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Small and Abundant but Understudied Ribbed Sculpin *Triglops pingelii* (Cottidae, Teleostei) from the Kara Sea (Siberian Arctic): Distribution, Biology, and Comparison with Congeners

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Abstract: The features of the spatial and vertical distributions, and size–age and size–sex structures of the ribbed sculpin *Triglops pingelii* of the Kara Sea are presented. In September 2019, this species was recorded at depths from 18 to 235 m at a bottom temperature from −1.5 to +1.6 °C. The densest concentrations were recorded northeastward of the Yamal Peninsula, at the outlet of the Gulf of Ob at a depth of 18–21 m and a bottom temperature from −1.5 to −1.0 °C. Individuals with a length of 46–126 mm and a body weight of 0.35–15.60 g aged 1+ to 4+ years were recorded in trawl catches. However, fish with a length of 51–90 mm and a body weight < 6 g aged 1+–2+ years dominated. Among fish > 71 mm long, the proportion of females increased sharply, reaching 100% with a length of 120 mm. The individual fecundity of female ribbed sculpins in the Kara Sea with a length of 89–123 mm varied from 100 to 316 (on average 215 ± 15) eggs. It is shown that this species is a necto-bentho-ichthyophage whose main prey are benthic and bentho-pelagic crustaceans (mainly amphipods and mysids), as well as juveniles of various fish, the total proportion of which is >99% of the food weight. In this sculpin, age-related changes in the diet composition are well expressed, i.e., as the size increases, the relative importance of the former prey group decreases sharply, and that of the latter two groups, on the contrary, increases. A comparative analysis of data on the biology and distribution of the six most abundant or common *Triglops* spp. makes it possible to attribute the ribbed sculpin to medium-sized representatives of the genus, whose maximum length is similar to those of *T. jordani* from the North Pacific, as well as *T. murrayi* and *T. nibelyni* from the Arctic. The lifespan of the ribbed sculpin is within the same limits as reported for other *Triglops* spp. Its individual fecundity in the Arctic seas is comparable to that of other *Triglops* species living here, but is significantly lower than that of individuals of this species and other congeners from the northwest Pacific Ocean.

Keywords: spatial distribution; vertical distribution; bottom temperature; sexual dimorphism; fecundity; size–age structure; size–sex structure; diet composition; North Pacific

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1. Introduction

The ribbed sculpin *Triglops pingelii* Reinhardt, 1837 is a representative of the family Cottidae, which is characterized by a circumpolar distribution and is found everywhere in the Arctic waters from the Barents Sea to the Beaufort Sea. It is also distributed in the adjacent North Atlantic (along the European coast west to Svalbard and southeastern Barents Sea, off Greenland and Iceland, along the North America to Cape Code) and North Pacific (from the Bering Strait along the Asian coast southward to the coasts of Japan and North Korea, and along the American coast to Washington State) [1–21]. Despite the fact that this species is considered common or even abundant in many parts of its wide range [11,17,19,20,22], it does not have any commercial importance [23–26], and the data on its distribution and biology in Arctic waters remain extremely limited and fragmentary [4,14,15,25–31].

There is very little information on the biology and habitat of ribbed sculpin in Arctic waters. Individuals of this species can reach 242 mm TL [12]. They mature at 70–90 mm long and age 3–5 years, while their longevity is about 9 years [24]. This sculpin is characterized by benthic way of life in the sublittoral–eulittoral zone on mud, sand, pebble, gravel, and rocky substrates. *T. pingelii* inhabits depths from 5 to 930 m but typically can be found shallower than 200 m [12]. In the Arctic, this species occurs at temperatures near or below 0 °C and relatively low salinity (e.g., 16 psu in the Laptev Sea), while in the Bering Sea it inhabits waters with bottom temperatures from −1.7 °C to 3.8 °C and salinities >30 psu [4].

In 2019, during the transarctic expedition on board RV "Professor Levanidov" [32,33], the material was collected, which allowed us to characterize the features of distribution and biology of the number of species in the Kara Sea [34,35]. The aim of this paper is to present new data on size–age and size–sex structures, fecundity, growth, and diet of ribbed sculpin in the Kara Sea, and to compare the data obtained with those from other parts of this species' range, as well as with those of its most abundant and common congeners inhabiting the Northwest Pacific and Arctic.

2. Materials and Methods

Since two more congeners are found in the Kara Sea together with the ribbed sculpin, e.g., bigeye sculpin *Triglops nybelini* and moustache sculpin *T. murrayi* [4,9,17,25,36], we clarified the species affiliation of 89 specimens studied. According to the complex of morphometric and meristic characters, they all turned out to be individuals of the ribbed sculpin.

2.1. Survey Design

Sculpin sampling was carried out during the transarctic expedition on board the R/V *Professor Levanidov* (VNIRO, Moscow, Russia) in the southern part of the Kara Sea from 15 to 29 September 2019. During this period, 55 research stations (Figure 1) with bottom trawl hauls and bottom temperature measurements were completed (Table 1).

On average, the stations were separated by a distance of 39.96 ± 1.39 nautical miles. According to geographical longitude, the grid of stations included 8 meridional sections of 4–6 stations, separated from each other by a distance of about 70 miles, and covered the entire Kara Sea from the Vilkitsky Strait to the Karskiye Vorota Strait. In latitude, the boundary of the surveyed area reached 78 °N. In the latitudinal direction, the stations were separated from each other by a distance of 21 to 60 miles in order to cover the entire depth range in the studied area. The northern part of the Kara Sea, located between the archipelago of Severnaya Zemlya, Novaya Zemlya, and Franz Josef Land, has not been explored due to difficult ice conditions for navigation. Stations 1–6 were made as a latitudinal section, since the islands of the Nordenskiold Archipelago and the adjacent water area are a part of the Great Arctic State Nature Reserve.

A large-mesh bottom trawl "DT 27.1/24.4" was deployed. Trawl mesh size was 8.0 cm in the wings and body, 6.0 cm in the intermediate, 3.0 cm in the codend, and the codend was equipped with a 10 mm mesh liner. Spherical boards with an area of 4.3 m^2 were used. Contact of the gear with the seabed and parameters of the trawl opening were monitored with third-wire net controller SIMRAD FS 20/25 (Kongsberg Simrad Mesotech Ltd., Horten, Norway). Bottom trawl hauls were carried out in depths of 18 to 533 m; the wire length correspondingly varied from 40 to 1050 m. The trawling speed varied in the range from 3.0 to 3.5 knots, averaging 3.17 ± 0.12 knots. The horizontal opening of the trawl at the specified parameters of the speed and length of the wires varied from 6.0 to 16.0 m, averaging 12.36 ± 1.38 m. The vertical opening was in the range from 3.0 to

3.9 m, averaging 3.09 ± 0.20 m. An SBE 25 CTD operated together with Carousel Deck Unit SBE 33 (Sea-Bird Scientific, Bellevue, WA, USA) was used for the bottom temperature measurements.

