COASTAL MEROPLANKTON OF PETER THE GREAT BAY (SEA OF JAPAN) UNDER CONDITIONS OF POLLUTION

Kulikova V.A., Omelyanenko V.A., Propp L.N.

Institute of Marine Biology, Far East Branch, Russian Academy of Sciences, Vladivostok, Russia

Introduction

Peter the Great Bay is the largest bay in the northwestern Sea of Japan. The majority of towns, large seaports of Vladivostok and Nakhodka, railways, industrial enterprises, and agricultural farms are situated in the coastal area of the bay. Pollution and eutrophication of coastal waters in Peter the Great Bay result in the disturbance of ecological equilibrium and the complete degradation of marine communities (Vaschenko, 2000).

The larvae of bottom invertebrates (meroplankton, larvaton) are an essential and constant component of zooplankton systems of the neritic zone of the ocean. Numerous experimental works have shown that larvae of marine invertebrates are much more sensitive to environmental changes than parental individuals (Mileikovsky, 1976). At the same time, information on survival of larvae exposed to existing environmental anthropogenic load is extremely scanty and contradictory (Korn & Kulikova, 1997).

The aim of the present investigation is to demonstrate the number and distribution of the main taxa of meroplankton in polluted areas of Peter the Great Bay.

Material and Methods

Investigations were carried out in the northern part of Amursky Bay, in Gaidamak Bight (Vostok Bay) and in Nakhodka Bay, as the most polluted areas of Peter the Great Bay (Fig. 1a).

Plankton samples in Amursky Bay were taken out weekly throughout the year of 1996 at one station. In Gaidamak Bight (Vostok Bay) the plankton was collected from June to September 1998 at 5 stations: 1, 2 – harbor, 3, 4 – the open part of bight, 5 – control station (Fig. 1b). In Nakhodka Bay the material was collected from June to September 1995 at 7 stations (Fig. 1c). Stations 1, 3, 7 are situated in open areas with a good circulation of water. Station 4 is located in the innermost part of Nakhodka Bay where salinity of the water is lowered due to the inflow of Partizanskaya River waters. Stations 2, 5, 6 are situated in semi-enclosed bight where there are ports.

The plankton samples were taken from the bottom up to the surface by a Norpak and Juday nets with mesh size 168 μm. Samples were fixed with 4% formaldehyde. Larvae were enumerated in Bogorov's chamber under an MBS-9 binocular microscope.

Overall meroplankton and individual taxa were identified and counted in the plankton samples from Amursky Bay and Gaidamak Bight and only *Cirripedia, Molluska, Polychaeta* and *Echinodermata* larvae were studied in the samples from Nakhodka Bay.

The samples of water for hydrochemical analysis were taken simultaneously with plankton samples. The chemical water analysis was carried out with well known methods (Methods…, 1979).

Results and Discussion

<u>*Amursky Bay*</u>

A major source of eutrophication in the coastal waters of Amursky Bay are industrial and communal waste waters. Special measurements indicated that in close vicinity to the planktonic station there exists permanently a zone of the high chemical pollution with contents of silica, ammonia nitrogen and nitrites (40, 52 and 3.5 μM respectively) exceeding maximal concentration limit. Mean concentrations of ammonia nitrogen, phosphate, BOD-5, and oil products in 1993 were 14.8, 4.6, 89.7 and 4.5 mg/l; these values were significantly higher than maximal permissible concentrations – 11.1; 0.2; 8.1 and 0.3 mg/l respectively. The total concentration of nutrients in several areas in the northern part of the bay was 1.3-15 times higher than in the southern open part. Clearly the northern and north-eastern parts of the bay are most polluted and eutrophicated. Eutrophication is evident in the deterioration of oxygen regime of the bay waters and in a significant increase from the late 1980 in the density and biomass of saprophytic and oil oxidizing bacteria, which are indicators of the pollution of marine environment by easily oxidizable organic matter (Podorvanova *et al*., 1989; Report…, 1994).

