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Seasonal Distribution of Threaded Sculpin *Gymnocanthus pistilliger* (Cottidae) in Russian Waters of the Sea of Japan

V. V. Panchenko[a, b, *], A. A. Matveev[c], and L. L. Panchenko[d]

[a]*Russian Federal Research Institute of Fisheries and Oceanography, Pacific Branch, Vladivostok, Russia*
[b]*National Scientific Center of Marine Biology, Far Eastern Branch, Russian Academy of Sciences, Vladivostok, Russia*
[c]*Russian Federal Research Institute of Fisheries and Oceanography, Kamchatka Branch, Petropavlovsk-Kamchatsky, Russia*
[d]*Vladivostok State University of Economics and Service, Vladivostok, Russia*
**e-mail: vlad-panch@yandex.ru*

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Abstract—In Russian waters of the Sea of Japan, the threaded sculpin *Gymnocanthus pistilliger* occurs at depths of 5 to 217 m and water temperature in the near bottom layer from –1.4 to +18.7°C in the spring–autumn season. In spring, it migrates from the outer border of the shelf towards its heated middle and upper parts where it forms feeding aggregations in summer and prespawning aggregations in autumn. The largest concentrations are observed in Peter the Great Bay, while the smallest ones in the northern part of Tatar Strait. In summer, juveniles stay in a heated shallow zone that is avoided by adults. As the water temperature starts to get cooler in autumn, small-sized fishes move to deeper layers and spawners penetrate into shallow areas. Only adult fishes live at the maximum depths during all seasons. *G. pistilliger* reaches a larger size (33 cm) in waters of the Sea of Japan than in the northern part of its range. Females reaching larger sizes than males prevail in the population. In summer, the sex ratio is even at relatively small depths; the proportion of females gradually increases with depth.

Keywords: threaded sculpin *Gymnocanthus pistilliger*, distribution, depth, density, size, aggregations, Peter the Great Bay, Primorskii krai, Tatar Strait

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Threaded sculpin *Gymnocanthus pistilliger* is mainly a boreal species; in the Arctic, it occurs in the southern part of the Chukchi Sea; in Asia, the species is widespread in the Sea of Okhotsk and the Bering Sea, along the continental coast in the Sea of Japan to Busan, near Hokkaido, Kuril Islands, Southeastern Kamchatka, and the Gulf of Alaska (Chyung and Kim, 1959; Neelov, 1979; Son Yong Ho, 1986; Lindberg and Krasyukova, 1987; Kim and Yoon, 1992; Amaoka et al., 1995; Borets, 2000; Sheiko and Fedorov, 2000; Mecklenburg et al., 2002; Fedorov et al., 2003; Fadeev, 2005; Parin et al., 2014; Fricke et al., 2019; *FishBase*..., 2019). It is a common species in many regions, including Russian waters in the Sea of Japan (Sokolovskii et al., 2007); however, threaded sculpin is poorly exploited since it is a commercial fishery species.

Threaded sculpin remains insufficiently studied despite a vast distribution range. In the northern area of the range, there are only limited data on its distribution, age structure, and some biological features in the coastal waters of Kamchatka (Nikolotova, 1977; Tokranov, 1981, 1985, 1987, 1988, 1993; Tokranov and Polutov, 1984; Chuchukalo, 2006; Balanov and Matveev, 2018) and the eastern part of the Bering Sea (Hoff, 2000). In the south, targeted studies of *G. pistilliger* were carried out mainly in Peter the Great Bay bordering waters off the coast of the Korean Peninsula, where its distribution during a warm period of the year and at the beginning of autumn cooling (Vdovin et al., 1994), dynamics of its abundance (Panchenko, 2013), and age and growth here and in adjacent waters of Primorskii krai (Shelekhov and Panchenko, 2007; Panchenko, 2012) were studied. Other publications on the Sea of Japan contain only fragmentary information on its distribution and feeding (Vdovin and Zuenko, 1997; Kalchugin, 1998; Kim Sen Tok, 2001; Pushcina, 2005; Chuchukalo, 2006; Solomatov, 2008; Panchenko and Zuenko, 2009; Panchenko et al., 2016; Pushchina et al., 2016).