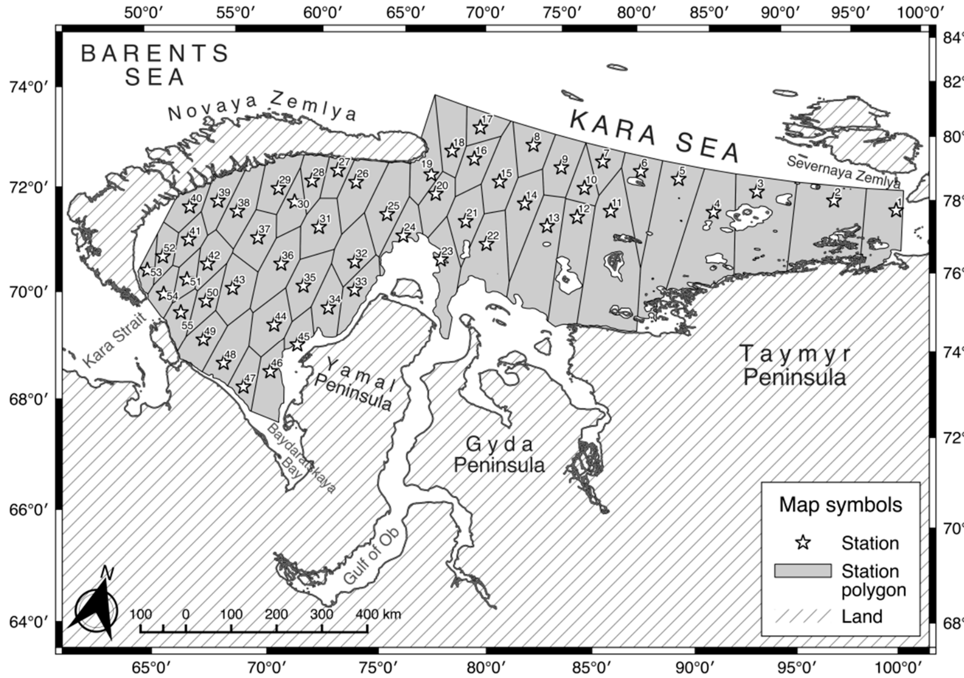

Figure 1. The study area of RV "Professor Levanidov" in the Kara Sea, September 2019.

Table 1. Squares of polygons during September 2019 research survey in the Kara Sea.

Station No.	Area Surveyed, km^2	Station No.	Area Surveyed, km^2	Station No.	Area Surveyed, km^2
1	12,458.7	21	7889.715	41	4833.349
2	22,776.87	22	13,315.62	42	5914.237
3	22,059.71	23	9364.74	43	8954.832
4	24,801.19	24	4917.381	44	8711.212
5	23,856.32	25	11,867.81	45	3542.206
6	11,116.17	26	9724.985	46	8435.111
7	5257.836	27	4142.302	47	5220.943
8	7304.257	28	5233.781	48	8974.715
9	8559.135	29	7917.345	49	7329.788
10	5178.299	30	5569.498	50	5132.056
11	29,960.82	31	9090.005	51	3593.312
12	15,076.19	32	8713.412	52	4411.633
13	18,821.87	33	6815.545	53	2772.137
14	10,924.8	34	7226.885	54	4257.445
15	10,005.91	35	8747.315	55	4916.166
16	6831.042	36	10,485.36		
17	5243.73	37	7916.764		
18	8998.251	38	9058.273		
19	8374.541	39	6369.133		
20	6924.034	40	5384.944		
		Total		55	511,279.636

2.2. Biological Sampling

Captured individual sculpin were frozen, delivered to VNIRO, and then transferred to the Kamchatka Branch of the Pacific Institute of Geography of the Far Eastern Branch of the Russian Academy of Sciences for subsequent processing in the laboratory. A total of

89 individuals of ribbed sculpin with a total length (*TL*) of 46 to 126 mm were examined with subsequent age determination using widely accepted methodology [37,38]. Length was measured with a measuring ruler with an accuracy of 1 mm, and body weight was measured on laboratory electronic scales CAS MWP 150 (CAS Corporation, Seoul, Korea) with an accuracy of 0.01 g.

Age was determined by otolith reading. Otoliths were broken across the area of the central hollow with a scalpel, then calcined on an electric stove and coated with glycerin (lightly polished if necessary) [39].

To assess the fecundity of the ribbed sculpin, the ovaries of 23 females with a total length of 89–123 mm at the IV stage of maturity (prespawning) were used, each of which was weighed, and a subsample (about 20–25% of the total weight of the ovary) was taken, eggs were calculated, and then individual fecundity was estimated.

Stomachs were dissected in the laboratory and stored in 10% formalin to fix stomach contents. Stomach contents were sorted to the lowest possible taxonomic level, weighed, and counted with subsequent calculation of the index of stomach fullness estimated as the weight of food divided by fish body weight and multiplied by 10^5 [40]. In total, the contents of 89 stomachs of sculpin (*TL* 46–126 mm) were examined.

2.3. Data Analysis and Statistics

The abundance and biomass per unit of the surveyed area (in individuals/km^2 and kg/km^2) for each *i*-trawling were calculated using the formulas

$$\frac{N_i}{A_i} = \frac{N_i}{1.852 \cdot v_i \cdot t_i \cdot 0.001 \cdot h_i} \text{ and } \frac{M_i}{A_i} = \frac{M_i}{1.852 \cdot v_i \cdot t_i \cdot 0.001 \cdot h_i},$$

where

N_i is a number (individuals) and M_i is the weight of fish in the catch of *i*-trawling (kg);
A_i is the area swept during trawling (km^2);
v_i is the trawling speed (knots);
t_i is the duration of haul (h);
h_i is the horizontal opening of the mouth of the trawl (m);
1.852 is the number of km in 1 nautical mile, and 0.001 is the conversion factor from m to km.

The values of the total abundance and biomass for the surveyed area were obtained as follows:

$$Abundance_{(total)} = \sum \frac{N_i}{A_i} \cdot S_i \text{ and } Biomass_{(total)} = \sum \frac{M_i}{A_i} \cdot S_i,$$

where

N_i is a number (individuals) and M_i is the weight of fish in the catch of *i*-trawling (kg);
A_i is the area caught during *i*-trawling (km^2);
S_i is the area of Thiessen polygon for each station.

An individual Thiessen polygon was calculated for each station [41,42]. The shallow part of the shelf was not surveyed. Therefore, the inner polygon boundaries were set along the contour of a 20 m isobath. The isobath boundary was obtained according to IBCAO Version 3.0 [43]. For 55 research stations, a total area of 511.28 thousand km^2 was surveyed (Table 1).

Geostatistical data processing, including the calculations of polygon areas and the drawing of spatial distribution maps, was performed in QGIS Desktop 3.16 (https://qgis.org/; accessed on 12 August 2022). The temperature distribution was interpolated by the Kriging (QGIS module: SAGA, https://docs.qgis.org/2.8/en/docs/user_manual/processing_algs/saga/index.html; accessed on 12 August 2022). The study area calculations were performed in the coordinate system WGS 84 [44], EPSG: 4326 (https://epsg.io/4326; accessed on 12 August 2022). The maps presented in this paper were plotted in the Asia North Albers Equal Area Conic projection (ESRI: 102025, https://epsg.io/102025; accessed on 12 August 2022).

For processing biological sample data, basic statistics [45] and the following tests and procedures were used.

For testing statistical differences in the observed frequencies of size, weight, and age classes, chi-square test was used (Table S1).

