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# Species Composition and Distribution of Ichthyoplankton in the Waters of Northeast Sakhalin

**I. N. Mukhametov* and O. N. Mukhametova**

*Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO), Yuzhno-Sakhalinsk, Russia*

**e-mail: moukh00@mail.ru*

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**Abstract**—Data on the species composition and abundance of the ichthyoplankton obtained in 2012, 2014, and 2015 in the waters of northeast Sakhalin are presented; these data were collected during the standard accounting surveys to estimate the egg concentration and breeders of Alaska pollock *Theragra chalcogramma*. The areas of the main concentrations of eggs and larvae of a number of commercial fish species have been determined, interannual variations in their abundance have been analyzed, and the distribution of ichthyoplankton with some parameters of the environment, such as depth, temperature, and main currents, has been linked. During the study period, 30 species representing 11 families were recorded in the ichthyoplankton. The average concentration of ichthyoplankton varies within the range of 113–201 ind./$m^2$. The pollock eggs absolutely dominated by 78–89%; followed by the eggs of the Bering flounder *Hippoglossoides robustus* (5–8%). It was found that the number of eggs and larvae of flounders and of a number of the other fish species in the northern part of the study area increases during the years characterized by a large volume of runoff of Amur River.

*Keywords:* species composition, Alaska pollock *Theragra chalcogramma*, Bering flounder *Hippoglossoides robustus*, eggs, larvae, abundance, spatial distribution, northeast Sakhalin

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The waters of northeast Sakhalin from Cape Terpeniya in the south to Cape Elizabeth in the north are the breeding grounds for many commercial and noncommercial fish species whose eggs and larvae can be found in plankton. In the first decade of the 21st century, Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO), after a long pause, resumed relatively regular ichthyoplankton surveys aimed at estimating the abundance of eggs and the stock of the main commercial species in this area, Alaska pollock *Theragra chalcogramma*. Until 2012, these surveys were limited to the estimation of the eggs' concentration and to the study of the distribution of the eggs of this species. Meanwhile, the spawning and larvae growth of many species of the Pleuronectidae family, of the saffron cod *Eleginus gracilis*, of Pacific herring *Clupea pallasii*, of Pacific sand lance *Ammodytes hexapterus*, of capelin *Mallotus villosus*, and of a number of noncommercial but fairly abundant families (Cottidae, Stichaeidae, Liparidae, and others) occur in the shelf waters of this region.

The work aims to study the interannual changes in the structure of the ichthyoplankton complex of northeast Sakhalin and to study the reproduction of particular fish species (based on the data obtained in the surveys performed in 2012, 2014, and 2015). The research tasks included the determination of the species composition of ichthyoplankton, the defining of the reproduction and growth areas of abundant fish species, and the assessment of the effect of various oceanological factors (currents, temperature) on the distribution of ichthyoplankton.

## MATERIALS AND METHODS

Ichthyoplankton samples were collected in the waters of northeast Sakhalin during the surveys with R/V *Dmitry Peskov* (SakhNIRO): 115 stations were performed during the period of June 9–21, 2012; 104 stations on June 5–16, 2014; and 96 stations on June 8–14, 2015 (Fig. 1). The ichthyoplankton sampling was performed using a plankton net with an opening mouth diameter of 80 cm (IKS-80), and the net was towed vertically from the depth of 200 m (at shallower depths, from the bottom) to the surface. The samples were fixed with a 4% formaldehyde solution. Hydrological parameters were recorded using an SBE#19-V2 probe (in 2012 and 2014) and a CTD-logger ACTD-CMP (in 2015).

Ichthyoplankton samples were processed in accordance with standard methods (Rass, 1965; Rass and Kazanova, 1966). Determination of species identity, as well as the measurement of the eggs and larvae, was performed in a laboratory using an Olympus SZX2

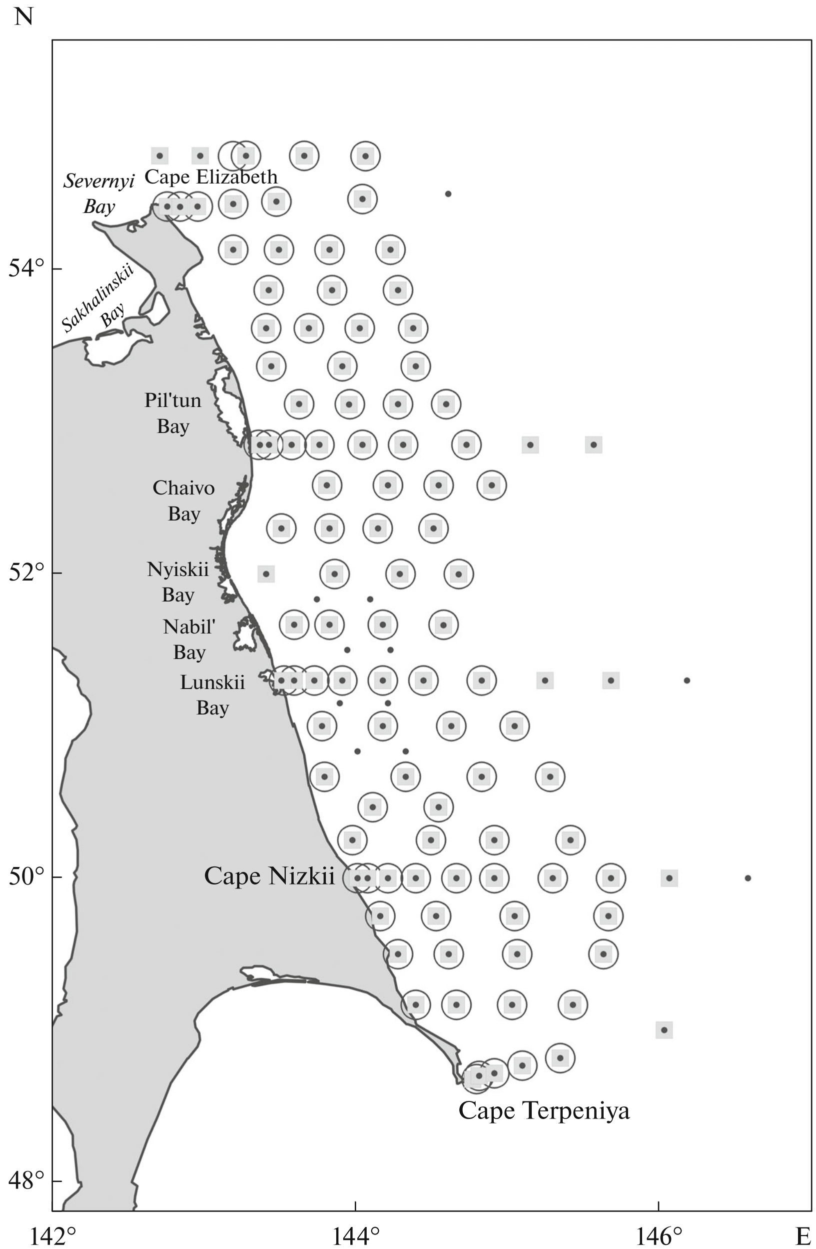


**Fig. 1.** Sampling site map: (●) 2012, (■) 2014, (○) 2015.

binocular microscope with an eyepiece micrometer. For species identification, the descriptions and figures provided in the publication of Russian and foreign researchers were used (Pertseva-Ostroumova, 1961; *An Atlas*..., 1988; Matarese et al., 1989; Sokolovskii and Sokolovskaya, 1997, 2003, 2008; Grigor'ev, 2003, 2004, 2007).