The aim of this study is to determine patterns of seasonal bathymetrical and spatial distribution and identify the trends of the distribution of all size groups of threaded sculpin in Russian waters of the Sea of Japan.

MATERIALS AND METHODS

The study is based on the data of trawl surveys and control trawling that were performed by the Pacific

Research Fisheries Center in the area of Russian waters of the Sea of Japan in different seasons from 1983 to 2017[1]. The data from 9486 trawling operations in the shelf and on the continental slope at depths from 2 to 935 m were analyzed; 4689 of these trawling operations were accompanied by measurements of the near-bottom water temperature. Most trawling operations below the 5-m isobaths were performed using bottom trawls with a soft ground rope, the length of head rope from 20 to 69 m (horizontal opening from 13 to 38 m) and a mesh size in the cod end from 10 to 30 mm at the rate of trawling of 1.5–4.5 (on average 2.6) knots. The main fishing gear at lower depths was a beam trawl modified at the Pacific Research Fisheries Center (Vdovin et al., 2009) with a cod-end mesh of 10 mm and horizontal opening of 3 m; the rate of trawling was 1.3–3.4 (2.4) knots. To obtain comparable results when using trawls of different design, we recalculated fish catches per density according to the formula: $P = B/S$, where P is the density, kg/km^2; B is the catch, kg; and S is the area of trawling, km^2. Since the question of the coefficients of catching efficiency is still disputable, the catchability coefficient recalculated per density was not included.

The hydrological seasons were distinguished according to the classification of Zuenko (1994): the spring season includes March and April, summer includes June–September, and autumn includes November and December; May is a transitional month between spring and summer. Since the pattern of distribution of bottom fish in May is more similar to that in spring (Solomatov, 2008) we attribute May to the spring season. The first half of October was analyzed together with the summer months; the second half was analyzed together with the autumn months.

The spatial distribution of threaded sculpin was analyzed using the Chartmaster software by the method of spline approximation. The total length (*TL*) of 53 663 specimens was measured and the sex of 20 322 specimens was determined; 1374 specimens were individually weighed.

RESULTS AND DISCUSSION

The spatial distribution of threaded sculpin in Russian waters of the Sea of Japan was inhomogeneous during all studied seasons (Fig. 1). The highest concentrations were formed in a wide shelf in the south of the region, in Peter the Great Bay in the spring–autumn period with maximum values during the summer feeding period (Fig. 1b). Two centers of density were observed during this season; one center was localized in the western part of the bay and the other one was in its eastern part. The same pattern was observed by Vdovin et al. (1994) when they studied the distribution of threaded sculpin in Peter the Great Bay in July–October. Based on the analysis, the authors suggested the existence of two intraspecific groups in the bay; the boundary between them is in the zone dividing the water circulation in the central part of the bay. They explained an increase in the concentration of sculpin without redistribution of aggregations by prespawning migration to the western part from North Korean waters and to the eastern part from waters of northern Primorye. Thus, the high density of threaded sculpin recorded in Peter the Great Bay in the autumn period (Fig. 1c) may be explained by the fish concentration in spawning grounds. In spring, the fish density is much lower; the main concentrations in the bay are shifted towards the east (Fig. 1a). If the assumption that a group of spawners from North Korean waters perform spawning migrations to the western part of Peter the Great Bay in autumn is correct, the absence of their high concentrations in spring may be explained by their return migration after spawning. Novikov et al. (2002) consider that, in general, spawning of threaded sculpin occurs in winter at depths of 60–110 m in waters of Primorye. Vdovin et al. (1994), with reference to the unpublished data of Streltsov, report that in Peter the Great Bay in the south of Primorsky krai the species spawns at smaller depths, 30–50 m. In the first half of December, we found prespawning and spawning specimens at smaller depths, 6–14 m in this region: seven females and one male of *G. pistilliger* were caught in the course of two trawling events. A male and four females had gonads at maturity stages IV–V (Sakun and Butskaya, 1968) and three females had running gonads.