The larvae of bottom invertebrates were recorded in plankton all the year round, excluding January. Their total monthly average density varied from 0 (January) to 14300 ind/m^3 (June) (see Table 1). Three peaks of meroplankton numbers were recorded: the first, less significant one, in April and two, more significant ones, in June and August (Fig. 2). The density of larvae was minimal in January-March and in December at low temperatures. An April rise of temperature induced a sharp increase in the number of larvae, and at maximum yearly water temperature in June-September the density of meroplankton reached the highest values.

Larvae of nine taxonomic groups were identified; larvae of three groups (*Bivalvia*, *Gastropoda* and *Polychaeta*) were occurred in plankton all the year round (see Table 1). The period of presence of decapods larvae in plankton was the shortest. In summer months larvae of all the taxonomic groups were present in meroplankton, in the cold season their number was significantly lower.

During the winter-spring season, larvae of *polychaetes* prevailed in meroplankton with a maximum of 6400 ind./m^3 in April. Among them, larvae of *Harmothoe sp.* dominated; they comprised 90% of the total number of polychaetes. This species provided the maximum density of meroplankton. The second peak of meroplankton number in June was caused by the prevalence of *Gastropod* and *Bivalve* larvae. These groups were mainly represented by periwinkles *Littorina brevicula*, *L. mandshurica*, and by *Epheria sp.* and by species of the *Veneridae* family. In August, 80-90% the total number of bivalve larvae (8250 ind./m^3) were larvae of the giant oyster *Crassostrea gigas*, which were responsible for the third maximum of meroplankton number in the course of the year. In autumn, the total abundance of meroplankton was low; the larvae of barnacles *Balanus rostratus*, of polychaetes *Polydora ciliata* and of *venerid bivalves* prevailed.

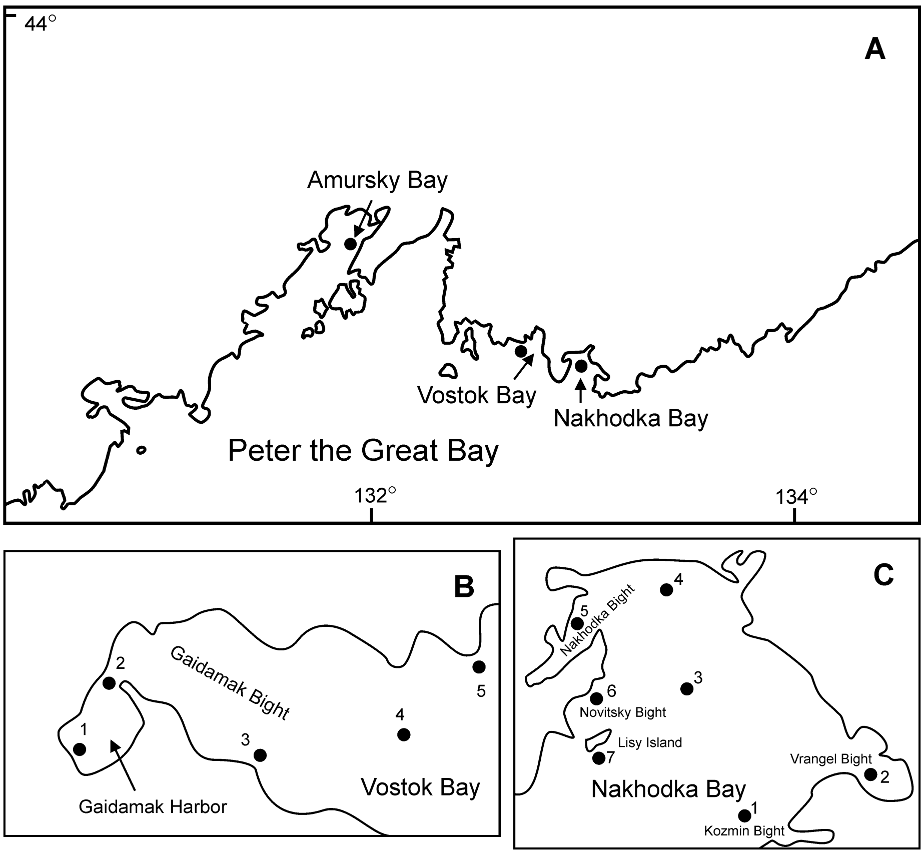

Fig. 1. Maps of the study areas: 1-7, numbers of stations.
(a) - Peter the Great Bay; (b) - Gaidamak Bight; (c) - Nakhodka Bay

