental part of the Russian waters of the Sea of Japan.

The purpose of this work was to analyze the regularities of the seasonal bathymetric and spatial distribution of the Black Edged sculpin at different stages of ontogeny in the mainland part of the Russian waters of the Sea of Japan.

MATERIALS AND METHODS

The paper used the materials performed by TINRO in March–January 1983–2017 of bottom trawl surveys and control trawls, which cover almost the entire area of the Russian inland waters of the Sea of Japan: from its southern border—the mouth of the Tumannaya River to the northern end of the Tatar Strait—Cape Yuzhny (Fig. 1). The data of 8670 trawls on the shelf and continental slope at depths of 2–935 m have been analyzed. As the analysis of the material showed, to the north of 48°40′ N, the Black Edged sculpin was not found in catches. Therefore, this area was excluded from further analysis. To the south, in the habitat of the studied species, 8063 trawls were carried out, of which 3716 were accompanied by measurements of the bottom water temperature. The size composition of the Black Edged sculpin in catches in different seasons

Table 1. Number of studied individuals of the Black Edged sculpin *Gymnocanthus herzensteini*, collected in the northwestern part of the Sea of Japan in the species habitat in different seasons of 1983–2017

Depths, m	Winter			Spring			Summer			Autumn		
	N	N_t	n	N	N_t	n	N	N_t	n	N	N_t	n
<10	2			4			343	33		77		
10–20	7			30	12	14	737	91	154	130	16	4
21–40	9	9	15	247	213	3908	1288	260	3494	166	51	950
41–60	16	15	14	155	133	4598	807	207	7584	104	43	1187
61–80	12	12	23	165	139	2543	789	289	5441	94	44	995
81–100	20	20		122	109	1863	308	105	1240	47	21	350
101–150	8	8	1	201	176	3041	287	147	606	50	32	294
151–200	11	11	17	116	89	853	72	60	47	41	30	89
201–250	17	16	147	160	137	1219	117	86	10	48	32	127
251–350	43	40	92	190	158	331	126	88	3	76	58	141
351–450	29	29	26	129	117	24	81	55		46	39	23
>450	67	65		306	272		103	96		60	53	
Total	241	225	335	1825	1555	18394	5058	1517	18579	939	419	4160

N, N_t—number of trawls, total and with bottom temperature measurements, n—number of individuals studied.

by depth ranges was characterized by the results of length measurements according to Smith (*FL*) of 41468 ind. (Table 1).

Trawling was carried out by bottom trawls with soft ground rope of various designs at a speed of 1.8–3.5 (2.6 on average) knots. To obtain comparable results, the catches in each trawl were recalculated into density using the formula: $P = B/S$, where P is the density (specific abundance), ind./km^2; B is the catch, ind.; S is the trawling area, km^2; catch efficiency factors were not included in the recalculation.

When analyzing the seasonal distribution, the classification of hydrological seasons by Zuenko (1994) was taken as the basis, according to which the winter period includes January–February, the spring period—March–April, the summer period—June–September, the autumn period—November–December; May is the transitional month between spring and summer, October—between summer and autumn. However, according to our data, in March the Black Edged sculpin does not yet leave its wintering grounds, and in December its distribution is similar to that in autumn only in the initial period. This is quite natural, since in December the active layer of the Sea of Japan is already cooled to values close to the winter months, and its maximum cooling usually occurs in February–March (Luchin, 2007). As a result, we adopted the following chronology of the seasonal rhythmic distribution of the Black Edged sculpin: winter—the second decade of December–March, spring—April–May, summer—June–September, autumn—October–November and the first decade of December.

Spatial distribution analysis was performed using the Surfer software package.

RESULTS AND DISCUSSION

In the northwestern part of the Sea of Japan, the Black Edged sculpin is classified as a group of sublittoral-elitoral species, whose representatives in the warm season mainly live at depths <50 m, and migrate to the outer edge of the shelf in winter to depths of 200 m, and sometimes up to 300 m (Solomatov, 2008).