Distributions of total length, weight, and age parameters were tested for normality (Shapiro–Wilk's W test, $p < 0.05$). Since they did not show normal distribution, nonparametric Kruskal–Wallis one-way analysis of variance by ranks was applied for comparison mean values between males and females. Results of testing are presented in Table 2.

Table 2. Mean total length and body weight of male and female ribbed sculpin *Triglops pingelii* in different age classes in the Kara Sea, September 2019 (SE = standard error).

Parameter	Age, Years				Kruskal–Wallis Test	
	1+	2+	3+	4+	H	p
			Males			
Mean total length ± SE, mm	62.5 ± 1.9	91.0 ± 3.1	110.0 ± 5.0	-	22,558	<0.001
Mean body weight ± SE, g	1.48 ± 0.13	4.90 ± 0.31	8.50 ± 1.00	-	22.504	<0.001
No. fish examined	20	10	2	0		
			Females			
Mean total length ± SE, mm	68.2 ± 2.0	89.5 ± 2.0	108.3 ± 1.4	124.2 ± 1.7	47.943	<0.001
Mean body weight ± SE, g	1.73 ± 0.15	4.85 ± 0.40	9.42 ± 0.34	13.67 ± 1.33	48.106	<0.001
No. fish examined	22	20	12	3		
			Kruskal–Wallis Test			
Total length	H = 3.029, p = 0.082	H = 1.031, p = 0.310	H = 1.655, p = 0.198	-		
Body weight	H = 2.135, p = 0.144	H = 0.436, p = 0.509	H = 0.300, p = 0.584	-		

Cluster analysis was used to reveal differences in the diet composition among three size groups. Tree-clustering was based on the Pearson-r dissimilarity matrix.

A permutational multivariate analysis of variance (one-way PERMANOVA) and analysis of similarities (one-way ANOSIM) were conducted to test the significant differences ($\alpha = 0.05$) in composition of prey items. Both PERMANOVA and ANOSIM were based on the Bray–Curtis similarity matrices.

For data curation and storage, Microsoft Access 2016 Database Management System was used. Statistical processing was performed in Microsoft Excel 2016, using Analysis ToolPack and PAST 4.02 software [45].

3. Results and Discussion

3.1. Distribution

In the Kara Sea in September 2019, the ribbed sculpin was found at depths from 18 to 235 m (Figure 2A) with bottom temperatures from −1.5 to 1.6 °C (Figure 2B). The depths of habitat and bottom temperatures of this species in other parts of its range differ significantly. In the waters of Svalbard in 1998–2002, this species was found at depths of 42–431 m (most often 107–355 m) at temperatures near the bottom of 1.2–4.4 °C [14]. In the Pacific waters of the Northern Kuril Islands and southeastern Kamchatka, it was recorded at depths of 82–289 m (most often 100–200 m) at bottom temperatures from −1.7 to 4.25 °C (most often <1.5 °C) [46]. In the Sea of Japan, this species is characterized by the deepest and warm-water lifestyle with depths of 30–424 m (usually 150–250 m) and bottom temperatures from −0.3 to 9.7 °C (usually 1.0–2.2 °C) [47].

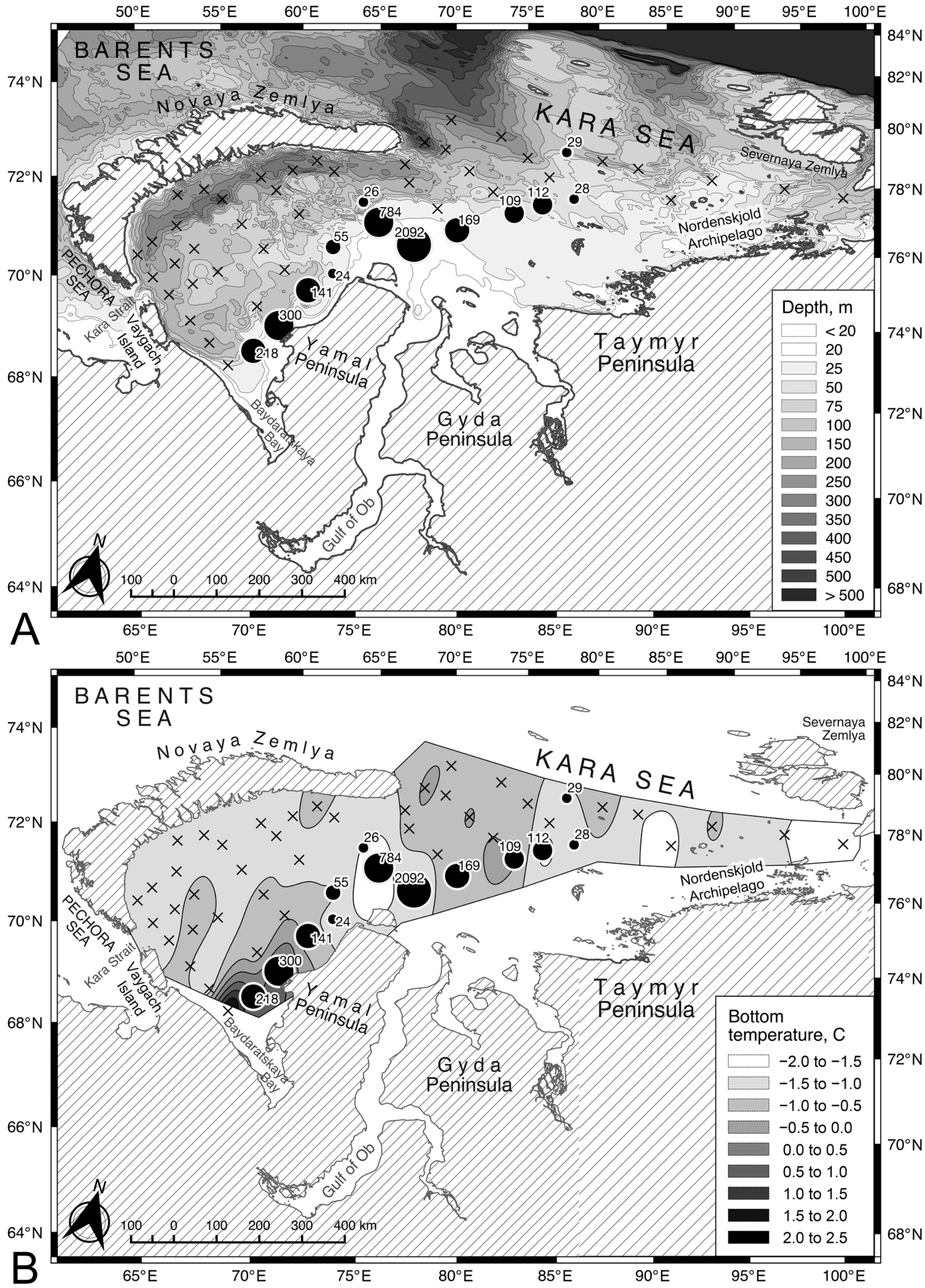

Figure 2. Spatial distribution of ribbed sculpin *Triglops pingelii* depending on depth (**A**) and bottom temperature (**B**) in the Kara Sea, September 2019.