Table 1

Monthly average density (ind./m³) of meroplankton in 1996 in Amursky Bay

Taxonomic group	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bivalvia	13	5	98	770	5831	2051	8250	1452	500	588	169
Gastropoda	59	5	38	2022	5844	920	868	88	160	18	14
Polychaeta	142	432	6412	981	431	670	1567	506	500	150	218
Cirripedia			283	483	722	175	682	109	1498	47	30
Echinodermata				56	1218	307	372	129	15		
Phoronidae					193	63	28	213	406	42	16
Nemertini			9	3	15	19	62	2	4		
Decapoda					35	93	42				
Actiniaria					6	9	8	10	46		
Total	214	442	6840	4315	14295	4308	11879	2511	2723	846	446

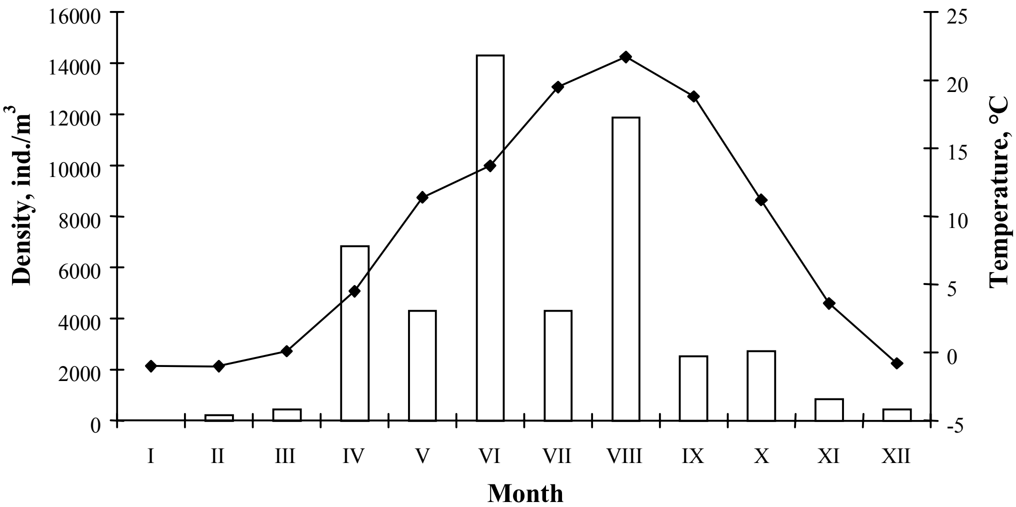

Fig. 2. Annual dynamics of meroplankton density and surface temperature of water in north part of Amursky Bay during 1996. Bars - meroplankton density, line - temperature

<u>*Gaidamak Bight (Vostok Bay)*</u>

A ship-repairing plant is located on the shore of a large harbor in the innermost part of Gaidamak Inlet. A river flows into the inlet, carrying polluted waste water from a small town. The bay water is enriched with biogenic elements, that is why microalgal densities here are much higher than in clean waters. There is oil film on the water surface in the harbor. The benthic communities of the inlet are impoverished: invertebrates sensitive to pollutants disappeared, whereas the number of eurybiotic forms, *e.g. Pseudopolydora sp.*, *Capitella capitata* and *Ophiura sarsi* increased (Report…, 1998).

In this bight the influence of riverine fresh-water discharge can be traced over the entire harbor, in the surface water layer with a salinity 18‰ and below. Inflowing riverine waters carry large amounts of ammonia – the first intermediate product of organic nitrogen transformation. Nitrites – a product of further ammonia oxidation (about 3 μM) were recorded in significant quantity only in the superficial layer inside the harbor. Easily degradable organic matter (OM) accumulates in the near-bottom layer in harbor center; with a weak water mixing and rather warm water, it is degraded by bacteria and mineral forms of nitrogen and phosphorus are released. OM degradation is accompanied by a decrease in oxygen content. While outside the harbor average oxygen saturation is 105%, inside the harbor it is decreased to 85%. Unlimited by mineral nutrients, planktonic microalgae produce in this part of the inlet high concentrations of chlorophyll A, up to 5.5 µg/l about one and a half orders of magnitude higher than in the surrounding waters. But even high rates of photosynthesis cannot compensate for the high oxygen demand for OM oxidation. However, Gaidamak Bight as a whole has enough reserves for self-purification and regulation. Even in the harbor center the hydrochemical regime is not significantly different from that of the control station.

