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LONG-TERM CHANGES IN THE SPECIES COMPOSITION AND ABUNDANCE OF COMMERCIAL FISH IN THE ICHTHYOPLANKTON OF THE EASTERN PART OF PETER THE GREAT GULF (SEA OF JAPAN)

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Abstract. Our study provides an analysis of the ongoing seasonal and interannual changes in ichthyoplankton in the eastern part of Peter the Great Bay (Sea of Japan), based on own data on the species composition and abundance of ichthyoplankton in the summer season in 2011–2012 and from autumn 2022 to spring 2024, and published data for the 1950-s and 1980-s and 2007. In the warm season, three periods with a characteristic composition and proportion of the studied species are clearly distinguished in the studied water area: 1. late spring (April–May), 2. early summer (June, occasionally May and July), 3. late summer – early autumn (July–October). 2023–2024 are characterized by a high, gradually decreasing share of pollock egg in catches in the spring period due to spawning individuals of the productive generation of 2014. Also noted is the appearance in ichthyoplankton, in noticeable quantities, of chub mackerel egg and, for the first time since the end of the last century, sardine, which indicates the imminent, previously predicted, next surge in the number of its population in the Japan Sea to a commercial level in the waters of Primorye. Reproduction of spring-summer spawning flounders, despite their fairly high share in catches, is currently at a low level compared to the 1950s and 1980s.

Keywords: *Sea of Japan, Peter the Great Bay, ichthyoplankton, species composition, interannual changes*

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INTRODUCTION

The history of the study of pelagic stages of fish development in the northern part of the Sea of Japan dates back to the Kurilo-Sakhalin Expedition (KSE) conducted in the late 1940s. During this period, the basic principles of ichthyoplankton surveys were developed, which allowed us to obtain quantitative estimates of catches that could be used to calculate the intensity of fish spawning [6, 7]. On the basis of ichthyoplankton surveys carried out in the 1940s-1950s, the first idea of the species composition and seasonal dynamics of ichthyoplankton in Peter the Great Bay was formed. The temperature ranges in which embryogenesis takes place were revealed and the development of eggs and larvae of commercial fish species spawning here was described [11, 17, 20, 26]. Materials on the pelagic stages of development of the most mass fish species of the southern Primorye [21, 27, 38, 39], collected during that period of research, made it possible to establish a much more northern than previously assumed distribution of spawning aggregations of a number of heat-loving species, such as Japanese anchovy *Engraulis japonicus, saira Cololabis* saira, Japanese mackerel *Scomber japonicus,* etc. [18].

From 1981 to 1990, the TINRO Center conducted ichthyoplankton surveys in Peter the Great Bay using a well-developed methodology and standardized grid of stations. The TINRO Center conducted ichthyoplankton surveys in Peter the Great Bay according to a well-developed methodology and standard grid of stations, mainly in spring and autumn, when mass spawning of commercial species, primarily pollock *Gadus chalcogrammus*, takes place. During this period, more than five and a half thousand samples were collected and processed and areas of maximum accumulations of eggs and larvae of commercial species were identified [23]. In accordance with the hydrology of the Peter the Great Hall. The schemes of ichthyoplankton transport in its water areas were determined. Based on ichthyoplankton surveys carried out in the open waters of the Sea of Japan, it was found that during the cooling of the northwestern part of the Sea of Japan in the “cold” periods of years, the proportion of subtropical fish decreases in ichthyoplankton, and eggs and larvae of pelagophilic species are replaced by larvae of viviparous and bottom-laying species [13]. Currently, TINRO Center conducts regular spring ichthyoplankton surveys to monitor the state of the pollock population in Peter the Great Bay. The population of pollock in Peter the Great Bay, whose numbers have been increasing noticeably since 2016 [4].

In the 2000s and 2010s, a significant contribution to studies of the species composition and seasonal dynamics of ichthyoplankton was made by studies conducted at IBM (currently NNSMB FEB RAS) under the supervision of A.S. Sokolovsky and, after his death, A.A. Balanov [15, 29, 31, 32, 34, 35, 45, 46]. In contrast to the work carried out at the TINRO Center, the NSCMB FEB RAS paid most attention to the description of the early stages of fish development, including dimersal eggs and larvae. In recent years, the quality of works devoted to the description of early stages of fish development, as well as the accuracy of species identification in ichthyoplankton, has been raised to a new level through the use of modern methods, in particular, methods of molecular genetic analysis [45, 46, 51].

The works by A.S. and T. G. Sokolovskikh et al. [30, 32] also continued the analysis of multiyear changes in the structure of ichioplankton in the area due to changes in hydrology.

The aim of this work is to study the current state of ichthyoplankton of the upper epipelagial of the eastern part of Peter the Great Bay in the period of reproduction of mass and commercial species and to evaluate the changes in species composition based on the analysis of own and literature data.

MATERIAL AND METHODS

For comparative analysis of the abundance and species composition of ichthyoplankton we used samples collected in Vostok Bay in the period from May 2011 to August 2012 and in the eastern part of Peter the Great Bay between Petra Veliky Island and Vostok Island. The samples were collected in the eastern part of Peter the Great Bay between Askold Island and the Black Sea. Askold Island and Passeki Sea from September 2022. Passeki from September 2022 to April 2024 (a total of 15 surveys, 292 stations and 297 samples) (Table 1, Fig. 1). Sampling was carried out during the daytime during a 5–10 minute trawl with an IKS-80 caviar net on circulation at speeds of up to 2.5 knots from the Vityaz motor vessel of the NSCMB FEB RAS, which allowed not only to catch fish eggs, which have positive buoyancy and are usually concentrated in the surface layer, but also to catch fish larvae with a higher probability than in vertical fisheries due to the higher speed and time of trawling [40]. Catch values for all species were converted to m^3 of water at the surface based on trawl parameters and previously developed guidelines [28, 33].

In April 2024, in addition to horizontal trawling with an IKS-80 net, 5 vertical catches were made with the same net from a depth of 30 m or from the bottom to clarify the vertical distribution of eggs of mass species and the comparability of catches per unit area and volume under different collection methods. In addition, we used materials obtained during our work in 2023 in Nakhodka Bay (Fig. 1). Nakhodka Bay (Fig. 1, Table 1).

At each station, water temperature was also measured from the surface to the bottom or 20 m horizon using a Cast Away CTD profiler. Water temperature readings at the surface of the ship’s standard onboard thermometer were also used.

Samples were fixed with 4% formalin for further chamber processing in laboratory conditions in accordance with standard methods [28, 33].

Table 1. Data on ichthyoplankton surveys used in this work

Year	Period	Neighborhood	Number of stations	Number of samples
2011	28–31.05	Vostok Bay	19	19
	18–19.06	–//–	19	19
	12–14.07	–//–	18	18
2012	16–18.06	–//–	19	19
	22.07	–//–	18	18
	27–28.08	–//–	18	18
2022	14–15.09	eastern part of the Peter the Great Bay	30	30
2023	27–28.04	–//–	30	30
	18–19.05	–//–	30	30
	03–04.07	–//–	30	30
	03.10	–//–	22	22
	13.06	Nakhodka Bay	3	3
	05.09	–//–	3	3
	09.10	–//–	3	3
2024	26–27.04	eastern part of the Peter the Great Bay	30	35
Total			292	297