Ichthyoplankton catches are recalculated for the water column under 1 $m^2$ of the surface water area, taking into account the diameter of the net and the length and angle of inclination of the slipped wire. Plotting of distribution patterns, assessment of the abundance of eggs and larvae was carried out using Surfer 11 software.

According to the hydrological characteristics, 2012 is classified as warm year and 2015 as a cold year, while 2014 was characterized by an intermediate temperature background. The analysis of spawning parameters and dependence of the distribution of fish eggs and larvae on temperature is performed for 2012 and 2015.

## RESULTS

The development of most of the fish eggs and larvae occurs in the near-surface 50-m layer (Pertseva-

Ostroumova, 1961; Ovsyannikov, 2004; Moukhametov and Chastikov, 2013). In 2012, significant positive temperature and salinity anomalies in this layer were observed in the study area. In 2014, a significant part of the water area from Schmidt Peninsula to 52° N was also filled with warm waters (up to 6–7°C) with low salinity (22–24‰). In 2015, the situation changed significantly. The flow of warmer desalinated waters was much weaker, and it was registered south of 54° N as separate spots; they did not spread, as usual, as a continuous stream from Schmidt Peninsula to Pil'tun Bay. During the years of study, a consistent linear decrease of the average temperature of this layer was recorded: 1.47 → 1.04 → 0.62°C (in June 2012, 2014, and 2015, respectively).

For a 3-year study period, the ichthyoplankton was represented by 30 species from 11 families (Table 1). The maximum number of species belonged to the three families: Pleuronectidae (27%), Cottidae (19%), and Stichaeidae (15%).

Zoogeographical composition of marine ichthyoplankton in the water area of northeast Sakhalin in June 2012, 2014, and 2015 did not differ in variety. The taxonomic list completely lacked the thermophilic forms that appear in the near-Sakhalin waters mainly during the period of maximum warm-up. In the waters of northeast Sakhalin, this group occasionally encounters eggs and larvae of the subtropical migrant of the Japanese anchovy *Engraulis japonicus*, as well as a number of low-boreal species of Pleuronectidae and Cottidae (Moukhametova, 2003). Unlike the waters of western, southern, and southeast Sakhalin, the thermophilic forms in ichthyoplankton are less regular north of Terpenia Cape, due to more severe habitat conditions, they do not form high concentrations, and their contributions both in species diversity and in the total number of ichthyoplankton are much lower. The maximum number of species was represented by the wide-boreal group, whose contribution to the total species list exceeded 40–50%.

Ichthyoplankton sampling was performed over a wide range of depths, resulting in a taxonomic composition of eggs and larvae of different biotopic groups living from the coastal shallow waters (sublittoral group) to relatively deep-water areas (mesobenthal). The number of the species belonging to these groups in all the years of study was small: 18–23% belonged to the sublittoral group and up to 9% to the mesobenthal group. The contribution of elittoral species that prevailed in the catches varied during the study period from 64 to 76%.

In all the years in June, a monodominant ichthyoplankton complex with an absolute prevalence of Alaska pollock eggs were formed in the waters of northeast Sakhalin, and the contribution of the eggs of this species increased from 78% in 2012 up to 89% in 2015. The second place belonged to the eggs of the Bering flounder *Hippoglossoides robustus*, and its relative contribution varied within 5–8%. Among the widely spread forms, one can note the eggs of the starry flounder *Platichthys stellatus*, the longhead dab *Limanda proboscidea,* and the Sakhalin sole *L. sakhalinensis* and the larvae of sand lance.

The average concentration of ichthyoplankton was within the range of 113–201 ind./m$^2$; the minimum occurred in 2012; in 2014 and 2015, the average abundance was almost the same: 201.2 and 200.5 ind./m$^2$, respectively.

A direct relationship between the distribution of ichthyoplankton in total and the distribution of the particular species with the main hydrological parameters of the environment (temperature, salinity) has not been revealed. The elevated concentrations (100–500 ind./m$^2$) were formed as the narrow bands mainly above the depths of 50–200 m with some interannual variations. In 2012, the areas occupied by such a concentration of ichthyoplankton were of lesser extent but covered the water area with smaller depths, extending to the south of Pil'tun Bay to coastal shallow waters. In 2015, the concentrations of more than 100 ind./m$^2$ were recorded mainly over the depths of less than 200 m, whereas higher population density was observed over large depths (up to 500 m) north of 51° N in 2012 and 2014.

The total concentrations of eggs and larvae exceeding 1000–1500 ind./m$^2$ had a very local distribution. The location of such concentrations changed annually; however, the spots of high concentrations were formed north of Pil'tun Bay and around 50° N in most cases.

**Alaska pollock.** The pollock spawning in June 2012, 2014, and 2015 had the following features: the area of the egg distribution reduced by 15–18% over the study period; the area of distribution of eggs at the first (I) stage of development, approximately corresponding to the spawning areas, decreased by 14–16% each year and amounted to 81170, 68000, and 58450 km$^2$, respectively. At the same time, the relative abundance of eggs at the first (I) stage of development increased from 37% in 2012 to 54% in 2015. The absolute number of eggs at the first (I) stage and the total amount of pollock eggs increased significantly in 2014 compared to 2012. But there has been a tendency to reduce the number of eggs and larvae of this species already in 2015.

The number of eggs in 2015 decreased 1.2 times, but the number of larvae decreased by an order of magnitude. Such a situation can be explained by the change in the temperature regime in the study area. The temperature of the upper 50-m layer, where pollock eggs' development predominantly occurs, decreased more than twice in comparison with 2012 (0.62 vs. 1.47°C), which led to a delay in spawning that can be indicated by the eggs at the first (I) stage of development, which, in turn, as mentioned above, had the maximum contribution in 2015. At the same time,