The frequency of occurrence of the ribbed sculpin in bottom trawl catches in the Kara Sea was low and averaged 24%. This species was not observed in the catches off the Nordenskjold Archipelago. Apparently, the abundance of ribbed sculpin in the Sea of Japan, where the frequency of its occurrence in certain temperature ranges can reach 49.5% [47], is significantly higher. The lowest occurrence of this species is characteristic of the Pacific waters of the Northern Kuril Islands and southeastern Kamchatka, where the corresponding average value is 0.05% only [46].

In the open part of the Kara Sea, on the traverse of the Taimyr Peninsula, the number of ribbed sculpin in catches was low and ranged from 28 to 112 ind./km^2. In the southwestern Kara Sea, between the Gyda Peninsula and the Novaya Zemlya Archipelago, the catches were localized in shallow water from Baydaratskaya Bay to the Gulf of Ob, where the relative abundance of the ribbed sculpin varied from 24 to 2092 ind./km^2. The maximum relative abundance was observed northeastward of the Yamal Peninsula, at the outlet of the Gulf of Ob, amounting to 784–2092 ind./km^2 at a depth of 18–21 m with bottom temperatures from −1.5 to −1.0 °C.

Data on the distribution and relative abundance of the ribbed sculpin in the published literature are quite limited and often incomparable with those obtained by us due to differences in units of measurement. Thus, in the waters of Svalbard in various years, the maximum catches of this species (8 to 78 inds. per h of trawling) were recorded in the coastal waters of the archipelago, averaging 0.09–0.28 inds. per h of trawling, respectively [14]. In the waters of the Novosibirsk Islands (separating the Chukchi and East Siberian Seas), the relative abundance of this species was 724.5 ind./km^2 [48], which is quite comparable with the data we obtained for the Kara Sea. In the Barents Sea, maximum catches exceeding 1000 specimens per nautical mile were recorded on the traverse between Svalbard and Novaya Zemlya [24]. In the northwestern Pacific, the ribbed sculpin is probably more abundant. In the Sea of Japan, its main concentrations widely distributed in the waters of the southern and central Primorye can reach 20–80 kg/km^2 [47]. In the Pacific waters, it is most abundant on the shelf of southeastern Kamchatka and Paramushir Island, where catches amount to 19.7–34.2 inds. per h of trawling [46], which is significantly higher compared to the Svalbard waters [14].

The surveyed area of the Kara Sea was characterized by the relative abundance of ribbed sculpin increasing with a decrease in the trawling depth. On average, for stations with effective catches, at a depth of up to 20 m, the relative abundance of the species was maximum and amounted to 1059 ind./km^2 (Figure 3A). Further, with increasing depth, the density of the population decreased. The spatial distribution relative to the bottom temperature was random. The high catches were characteristic of both negative and positive bottom temperatures (Figure 3B), which were caused by features of its spatial distribution in the study area.

The total abundance and biomass of the ribbed sculpin in the surveyed area were estimated as 35.31 million individuals and 266.78 tons, respectively. There are no published data on absolute estimates of abundance and biomass of the species under consideration in other parts of its range.

3.2. Length and Weight

According to the information available in the literature, the ribbed sculpin is a relatively small, short-lived cottid species, whose maximum length in the northwestern Pacific reaches 200 mm, and body weight is 50 g [49,50], although specimens up to 232 mm are found off the Aleutian Islands [12]. Data on the longevity of individuals of this species are somewhat contradictory. According to [49], it reaches 6 years in the Kamchatka waters. The maximum age of the ribbed sculpin in the Barents Sea is 9 years [13,24].

The relationship between the length (*TL*) and weight (*W*) of the body of the ribbed sculpin in the Kara Sea is well approximated (R^2 = 0.983) by the equation of the power function: $W = 5.496 \times 10^{-7}\ TL^{3.542}$. This species is characterized here by positive allometric growth (Figure 4). There is information in the literature [28] for the Barents Sea on the length–weight relationships for male and female ribbed sculpins. At the same time, the former are characterized by positive allometric growth (b = 3.117), while for the latter, it is negative (b = 2.608). Negative allometric growth is also characteristic for individuals of the species considered from the Sea of Japan (b = 2.868) [47]. Thus, the ribbed sculpin from the Kara Sea, in comparison with individuals from other parts of the range, has a more rounded shape [51], which may be due to its physiological condition [52,53] during our research.