Larvae of 87 taxa were identified. The highest number of taxa was recorded in July and August (Fig. 4b). High species diversity was observed at all stations. Peaks of meroplankton numbers at stations 1-2 in June and August were caused mainly by prevailing *eurytopic polychaete* larvae (*Pseudopolydora sp.*) and *cirripede* larvae inhabiting the anthropogenic substrates (*Balanus crenatus* and *Semibalanus cariosus*) (Fig. 3, 4). Moreover, larvae of *gastropods* and *echinoderms* were rather numerous here, with adults of these species being absent at these stations.

From the beginning to the end of June, concentration of meroplankton varied from 860 to 14400 ind./m^3. *Pseudopolydora sp.*, *Harmothoe imbricata*, *Capitella capitata* (*Polychaeta*) larvae prevailed. Prevailing cirripede larvae were *Balanus crenatus* and *Hesperibalanus hesperius* larvae, which took the second place in number. Among *gastropods* two species of the *Cecidae*, appeared in the second half of June and were highly abundant. Larval density of other groups of invertebrates was lower. The distribution of larvae was irregular; they concentrated in the harbor in Gaidamak Bight, mainly at stations 1 and 2.

In July total larval density varied from 1200-6800 ind./m^3 (at different stations) in the beginning to 500-4400 ind./m^3 at the end of the month. As before, larvae of *polychaetes* and *gastropods* of *fam. Cecidae* prevailed at all stations (Fig. 3). In comparison with June, the increased number of *bivalve* larvae was caused by the appearance of *Modiolus kurilensis*, *Crenomytilus grayanus*, *Mya sulcataria* and *Veneridae sp. veligers*. Larvae of *Echinocardium cordatum* and starfish of fam. *Asteriidae* larvae were most numerous among echinoderm larvae. As in June, the concentration of meroplankton was higher at stations 1, 2 and 3.

In the beginning of August, total larvae density varied from 2792 to 6175 ind./m^3 at different stations. At the end of the month, it varied more widely – from 1468 ind/m^3 in the open part of Gaidamak Bight to 14316 ind./m^3 at st. 1 (Fig. 4a). Larvae of *Alaba vladivostokensis* (*Molluska, Gastropoda*) prevailed in early August and they were distributed over the inlet more or less regularly (Fig. 3). At the end of August, total larval density increased considerably in the harbor of Gaidamak Bight as a result of increased number of *Pseudopolydora sp.* (*Polychaeta*) and starfish of *fam. Asteriidae* larvae. As before, highest larval density was observed at stations 1 and 2.

In September larval abundance sharply decreased to 1900-3700 ind./m^3 (Fig. 4a). The species composition of larvae and dominants changed substantially. *Polydora sp.* superseded *Pseudopolydora sp.*, number of latter decreased considerably (Fig. 3). Veligers of *fam. Cecidae* and *Alaba vladivostokensis* were abundant; veligers of *Teredo navalis*, *Modiolus kurilensis*, *Montacuta sp.* and species of *fam. Veneridae* were less numerous. *H. hesperius nauplial* density increased and *B. improvisus* larvae which were absent before appeared. In September, total larval densities at stations 2 and 3 were two times higher than those at stations 1 (situated in the innermost part of harbor) and 5 (control station outside Gaidamak Bight).

Nakhodka Bay

In the northern part of the bay there are mouths of several rivers; the Partizanskaya River is the largest. Port Vostochniy, Port Nakhodka and a bulk-oil port are situated on the coast line. In the south-east, a current goes into the Nakhodka Bay, and flows out in the south-western part. Analysis of the hydrochemical data (Naumov, 1996) suggests that the extent of pollution, especially in the northern and western parts of the bay, considerably exceeds maximum permissible concentrations. The north-western part of Nakhodka Bay is heavily contaminated by a variety of pollutants. Only in the southern part there were areas with relatively clean water. Detailed researches of anthropogenic influence in Nakhodka Bay were conducted in 1990-1991 (Report, 1992).