As our studies have shown, the latitudinal discreteness of the density distribution of the clusters of the Black Edged sculpin does not have pronounced seasonal differences (Fig. 1). Apparently, a significant part of its individuals is characterized by low migratory activity, which is typical for most species of mobile animals (Grant, 1980; Yablokov, 1980). Constantly, the main aggregations were formed in the southern part of the region: in Peter the Great Bay, located between the mouth of the Tumannaya River and Cape Povorotny, as well as to the north of Cape Povorotny. However, it should be noted that during the cold period of the year this species uses the northern part of the water area somewhat more intensively than during the warm season. In winter, the main area of fish concentrations was confined to the indicated areas, however, relatively high catches were also recorded much further north, at 46° N (Fig. 1a). In spring, this grouping shifts southward (Fig. 1b), and in summer there are significant concentrations of fish were not observed north of 45° N (Fig. 1c). In autumn, a reverse shift of

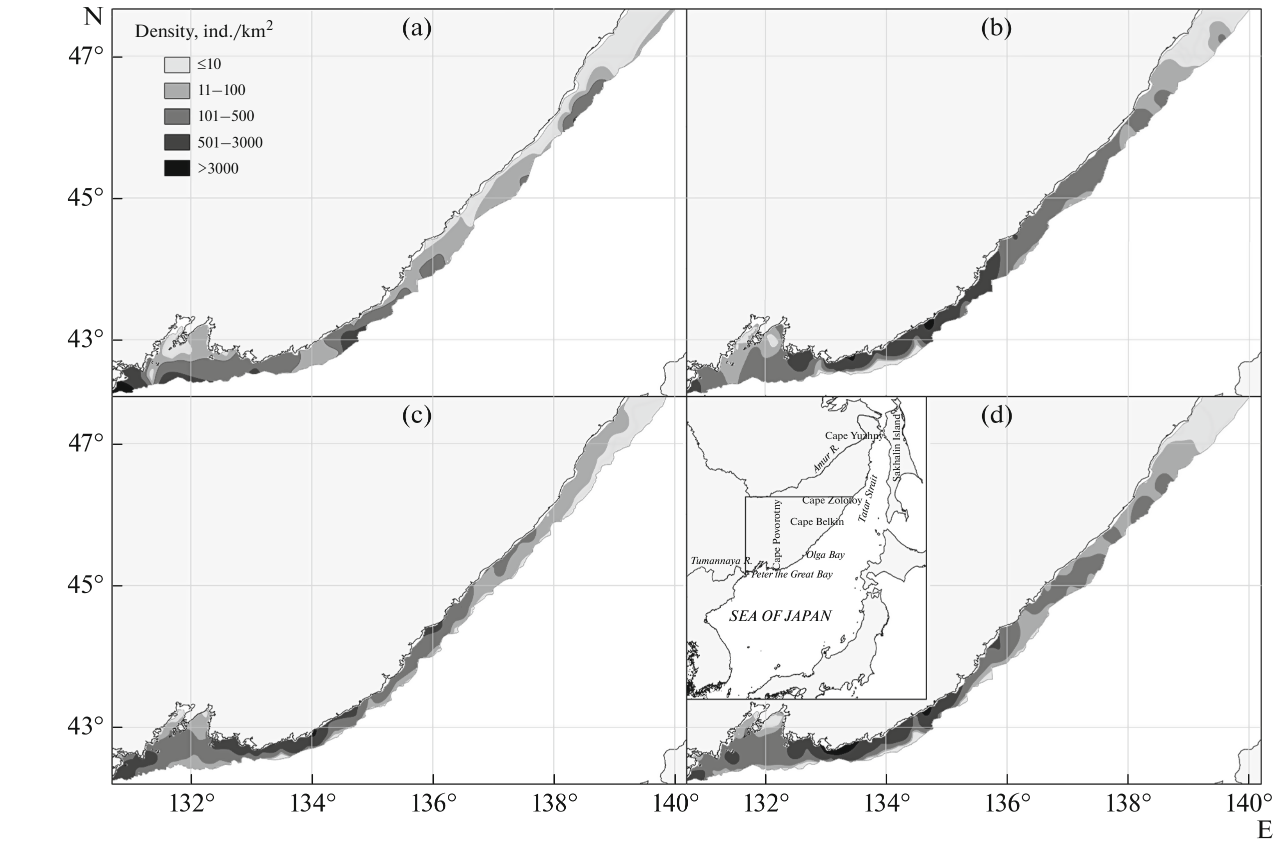

Fig. 1. Seasonal distribution of the Black Edged sculpin *Gymnocanthus herzensteini* in the waters of the northwestern part of the Sea of Japan: a—winter, b—spring, c—summer, d—autumn.

some fish to the north is noticeable (Fig. 1d). Meanwhile, further, in the water area adjacent to Cape Zolotoy, in all seasons, catches of this species were only occasionally recorded. North of 48°40′ N, the Black Edged sculpin was observed in none of the seasons, although there is an extended section of the water area with depths widely used by it in the southern regions.