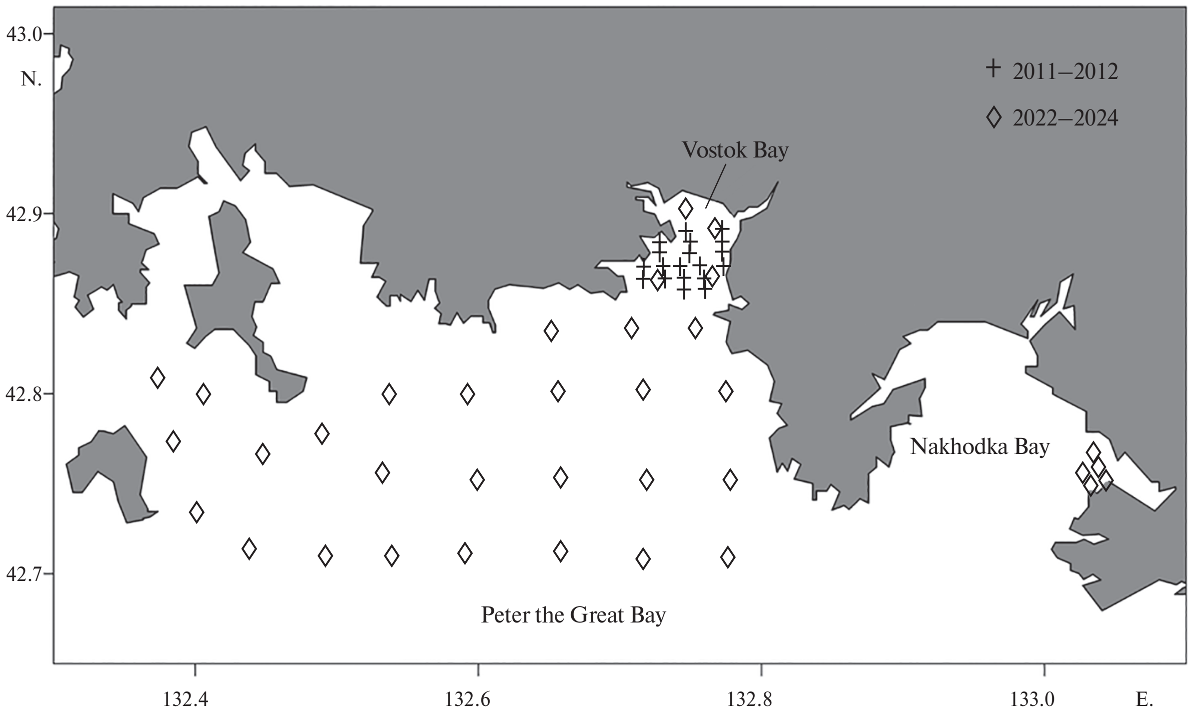

Fig. 1. Scheme of ichthyoplankton surveys during the work period.

Identification of eggs, measurements of larvae and fry were performed in accordance with previously developed methods and recommendations [25, 26, 31, 33, 43, 44, 48]. The total length (*TL*) of larvae and fry and the diameter of eggs were measured to an accuracy of 0.1 mm with using an ocular micrometer on an Olympus microscope. The systematic position of taxa is given according to the catalog [47].

Sample processing and species identification were carried out by the authors using existing identifiers of the early stages of fish development and personal research [31, 45, 46].

To identify similarities in the species composition of catches in individual months, we used only those periods of years in which it was determined taking into account all the species we considered (21 mass species). Comparison of individual years was made on a monthly basis by species composition, taking into account the proportion of species from the total maximum catch (ind./m$^{2)}$ in the water area under consideration using cluster analysis. We used hierarchical clustering based on the obvious seasonal changes in the species composition of ichthyoplankton observed annually in this water area, in accordance with the recommendations made by A.I. Kafanov et al [22] on the application of cluster analysis in biogeographic studies. The hierarchical tree was built according to the calculated Euclidean distances taking into account the full connection of samples in Statistica 8.0 program, since this method of clustering allows to obtain a dendrogram most clearly demonstrating seasonal changes in ichthyoplankton in comparison with other methods, which also gave similar results.

RESULTS

In 2011–2012, surveys were carried out in a limited water area inside Vostok Bay and only from May to August (Fig. 1). The surveys were conducted in a limited area within Vostok Bay and only from May to August (Fig. 1). In May 2011, the catches included eggs of 4 fish species and larvae and fry of 16 species. Pollock eggs were recorded at 19 stations out of 19 (100.0%) (mean catch 3.0302 eggs/m^3 (0.2986–6.8505 eggs/m$^{3)}$, 64.3% of all eggs caught). Longsnout flounder *Myzopsetta punctatissima* eggs were also present at all stations (mean catch 1.0849 ind./m^3 (0.1493–4.9042 ind./m^3), 23.0%), as were yellowbandet flounder *Pseudopleuronectes herzensteini* eggs (mean catch 0.5088 ind./m^3 (0.0442–2.5876 ind./m^3), 10.7%). Eggs of flathead flounder *Hippoglossoides dubius* were present in 73.7% of catches (mean catch 0.09 ind./m^3 (0.0166–0.2986 ind./m^3 in performance catches), 1.9%). Fish larvae and fry were present at all stations, but sporadically. Larvae *of Stichaeus ohriamkini* (up to 0.06 ind./m$^{3)}$, yelloweye rockfish (up to 0.0663 ind./m^3) and Pacific herring

Clupea pallasii (up to 0.0498 ind./m^3) were the largest catches. Water temperature at the surface during this period was about 11.4°C throughout the entire bay area (Table 2).

In June 2011, the species composition of catches changed slightly: pollock caviar disappeared from catches, but caviar of yelloweye rockfish and starry flounder *Platichthys stellatus* appeared, as well as pilengasas *Planiliza haematocheilus*, Japanese anchovy and dotted gizzard shad *Konosirus punctatus* (Table 2). Yellowfin sole *Limanda aspera* had the highest proportion of eggs in the catches and occurred at all stations (mean 3.8376 ind./m^3 (0.4534–8.4262 ind./m^3), 48.2%). The proportion of yellowfin sole also increased, occurring in catches everywhere (mean 3.5296 ind./m^3 (0.5418–10.7042 ind./m^3), 44.2%). In contrast, the proportion of longsnout flaunder decreased slightly, although it occurred at 63.2% of stations, but catches decreased compared to May (mean catch 0.4286 ind./m^3 (0.0033–1.1887 ind./m^3), 23.0%). Starry flounder eggs, although more abundant (94.7% of catches), were low in abundance (mean catch 0.1067 ind./m^3 (0.0442–0.3096 ind./m^3), 1.3%). Eggs of southern species occurred in catches in insignificant quantities and amounted to 0.7% (for Japanese anchovy) of the total egg catch (Table 2). Larvae and fry of 9 fish species, including commercial fish species such as Pacific herring, saffron cod *Eleginus gracilis* and Korean flounder *Glyptocephalus stelleri*, also occurred in catches, but all catches were sporadic and at no more than 10% of stations for each of these species. Larvae of goby of the genus *Radulinopsis* were represented in the highest number (up to 0.0309 ind./m^3) (the first description of larvae of a species of this genus was made by us recently [46]). Water temperature near the surface was on average about 15.4°C throughout the entire water area.

In July 2011, the species composition of catches decreased, with eggs of 4 species and larvae and juveniles of 7 fish species. Japanese anchovy roe dominated the catches and was present at all stations (mean catch 2.7173 eggs/m^3 (0.1239–15.0389 eggs/m^3), 79.21%). Catches of yellowfin sole eggs decreased almost 6-fold compared to June (mean catch 0.4573 ind./m^3 (0.0089–3.1449 ind./m^3), 13.3%) and occurrence to 88.9%. Catches of longsnout flaunder eggs also declined (mean catch 0.2448 ind./m^3 (0.0885–1.4199 ind./m^3), 7.1%), although they were still nearly ubiquitous (94.4%). Dotted gizzard shad occurred regularly, but its proportion in catches was still very low (0.3%). Among commercial fish species, only larvae of Japanese anchovy occurred in catches. Larvae of three species of gobies of the family Gobiidae were present in the highest numbers (up to 0.1039 larv./m^3). Gobiidae (Table 2). Water temperature near the surface was about 21.3°C throughout the entire water area.