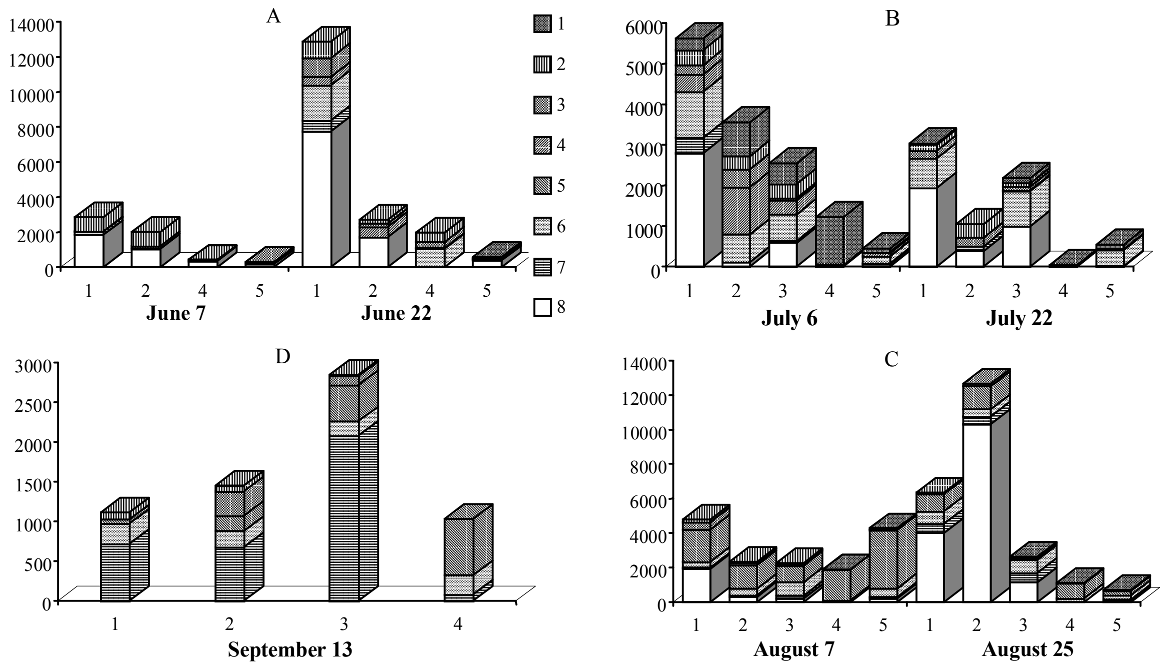

Fig. 3. Larval density (ind./m^3) of prevailed species of meroplankton in Gaidamak Bight in summer 1998. 1 - Echinocardium cordatum; 2 - Balanus crenatus; 3 - Hesperibalanus hesperius; 4 - Mytilus trossulus; 5 - Alaba vladivostokensis; 6 - Cecidae; 7 - Polydora sp.; 8 - Pseudopolydora sp. Abscissa - numbers of stations; ordinate - density (ind./m^3)