There is a wide shelf in Tatar Strait like that in Peter the Great Bay; however, large concentrations of threaded sculpin were not observed there in any season (Fig. 1); the minimum catches occurred in autumn and the maximum in summer. Judging by a sharp decline (especially in the apex part) in the fish density in autumn (Fig. 1c) during this period, *G. pistilliger* migrates from waters of Tatar Strait so we can conclude that spawning grounds are absent in its northern and central parts. After spawning, wintering migrations are probably not performed towards waters of Tatar Strait. This region in the Sea of Japan is characterized by a subarctic type of vertical water structure with low values of temperature and salinity (Yarichin, 1980; Zuenko, 2008) unfavorable (especially in the winter period) for habitation of many hydrobiont species, including representatives of the family Cottidae, in particular, the Gilbert'Irish lord *Hemilepidotus gilberti* and the antlered sculpin *Enophrys diceraus* (Panchenko and Pushchina, 2018, 2019). Only the south of the insular coast is subjected to the effect of the warm Tsushima Current where a relatively high density of fish remains throughout all studied seasons.

[1] In this century, the studies were carried out only in spring–autumn months, and previously, the total species identification of sculpins of the genus *Gymnocanthus* was not often made, though studies covered a winter season as well. In this respect, we have no representative data on *G. pistilliger* for January–February.

The part of the fish population moves for wintering southward to the coast of Hokkaido Island (Kim Sen Tok, 2004). When water warms up in spring, aggregations of threaded sculpin in waters of Tatar Strait from the landward side and Sakhalin Island start migration to the north and reach the central part in the insular region and the apex part in the continental region in summer.

When considering the other region of the continental area in Russian waters of the Sea of Japan, the absence of large concentrations of threaded sculpin in the shelf adjacent to Peter the Great Bay in the northeast (Fig. 1) may be noted. Formation of aggregations in the southern region of northern Primorye and the gap between it and the central region may be explained by the system of water vergences, the most important of which is the divergence zone. It is located in the central part of the sea and is extended to the northeast but it is latitudinally directed and is closely adjacent to the continental shelf in the area of 44° N (Yarichin and Pokudov, 1982). The divergence zone is characterized by a quasistationary location, great vertical power, and wedges out to the shelf breaking the current flowing from the north to the south. The difference in the fish distribution in this region, including representatives of Cottidae, was reported earlier (Kalchugin, 1998; Solomatov, 2008). The smallest region of increased catches was observed higher, in the central part of the continental waters (Fig. 1b) that may be due to the preference by the main part of fish during the feeding period of wide shelf zones the nearest of which is in the north of the region. In autumn, the concentration of fish increases in the central part of the continental waters, which is, apparently, explained by spawning migration of fish from the north, from waters of Tatar Strait; in spring, the concentration decreases when fish disperse in the shelf northward.

In the northwestern part of the Sea of Japan, threaded sculpin belongs to a sublittoral-elittoral group of fish inhabiting waters at depths of <50 m during the warm season of the year and migrating to the outer edge of the shelf for winter (Solomatov, 2008). It is natural that its narrowest bathymetrical range is observed in summer: in general, the smallest depth of catches was 5 m in the region, while the largest depth was 135 m (Fig. 2). It should be noted that only one specimen of threaded sculpin was caught at the depth of 135 m and at the end of the hydrological summer (the end of September). The next capture in respect to water depth was recorded at the depth of 107 m in summer. Aggregations of *G. pistilliger* were formed in summer in the depth ranges of 40–60, 60–80, and to a lesser degree of 20–40 m. The average temperature at these depths was 4.8, 2.8, and 9.2°C, respectively. In general, the temperature range of findings of threaded sculpin in summer varied from negative values (–0.6...–0.1°C) recorded at the end of the summer season in the northern part of Tatar Strait to +18.7°C. It should be noted that threaded sculpin inhabits