Most of the water area studied by us belongs to the open waters of the Sea of Japan; to the north of Cape Belkin there are the waters of the Tatar Strait, which separates Sakhalin Island from the mainland (Fig. 1). Thus, the most noticeable decrease in the density of the Black Edged sculpin, culminating in its complete absence in catches at habitat depths, occurs with advancement into the depths of the Tatar Strait. It should be noted that near the island coast of the strait, in contrast to the mainland, the Black Edged sculpin is much more widespread and forms significant concentrations (Kalchugin et al., 2016).

Features of the distribution of fish in different parts of the water area are largely due to the peculiarities of the water regime. In the northern part of the Tatar Strait, a subsurface water layer with low temperature and salinity is formed, which sinks to the bottom areas due to winter convection and forms a cold underlying layer (Zuenko, 2008). The decrease in salinity in the apex of the strait is due to the intensity of the continental runoff, for the most part, of the Amur River. In the area of Cape Zolotoy, the influence of the northern water regime is gradually weakening, and at the exit from the Tatar Strait, such a severe hydrological regime is not typical for the waters of Primorye. In contrast to the mainland coast, the water area of the Tatar Strait near Southwestern Sakhalin is less affected by the subsurface layer of water, as it is under the influence of the warm Tsushima Current penetrating along the Japanese Islands. It can be summarized that in all seasons the Black Edged sculpin avoids the freshened chilled waters of the continental part of the Tatar Strait.

In the waters of the Sea of Japan, the Black Edged sculpin spawns in December–February (Park et al., 2007; Sokolovsky and Sokolovskaya, 2008). Seasonal movements of some individuals by this period in the meridional direction to the area of 46° N may be due to spawning migrations to the northernmost of the spawning grounds located near the mainland. An ech-