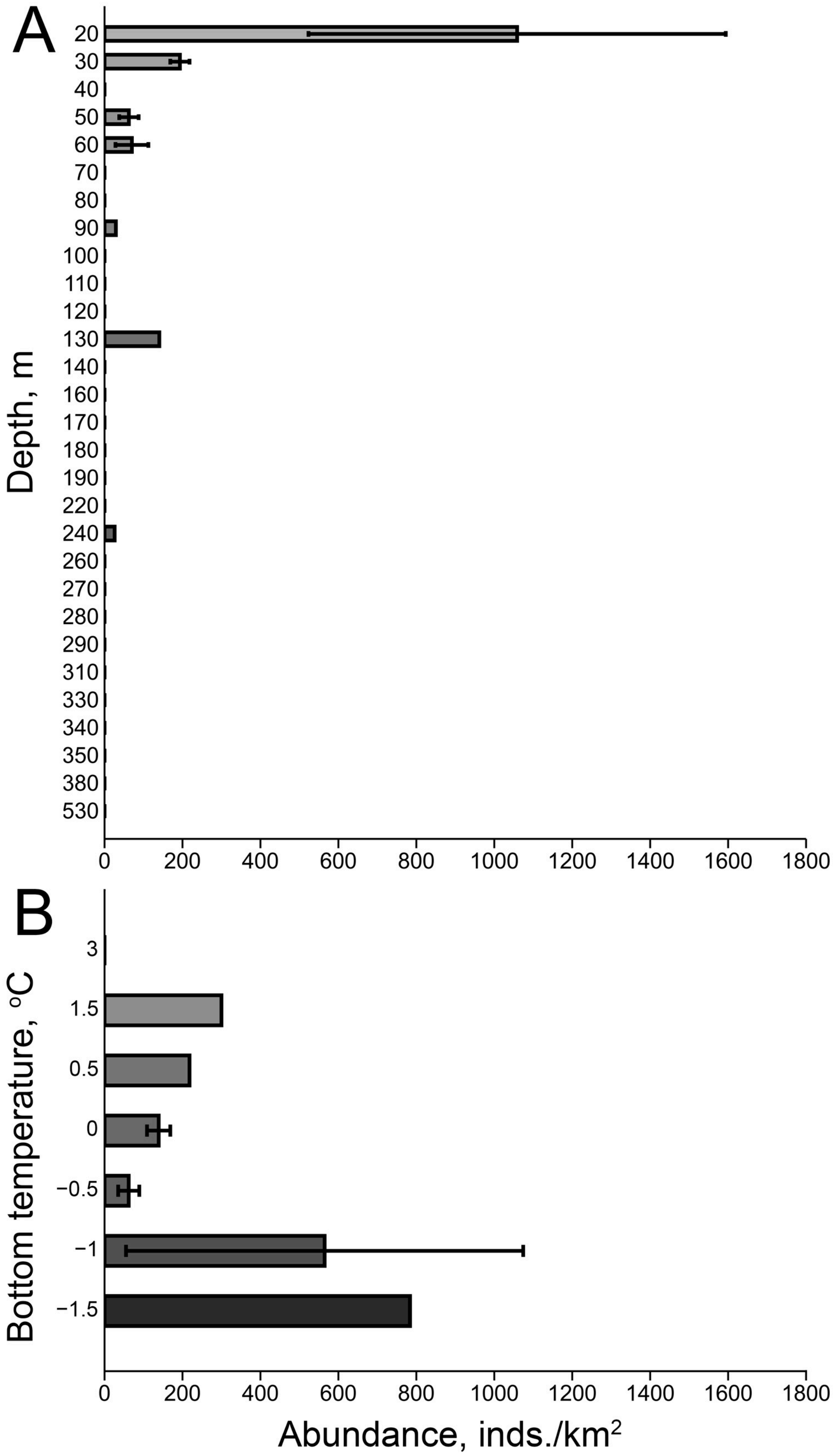

Figure 3. Bar chart for ribbed sculpin *Triglops pingelii* abundance (inds./km^2) mean values relative to depth (**A**) and bottom temperature (**B**). Whiskers, where available, represent the standard error of mean. Whisker length is one sigma.

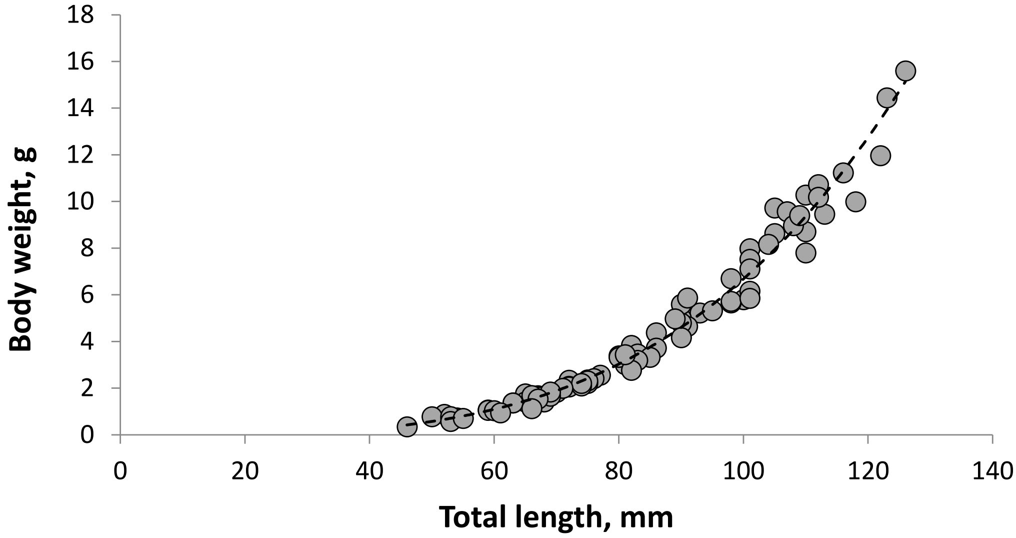

Figure 4. Length–weight relationship of the ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019.

In the Kara Sea, the maximum length and weight of the species considered are smaller, as compared to those in other parts of its range, and do not exceed 150 mm and 14 g respectively [4,25,31]. According to our data, the maximum length of ribbed sculpin in the Kara Sea in September 2019 was 126 mm, body weight 15.6 g, and age 4+ years. In general, in the study area, this species was represented by individuals with a length of 46–126 (mean 82.5 ± 2.1 SE) mm, body weight of 0.35–15.60 (mean 4.24 ± 0.37) g, aged 1+ to 4+ (mean 2.8 ± 0.8) years (Figure 5, Table S1). However, the fish with a length of 51–90 mm (64%) and a body weight of <6 g (75.2%) aged 1+ to 2+ years (80.7%) dominated in catches. More than half of the studied individuals (59.4% of males and 50.9% of females) were immature. In the Barents Sea, individuals of this species reach larger sizes, i.e., their maximum and mean lengths here are 18 and 11.3 cm, respectively [24].