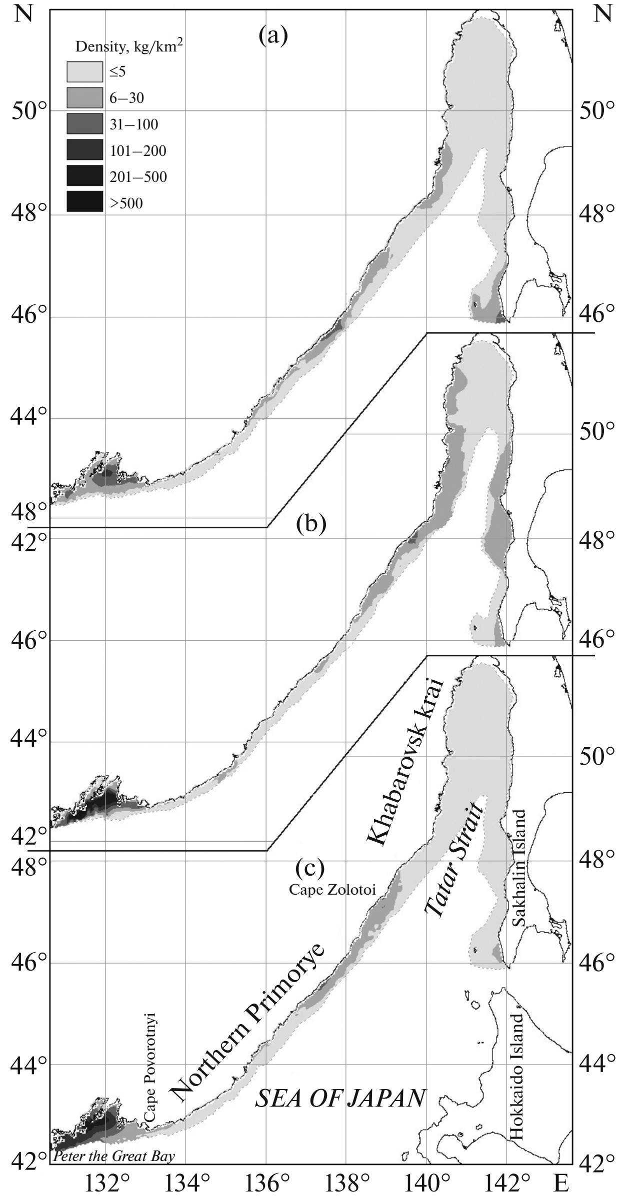

Fig. 1. Spatial distribution of threaded sculpin *Gymnocanthus pistilliger* in Russian waters of the Sea of Japan in respect to seasons: (a) spring, (b) summer, (c) autumn.

smaller depths in the north of the range in summer according to the literature data. Thus, threaded sculpin prefers the depth range within 20–40 m and depths of <20 m in the western Kamchatka shelf in summer; it episodically occurs at the depths of 40–60 and 60–80 m, thermopathy is 2–12°C (Tokranov, 1981; Balanov and Matveev, 2018). The species inhabits coastal waters to the depths of <50 m in the eastern Bering Sea during the warm period of the year (Hoff, 2000).

In autumn, the range of habitation of threaded sculpin in the studied northwestern part of the Sea of Japan increased due to deep-water layers, amounting