**Table 1.** Species composition of ichthyoplankton in the waters of northeast Sakhalin in 2012, 2014, and 2015

| Species composition | Develop-mental stage | Year | | |
|---|---|---|---|---|
| | | 2012 | 2014 | 2015 |
| Family Clupeidae—Herrings, shads, sardines, menhadens | | | | |
| *Clupea pallasii* Valenciennes, 1847, Pacific herring | Larvae | + | + | |
| Family Osmeridae—Smelts | | | | |
| *Mallotus villosus* (Müller, 1776), Capelin | Juveniles | | | + |
| Family Gadidae—Cods and haddocks | | | | |
| *Eleginus gracilis* (Tilesius, 1810), Saffron cod | Larvae | + | + | + |
| *Theragra chalcogramma* (Pallas, 1811), Alaska pollock | Eggs | + | + | + |
| | Larvae | + | + | + |
| Family Cottidae—Sculpins | | | | |
| *Enophrys diceraus* (Pallas, 1788), Antlered sculpin | ″ | | + | |
| *Icelus cataphractus* (Pavlenko, 1910), Scaled sculpin | ″ | | + | |
| *Megalocottus platycephalus* (Pallas, 1814), Belligerent sculpin | ″ | | | + |
| *Myoxocephalus jaok* (Cuvier, 1829), Plain sculpin | ″ | | | + |
| *Myoxocephalus* sp., Sculpin | ″ | | + | |
| Cottidae gen. sp. | ″ | | + | |
| Family Psychrolutidae—Fatheads | | | | |
| *Malacocottus zonurus* Bean, 1890, Darkfin sculpin | ″ | | | + |
| Family Agonidae—Poachers | | | | |
| *Aspidophoroides monopterygius* (Bloch, 1786) (=*Aspidophoroides bartoni*), Alligatorfish | ″ | | + | + |
| *Leptagonus decagonus* (Bloch & Schneider, 1801), Atlantic poacher | ″ | | | + |
| Family Liparidae—Snailfishes | | | | |
| *Liparis kusnetzovi* Taranetz, 1936, Kuznetsov's snailfish | ″ | + | | |
| *L. latifrons* Schmidt, 1950, striped sea snail | ″ | | + | + |
| *L. ochotensis* Schmidt, 1904, Okhotsk snailfish | ″ | | + | + |
| Family Stichaeidae, Pricklebacks | | | | |
| *Leptoclinus maculatus* (Fries, 1838), Daubed shanny | ″ | | + | + |
| *Lumpenella longirostris* (Evermann & Goldsborough, 1907), Longsnout prickleback | ″ | | | + |
| *Lumpenus sagitta* Wilimovsky, 1956, Snake prickleback | ″ | | | + |
| *Stichaeus punctatus* (Fabricius, 1780), Arctic shanny | ″ | | + | + |
| Family Pholidae—Gunnels | | | | |
| *Pholis fasciata* (Bloch et Schneider, 1801), Banded gunnel | ″ | | + | |
| Family Ammodytidae, Sand lances | | | | |
| *Ammodytes hexapterus* Pallas, 1814, Pacific sand lance | ″ | + | + | + |
| Family Pleuronectidae—Righteye flounders | | | | |
| *Glyptocephalus stelleri* (Schmidt, 1904), Blackfin flounder | Eggs | + | + | + |
| *Hippoglossoides robustus* Shmidt, 1904, Bering flounder | ″ | + | + | + |
| *Limanda aspera* Pallas, 1811, Yellowfin sole | Larvae | + | + | |
| | Eggs | | + | + |
| *L. sakhalinensis* Hubbs, 1915, Sakhalin sole | Larvae | + | + | |
| | Eggs | + | + | + |
| *L. proboscidea* (Gilbert, 1896), Longhead dab | ″ | + | + | + |
| *Platichthys stellatus* (Pallas, 1787), Starry flounder | ″ | + | + | + |
| *Pleuronectes quadrituberculatus* Pallas, [1814], Alaska plaice | Larvae Eggs | + | + | |
| Pisces gen. sp. | Larvae | | + | + |
| Total number of species | | 12 | 22 | 22 |

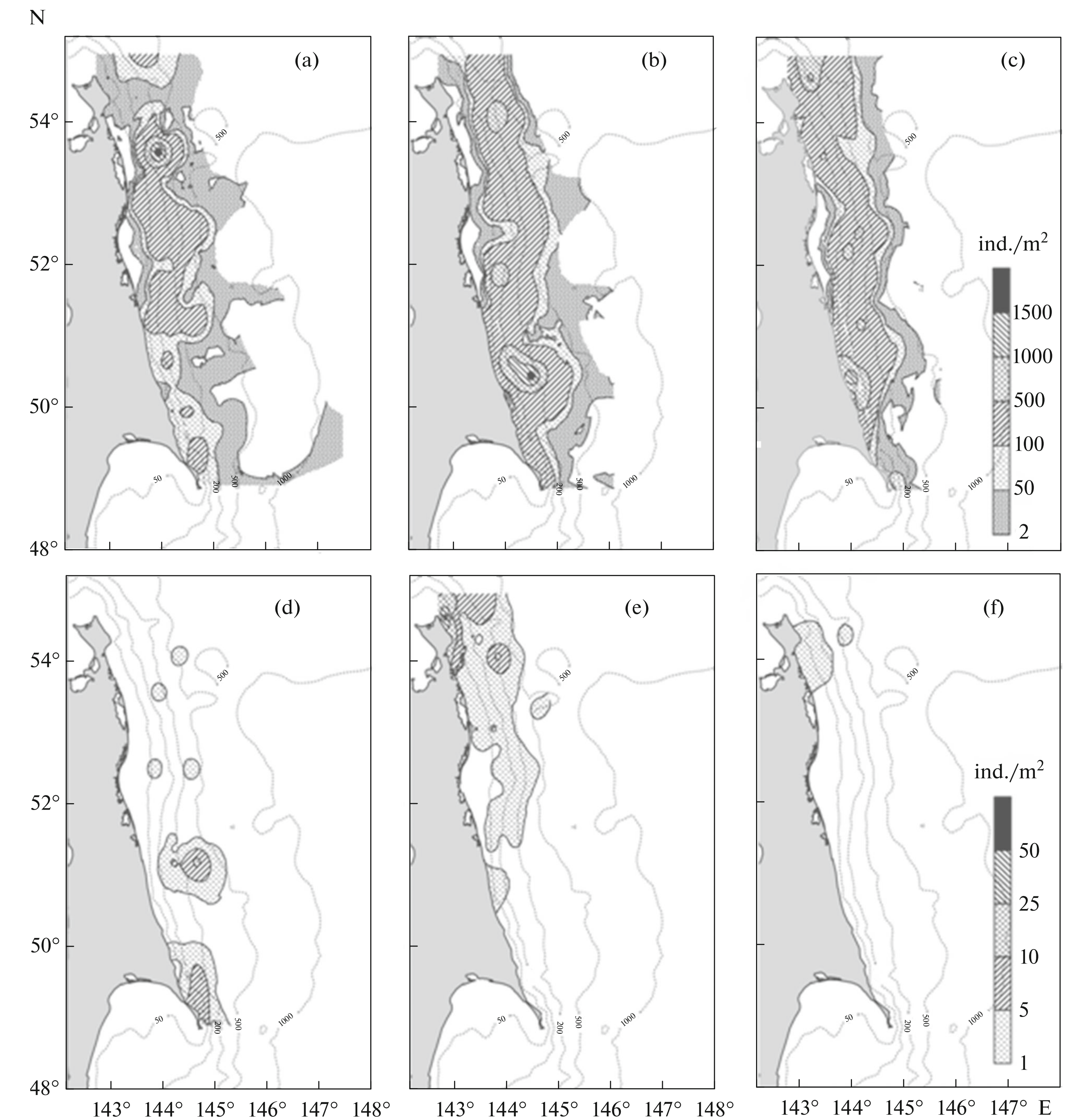


**Fig. 2.** Distribution of the (a–c) eggs and (d–f) larvae of Alaska pollock *Theragra chalcogramma* in (a, d) 2012, (b, e) 2014, and (c, f) 2015.

a slight decrease in salinity from 32.5 to 32.1‰ was observed, which could be a result of more intensive melting of ice. The lower water temperature caused, on the one hand, a delay in the spawning of pollock, while, on the other hand, an increase in the duration of eggs development, i.e. the hatching of the larvae en masse had to occur at a later time, i.e. not covered by the survey. As a result, the registered abundance of larvae is probably underestimated.

The pollock eggs were distributed along the entire northeast coast of Sakhalin mainly over 50–200-m isobaths (Figs. 2a–2c). The maximum concentrations of eggs were registered at the temperature range from −1 to +1°C.

In 2012, the highest concentrations of pollock larvae were observed at a temperature of 1–2°C. In 2015, the maximum concentrations of eggs and larvae were observed at the negative temperatures, which was primarily due to a general decrease in the temperature background. Hatching of the larvae probably began in the northern part of the region, and further they drift in the waters of the East Sakhalin Current southwards. In 2012, when the near-surface layer was heated, the concentrations of pollock larvae were recorded south of 51° N (Fig. 2d). The largest area of distribution and the total number of pollock larvae was recorded in 2014. The maximum density of larvae (68 ind./$m^2$) was also registered in 2014 at the northern tip of Sakhalin near Cape Elizabeth (Fig. 2e). The minimum concentrations were observed in the cold 2015; a single concentration of larvae with a population density of up to 4 ind./$m^2$ was formed near Schmidt Peninsula (Fig. 2f).