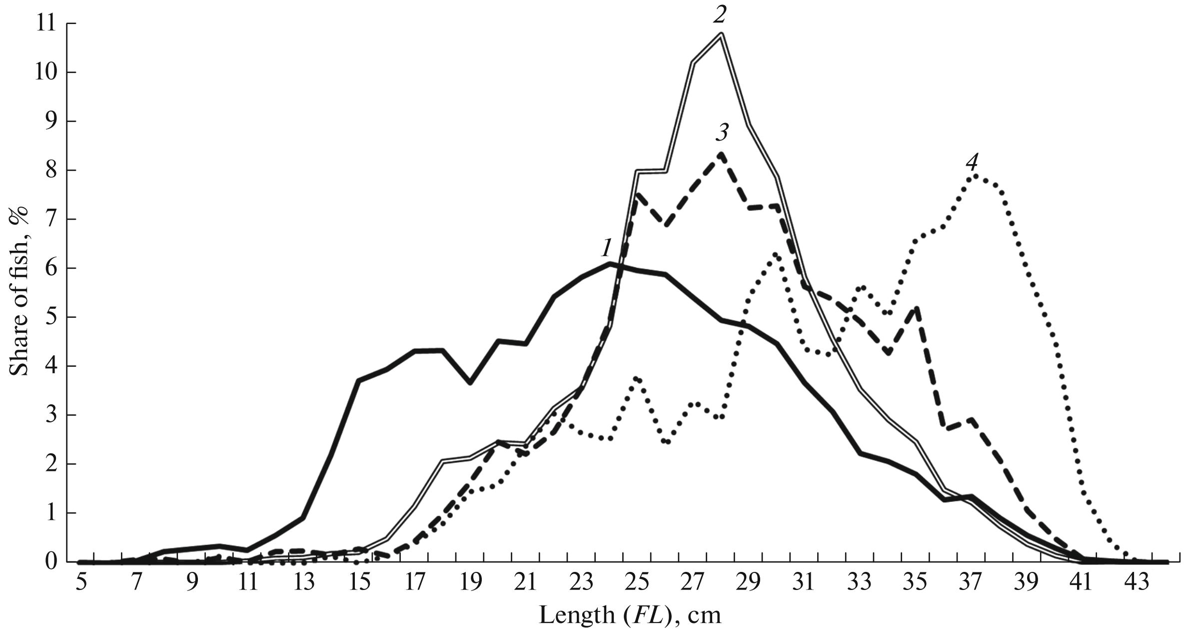

Fig. 2. Size composition of the Black Edged sculpin *Gymnocanthus herzensteini* in bottom trawl catches in different areas of the northwestern part of the Sea of Japan: *1*—Peter the Great Bay, *2*—from Cape Povorotny to Olga Bay, *3*—from Olga Bay to Cape Belkin, *4*—north of Cape Belkin.

eloned shift of clusters in seasonal density dynamics is not traced. This suggests that relatively long migrations are performed by only a part of individuals, most likely, sexually mature ones. Sexual maturation of individuals of the Black Edged sculpin occurs at *FL* 19–20 cm, all individuals $FL \geq 25$ cm, as a rule, are sexually mature (Panchenko and Antonenko, 2004; Panchenko, 2010). The minimum size of individuals recorded in winter north of Cape Belkin was 23 cm. In other seasons, a certain number of individuals with sizes that allow them to be unambiguously attributed to juveniles were noted in this area, but compared to other water areas, their proportion was minimal, which is clearly seen in combined data, without breaking it down into seasons (Fig. 2).

In general, clinal (in this case, latitudinal) variability in the size of the Black Edged sculpin in catches was revealed for the study area, which is expressed in their increase in the northerly direction (Fig. 2). This is due to both a decrease in the proportion of juveniles and an increase in modal sizes. We emphasize that in all areas the length of fish in catches varied within similar limits. Details do not matter here, since individuals of extreme sizes are always represented in scanty numbers. The modal classes of individuals present in the catches in all areas are represented by sexually mature fish. The largest proportion of juveniles was noted in the southern region, in Peter the Great Bay. Here, there was the smallest modal group of fish that formed the basis of catches—22–27 cm. As a result, the average length of individuals turned out to be less than in other areas—only 23.8 cm. Moving further north, between Cape Povorotny and Olga Bay, the modal group was already composed of individuals *FL* 25–30 cm. Fish of the same size generally dominated in the catches further north, between Olga Bay and Cape Belkin, but the proportion of large individuals $FL > 31$ cm in the second area was higher. The average fish size in these two areas was 26.9 and 28.0 cm, respectively. Further north of Cape Belkin, this figure increased significantly to 31.4 cm, which was due to the dominance of large adults. Thus, habitation in marginal unfavorable conditions on the outskirts of the range is more characteristic of adult fish of large size than of juveniles.