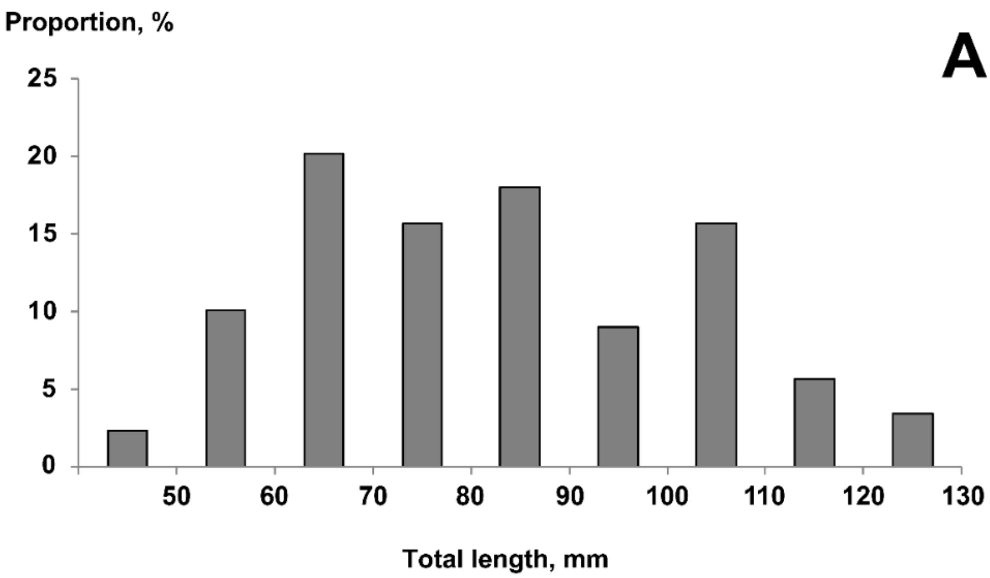

Figure 5. *Cont.*

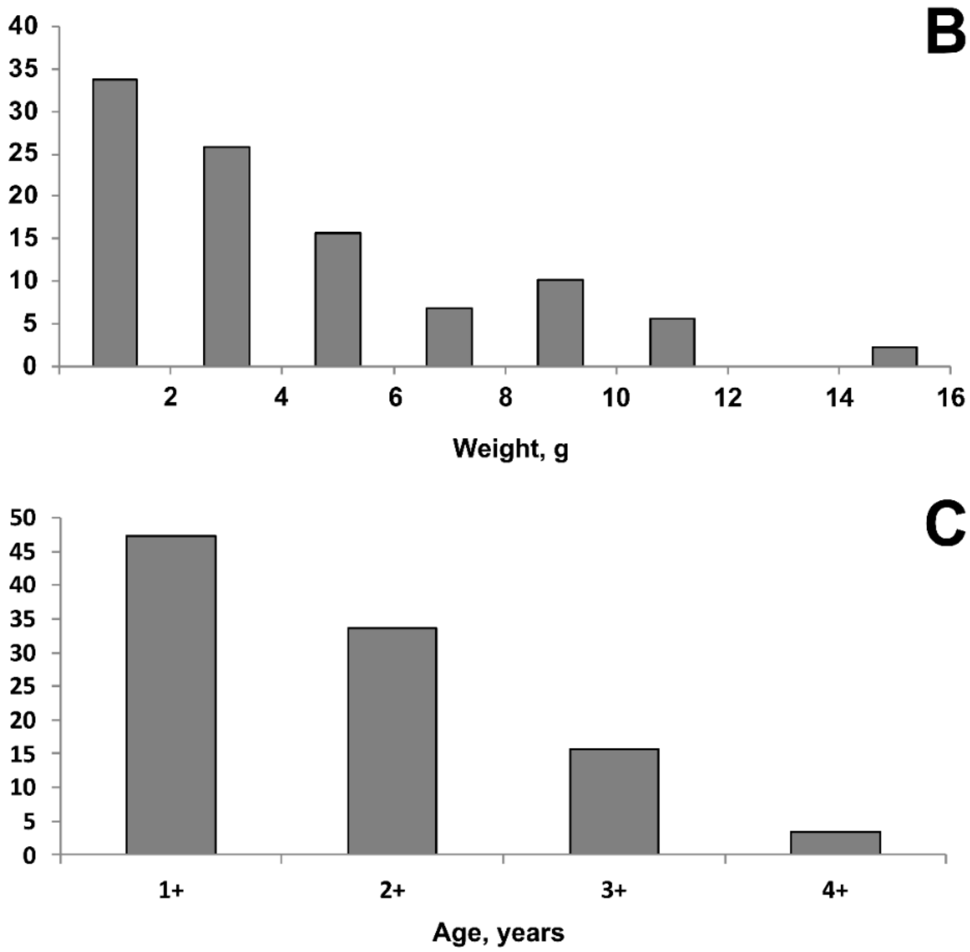

Figure 5. Size (**A**), weight (**B**), and age (**C**) compositions of ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019.

3.3. Sexual Dimorphism and Fecundity

The ribbed sculpin is characterized by sexual dimorphism in such exterior features as different sizes of some fins and the presence of anal papillae in males [2,4,25,49,50], which, according to our data, is clearly visible already at a length of >41 mm (Figure 6). In addition, this species is also characterized by the presence of sexual dimorphism in the size of mature individuals of different sexes (males are smaller than females) [23,25,31,47,49,50]. The maturation of males occurs at an earlier age, which leads to a significant increase in their proportion in the spawning part of the population. Females have a longer lifespan compared to males, and therefore the proportion of males is significant among relatively small individuals and decreases to zero among the largest ones. According to our data, males of the ribbed sculpin in the Kara Sea in September 2019 were represented in catches by individuals with a length of 50–118 (mean 74.4 ± 3.2) mm with a body weight of 0.71–9.99 (mean 2.88 ± 0.40) g aged 1+ to 3+ (mean 2.4 ± 0.6) years; females were, respectively, 46–126 (mean 87.1 ± 2.6) mm long and 0.35–15.60 (mean 5.0 ± 0.5) g in weight aged 1+ to 4+ (mean 2.9 ± 0.9) years (Figure 7). According to the results of Kruskal–Wallis test, there were significant differences between the males and females in total length ($H = 7.305$, $p = 0.007$), weight ($H = 7.769$, $p = 0.005$) and age ($H = 6.529$, $p = 0.011$). Similar differences in the maximum sizes of male and female ribbed sculpins in the Kara Sea were noted earlier [4,25,31]. However, according to our data, the length and weight of male and female ribbed sculpin of the same age are quite similar, which is apparently due to minor differences in their growth rate and longevity (Table 2). Statistically significant differences were observed only among age groups for each sex separately ($p < 0.001$). Therefore, if the sex ratio is approximately equal among small specimens of this species (<50 mm), then the individuals 51–60 mm long are dominated by males, for which proportion increases up to 77.8%. However, among larger fish with a length of >71 mm, the proportion of females begins to increase sharply, reaching 100% in specimens with a length of >120 mm (Figure 8). In general, according to our data, in the Kara Sea, females of the ribbed sculpin significantly predominate (by 1.78 times) over males, which is probably due to the low individual fecundity of this species. According to the available literature data [4], it is 297 eggs only in the Kara Sea, 260 to 730 eggs in the Barents Sea, and about 400 eggs off the coast of Greenland [28]. According to our data, the individual fecundity of the ribbed sculpin measuring 89–123 mm long in the Kara Sea varies from 100 to 316 (mean 215 ± 15) eggs. As with many other fish species, with an increase in the size and age of females of this species, the number of eggs produced by them increases, despite significant fluctuations in individual fecundity within each size, weight, and age group (Table 3).

Figure 6. Female (**top**, photo courtesy Andrei Dolgov) and male (**bottom**, photo by A.M. Orlov) ribbed sculpin *Triglops pingelii* (black arrow points to anal papilla).

Table 3. Changes of individual fecundity of ribbed sculpin *Triglops pingelii* in the Kara Sea with increase of total length, body weight, and age (SE = standard error).

Parameter		Individual Fecundity, Eggs		
		Mean ± SE	Variations	No. Fish Examined
Total length, mm	81–90	148 ± 1	147–150	2
	91–100	150 ± 24	100–193	4
	101–110	225 ± 19	145–316	11
	111–120	239 ± 29	148–268	4
	121–130	250 ± 75	162–307	2
Body weight, g	4–6	125 ± 16	100–186	5
	6–8	238 ± 31	193–307	4
	8–10	225 ± 23	145–316	8
	10–12	205 ± 30	148–268	5
	>14	307	-	1
Age, years	2+	186 ± 30	100–316	9
	3+	217 ± 19	145–268	12
	4+	250 ± 75	162–307	2