As observed in other areas of the Sea of Okhotsk (Zver'kova, 1999), the reproduction of pollock in the waters of northeast Sakhalin is limited mainly to the shelf, and the bulk of eggs and larvae develop within this region. Nevertheless, the transfer of eggs and larvae of early stages of development is a complex event with the certain limits. The direction of transfer varies and depends on the meteorological and hydrological conditions. In 2012, the formation of the main concentrations of eggs (>50 eggs/$m^2$) and larvae indicated that their main transporting from spawning areas occurred at the south and sometimes at the southeast directions. In 2014, the increased concentrations of eggs at the late stages of development (III and IV) were formed both in the marine parts of spawning areas and in the coastal zone, which indicated a multidirectional transfer. In 2015, the transfer was insignificant and also multidirectional.

Two or four zones are formed usually along the coast, the development of eggs mainly proceeds within these zones. In the coastal area between Piltun and Nyiskii bays, the number of eggs is usually low, which is due to the high desalinization of this area as a result of the first impact of the transformed Amur River waters, as well as the runoff from the bays. One also cannot exclude the influence of upwelling that periodically develops in this area.

Analysis of the distribution of the eggs at different stages of development in regard to the depth (data for 2015) evidences to their multidirectional transport in the whole region. The contribution of the eggs at the first (I) stage of development was quite high for the entire depth range. Within the zones of the highest concentrations (depths from 10 to 250 m), where approximately 70% of the sampling stations are located, this index ranged from 43 to 63%. Above the isobates from 250 to 400–600 m, there was a slight decrease in the relative abundance of eggs at the first (I) stage. But above the depths of more than 600 m, the contribution of the eggs at early developmental stages varied greatly (20–70%). The relative abundance of eggs at stage III was fairly stable (20–27%) to the 200-m isobath; above greater depths, the range of variation increased as a result of multidirectional transfer, and the contribution of the eggs at this stage of embryogenesis ranged from 3 to 57%.

**Bering flounder.** The number of eggs of the Bering flounder varied insignificantly for three years, from $6.5 \times 10^{11}$ to $7.8 \times 10^{11}$ eggs. The minimum abundance was registered in 2015. The interannual peculiarities of the spawning of the Bering flounder had features similar to that noted for pollock, namely, a higher concentration of eggs at the first (I) stage of development (both absolute and relative) was registered in the cold year of 2015.

Eggs were found along the entire coast of northeast Sakhalin. The main concentrations (>100–150 eggs/$m^2$) were formed on a section of a shallow shelf with sandy bottom from the southern tip of Pil'tun Bay to Lunskii Bay. Small congregations in particular years were found in the area of 51° N and southwards (Figs. 3a–3c).

Spawning grounds, determined by the presence of eggs at the first (I) stage, located in the areas of maximum accumulation of eggs (Figs. 3d, 3e). The developing eggs were found throughout the entire temperature range observed, but the nature of concentrations' dependence on the temperature regime of the particular area was a subject to interannual changes. In warm 2012, the concentrations of eggs increased as the temperature did, and a maximum (>25 eggs/$m^2$) was observed at a temperature of 3–4°C. In the cold year of 2015, high concentrations of eggs were formed both at a positive temperature (3–4°C) and in the areas characterized by the negative values.

Eggs of the Bering flounder were found in the study area within a wide range of depths, but the maximum depths differed from year to year. In 2012, the maximum depth above which the eggs were found reached 600 m, 675 m in 2014, and did not exceed 293 m in the cold 2015. The main egg concentrations were distributed at the depth range of 50–100 m, which is in accordance with the data obtained earlier (Tarasyuk and Pushnikov, 1982). The spawning areas differed insignificantly from the areas of the egg distribution. The difference was only in the reduction of total concentrations, which occurred as a result of the transition of part of the eggs to the elder stages, and due to their transport across the greater water area.

According to the depth-dependent distribution of the eggs, there was no noticeable carry-out of them to the open sea areas. Single larvae of the Bering flounder were noted only in 2014 (Fig. 3f). The area of their development fell to the coastal shallow waters; this indicated the removal of eggs at the late stages of development, including the direction towards the shore.

**Starry flounder.** The number of eggs of this species varied considerably by years. The maximum ($32.3 \times 10^{10}$ eggs) was registered in the warm 2012; in 2014, there was a slight decrease in the number, and it was

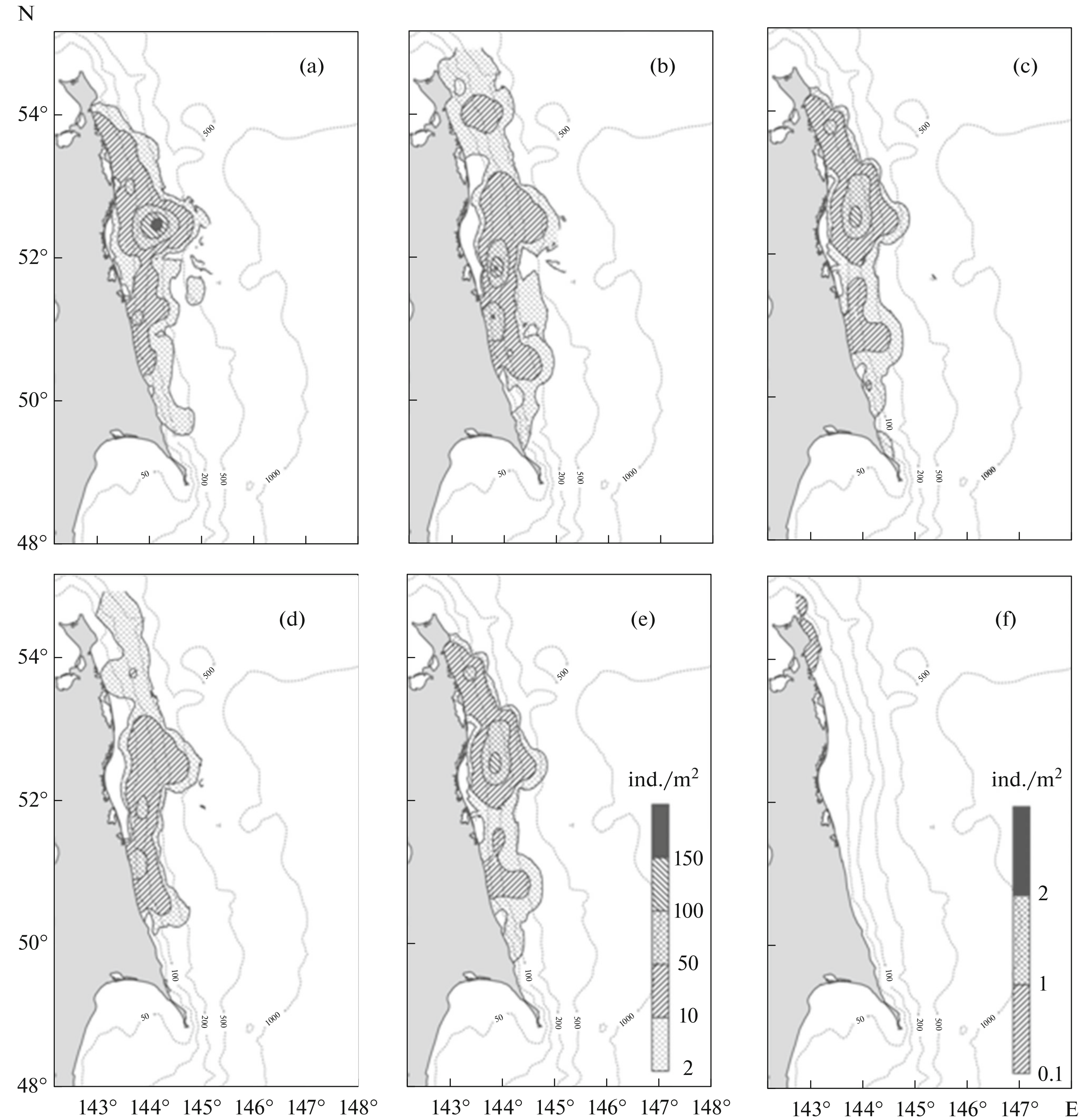


**Fig. 3.** Distribution of the eggs of (a–c) I–IV and (d–f) I developmental stages and the (e) larvae of Bering flounder *Hippoglossoides robustus*: (a) 2012, (b, d, f) 2014, (c, e) 2015.