According to the literature (Novikov et al., 2002; Parin et al., 2014), the Black Edged sculpin occurs at depths of 5 m or more. However, in our studies, the minimum depth of its capture was greater, 10 m. It was recorded in the summer period (Fig. 3c). The maximum depth of capture at that time was 255 m. The water temperature in the habitats of the Black Edged sculpin during this period varied within 1–7°C. In all areas, the trends in the bathymetric distribution of the studied species in summer, as in other seasons, were similar. The highest density of fish in summer was observed in the depth ranges of 41–60 and 61–80 m, where the average temperature was 4.5 and 3.0°C, respectively. However, the highest catches of the Black Edged sculpin were recorded here within a much wider range, from 2.5 to 7.5°C.

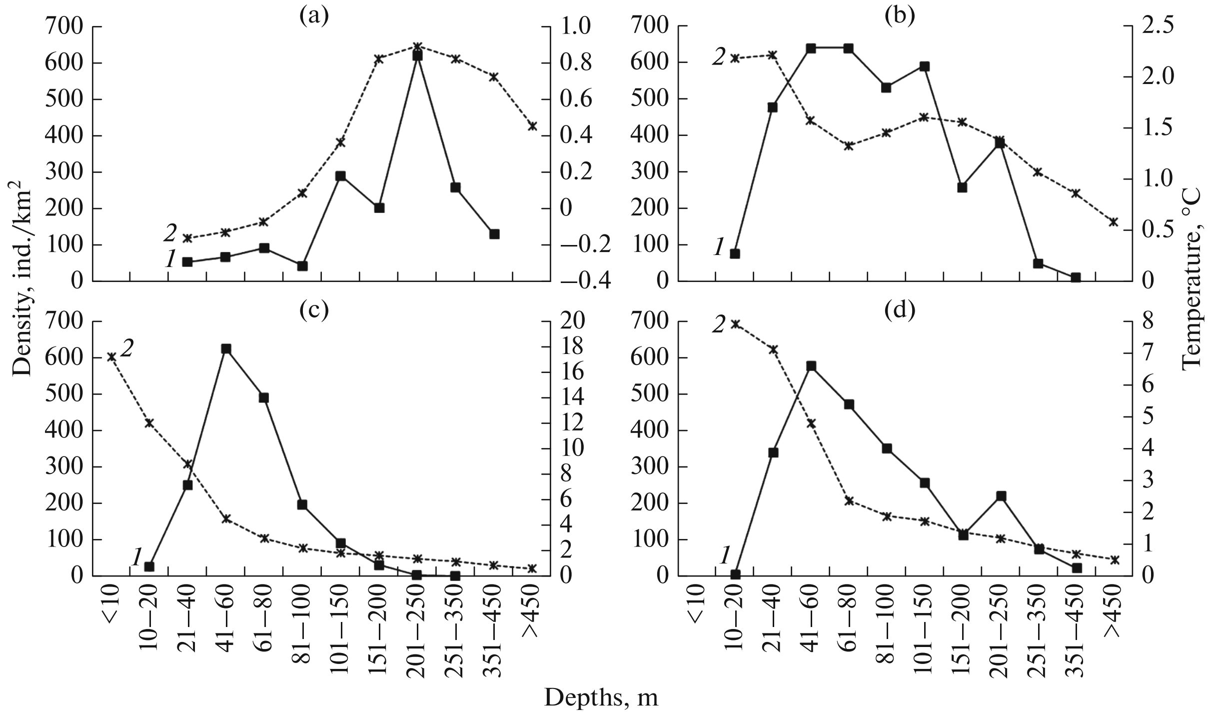

Fig. 3. Average distribution densities of the Black Edged sculpin *Gymnocanthus herzensteini* (*1*) and temperature regime (*2*) in different depth ranges in the northwestern part of the Sea of Japan by seasons: a—winter, b—spring, c—summer, d—autumn.

In autumn, the main concentrations of the Black Edged sculpin remained in the same depth ranges, 41–60 and 61–80 m (Fig. 3d), the temperature background of which has not yet undergone significant changes. But their dominance was already expressed to a lesser extent as a result of the transition of some fish to other depths. Despite the fact that the minimum detection depth of the Black Edged sculpin became greater (16 m), some fish shifted towards the shallow water zone, to the depths of the range of 21–40 m cooled to a more comfortable temperature. However, a shift towards the deep-water zone was observed to a much greater extent: lower below the 80-meter isobath, the density of fish increased, and the maximum habitat depth increased to 410 m. The main concentration of fish moving to the deep-water zone was traced in the range of 201–250 m, where, apparently, wintering aggregations of the Black Edged sculpin began to form in autumn.