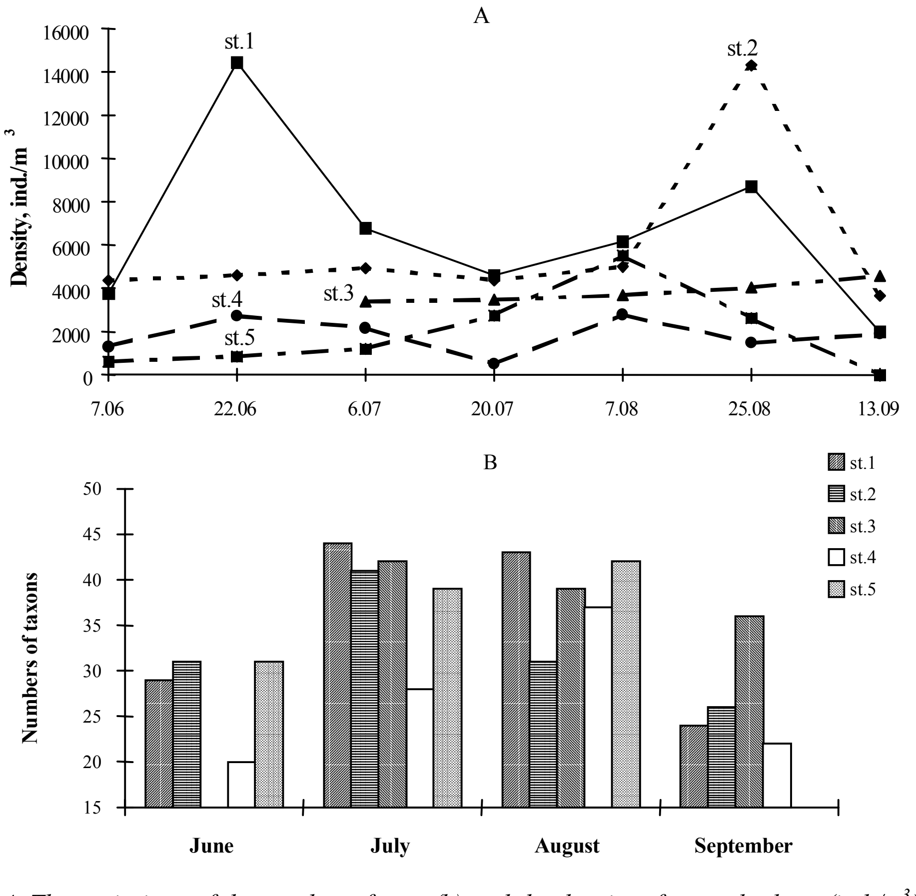

Fig. 4. The variations of the number of taxa (b) and the density of meroplankton (ind./m^3) (a) at the different stations in Gaidamak Bight in summer 1998

Most polluted areas were Nakhodka Bay, Vrangel Inlet and the mouth area of the Partizanskaya River, which carries to the bay immense amounts of chlorides, sulfates, oil, nitrites, nitrates and heavy metals. In Nakhodka Bay as a result of waste water influx the salinity periodically decreases to 5-6‰, concentrations of phosphate increase up to 43 µg/l; of nitrites, 20 µg/l; of oil products, 0.58 mg/l (12 of maximal concentration limit); and of synthetic detergents, up to 5.2 mg/l (52 MCL). This level of pollution jeopardizes the degradation of the marine communities in the bay. The floral and faunistic complexes are characterized by an extremely decreased diversity of species and the dominance of highly eurytopic species.

Larvae of several species of *cirripedes, bivalves, polychaetes* and *echinoderms* were investigated. The distribution of meroplankton was irregular (Fig. 5). Four species of barnacle larvae were found at all stations during all the period of research: *Balanus crenatus, B. improvisus, Hesperibalanus hesperius* and *Chthamalus dalli*. *B. crenatus nauplii* were dominant among them. High *cirripeds larval* density was recorded at stations 5, 6 and 7, and low density occurred at st. 1 and 2. Among *bivalve* larvae only some commercially important species *Mizuhopecten yessoensis, Swiftopecten swifti, Mytilus trossulus*, *Crenomytilus grayanus* and *Modiolus kurilenis* were investigated. The *C. grayanus* and *S. swifti* larvae prevailed with a maximum density of 800 and 625 ind./m^3, respectively. *C. grayanus* larvae occurred from the end of July to the end of August with a peak of number on August 4 at st. 3. At other stations their density was lower (Fig. 5). S. swifti larvae were first recorded on July 8 in the south-western part of Nakhodka Bay, in Vrangel Inlet (st. 2), and later – at the other stations, where they occurred until August 4 with a maximum 625 ind./m^3 on July 20 at st. 7 (Fig. 5). *Modiolus kurilenis* larvae occurred in plankton of Nakhodka Bay from the end of August to the end of September at all stations. Their density reached a peak of 246 ind./m^3 on August 20 in Vrangel Inlet (st. 2). At other stations *M. kurilensis larval* density was rather low except st. 5, where the recorded maximum was 112 ind./m^3. Larvae *of Mizuhopecten yessoensis* and *Mytilus trossulus* present in meroplankton very scanty, their highest density was noted at stations 2 and 5 with a maximum 120 and 37 ind./m^3 for the both species on July 8. *Pseudopolydora kempi* prevailed among *polychaete* larvae. They occurred all over Nakhodka Bay during the whole investigation period with maximum a value 155, 200 and 520 ind./m^3 at stations 1, 6 and 5, respectively. The period of maximum density continued during July and August. *Ophiura sarsi* occurred at all stations during August and the first week of September with a low density (6-88 ind./m^3). Peak of their number was recorded at st. 2 on August 22 (Fig. 5). *Strongylocentrotus nudus* larval density was more significant at the same station at the same time and it varied from 32 to 140 ind./m^3 at the different stations, except st. 6, where S. nudus larvae weren't found.