even more significant in 2015 ($30.6 \times 10^{10}$ and $27.2 \times 10^{10}$ eggs, respectively). The overall decrease in the number of eggs was associated with a reduction of the distribution area. The areas and their locations changed annually. In 2012, the main concentrations were recorded in the northern part: from the coastal zone of Schmidt Peninsula to the areas with depths of more than 900 m. Smaller areas were situated near Chaivo Bay and Nyiskii Bay on shallow water with a depth of 50–60 m (Fig. 4a). In 2014, the eggs were found at a much more extensive area, which stretched as a continuous strip from Cape Elizabeth to Lunskii Bay (Fig. 4b). However, the maximum isobaths did not exceed 525 m. In 2015, the area of egg distribution was the three separate zones, one of which was to the north of Pil'tun Bay, the other was near Lunskii Bay, and the third was southwards 51° N. (Figs. 4c, 4d).

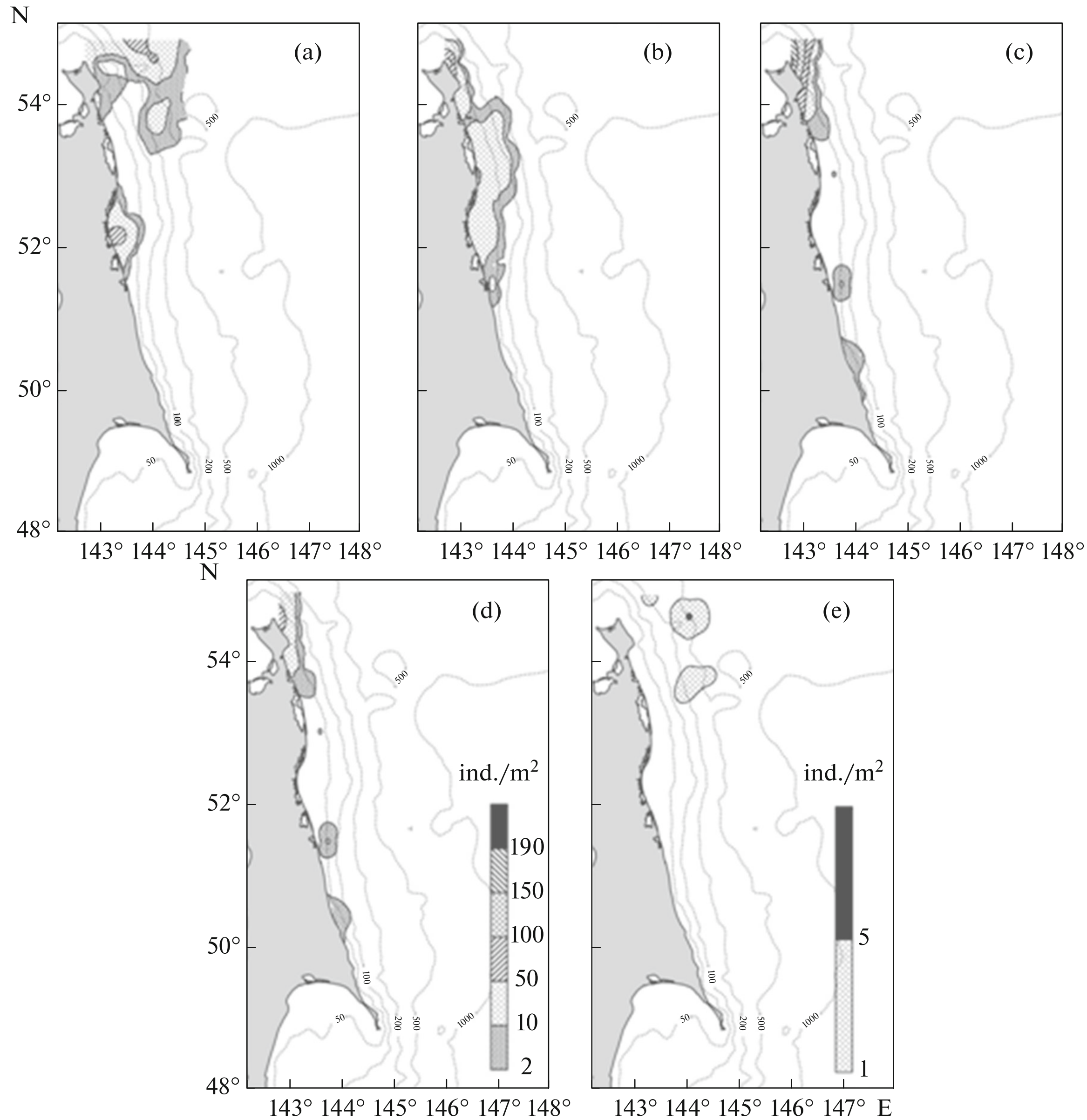


**Fig. 4.** Distribution of the eggs of (a–c) I–IV and (d) I developmental stages and the (e) larvae of starry flounder *Platichthys stellatus*: (a, e) 2012, (b) 2014, (c–d) 2015.

The maximum concentration of eggs (212 eggs/m$^2$) was recorded in 2015 within its interannual minimum in the total number of eggs. The larvae were registered only in warm 2012 (Fig. 4e). In 2015, the larvae in the catches were absent, but the eggs at the III–IV stages prevailed (approximately 52%).

The location of the spawning grounds and the development of eggs of starry flounder along the shores of northeast Sakhalin is associated not only with the coastal zone and sandy bottom but also with the desalinated runoff of Amur River and of the sea bays. The northern spawning grounds, according to the main concentrations of eggs, were a continuation of the spawning grounds located in Severnyi Bay and Sakhalinskii Bay. Depending on the number of breeders and the hydrological conditions, the southern spawning grounds may be a continuation of the northern reproductive zone or represent small isolated reproduction areas (Fig. 4d).

Other species of Pleuronectidae were represented in the ichthyoplankton by eggs, and their number was insignificant. The eggs of *longhead dab* (Fig. 5a) had the widest distribution in 2012: from 51° N down to the northernmost area at Cape Elizabeth; the maximum concentration (260 eggs/m$^2$) was registered at Nyiskii Bay. In 2014, this species was found in the area from

Cape Elizabeth and northwards up to Lunskii Bay, usually at the depths of less than 50 m. Single eggs were found at the stations with depths of down to 200 m. In 2015, the distribution of the eggs of longhead dab was minimal for the 3 years of study, from Cape Elizabeth to Pil'tun Bay, mainly in areas with depths of less than 50 m, where the density of egg concentrations reached 50 eggs/$m^2$.