In winter, it was in the range of 201–250 m that its main concentrations were observed (Fig. 3a). The next largest specific abundance was the range of 101–150 m; it is possible that in the region of these depths spawning areas of the Black Edged sculpin are located, from where, after spawning, it migrates for wintering beyond the 200-meter isobath. The considered species was encountered in winter at depths of 24–385 m in the temperature range from negative values (−0.7°) in the upper part of the shelf, where it did not form large concentrations, to weakly positive values (1.4°C) in the lower part of the shelf and the upper part of the continental slope. Probably, the maximum depths of habitat of the Black Edged sculpin in winter, due to the relatively small amount of data for this season (Table 1), were not fully covered, and the lower limit is below the 400-m isobath, i.e., close to the values noted in autumn and spring.

During the period of spring migrations from wintering areas to summer feeding grounds, the Black Edged sculpin was observed at depths of 19–424 m (Fig. 3b). The distribution of fish at that time was largely similar to that in autumn. In spring, as in autumn, an increased density of fish relative to adjacent ranges was observed at depths of 201–250 m, but the main concentrations shifted to the shelf zone. As in autumn, much higher concentrations of fish in the range of 21–40 m were formed in spring compared to summer. The water temperature in the places where the species was found varied from negative values (−0.5°C) in the shelf zone at the beginning of the spring period to 5.0°C at its end; the largest catches were recorded at a temperature of 0.4–1.5°C.

Considering the distribution of fish of different sizes relative to the depths of habitat (Fig. 4), we note that in all seasons there is a tendency for an increase in the average length with an increase in depth, which is