In 2012, surveys continued from June. The catches included eggs of 5 species, larvae and fry of 15 fish species. The total abundance of eggs decreased slightly compared to the previous year, but the catches were still dominated by Yellowfin sole eggs, which occurred everywhere (mean of 3.0683 eggs/m^3 (0.0265–23.5757 eggs/m^3), 57.1%). Yellowbandet flounder eggs were the second most common (in 78.9% of catches) (mean catch 2.6436 ind./m^3 (0.0487–17.3301 ind./m^3), 38.8%). The proportion of longsnout flounder eggs decreased markedly compared to the same period in 2011, although they did occur at 63.2% of stations (mean catch 0.2466 ind./m^3 (0.0177–0.7431 ind./m^3), 2.9%). The proportion of eggs of starry flounder and Japanese anchovy was also insignificant (Table 2). Larvae were sporadic in the catches, but their number almost doubled compared to 2011. Gobies of two species from the families Psychrolutidae and Gobolutidae were found in the highest numbers (up to 0.1039 ind./m^3). Psychrolutidae and Gobiidae. Larvae of 4 species of flatfish, Pacific herring, Japanese anchovy and Pilengasus were recorded among commercial species (Table 2). Water temperature at the surface averaged about 14.5°C (13.0–15.2°C), which was almost a degree lower than at similar times a year earlier.

July catches in 2012, as in the year before, were characterized by a significant reduction in species composition compared to June: eggs of three species and larvae were present. The abundance of eggs decreased more than 10-fold compared to the same period a year earlier. Japanese anchovy caviar dominated the catches, occurring in 88.9% of catches (mean 4.5869 eggs/m^3 (0.0133–1.2297 eggs/m^3), 87.7%). Yellowfin sole eggs accounted for 11.4% of the total and were already found at only 50.0% of stations (mean catch 0.5971 eggs/m^3 (0.0089–0.1769 eggs/m^3), 11.4%). Dotted gizzard shad spawn was present in small numbers. Japanese anchovy larvae and fry of seaweed pipefish *Syngnathus schlegeli* were sporadically recorded in catches (Table 2). The temperature background was significantly colder (by almost 4.0°C) than in 2011 (average 17.2°C at the surface (16.5–17.7°C)), although the work was carried out a week later.

In August 2012, fish eggs were absent in the catches. Larvae of Japanese anchovy were most widely represented (at 94.4% of stations). Juvenile seaweed pipefish were present in small numbers (up to 0.0155 ind./m^3) at more than half of the

Table 2. Characteristics of catches of early developmental stages of mass commercial fish species in ichthyoplankton in the eastern part of Peter the Great Bay in the period from 2011 to 2024 (mean catches per 10 minutes of trawling ± error of the mean (min-max effective catches), occurrence %) and mean surface water temperature

№	Kind	Stage divorce.	05.2011	06.2011	07.2011	06.2012	07.2012	08.2012	09.2022	04.2023	05.2023	07.2023	10.2023	06.2023*	09.2023*	10.2023*	04.2024*
1	*Clupea pallasii*	larv.	0.0084 ±0.0036 (0.0055–0.0498), 36.8	0.0009 ±0.0006 (0.0055–0.0111), 10.5	–	0.0056 ±0.0025 (0.0089–0.3539), 26.3	–	–	–	–	0.0001 ±0.0001 (0.0022–0.0022), 3.3	–	–	–	–	–	0.0004 ±0.0004 (0.0133–0.0133), 3.3
2	*Konosirus punctatus*	egg	–	0.0041 ±0.0027 (0.0055–0.0498), 21.1	0.0113 ±0.0038 (0.0044–0.0487), 44.4	–	0.0442 ±0.002 (0.0089–0.0354), 11.1	–	–	–	-	–	–	–	–	–	–
3	*Sardinops melanostictus*	egg	–	–	–	–	–	–	–	–	–	0.0012 ±0.0007 (0.0066–0.0155), 10.0	0.0003 ±0.0003 (0.0066–0.0066), 4.5	–	–	–	–
4	*Engraulis japonicus*	egg	–	0.0565 ±0.0174 (0.0332–0.2875), 68.4	2.7173 ±0.9184 (0.1239–15.0389), 100	0.0424 ±0.0024 (0.0044–0.115), 89.5	4.5869 ±0.0857 (0.0133–1.2297), 88.9	–	0.0048 ±0.0021 (0.0022–0.0044), 50.0	–	–	0.0324 ±0.0208 (0.0044–0.6193), 50.0	0.0005 ±0.0003 (0.0022–0.0044), 13.6	0.216 ±0.0762 (0.1017–0.3605), 100	0.0464 ±0.0464 (0.1393–0.1393), 33.3	–	–
		larv.	–	–	0.0049 ±0.0022 (0.0044–0.031), 38.9	0.0061 ±0.0024 (0.0089–0.031), 31.6	0.003 ±0.0019 (0.0044–0.0265), 16.7	0.045 ±0.0111 (0.0088–0.2035), 94.4	0.0002 ±0.0001 (0.0002–0.0002), 10.0	–	–	0.001 ±0.0009 (0.0022–0.0265), 6.7	0.0004 ±0.0002 (0.0022–0.0044), 13.6	–	0.0147 ±0.0055 (0.0022–0.031), 100.0	0.0007 ±0.0007 (0.0022–0.0022), 33.3	–
5	*Hypomesus japonicus*	larv.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.0001 ±0.0001 (0.0022–0.0022), 3.3
6	*Eleginus gracilis*	larv.	0.0009 ±0.0009 (0.0166–0.0166), 5.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		fry	–	0.0012 ±0.0009 (0.0055–0.0166), 10.5	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Continued

№	Kind	Stage divorce.	05.2011	06.2011	07.2011	06.2012	07.2012	08.2012	09.2022	04.2023	05.2023	07.2023	10.2023	06.2023*	09.2023*	10.2023*	04.2024*
7	*Gadus chalcogrammus*	egg	3.0302 ±0.432 (0.2986–6.8505), 100.0	–	–	–	–	–	–	13.6677 ±4.7956 (0.0044–92.109), 100.0	0.4817 ±0.2249 (0.0066–5.0602), 76.7	–	–	–	–	–	3.7325 ±2.0428 (0.0089–55.2614), 100.0
		larv.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.0001 ±0.0001 (0.0022–0.0022), 3.3
8	*Hyporhamphus sajori*	larv.	–	–	–	–	–	–	–	–	–	0.0003 ±0.0002 (0.0022–0.0044), 10.0	–	–	–	–	–
9	*Cololabis saira*	egg	–	–	–	–	–	–	–	–	–	0.0009 ±0.0005 (0.0066–0.0133), 10.0	–	–	–	–	–
10	*Hexagrammos octogrammus*	larv.	–	–	–	–	–	–	–	–	–	–	0.00001 ±0.0001 (0.0022–0.0022), 4.5	–	–	0.0015 ±0.0007 (0.0022–0.0022), 66.7	–
		fry	0.0003 ±0.0003 (0.0055–0.0055), 5.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
11	*Planiliza haematocheilus*	egg	–	0.0067 ±0.005 (0.0387–0.0885), 10.5	–	–	–	–	–	–	–	–	–	–	–	–	–
		larv.	–	0.0003 ±0.0003 (0.0055–0.0055), 5.3	–	0.0005 ±0.0003 (0.0044–0.0044), 10.5	–	–	–	–	–	–	–	–	–	–	–
12	*Scomber japonicus*	egg	–	–	–	–	–	–	0.0004 ±0.0003 (0.0022–0.0663), 13.3	–	–	0.1155 ±0.034 (0.0089–0.7254), 73.3	–	–	–	–	–