**Sakhalin sole** (Fig. 5b) was quite numerous in the ichthyoplankton. In 2014, when the frequency of occurrence of the eggs of this species exceeded that of 2012 and 2015, the density of egg concentrations reached 250 eggs/$m^2$. The main concentrations in the 3-year research period were located in the northernmost area: from the area adjacent to Cape Elizabeth to Pil'tun Bay. In a small quantity, the eggs of Sakhalin sole were distributed along the entire northeast Sakhalin. The concentration of the eggs of yellowfin sole *Limanda aspera* did not exceed 10 eggs/$m^2$ (Fig. 5c). In 2012, this species was observed at a single station northeastern Cape Elizabeth above the large depths; in 2014 and 2015, the eggs of this species were spread quite widely, i.e., in the area from Cape Elizabeth to Lunskii Bay. The eggs of the Alaska plaice *Pleuronectes quadrituberculatus* has been found throughout the years of research commonly up to the 50° N. (Fig. 5d). The egg concentration was low and did not exceed 7 eggs/$m^2$. The range of depths over which it was taken included the areas of the coastal shallow waters to the zones of the depths of more than 500 m. The eggs of the blackfin flounder *Glyptocephalus stelleri* also were of a low density during the study period, and the maximum density of egg concentrations was 30 eggs/$m^2$ (Fig. 5e). In 2012, the eggs of this species were observed above the depths of 50–200 m from Lunskii Bay up to 54° N; in 2014 and 2015, they were present only in the southern areas of the study region, above the depths of 100–200 and 50 m, respectively, but the density did not exceed 10 eggs/$m^2$.

**Pacific herring.** The distribution of herring larvae in the study area was limited to the coastal waters of Schmidt Peninsula (Fig. 6a). Similar to some other species, herring larvae were found in the stream of the Amur Current, and their abundance depended on the intensity of the runoff. The seaward migration of herring larvae to the marine zone of northeast Sakhalin was not abundant. Passive migration from the bays of northeast Sakhalin is likely to occur at a later date: larvae that originated from the local herring breeders are not found in these waters in June. The total number of larvae in 2014 was almost five times lower than in 2012 ($0.3 \times 10^{10}$ vs. $1.4 \times 10^{10}$ ind.). The area of their distribution is within the depths of 25–120 m. In 2015, the herring larvae were not present in the catches.

**Pacific sand lance.** The number of sand lance larvae varied considerably by year (Fig. 6b). The maximum, as for many other species, occurred in 2012. In subsequent years, the number decreased dramatically. The area of larvae distribution was northwards 51° N. The location of the growing grounds with the highest density of larvae concentrations varied depending on the intensity of the Amur River runoff and/or temperature conditions. In warm 2012, sand lance larvae were found in a vast area with the depths from 30 to 340 m, mainly northwards 52° N. The zones of maximum concentrations were formed on the traverse of Schmidt Peninsula (≥250 ind./$m^2$) and near Pil'tun Bay (>100 ind./$m^2$); south of 52° N, the larvae were few in numbers. In 2014, the larvae were mostly caught at 54° N and northwards. The maximum (50 ind./$m^2$) was recorded near Schmidt Peninsula. The distribution of larvae was limited to the depths of 20–135 m. In 2015, the area of larval distribution has increased again, but the number was low, not exceeding 11–13 ind./$m^2$. The larvae were distributed over the entire shelf zone (above the depths of 20–214 m) to the north of 52°30' N. Some small concentrations formed south of 52° N. Taking into account that the area covered by the Amur River runoff was minimal in 2015 and the average water temperature in the area was low, but the zone of distribution of sand lance larvae was quite extensive, we can assume that the larvae appeared both directly in the area of Pil'tun Bay and other bays and drift here within the transformed Amur River waters.

**Saffron cod.** The larvae of the saffron cod were few in all the years of study (0.06–0.14% of the total ichthyoplankton abundance). Their number varied insignificantly from $1.0 \times 10^{10}$ ind. in 2014 to $1.5 \times 10^{10}$ ind. in 2015. The zone of larvae distribution was limited to the area lying northwards 52° N. (Fig. 6c). When Amur River runoff was significant (2012 and 2014), two zones of larvae development were clearly distinguished, one of which was along Schmidt peninsula, the other on the traverse of the northeastern bays of Sakhalin. The distribution of the larvae also depended on the distribution of the Amur River runoff. A large drainage in 2012 at the southeast of Schmidt Peninsula forced the larvae to move to the areas with depths of down to 737 m; in 2014, the maximum depth above which the larvae were found did not exceed 300 m; in 2015, at a minimal Amur River runoff, the zone of the larvae development did not exceed the depths over 135 m.

**Sculpins** were represented by six species in ichthyoplankton and were found along the entire coast of northeast Sakhalin (Fig. 6d). The total population density was low and did not exceed 6 ind./$m^2$. The most widely the sculpins were distributed in 2014. In the southern part of the study area, the depths above which the larvae were found did not exceed 100 m. In the north, above 52° N, the sculpins were recorded from shallow coastal waters to the depths of more than 200 m.

**Stichaeidae** also had a low population density (up to 6 ind./$m^2$) and were found in all the years of observations at the depths of less than 200 m. The sites of