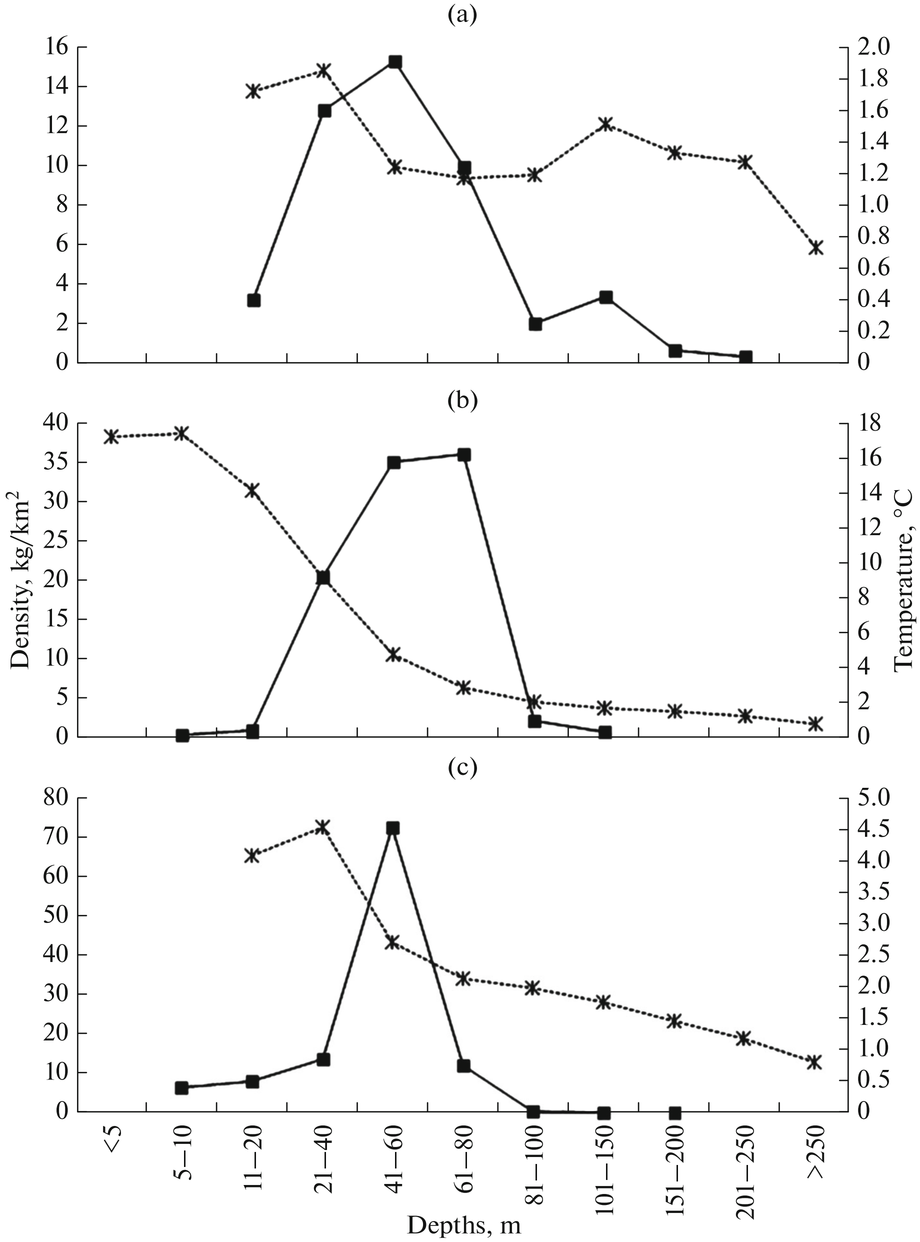

Fig. 2. Average densities of threaded sculpin *Gymnocanthus pistilliger* (■) and temperature regime (⚹) in different ranges of depths in Russian waters of the Sea of Japan in respect to seasons: (a) spring, (b) summer, (c) autumn.

to 6–200 m (Fig. 2c). However, major aggregations were concentrated in the upper part of the shelf, which may be explained by spawning, apparently beginning since December. The leading three ranges were the same as in summer; however, if the fish density increased twice at depths of 40–60 m, it notably decreased at depths of 60–80 and 20–40 m. The changes occurred against the background of decreasing water temperature whose importance increased with decreasing depth. In autumn, *G. pistilliger* occurred in the temperature range from 0.1 to 7.2°C. The fish density in a shallow zone at depths of 5–10 and 10–20 m slightly increased probably due to the decrease in water temperature to values comfortable for the species.

In the spring season, threaded sculpin occurred at depths in the range of 15–217 m; as in autumn, the main bulk of fish was recorded at depths of 20–80 m with peak values in the range of 40–60 m (Fig. 2a); however, the latter range was leading to a lesser extent. We should note a slight increase in the fish density at depths of 100–150 m compared to adjacent ranges, which is apparently determined by the presence of specimens that did not migrate from wintering grounds. The average temperature at the depths of habitation of threaded sculpin insignificantly varied from 1.2 to 1.8°C; however, in general, the temperature range of its occurrence was much broader: from −1.4°C in a relatively shallow zone at the beginning of spring to +7.6°C in this zone at the end of spring.