Table 2. Continued

№	Kind	Stage divorce.	05.2011	06.2011	07.2011	06.2012	07.2012	08.2012	09.2022	04.2023	05.2023	07.2023	10.2023	06.2023*	09.2023*	10.2023*	04.2024*
13	*Hippoglossoides dubius*	egg	0.09 ±0.0217 (0.0166–0.2986), 73.7	–	–	–	–	–	–	0.3136 ±0.1542 (0.0022–3.3882), 60.0	0.0097 ±0.0029 (0.0022–0.0619), 63.3	–	–	0.0015 ±0.0007 (0.0002–0.0002), 66.7	–	–	0.1865 ±0.9121 (0.0022–2.1054), 80.0
14	*Limanda aspera*	egg	–	3.8376 ±0.5128 (0.4534–8.4262), 100.0	0.4573 ±0.1846 (0.0089–3.1449), 88.9	3.0683 ±1.2048 (0.0265–23.5757), 100.0	0.5971 ±0.013 (0.0089–0.1769), 50.0	–	0.0003 ±0.0003 (0.0022–0.0044), 10.0	–	–	–	–	5.8379 ±1.0101 (4.0517–7.5482), 100	–	–	–
15	*Pseudopleuronectes herzensteini*	egg	0.5088 ±0.1329 (0.0442–2.5876), 100.0	3.5296 ±0.5501 (0.5418–10.7042), 100.0	–	2.6436 ±0.8913 (0.0487–17.3301), 78.9	–	–	–	–	–	–	–	0.1224 ±0.0269 (0.0686–0.1504), 100.0	–	–	–
		larv.	0.0085 ±0.0044 (0.0055–0.0663), 31.6	–	–	0.0317 ±0.0075 (0.0044–0.1194), 78.9	–	–	–	–	–	–	–	–	–	–	–
16	*Platichthys stellatus*	egg	–	0.1067 ±0.0199 (0.0442–0.3096), 94.7	–	0.0531 ±0.0174 (0.0044–0.3317), 47.4	–	–	–	–	–	–	–	–	–	–	1.1749 ±0.981 (0.0177–29.5957), 90.0
		larv.	–	–	–	0.0002 ±0.0002 (0.0044–0.0044), 5.3	–	–	–	–	–	–	–	–	–	–	–
17	*Glyptocephalus stelleri*	egg	–	–	–	–	–	–	–	–	–	0.0156 ±0.0056 (0.0022–0.1327), 53.3	–	0.0133 ±0.0046 (0.0066–0.0221), 100.0	–	–	–
		larv.	–	0.0017 ±0.0009 (0.0055–0.0166), 10.5	–	0.0002 ±0.0002 (0.0044–0.0044), 5.3	–	–	–	–	–	–	–	–	–	–	–

Table 2. The End

№	Kind	Stage divorce.	05.2011	06.2011	07.2011	06.2012	07.2012	08.2012	09.2022	04.2023	05.2023	07.2023	10.2023	06.2023*	09.2023*	10.2023*	04.2024*
18	*Myzopsetta punctatissima*	egg	1.0849 ±0.245 (0.1493–4.9042), 100.0	0.4286 ±0.1066 (0.0033–1.1887), 63.2	0.2448 ±0.0789 (0.0885–1.4199), 94.4	0.2466 ±0.0509 (0.0177–0.7431), 63.2	0.0003 ±0.0003 (0.0044–0.0044) 5.6	–	–	–	0.0281 ±0.0202 (0.0044–0.5994), 30.0	–	–	2.8036 ±0.7022 (1.7715–4.1446), 100.0	–	–	–
		larv.	–	–	–	–	–	–	–	–	–	–	–	0.0015 ±0.0015 (0.0044–0.0044), 33.3	–	–	–
19	*Cleisthenes pinetorum*	egg	–	–	–	–	–	–	–	–	–	0.0045 ±0.0026 (0.0022–0.0774), 23.3	–	–	–	–	–
	surface water temperature, X_{avg}, °C		11.4	15.4	21.3	14.5	17.2	21.1	16.0	4.7	10.3	18.5	14.5	15.8	21.6	10.4	6.9

Note. * samples were taken in the Nakhodka Bay.

stations. Juveniles of the threespine stickleback *Gasterosteus aculeatus* and goby *Gymnogobius heptacanthus* were also present in the catches. Water temperature at the surface averaged about 21.1°C (18.9–22.0°C).

In September 2022, eggs of three species, larvae and fry of 4 fish species were recorded in the ichthyoplankton (Table 2). The distribution density of eggs was extremely low, with a maximum of up to 0.0044 ind./m^3 for Japanese anchovy. Catches of yelloweye rockfish eggs were recorded at 3 stations out of 30 (10.0%) (mean catch 0.0003 ind./m^3 (0.0022–0.0044 ind./m^3), 5.3%), Japanese anchovy eggs was present at 50.0% of stations (mean catch 0.0048 eggs/m^3 (0.0022–0.0044 eggs/m^3), 86.7%), Japanese mackerel eggs was observed by us at 13.3% of stations (mean catch 0.0004 ind./m^3 (0.0022–0.0663 ind./m^3), 8.0%) – and this is the first time for the northwestern part of the Sea of Japan since 2017, when caviar of this species was also found in catches, but in significantly lower numbers [42]. The eggs of Japanese anchovy and Japanese mackerel were concentrated mainly in the western part of the area in the strait between Putyatin and Askold Islands, which, probably, taking into account the currents characteristic of the area at this time of year with prevailing winds from both southern and northern directions [14, 37], indicates their introduction mainly from the Ussuri Bay. In contrast, yellowfin sole eggs were found in the eastern part of the area, mainly at coastal stations (Fig. 2*a*).

Larvae and fry were present at individual stations sporadically, mainly in the western part of the study area. Piece catches of Japanese anchovy larvae were recorded at three stations in the vicinity of Putyatin and Askold Islands. Fry of wonder dragonet *Draculo mirabilis*, threespine stickleback and seaweed pipefish were also caught there. Water temperature at the surface during this period was in the range of 14.1–17.6°C, with an average of 16.0°C.

In April 2023, two species of fish eggs were present in the catches: pollock eggs occurred at all stations (100.0%) (mean 13.6677 eggs/m^3 (0.0044–92.109 eggs/m^3), 97.8%) and flathead flounder eggs were found in catches at 60.0% of stations (on average, 0.3136 ind./m^3 (0.0022–3.3882 ind./m^3), 2.2%). The