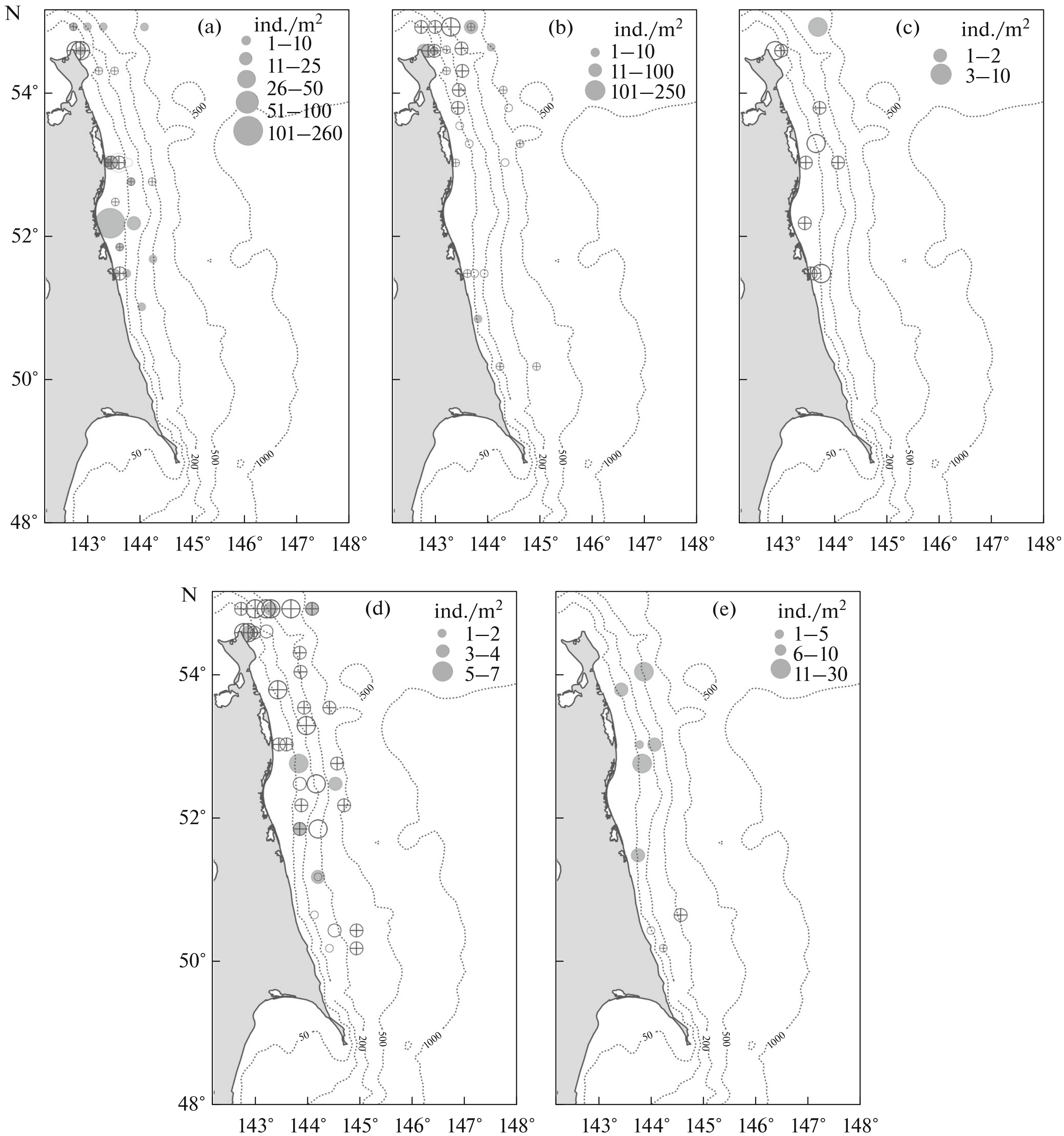


**Fig. 5.** Distribution of the eggs of the other species of flatfish in (●) 2012, (⊕) 2014, and (○) 2015: (a) longhead dab *Limanda proboscidea*, (b) Sakhalin sole *L. sakhalinensis*, (c) yellowfin sole *L. aspera*, (d) Alaska plaice *Pleuronectes quadrituberculatus*, (e) blackfin flounder *Glyptocephalus stelleri*.

Stichaeidae catches were located in the northern part of the study area from Cape Elizabeth to Pil'tun Bay, while those in the southern part were southwards of Lunskii Bay up to Cape Terpeniya; they were absent in the desalinated waters of the coast near the bays of northeast Sakhalin (Fig. 6e).

**Liparidae** were the most numerous larvae in the ichthyoplankton, and their population density reached 95 ind./m$^2$. Most often, Liparidae were observed at depths of 100 m and deeper, but they were sometimes present in the catches performed in the shallow waters. The larvae were distributed along the

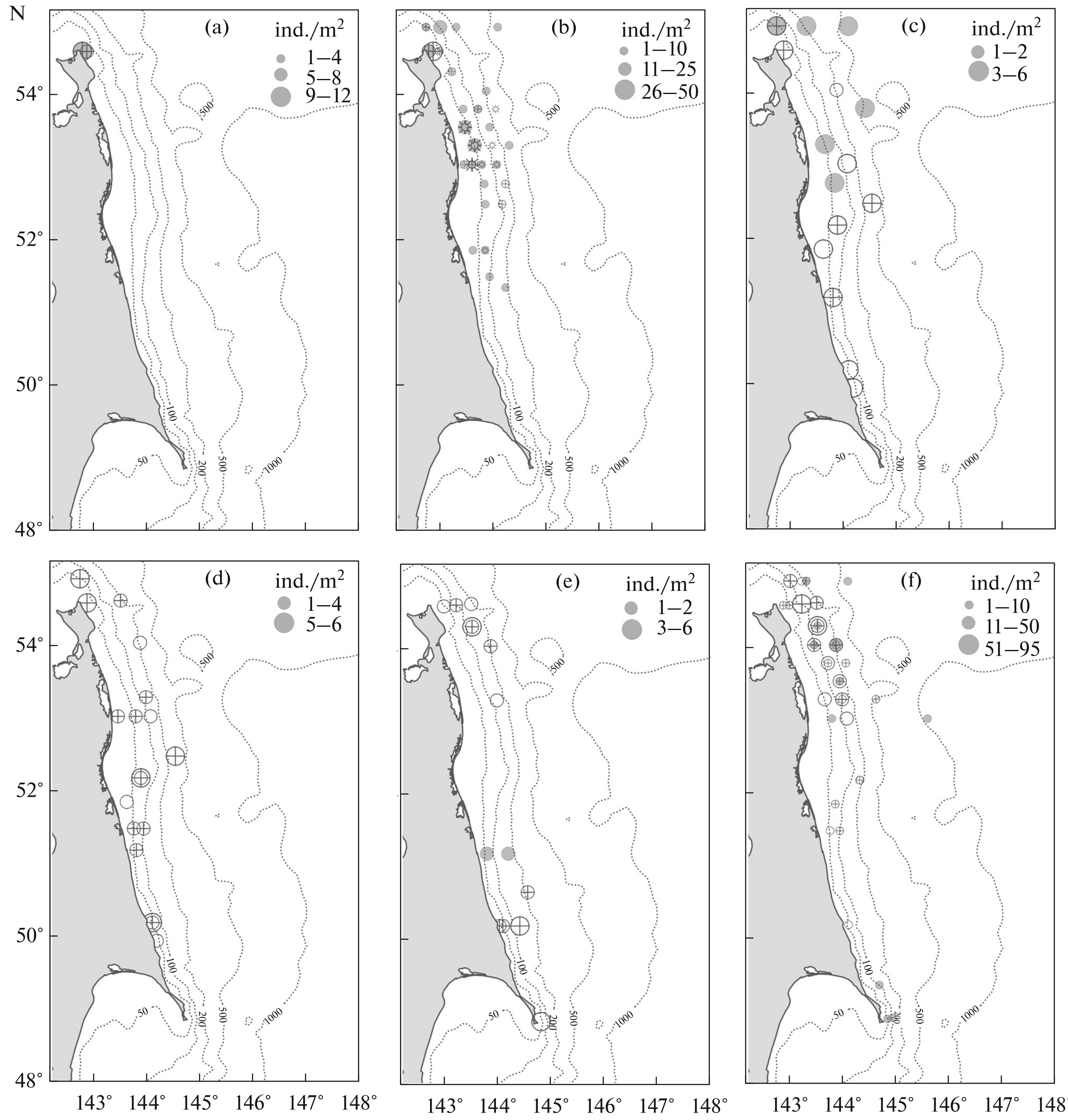


**Fig. 6.** Distribution of fish larvae in 2012, 2014, and 2015: (a) Pacific herring *Clupea pallasii*, (b) Pacific sand lance *Ammodytes hexapterus*, (c) saffron cod *Eleginus gracilis*, (d) Cottidae, (e) Stichaeidae, (f) Liparidae; refer to Fig. 5 for the legend.

entire coast of northeast Sakhalin, forming an elevated population density north of 53° N (Fig. 6f).

## DISCUSSION

Significant changes in temperature and salinity off the coasts of northeast Sakhalin affect mainly the near-surface 20–30-m layer. In June, the northern part of the study area is characterized by the presence of both warm and cold layers of desalinated water. Warmer waters are associated with the Amur River runoff, the colder waters are associated with the ice melting, and ice fields are observed in June in this area (Krasavtsev et al., 2000; Moukhametov and Chastikov, 2013). Desalinated waters off the coast of northeast Sakhalin stretch along the coastline forming a belt from Cape Elizabeth to Pil'tun Bay and Chaivo Bay, and they sometimes protrude to the south, undergoing a transformation accompanied by a gradual decrease in the surface layer temperature from 10 down to 3–5°C and an increase of salinity from 15 up to 27–29‰. At the 10-m depth and deeper, the effect of the cold intermediate layer begins to manifest, and the distribution of the thermohaline characteristics varies significantly. The temperature minimum occurs in the northern part of the region at low salinity values (26–27‰). The salinity stabilizes at a depth of approximately 30 m.