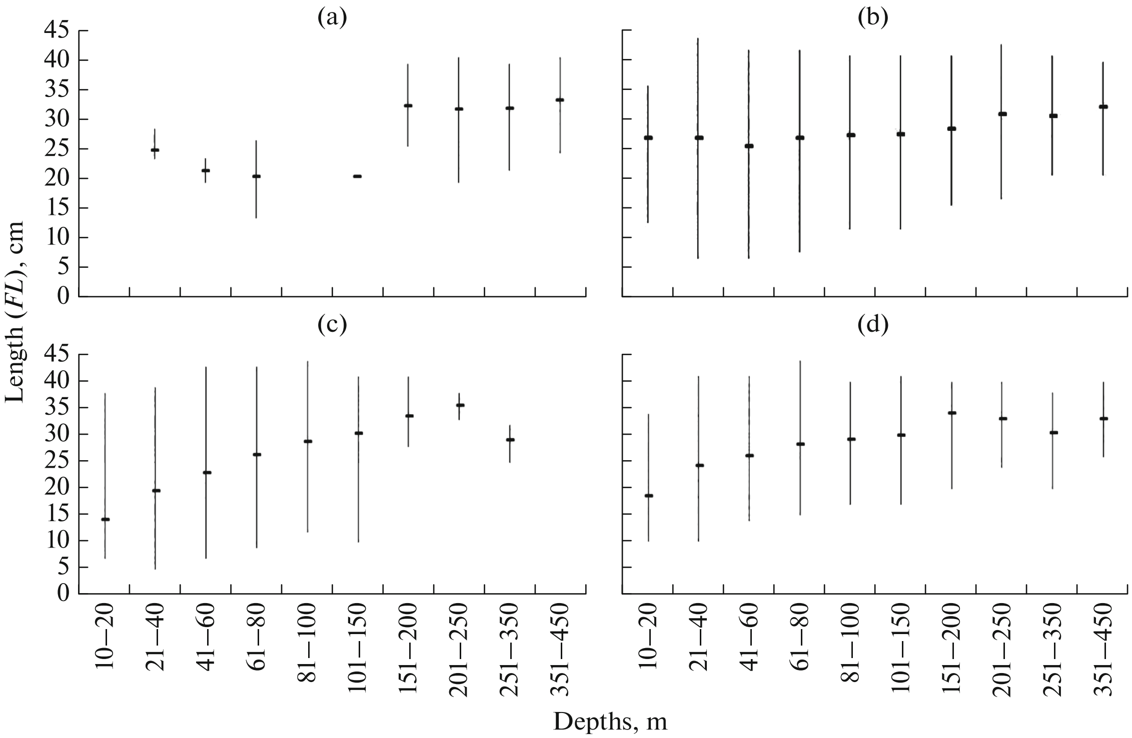

Fig. 4. Size composition of the Black Edged sculpin *Gymnocanthus herzensteini* in bottom trawl catches in the northwestern Sea of Japan in different depth ranges by season: a—winter, b—spring, c—summer, d—autumn; (-)—mean value, (|)—indicator variation limits.

mainly due to the preference of juveniles for shallower depths than adult fish. This trend is least pronounced in the northern region, to the north of Cape Belkin, where, as indicated above, adult fish are found for the most part. The preference of juveniles for shallower depths than adult fish is most pronounced in summer (Fig. 4c). The smallest juveniles (*FL* ≤ 5 cm) recorded by us in this season in the depth range of 21–40 m belong to the underyearlings (Panchenko, 2010), which descended into the bottom layers of water in April–May after the completion of the pelagic larval stage (Novikov et al., 2002; Sokolovsky, Sokolovskaya, 2008). At shallower depths (10–20 m), juveniles were also observed mainly; up to a depth of 13 m, the length of the caught fish did not exceed 8 cm. Below, the maximum sizes of fish increased, but only immature individuals were recorded down to a depth of 16 m. Only below this isobath, individuals *FL* 19–24 cm began to occur and, to a lesser extent, larger fish. In general, juveniles *FL* ≤ 8 cm lived only at depths < 60 m. With increasing depths, below 120 m, only fish *FL* ≥ 22 cm were found in summer, and below the 150-m isobath—≥ 25 cm, i.e., unambiguously belonging to adults. In other seasons, juveniles also mostly stayed on the upper and middle parts of the shelf. This fully applies to the winter season, when negative water temperatures prevailed here; therefore, it can be concluded that juveniles of the Black Edged sculpin, especially at the initial stage of development, are more eurythermic than adults. In the community of demersal fish, which includes the Black Edged sculpin, with growth, a tendency to greater depths with a relatively stable temperature background can be traced (Vdovin and Zuenko, 1997). In other words, as they age, many bottom-dwelling fish become more stenothermic and eurybatic. The aspiration of cold-blooded animals with age to biotopes with relatively low and stable temperatures contributes to the slowdown and stabilization of metabolic processes in the body, which leads to an increase in their life expectancy (Brett and Groves, 1983; Radzinskaya et al., 1987; Schmidt-Nielsen, 1987; Vdovin and Chetyrbotsky, 2018).

CONCLUSIONS

1. In the northwestern part of the Sea of Japan, the Black Edged sculpin occurs at depths of 10–424 m. The water temperature in habitats varies within 1.0–17.0°C in summer, and from –0.7 to 1.4°C in winter.

2. The Black Edged sculpin enters the continental waters of the Tatar Strait only in its southern part, which is due to the avoidance of freshened chilled waters located above. In the cold period of the year,

the species uses the waters of the pre-strait area to a greater extent than in the warm one, but the main aggregations throughout the year are formed in the southern part of the area: in Peter the Great Bay and to the north of Cape Povorotny.

3. Living in unfavorable conditions on the outskirts of the range is more typical for large adult fish than for juveniles.

4. Juveniles in all seasons adhere to the shelf zone, being more eurythermal than adults. With growth, the Black Edged sculpin becomes more stenothermic and eurybatic.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflict 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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