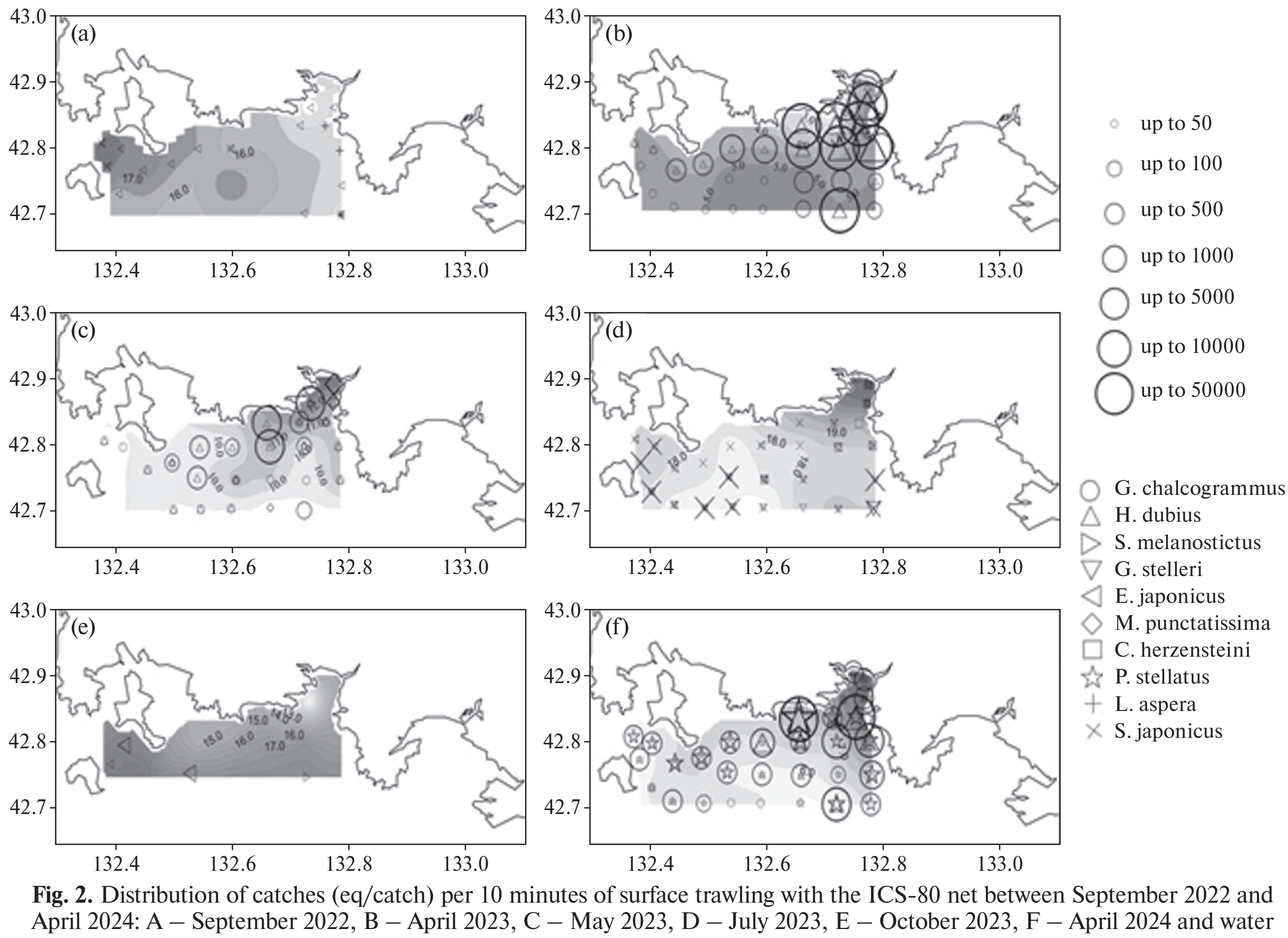

Fig. 2. Distribution of catches (eq/catch) per 10 minutes of surface trawling with the ICS-80 net between September 2022 and April 2024: A – September 2022, B – April 2023, C – May 2023, D – July 2023, E – October 2023, F – April 2024 and water temperature at the surface.

highest concentrations of eggs of both species were observed at the entrance to Vostok Bay (Fig. 2b). Vostok Bay (Fig. 2*b*).

Larvae of 5 fish species were also present in the catches: two species of the family Stichaeidae, two of the family Psychrolutidae and one of the family Liparidae. Stichaeidae, two species of Psychrolutidae and one species of Liparidae. Their catches were sporadic (up to 0.1327 ind./m^3 – only one catch of the whip sculpin *Gymocanthus intermedius*) and confined mainly to stations in the eastern part of the study area. Water temperature near the surface during the study period ranged from 2.7 to 5.6°C, with an average of 4.7°C.

In May 2023, eggs of two fish species were present in catches: pollock (23 catches, average 0.4817 eggs/m^3 (0.0066–5.0602 eggs/m$^{3)}$, 92.7%) and two species of flatfish: longsnout flounder (9 stations out of 30, average 0.028 eggs/m^3 (0.0044–0.5994 eggs/m^3), 5.4%) and southern halibut (7 catches, average 0.0097 eggs/m^3 (0.0022–0.0619 eggs/m^3), 1.9%). Pollock and southern halibut flounder eggs were again concentrated in a similar pattern, but, in contrast to April, mainly at coastal stations from the entrance to Vostok Bay to Putyatin Island. Vostok to Putyatin Island. Longsnout flounder eggs were concentrated mainly in the inner part of Vostok Hall. Vostok above depths of 12–20 m (Fig. 2*c*).

Single larvae of two fish species were also recorded in three catches: *Stichaeus ochriamkini* and Pacific herring. Two larvae of the first species were caught at the exit of Vostok Bay. Two larvae of the first species were caught at the exit of Vostok Bay, and a larva of Pacific herring was found in the catch in the bay apex. Water temperatures near the surface increased significantly and ranged from 9.1 to 13.2°C, averaging 10.3°C.

In July 2023, eggs of 6 fish species were recorded in ichthyoplankton. Flounder were represented by two species: Korean flounder, whose eggs were still found in small numbers at 16 stations out of 30 (53.3%) (average catch 0.0156 ind./m^3 (0.0022–0.1327 ind./m$^{3)}$, 9.2%) and sohachi flounder *Cleisthenes pinetorum*, whose eggs were found in 23.3% of catches (mean catch 0.0045 ind./m^3 (0.0022–0.0774 ind./m^3), 2.6%). Early developmental stages of southern migrants dominated the catches at this time: Japanese mackerel eggs were found at 73.3% of stations (mean catch 0.1155 ind./m^3 (0.0089–0.725416 ind./m^3), 67.9%), Japanese anchovy eggs at 50.0% of stations (mean catch 0. 0324 ind./m^3), 2.6%).0324 ind./m^3 (0.0044–0.6193 ind./m$^{3)}$, 19.0%), *Sardinops melanostictus* – at 10.0% of stations (mean catch 0.0012 ind./m^3 (0.0066–0.0155 ind./m^3), 0.7%), and *C. saira* – at 10.0% of stations, on scraps of brown algae of the genus *Sargassum* (mean catch 0.0009 eggs/m^3 (0.0066–0.0133 eggs/m^3), 0.5%).

In terms of the distribution of eggs of different species in this month, two areas were distinguished: one group (Japanese anchovy, sardine-wiwashi and sharphead flounder) had eggs confined to coastal stations in the eastern part of the survey area and directly into Vostok Bay. In contrast, the eggs of the other group of species (Steller's marolot, Japanese mackerel and saira) were concentrated in the deepest part of the area from Askold and Putyatin Islands to Likhachev Bay (Fig. 2*g*).

There were also single catches of larvae of the goby *G. castaneus* (0.0111 ind./m^3) and Japanese halfbeak *Hyporhamphus sajori* (0.0022–0.0044 ind./m^3) in the catches in the kut part, and outside the Vostok Bay of Japanese anchovy larvae (up to 0.0265 ind./m$^{3)}$. Outside Vostok Bay, larvae of Japanese anchovy (up to 0.0265 ind./m^3). Water temperature near the surface ranged from 16.7 to 21.1°C, with an average of 18.5°C.

In October 2023, due to worsening weather conditions, the number of stations had to be reduced to 22, removing the most moribund ones from the net. Fish eggs at this time were found in catches only outside Vostok Bay. Vostok. Two species were recorded in the catches: Ivassi sardine at only one station 0.0066 ind./m^3, 37.5%, and Japanese anchovy at three stations (average 0.0005 ind./m^3 (0.0022–0.0044 ind./m^3), 62.5%). As in the fall of 2022, the highest concentrations of Japanese anchovy eggs were recorded in the strait between Askold and Putyatin Islands (Fig. 2*d*).