Hydrological processes in the shelf zone of northeast Sakhalin are characterized by a complex system of currents. The peculiarities of this region include high rates of daily tidal currents (2–3 knots) in the coastal zone from Cape Elizabeth to Lunskii Bay, the formation of coastal upwelling under the influence of winds of southern and southeastern directions usual for the summer season, and the presence of a coastal flow caused by the Amur River runoff directed to the south and increasing in the autumn (Shevchenko et al., 2009). In the region of Schmidt Peninsula, nonperiodic currents in the surface water layer directed to the south-southeast are strong enough in summer (up to 80 cm/s). In the area of Lunskii Bay, the velocity of the general flow of the southern direction is higher than in the area northwards Lunskii Bay up to 54° N, where a great variability of the currents in speed and direction is observed. The meridional component of the current weakens as it approaches the shore. Along the coastline, from Cape Elizabeth to Pil'tun Bay, and sometimes up to Lunskii Bay, the local flows of different directions dominate in the upper and lower layers, indicating the formation of coastal upwelling (Krasavtsev et al., 2000, 2001). In the upwelling zone in the upper 20-m layer, salinity may change by 4–5‰ in the area of Pil'tun Bay and by 8–9‰ near Cape Elizabeth. Upwelling is typical for the entire coastal zone of northeast Sakhalin. In areas with a shallower shelf, near Chaivo Bay, it occupies a large area. In the areas characterized by a steep slope, this zone narrows. In the northern part of the area, the upwelling zone can reach 145° E, and the temperature difference near the shore and in the open sea may reach 6°C and, sometimes, 10–12°C. In the region of the capes, the constant gyres are formed; they contribute to the accumulation of the planktonic and commercial organisms. This picture is typical for Cape Elizabeth, Cape Nizkii, etc.

The productive zones characterized by a high number of plankton organisms, including ichthyoplankton, are relatively stationary and are associated with the hydrodynamic formations (Mukhametova et al., 2001). In the waters of northeast Sakhalin, high concentrations of ichthyoplankton form within the northern Sakhalin frontal section that is formed along Schmidt Peninsula at the confluence of the desalinated waters of the Amur Current with more saline waters of the Sea of Okhotsk (Chernyavskii, 1981) and in the local gyres in the south of the study area near the Gvozdev Cape, Cape Nizkii, etc. The northern Sakhalin frontal section is a part of the NNW hydrodynamic system, and it belongs to one of the most productive zones of the Sea of Okhotsk. Local anticyclonic circulation, formed beyond the peninsulas and far protruding capes, also plays an important role in the formation of zones favorable for the development of invertebrates and fish in the early stages of ontogeny (Chernyavskii et al., 1981).

The Alaska pollock eggs are the absolute dominant form of the ichthyoplankton in the study area and study period, followed by the eggs of the Bering flounder. Among the widespread forms, whose contribution is subject to significant interannual changes, it is still possible to note the eggs of starry flounder, longhead dab, and Sakhalin sole, larvae of sand lance and of some Liparidae. The number of eggs and larvae of the flounders and of a number of other fish species (sand lance, herring, and saffron cod) in the northern part of the study area depends on the intensity and direction of the Amur Current: it increases in the years with a large Amur River runoff.

The main spawning grounds of Alaska pollock extend along the entire northeast coast of Sakhalin mainly above the 50–200-m isobaths. In the south of the region, where the narrowing of the shelf and a rapid increase in depth are observed and where the noticeable desalinization of the coastal zone is absent, the spawning can occur even at the minimal depths. In the north, spawning in coastal areas was possible only in 2015, when the Amur Current weakened. In Pil'tun, Chaivo, and Nyiskii bays, where extensive desalinization of the coastal zone occurs in June, the pollock eggs are absent or are very small in number. The formation of the pollock egg and larvae concentrations in different years along the shelf areas of northeast Sakhalin at different temperature conditions indicates the possibility of their development in a wide range of environmental parameters, but how this affects their future survival yet remains unclear. Probably, the choice of spawning grounds is determined not only by favorable conditions for the development of eggs but also by the possibility of getting larvae into a suitable environment for development and feeding, on which the survival of particular generation ultimately depends.

Taking into account that the higher temperatures in the waters of northeast Sakhalin are a characteristic of the transformed Amur River waters, which in June are distributed in the coastal zone from Cape Elizabeth to Chaivo Cape, and along the bays they indicate the freshwater runoff, we can say with certainty that the reproductive zones of pollock are located in such a way to prevent the removal of eggs and larvae en masse to the desalinated areas. This is clearly seen by the spatial-bathymetric distribution of pollock at the early stages of ontogeny. In 2012, when the desalinated waters were widespread in the northern part of the study area, the maximum concentrations of eggs and larvae were shifted to the greater depths of 100–200 m. In 2014, the tendency of leveling of the population in the depth range of 10–200 m was noted. In 2015, when the income of warm, desalinated waters was weakened, the pollock eggs and larvae were concentrated at shallower depths, where the thermohaline characteristics in the near-surface layer differed little from the rest of the shelf area.

The drift of the pollock eggs from the main reproduction areas can vary significantly by the year, depending on the wind direction and on the local currents. In some years, eggs and larvae can move from the northern part of the Sea of Okhotsk within a system of surface currents along the northeast coast of Sakhalin in a southerly direction (Zver'kova, 1999). Comparing the distribution of the main concentrations of larvae in 2012–2015, we can note that the larvae concentrations increased above the depths of 200–500 m in 2012 in the main spawning grounds above the depths of 50–200 m, i.e., the main outflow was directed to the east. In 2014, a completely different picture was observed. The maximum eggs concentrations, including the eggs at the first (I) stage of development, were in the 100–200-m isobath region, and the number of larvae was significantly higher above the depths of 50–100 m, which presupposes a predominantly western drift toward the shallow waters. In 2015, both eggs and larvae formed the maximum concentrations in the same depth range of 50–100 m.

The importance of the larvae transporting to certain sites has been studied by many authors. The results of the main studies are summarized in the publications by Shuntov et al. (1993) and Zver'kova (2003). An increase in the survival rate of both eggs and larvae in warmer years has been found for the waters of the Sea of Japan and also when larvae enter highly productive areas rich in phyto- and zooplankton.

Based on the obtained data on the abundance and distribution of ichthyoplankton in the waters of northeast Sakhalin, we can state that a significant part of the eggs and larvae penetrate here from the bays of northwest Sakhalin and possibly from the northwestern part of the Sea of Okhotsk in some years. With an increase of the intensity of the Amur Current, the ichthyoplankton abundance in the northern part of the study area increases substantially due to the increase of its transport from adjacent areas. Consequently, the calculations of the producer stocks in the east Sakhalin subzone, based on the ichthyoplankton surveys, may be overestimated. To reduce the risk of overestimation of reserves, an estimate of the abundance of the early developmental stages and of the producers should be carried out within the framework of general ichthyoplankton surveys covering at least the waters of Sakhalin Bay and northeast Sakhalin or by omitting the ichthyoplankton corresponding to the Amur River runoff volume from the calculations for the east Sakhalin subzone as characterizing the stock of Sakhalin Bay. The results obtained in the present study can be used for the environmental zoning of the east Sakhalin fishing subzone and the identification of areas most vulnerable to economic activity.

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