Based on the distribution of *G. pistilliger* in autumn and spring and on the literature data, its bathymetrical preferences during the wintering period may be suggested. According to the literature data (Novikov et al., 2002; Solomatov et al., 2008), threaded sculpin performs overwintering migration in waters of Primorye over the 100-m isobaths to depths of 200–300 m. Therefore, it may be suggested that the maximum depths of habitation (200 m) recorded during the period of autumn migrations to wintering grounds and during spring migrations to feeding grounds (217 m) are similar to those in the winter period. Though Kim Sen Tok (2001) and then Sokolovskii et al. (2007) consider that *G. pistilliger* penetrates to the depth of 442 m in winter along the continental slope near southwestern Sakhalin, we think it to be doubtful. We also have information about its presence in some trawl catches performed at depths of more than 217 m, but the critical analysis of the depths of habitation of fish in the Russian zone of the Sea of Japan (Panchenko et al., 2016) showed that the representatives of the species were objectively present in the preceding catches at smaller depths. Since some specimens might be trapped in the trawl and were detected only in the next catch, such data were excluded from the analysis.

We may supplement the literature data on the wintering period with our few available reliable data. At the beginning of the wintering period (in the first decade of January), five trawling operations were performed at depths of 55–70 m in Peter the Great Bay; the temperature was negative (–0.3...–0.7°C) during four trawling events and low-positive (0.1°C) during only one trawling at the maximum depth. Specimens of threaded sculpin were recorded in all trawl catches; its maximum density (65 kg/km^2) was observed at positive temperature values, but slightly lower specific biomass (48 kg/km^2) was recorded at the lowest temperature. Findings of *G. pistilliger* in winter at these depths may be due to spawning occurring in the cold period or migration for wintering towards the outer boundary of the shelf to waters with stable low-positive temperature. However, it is possible that a part of fishes overwinter at a negative water temperature in the middle and upper parts of the shelf.

According to our data, *G. pistilliger* reaches larger sizes in the Sea of Japan in the southern part of the range than in the northern one: specimens of the length up to 33 cm were found in catches, while fishes of *TL* 17–23 cm prevailed. Whereas specimens of *TL* > 27 cm in the waters of Kamchatka (Tokranov, 1987) and 20.1 cm in the eastern part of the Bering Sea (Hoff, 2000) were not found. Individual weighing was

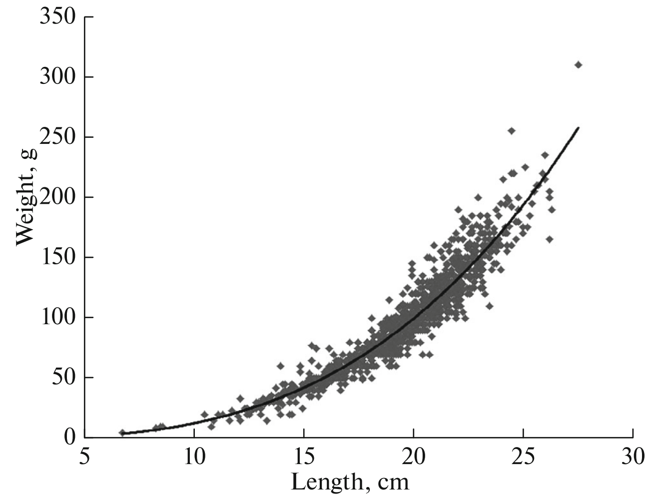

Fig. 3. Relationship between body length (*TL*) and body weight of threaded sculpin in Russian waters of the Sea of Japan.

performed of specimens of *G. pistilliger TL* 7.0–27.5 cm and mass 5–310 g in the Sea of Japan mainly in the warm period of the year. Unfortunately, specimens of larger sizes were not found in samples because of extremely low occurrence of large fishes in catches (Panchenko, 2013). The relationship between the length (*TL*, cm) and weight (*W*, g) of threaded sculpin in the surveyed region is described by the power dependence $W = 0.0113\ TL^{3.027}$ ($R^2 = 0.9406$) (Fig. 3) according to which the weight of fish of the maximum size (33 cm) is ~450 g.