Larvae and juveniles of 4 fish species were encountered in the catches, but almost all catches were piecemeal. Japanese anchovy larvae were found at three stations (average 0.0004 eq/m^3 (0.0022–0.0044 eq/m^3), dragonfish and Pacific needlefish larvae were caught in the western part of the study area, and masked greenling larvae *Hexagrammos octogrammus* caught in the eastern part.

The surface water temperature in the area varied significantly from 6.0 to 20.0°C and averaged 14.5°C. The lowest water temperature was observed in the kut part of the bay due to upwelling caused by strong downwinds blowing the previous day. In connection with this phenomenon, we also observed a freeze of Ivassi sardine, which lay on the bottom near the shore due to a sharp drop in water temperature at the surface by about 10°C overnight. Individuals with *TL* body lengths ranging from 14 to 21 cm were present in the aggregations. Two modal age groups with body lengths of *TL* 16 and 20 cm (2–3 yearlings) (1+ – 2+) were distinguished [49, 50].

The ichthyplankton surveys in Nakhodka Bay, although conducted in a limited water area, can, in our opinion, serve as a source of additional information on the spawning activity of mass species in this easternmost part of Peter the Great Bay. Peter the Great Bay. In the middle of June 2023, samples here contained eggs of 6 species of fish (Japanese anchovy, southern halibut, yellowfin, longfin, yellowstriped flounder and Steller's minnow) and larvae of two species (Kuznetsov's liparis *Liparis kusnetzovi* and longfin flounder). Eggs at all stages of development were present in the catches. The highest percentage of eggs at the last stages (III-IV) of development was observed in longfin flounder, which usually starts spawning slightly earlier than the other 4 species of flatfish present in the catches. Temperatures during the survey ranged from 15.0–16.9°C near the surface and 9.0–13.0°C near the bottom.

The second ichthyoplankton survey under this station scheme was carried out in the first decade of September 2023. Only Japanese anchovy (both eggs and larvae) early developmental stages were encountered in the ichthyoplankton net catches. Eggs were live, developing from developmental stages I through III, but were present in the catch at only one station. Catch per 10 minute trawl was negligible (up to 0.1393 eq/m^3), but comparable to catches during the June survey. Larvae with *TL* lengths ranging from 3.5 to 6.5 mm occurred at all three stations (mean 0.0147 eggs/m^3 (0.0022–0.031 eggs/m^3). The water throughout the entire strata in the area of work was warmed up to 19.8–21.6°C.

During the third survey, in October, only single fish larvae were present in the samples: Japanese anchovy larvae and brown terrapin larvae. Water temperatures during the survey were 10.0–11.1°C at the surface and 8.7–9.1°C at the bottom, which was significantly lower than those we had recorded in the area a month earlier (about 20.0°C throughout the water column).

Three fish species were present in the April 2024 catch: pollock roe occurred at all stations (100.0%) (average 3.7325 eggs/m^3 (0.0089–55.2614 eggs/m^3), 73.3%), southern fluke eggs at 24 of 30 stations (80.0%) (average 0.1865 eggs/m^3 (0.0022–2.1054 eggs/m^3), 3.7%), starry flounder eggs at 27 of 30 stations (90.0%) (average 1.1749 eggs/m^3 (0.0177–29.5957 eggs/m^3), 23.1%). The eggs of the most abundant species, walleye pollock and southern halibut flounder, were concentrated at the entrance to Vostok Bay. The eggs of the most abundant species – walleye pollock and southern halibut flounder – were concentrated at the entrance to Vostok Bay, and starry flounder – at practically all coastal stations except those in Vostok Bay itself. Vostok (Fig. 2E). Larvae of 12 fish species were also present in the catches: three fish species of the family Psychrolutidae, two species of the family Psychrolutidae, two species of the family Psychrolutidae, two species of the family Psychrolutidae, and two species of the family Psychrolutidae. Psychrolutidae, two – Stichaeidae, one each – Opisthocentridae, Pholidae, Ammodytidae, Osmeridae, Gadidae and Liparidae. Their catches were sporadic (up to 0.0221 ind./m^3 – only one catch of Liparidae *L. agassizii* and up to 0.0184 ind./m^3 – in one of three catches of *Ammodytes* sp. larvae) and confined mainly to stations in the eastern part of the study area at the entrance to Vostok Bay and inside it. Vostok Bay and within it.

A total of 50 fish species, 19 of which are traditionally considered commercially important, were recorded in the catches during the period of our work (Table 2). Data on these and two other fish species (scale-eye plaice *Acanthpsetta nadeshnyi* and capelin *Mallotus villosus*), which were encountered in catches in this water area during earlier study periods, were included in further analysis of interannual changes in the species composition of ichthyoplankton. Scale-eye plaice eggs are generally present in the surface layer in proportion to their concentrations throughout the water column [26, 40] and, if present, are also caught in horizontal fisheries. Capelin larvae are also usually present in the surface water layer [24, 32] and are easily captured by our gear. Their complete absence in our catches therefore requires explanation, as it could indicate, among other things, changes in their populations.

DISCUSSION

According to the results of previous studies [9, 17, 20, 21, 24, 26, 26, 32, 36], it is known that in the eastern part of Peter the Great Bay, significant concentrations of eggs of mass commercial fish species are usually observed in spring and the first half of summer. As a rule, significant concentrations of eggs of mass commercial fish species are observed in the eastern part of Peter the Great Bay in spring and the first half of summer, confined mainly to the water areas at the entrance to Strelok, Vostok and Nakhodka Bay. Strelok, Vostok and Nakhodka. This indicates, in our opinion, that spawning grounds for at least several of these species (yellowfin sole, yellowbandet flounder, sohachi, starry, dotted, and flathead flounders, and pollock) are located here. Japanese anchovy and Iwasi sardine also spawn regularly in this water area in summer in years of high abundance [12, 38, 39]. Mass spawning of Japanese mackerel at its high abundance was noted earlier in the adjacent waters of the Ussuriysky Bay and in the deeper part of Peter the Great Bay [8, 17, 17]. Peter the Great Bay [8, 17]. The presence of its eggs in the coastal water areas in the eastern part of the Gulf at present also indicates the presence of spawning aggregations here and a general increase in the abundance of the Japanese mackerel population.

Changes in the species composition of the ichthyocene of the northwestern part of the Sea of Japan occur cyclically [12], and the last warming period of gradual increase in the proportion of southern migrants here has been observed since about 1965 (the minimum of their representation in Peter the Great Bay in the second half of the 20th century [30]. Peter the Great Bay in the second half of the 20th century) [30]. In the 2000s, their number approached the values characteristic of the 30s of the XX century, when warming was also observed (50 species vs. 53). The most widespread and numerous among representatives of the warm-water ichthyocomplex from the late 1990s to the 2000s were Japanese anchovy and saira. The warming process continues at present [16], and in this connection, in our opinion, it is interesting to establish similarities in the species composition of ichthyoplankton catches of years classified by experts as warm or cold.

As already mentioned, we compared pelagic stages of early development only for 21 species of commercial and mass fishes, as we consider their identification and accounting to be more reliable and systematic. In all of these species, eggs, and in some species larvae, concentrate directly near the surface [10, 11, 20, 26, 40, 41]. Maximum catches in horizontal trawls in this case tend to coincide with those in vertical trawls, at least during daylight hours. At low concentrations, eggs of these species occur in horizontal catches even when they are absent in vertical catches due to the many times greater volume of water being filtered. For example, for walleye pollock it is known that its spawning in Peter the Great Bay occurs in the thickest part of the water. Peter the Great Bay spawning occurs in the water column, usually above depths of less than 200 m. At the beginning of spawning, the main spawning aggregations are observed at depths of 100–80 m, and further spawning pollock approach closer to the shore at depths of 30 m and less [11, 19, 20]. Mass spawning in Peter the Great Bay occurs from the second half of the second half of the year. Mass spawning in Peter the Great Bay occurs from the second half of March to mid-April at water temperatures near the surface of 0–1.5°C [11] or, in recent years, until the first decade of May [4] at higher temperatures (average water column temperature up to 4.6°C). At the beginning of development, eggs are kept mainly near the water surface, only slightly sinking as they develop in the 0–50 m horizon (according to S.M. Kaganovskaya, the upper 10 m layer may contain from 51.2 to almost 100.0% of pollock eggs [20], and according to N.N. Gorbunova, in the Gulf of Korea, this layer concentrates on average about 72.0% of eggs [11]). It is known that in some populations the development of pollock eggs up to hatching can take place at depths of more than 200 m, but this is due to local hydrological conditions that are formed, for example, in canyons in Avacha and Kronotsky Bays, and prevent the eggs from rising to the surface layer [2, 3].