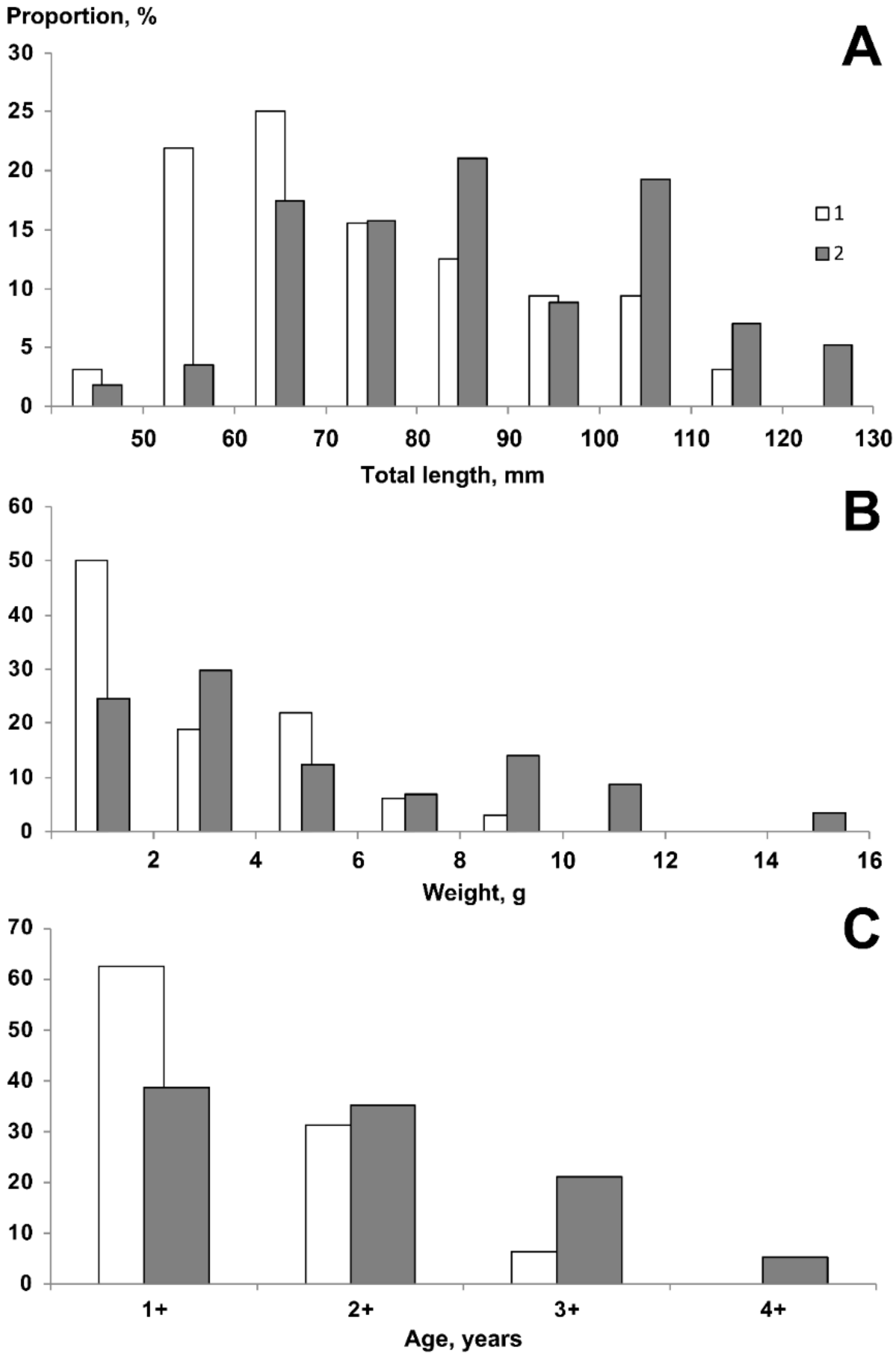

Figure 7. Size (**A**), weight (**B**), and age (**C**) compositions of male (1) and female (2) ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019.

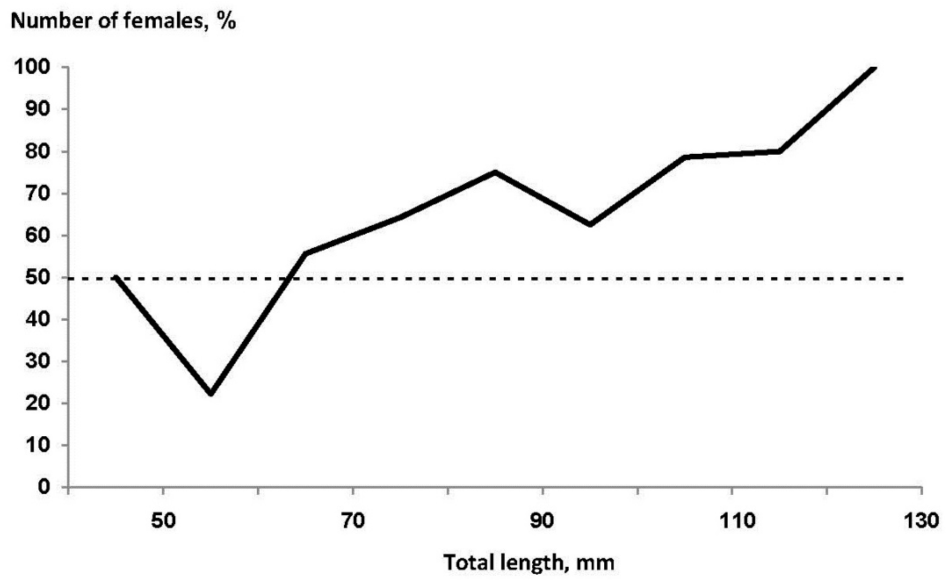

Figure 8. Relative number of females (%) in different sculpin size classes in the Kara Sea, September 2019.

3.4. Diet Composition and Feeding Habits

The data available in the literature [4,19,23,25,28–30,54–57] show that, according to the feeding type, the ribbed sculpin can be attributed to necto-benthophage consuming benthic and bentho-pelagic crustaceans, mainly amphipods, mysids, hyperiids, and small shrimps, as well as juvenile fish (polar cod *Boreogadus saida*, small pricklebacks Stichaeidae, etc.). The results of our research indicate that sculpins in the Kara Sea are characterized by a relatively narrow diet spectrum, including representatives of five different groups of prey organisms only (Table 4). However, the bulk of its diet (over 99%) is formed by three groups of prey only: amphipods, mysids, and juvenile fish (according to our identifications, mainly capelin *Mallotus villosus*, subspecies of Pacific herring *Clupea pallasii suworowi*, and polar cod). Although occasional cannibalism in ribbed sculpin has been observed in the Kara Sea before [25,31], such a significant consumption of juveniles of other fishes by this species was registered here for the first time. One of the possible explanations for this is the high concentration of juvenile fishes within ribbed sculpin feeding grounds that commensurate in size with mysids, which are its important traditional prey.

Table 4. Diet composition (% by weight) of ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019 (FO = frequency of occurrence).

Prey	FO, %	Total Length, mm			Total
		41–70	71–100	>100	
Isopoda	1.1	-	0.8	-	0.3
Amphipoda	49.4	54.9	34.1	7.3	22.1
Mysidacea	27.0	28.9	19.6	48.0	35.4
Decapoda	1.1	4.5	-	-	0.4
Teleostei, including:	18.0	11.7	45.5	44.1	41.8
Gymnocanthus tricuspis, juv.	3.4	-	7.8	22.2	14.6
Triglops pingelii, juv.	1.1	-	-	7.0	3.6
Other teleosts, juv.	13.5	11.7	37.7	14.9	23.6
Proportion of empty stomachs, %		34.5	7.9	18.2	19.1
Index of stomach fullness, $‰_{o}$		156	177	147	163
No. fish examined		29	38	22	89

As in other parts of the species' range [54], with an increase in the size of the ribbed sculpin, its consumption of various groups of prey items in the Kara Sea changes significantly. If the main food for small individuals (41–70 mm) are amphipods and mysids (54.9 and 28.9% by weight, respectively), then the bulk of the diet of the largest specimens (>100 mm) are mysids (48.0%) and juvenile fish (44.1%), while the value of amphipods is reduced to 7.3% by weight (Table 4). Variation of prey items distribution among the ribbed sculpin size groups was statistically significant (PERMANOVA: $F = 4.08$, $p = 0.001$). Results of group-by-group comparison by PERMANOVA are presented in Table S2.