Representatives of the family Cottidae have differences in the bathymetric distribution of specimens of different sizes. In a warm season, juveniles prefer heated shallow water and adult fishes prefer larger depths (Panchenko and Zuenko, 2009). This is typical to a certain degree for threaded sculpin as well. Judging by the size composition, only adult specimens migrated to depths of >80 m in summer (Fig. 4) since males and females reach sexual maturity at the age of 2–3 years at the length of 11.6–16.3 and 13.1–17.5 cm, respectively, in the studied region (Panchenko, 2012). Average sizes increased with depth in summer, though the largest specimens preferred to feed at depths of formation of aggregations, 40–60 m and in the adjacent ranges. Fingerlings (the minimum *TL* 3.5 cm) stayed in the shallow zone.

In autumn, juveniles abandoned the intensively cooling shallow zone. The size of caught fishes to a 17-m isobath was not less than 17 cm, and small specimens, including grown-up fingerlings of more than 5 cm in length, were recorded in deeper layers (Fig. 4c). The size structure in other bathymetric ranges did not differ significantly in summer and autumn except changes in the size structure of threaded sculpin in the

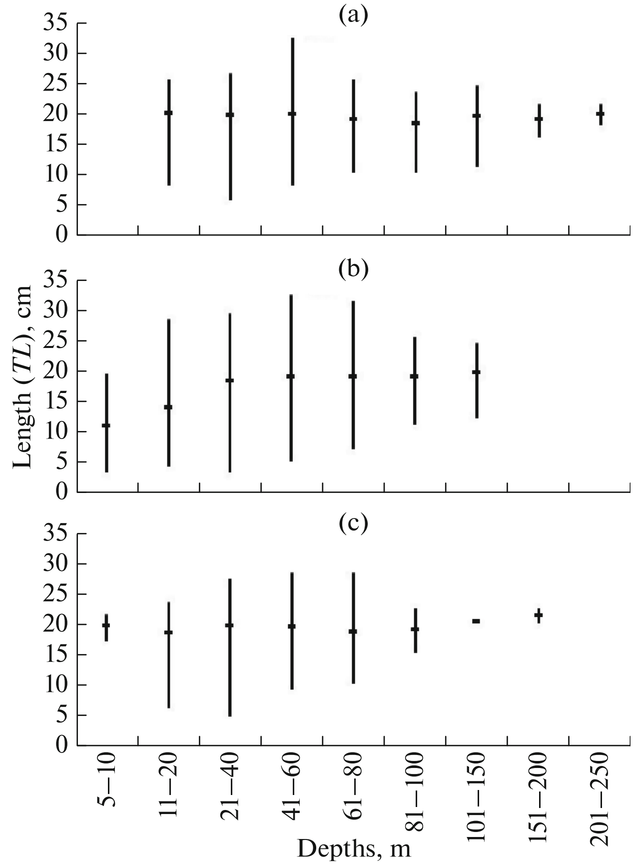

Fig. 4. Size composition of threaded sculpin *Gymnocanthus pistilliger* in bottom trawl catches at different depths in Russian waters of the Sea of Japan: (a) spring, (b) summer, (c) autumn; (—) mean value, (|) ranges of variation of the parameter.