Using literature data [11, 20] on the characteristic vertical distribution of eggs in the Sea of Japan, and our derived catch ratios per m^2 for horizontal and vertical catches in our April 2024 survey, we recalculated our horizontal catches of pollock eggs for 2023–2024 per m^2 of the entire water column.

When we conducted a series of horizontal and vertical catches at the same points and comparative analysis of catches, a formula was derived to calculate the decreasing amount of pollock eggs with increasing depth:

$$N_h = N_1 * h^{-1,701},$$

where N_h – number of eggs at depth h, N_1 – number of eggs in the surface 1 m layer, h – depth, m.

The number of eggs decreases with increasing depth almost exponentially. Thus, the number of eggs in the vertical column under the upper one-meter layer is close to the number of eggs in the one-meter layer of water near the surface. Using these data, as well as the results of our experiments comparing the number of eggs in vertical and horizontal fisheries, an empirical coefficient was derived that allows us to compare survey results using these two methods of estimating the number of pollock eggs, for 1 m^2:

$$N = 6.3 * V,$$

where N is the number of pollock eggs per 1 m^2 in surface fishing, V is the number of eggs per 1 m^2 in vertical fishing.

The obtained values of catches in terms of m^2 correlate well with the data of A.V. Buslov et al [4] for the period 2019–2022 and indicate a further decline in the current reproduction of pollock in the Bay, associated with natural attrition in the only high-yielding generation of 2014 over the last decade.

For practically all other species, there is no need for such recalculations, as the literature sources used contain data on both horizontal catches and per 1 m^2 of surface area. In addition, based on the comparative analysis of catches, we believe that a comparison of species composition, taking into account the percentage contribution of each of these species to the total maximum catch, would also be correct for surveys in which different recording methods (horizontal or vertical catches) were used.

Unfortunately, for the groups of years we compared, not all of the selected species have data on the characteristics of caviar catches in the eastern part of Peter the Great Bay, even at high abundance. Even with high abundance of these species, there are no data on caviar catches in the eastern part of Peter the Great Bay. For example, for the 50s of the last century there are no data on caviar catches for pollock and plaice in the spring period, and in the summer period for Japanese mackerel and saury, in the 90s there are no data on plaice caviar catches in the summer period, which greatly limits the possibility of making comparisons with data from recent years. The level of reproduction of these species can only be judged roughly from indirect data from the fisheries of those years.

The monthly periods of work from April to October (warm season) considered by us in different years were naturally grouped on the similarity dendrogram into three large clusters: the end of spring (April-May), the beginning of summer (June, in some years July) and the second half of summer and the beginning of autumn (July-August to October) (Fig. 3). In general, in the water area under consideration, the first period is characterized by insignificant species diversity: two or three mass species, with the overwhelming predominance of pollock (Table 2, Fig. 4). The second period is characterized by a slightly higher species diversity with the predominance of two or three species of flatfish and the appearance of eggs of Japanese anchovy and other southern migrants in the plankton. The third period, the longest, is characterized in the area by the end of flounder spawning and the predominance of eggs and larvae of southern migrants, mainly Japanese anchovy, as well as sardine and Japanese mackerel in years of high abundance. Species diversity of ichthyoplankton during this period is generally minimal due to the cessation of spawning of summer spawning species, while spawning of the small number of fall spawning commercial fish species, such as terpugas, is just beginning, their eggs are bottom-dwelling and larvae in the surface layer are still extremely scarce.

The first group isolates the 2023–2024 catches, in which the proportion of pollock roe is significantly higher (up to 96.5% in April 2023 and 64.5% in April 2024) than in the 1980s and 2007 and 2011 catches, and the proportion of eggs of southern halibut flounder is noticeably lower, although in absolute values per m^2 the catches of both species were higher in the 1980s and lower in 2011, but in the latter case the surveyed water area did not cover their mass spawning grounds (Fig. 4).

A rather high concentration and share of the total catch of pollock caviar in recent years is due to the still high abundance of pollock producers of the

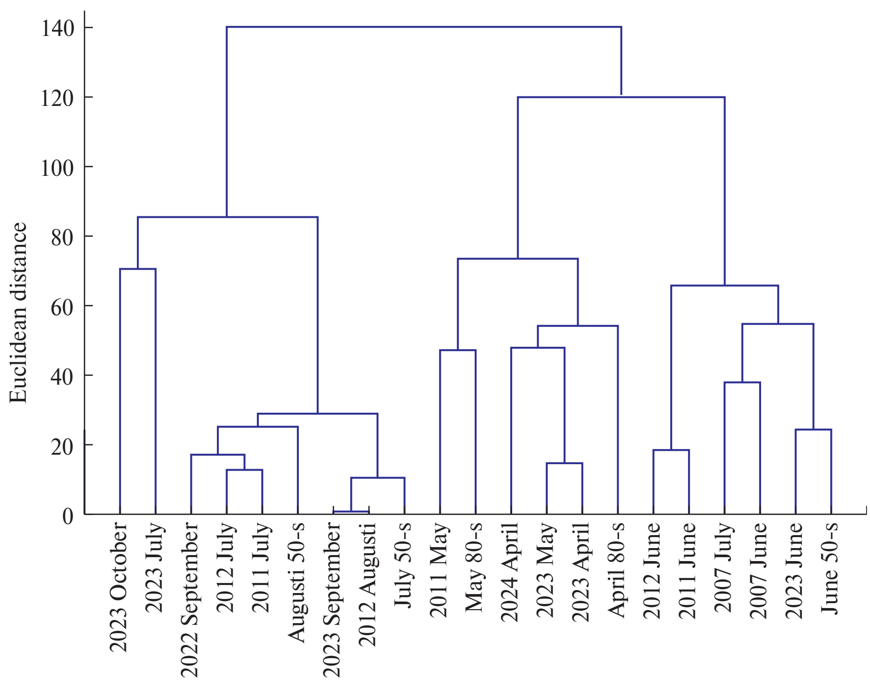

Fig. 3. Dendrogram of similarity of years in terms of ichthyoplankton species composition and proportion of species in the total catch of eggs and larvae (data for 1950s [20, 21, 26, 28, 38, 39], for the 1980s [23, 24], and for 2007 [32].

2014 harvest generation [4] against the background of relatively low abundance of other spring spawning species. [4] against the background of relatively low abundance of other spring spawning species.

The spawning dynamics of starry flounder based on the results of spring surveys of different periods was less predictable than for other species: in April 2024 and April-May of the 1950s and 1980s the proportion of its eggs was high, while in the similar period of 2011 and 2023 the eggs of this species were absent in catches in this water area. In May 2011, in contrast to other years, the proportion of longsnout flounder was significant, which is probably due to higher average surface water temperatures (Table 2). The earlier warming of the water may have contributed to earlier spawning, which usually peaks in early summer for this species [26].