Tree-clustering results showed that three size groups of ribbed sculpin are divided into two clusters according to the diet composition (Figure 9). The first cluster was formed by specimens of 41–70 and 71–100 size groups, while the second one by specimens with TL >100 mm. Results of group-by-group comparison by ANOSIM (Supplementary Material Table S3) showed that the maximum differences were observed between the size group >100 m and the size group 41–70 mm ($R = 0.308$, $p = 0.001$), and between the size group >100 m and the size group 71–100 mm ($R = 0.078$, $p = 0.035$).

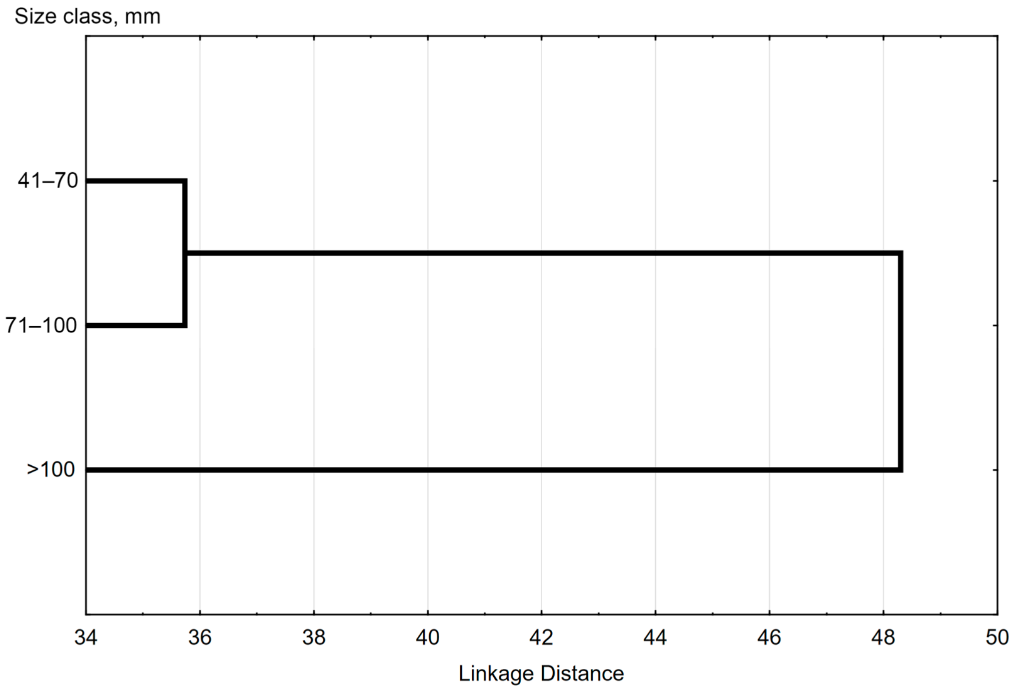

Figure 9. Tree diagram (Euclidean distances) showing differences in the diet composition of ribbed sculpin Triglops pingelii size groups in the Kara Sea, September 2019.

It should also be noted that, along with the change in the diet composition, as the ribbed sculpin grows, the amount of prey items consumed by it increases. Thus, if crustaceans sized 2–17 mm are found in the stomachs of sculpins up to 100 mm long, then in fish with a length of 101–120 mm, the size of crustaceans was 3–28 mm.

3.5. Comparison with Congeners

Since there is practically no information about four rare representatives of the genus *Triglops*: roughspine sculpin *T. macellus*, Alaskan sculpin *T. metopias*, scaly breasted sculpin *T. xenostethus*, and Dorothy's sculpin *T. dorothy*, we do not consider them in this paper. Analysis of the available literature data on the biology and vertical distribution of the six most abundant or common *Triglops* species makes it possible to attribute the ribbed sculpin to medium-sized cottids [4,12–14,17,22,25,28,30,47,49,50,54–57]. Its maximum length is similar to that of the Jordan's sculpin *T. jordani* inhabiting the North Pacific, as well as moustache sculpin *T. murrayi* from the North Atlantic and bigeye sculpin *T. nybelini* from the Arctic Ocean (Table 5). At the same time, in the Kara Sea and other Arctic seas, the length and weight of this species are much smaller than in the Pacific waters. Unlike sizes, the lifespan of the ribbed sculpin (9 years) is within the same limits as the other species of this genus. The individual fecundity of the ribbed sculpin in the Kara Sea and other Arctic seas is small (100–730 eggs) and is comparable to that of the moustache sculpin and bigeye sculpin living here. However, it is significantly lower than that of individuals of this and other *Triglops* species from the northwestern Pacific Ocean (see Table 5). Despite the captures of individual ribbed sculpins within the upper zone of the continental slope, its main habitat in the Kara Sea, where its highest concentrations are observed, is shelf waters with low positive and negative temperatures. Since the bulk of the biomass (about 99%) of the ribbed sculpin in the Kara Sea is formed by three prey groups (amphipods, mysids, and juvenile fish) only, according to the feeding type it can be attributed to necto-bentho-ichthyophage here, which distinguishes it from other closely related species (see Table 5).

Table 5. Some biological parameters and habitat depths of the most numerous or common sculpin species of genus *Triglops* (based on [4,12,14,17,22,24,25,28,30,47–50,54–59]).

Parameter	*T. nybelini*	*T. murrayi*	*T. jordani*	*T. pingelii* AO	*T. pingelii* PO	*T. forficatus*	*T. scepticus*
Maximum total length, mm	170	200	200	180	232	323	354
Maximum total length (males/females), mm	125/170	108/170	170/200	120/150	200/220	250/300	250/260
Maximum body weight (males/females), g	No data	No data	No data	9/15	23/50	66/111	136/138
Length–weight relationship	No data	No data	$W = 0.0389TL^{2.3317}$	$W = 0.05496TL^{3.542}$	$W = 0.0110TL^{2.8675}$	No data	$W = 0.0025TL^{3.4871}$
Maximum age, years	7	10	No data	9	6	7	9
Maximum age (males/females), years	No data	No data	No data	No data	5/6	5/6	8/8
Individual fecundity, eggs *	No data 300–600	No data 100–2739	No data No data	215 100–730	1800 No data	1700 No data	3100 No data
Feeding type	Plankto-benthophage	Bentho-planktophage	Necto-benthophage	Necto-bentho-ichthyophage	Necto-benthophage	Bentho-macro-planktophage	Bentho-macro-planktophage
Habitation depths, m **	10–930 117–600	7–500 50–355	15–460 38–256	5–431 100–200	5–745 10–355	20–470 75–200	25–925 100–380

* Above the line is the average value; below the line are the limits of fluctuations. ** Above the line are observed values; below the line are preferred values. AO—Arctic Ocean, PO—Pacific Ocean.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d14100853/s1, Table S1: Chi-square tests obtained for frequencies of size, weight, and age classes of ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019. Values in bold font indicate statistical significance; Table S2: Results of PERMANOVA test for diet composition among various size groups of ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019 (permutation N = 999, $\alpha = 0.05$, F = 4.078, $p = 0.001$). Values in bold are statistically significant; Table S3: Results of ANOSIM test for diet composition among various size groups of ribbed sculpin *Triglops pingelii* in the Kara Sea, September 2019 (permutation N = 999, $\alpha = 0.05$, R = 0.088, $p = 0.012$). Values in bold are statistically significant.

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