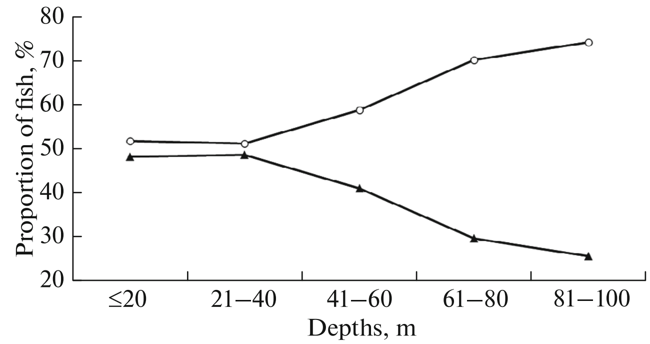

Fig. 5. Sex ratio (males (▲) : females (○)) of threaded sculpin *Gymnocanthus pistilliger* in different ranges of depths in Peter the Great Bay in summer.

sublittoral zone and penetration of adult fish to the lower boundary of the shelf in autumn.

In the abovementioned five catches performed in January at depths of 55–70 m, the minimum size of *G. pistilliger* was 11 cm. The smallest specimens were recorded at low positive water temperature during the deepest trawling. In other catches performed at negative temperatures, the minimum size of fish varied from 14 to 24 cm, i.e., corresponded mainly to adult specimens. In other trawl catches performed at negative temperatures, the minimum size of fishes varied from 14 to 24 cm, i.e., corresponded mainly to adult specimens.

In spring, yearlings $TL \geq 6$ cm occurred at depths of 15–43 m (Fig. 4a) at a temperature of 0.6...+5.3°C. The largest specimens were recorded within the range of 40–60 m where the maximum concentration of fish was observed. The minimum sizes increased with depth, except the shallow zone.

In all sculpins inhabiting coastal waters of Primorsky krai, including threaded sculpin, the sex ratio changes with growth, but females prevail in the population in general (Panchenko, 2012). It is determined by sexual dimorphism, one of the manifestations of which is smaller sizes of males and their shorter lifespan. In this regard, the proportion of females among adult fishes constantly increases with increasing sizes. We traced changes in the sex ratio in summer in Peter the Great Bay (where the main bulk of measurements was performed with sex differentiation) according to depths of habitation. The proportion of females in a relatively deep zone exceeded the proportion of males almost three times; the difference gradually decreased with decreasing depth and the differences were minimal at depths of <40 m (Fig. 5). Of course, the trend of an increasing proportion of females with increasing depth may be partially explained by increasing sizes of fish with depth in summer. However, though the length of males in measurements with sex differentiation was naturally smaller (to 26 cm), the sizes of fish in each of the ranges varied within the limits reaching by specimens of both sexes. Earlier, we paid attention to the trend toward an increasing portion of females in summer with increasing depth in the representative of the other genus, graypurple sculpin *G. detrisus.* In this species, the tendency is expressed even greater up to complete absence of males in the deep-water zone (Panchenko, 2009).

CONCLUSIONS

(1) Threaded sculpin occurs over all areas of Russian waters of the Sea of Japan, but its distribution is sufficiently different in different parts. The maximum concentrations are observed in a wide shelf in the south of the region, in Peter the Great Bay. Such shelf zone in the north, in the Tatar Strait is used to a much lesser extent, especially on the side of the continental coast that is due to a specific character of the hydrological regime.

(2) *G. pistilliger* occurs at depths from 5 to 217 m at a water temperature in the near-bottom layer between –1.4 and +18.7°C. Its smallest bathymetrical range (5–135 m) is typical for the summer season, but it con-

centrates at similar depths both in summer and in spring and autumn: mainly in the upper and middle parts of the shelf. In spring, it is associated with migrations to summer feeding areas in the heated shelf zone, while with formation of feeding aggregations in summer and migrations to spawning grounds in the upper part of the shelf in autumn.

(3) In the summer period, juveniles stay in the intensively heated shallow zone, which is avoided by adult fishes. With the beginning of autumn cooling, small fishes move deeper and spawners penetrate to shallow areas. The maximum depths of habitation are typical only for adult fishes during all seasons.

(4) Threaded sculpin reaches *TL* 33 cm in waters of the Sea of Japan, which is much larger than in the north of the range. In summer, the ratio of males to females of threaded sculpin at relatively small depths is almost similar; the proportion of females gradually increases at larger depths. In general, females that reach larger sizes and have longer lifespans than males prevail in the population.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. 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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