In the second group, the 2023 data were grouped with the June 1950s data, while the 2011–2012 and 2007 data, both for June and July, were grouped separately (Fig. 3). This is because, although in all years in June, yellowfin sole eggs had the largest proportion of the catch (35.2 to 61.7%) and the proportion of Japanese anchovy roe was not significant, in the 1950s, as in 2023, the proportion of longsnout flounder eggs was high (33.8–38.7% vs. approximately 6.0% in 2011–2012 and 0.63% in June-July 2007), and in contrast, starry flounder eggs was absent. It can be assumed, given the large catches of longsnout flounder eggs in May 2011, that longfin flounder spawned earlier in 2011–2012, and possibly in 2007. In addition, in July 2007, the proportion of eggs of Korean flounder seatrout and longsnout flounder was noticeably higher in the catches.

The third period was characterized by the overwhelming predominance of caviar of southern migrants, mainly Japanese anchovy (up to 100.0% of caviar). July and October 2023 are somewhat special, which were characterized by the presence in catches of eggs of sardine (for the first time in the last 20 years) and eggs of Japanese mackerel (July, up to 45.0% of maximum catches). A higher proportion of eggs of sardine was observed only in the late 80s – early 90s [12], which undoubtedly indicates a significant increase in the Japan Sea population of this species at present. In July 2023, the proportion of Korean flounder was also noticeable, which is not typical for other years. Its eggs were found in larger numbers only in July in the 1950s. At the same time, a noticeable proportion of scaleeye plaice eggs was recorded in the catches (up to 17.0% of the total catch in August), which was later recorded by no one in Peter the Great Bay in appreciable quantities. It has not been recorded in appreciable quantities in Peter the Great Bay.

According to literature data, spawning of scaleeye plaice in the Bay occurs from June through August

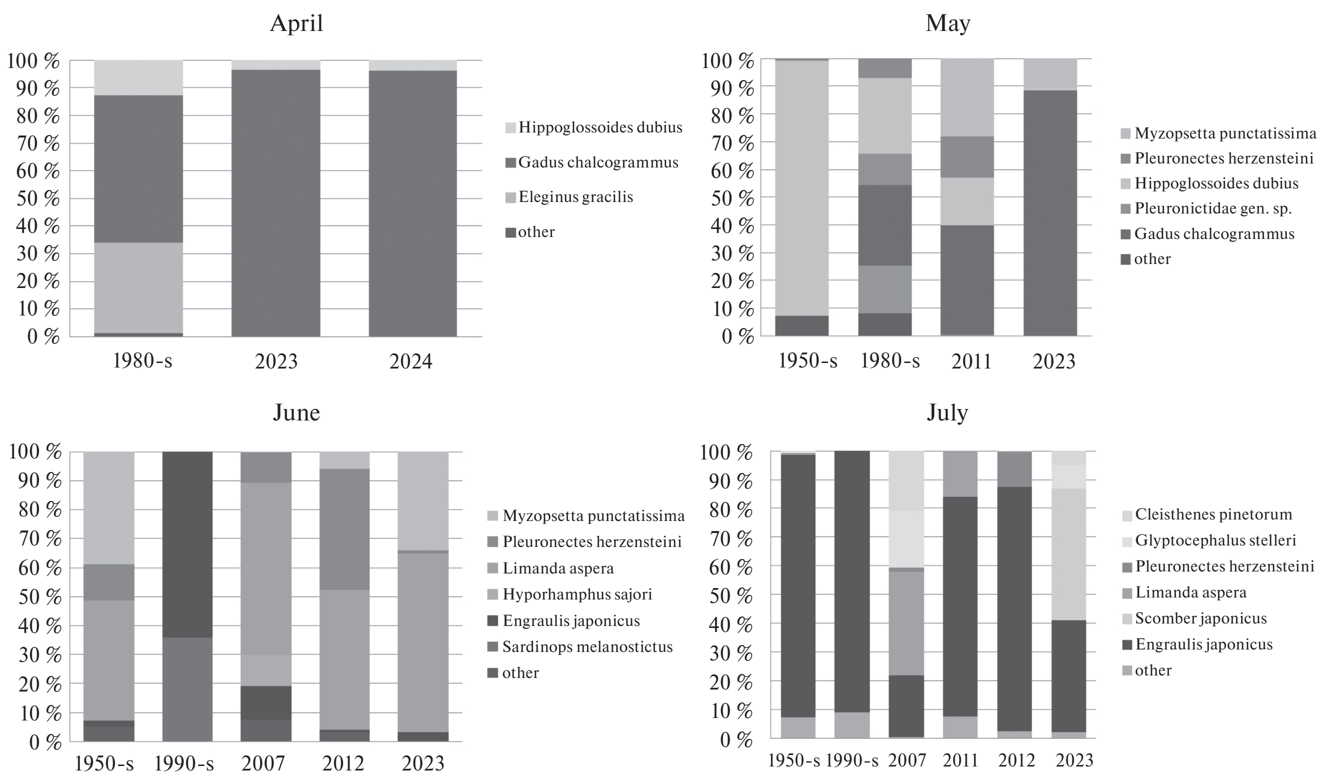

Fig. 4. Change in the proportion of commercial species in catches by month during different periods of the year.

[26] or even early September [5] with a peak in July, but even in these months sexually mature individuals are mainly found at depths of 100 m and deeper, in contrast to the Tatar Strait, where it approaches shallow waters and where its eggs were found above depths of 35 m [42]. In June, when spawning begins, dense aggregations of scaleeye plaice have been observed at depths of about 300 m [5]. According to the data of Pertseva-Ostroumova T.A. [26] the eggs of this species were not found in the Peter the Great Bay above the depths of about 300 m [5]. According to Pertseva-Ostroumova T.A. [26] eggs of this species were not found in Peter the Great Bay above depths less than 50- 60 m and earlier, and at present, probably, its accumulations are located above even greater depths in the open part of Peter the Great Bay. The accumulations are probably located above even greater depths in the open part of the Peter the Great Bay and beyond its boundaries. This, apparently, can explain the complete absence of its eggs during the period of our work.

As for capelin larvae identified in catches in June 2007 [32], it should be noted that this species during the period of systematic observations in Primorye waters was sufficiently abundant only in the 1940s. Its abundance is subject to high fluctuations and, as a rule, increases in cooling periods, and it is not surprising that during the ongoing warming period [30] its larvae are extremely few in catches [32] or completely absent, as in our catches.

Hence, as follows from the above data, peak egg concentrations and proportion of eggs of certain fish species in ichthyoplankton in the study water area can change substantially depending on thermal conditions of a particular year. However, for the entire observation period under consideration, in waters of eastern Peter the Great Bay, three periods with a characteristic set and proportion of early development stages of the studied species in ichthyoplankton are clearly distinguished in the warm season: late spring (April–May), early summer (June, occasionally, May and July), and late summer–early autumn (July–October).

Our data confirm that recent years in the study area have been characterized by a high, gradually decreasing proportion of pollock eggs in spring catches due to a high abundance of the strong 2014 year-class. In addition, they indicate the appearance of noticeable quantities of chub mackerel and sardine eggas in the plankton in summer and early autumn. The latter may be evidence of the soon upcoming and long-predicted increase in the abundance of its Sea of Japan population [1] to commercial levels in Primorye waters. We also suggest that the reproduction of spring–summer spawning flounders, despite their generally high proportion in catches, is currently at a low level compared to the 1950s and 1980s.

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ETHICS DECLARATIONS

Experiments with animals were conducted in accordance with national, international and institutional guidelines for conducting research with animals. This is confirmed by Statement No. 1-240924 minutes of meeting No. 9 of 09.24.2024 of the Biomedical Ethics Commission of the NSCMB DVO).

CONFLICT OF INTERESTS

The authors of this paper declare that they have no conflicts of interests.

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