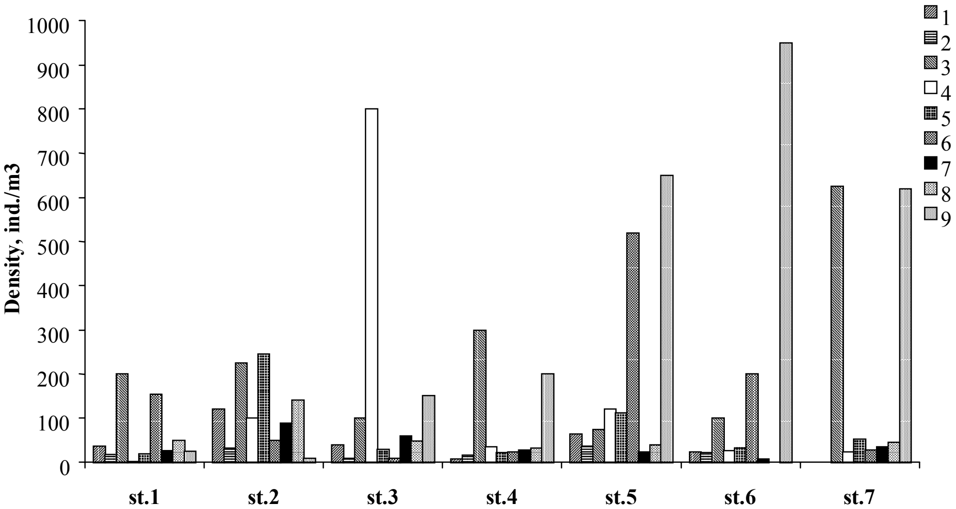

Fig. 5. Larval density of some taxa in Nakhodka Bay in the period of its maximum in summer 1995. 1- Mizuhopecten yessoensis; 2 - Mytilus trossulus; 3 - Swiftopecten swifti; 4 -Crenomytilus grayanus; 5 - Modiolus kurilensis; 6 - Pseudopolydora kempi; 7 - Ophiura sarsi; 8 - Strongylocentrotus nudus; 9 - Cirripedia

Species composition, the number and distribution of larvae are known to be primarily affected by currents and the distribution of adult specimens in the bottom communities. It is evident that the concentrations of pollutant in shallow bights of Peter the Great Bay are by far higher than permissible levels, which would have seemingly prevent larvae of bottom invertebrates from penetrating into these areas and thriving. Our study has shown that there are no any considerable variations in meroplankton abundance and species diversity among areas of Peter the Great Bay with different levels of pollution. Thus, in Amursky Bay the total density of meroplankton, which is experiencing a rather high anthropogenous pressure reached 12000-14000 ind./m in summer. It is close to that of fairly clean inshore water areas of Peter the Great Bay studied earlier: Novgorodskaya Bight in Posyet Bay (Vyshkvartsev *et al*., 1979), Alekseev Bight at Popov Island (Mikulich & Biryulina, 1977), Vostok Bay (Kasyanov *et al*., 1978), but it is several times higher than the concentration of meroplankton in Alekseev Bight where the mariculture farm is located (Maslennikov *et al*., 1994). Despite its proximity to Vladivostok, this area is rather safe to larvae plankton. In Nakhodka Bay, due to transport by currents high abundance of larvae of filter-feeding molluscs and echinoderms was observed over the most polluted bottom areas. In Gaidamak Bight, despite considerable pollution, meroplankton exhibited high species diversity and density, which varied from 4000 to 14000 ind./m^3 at different stations, often being higher than in clean waters. Numerous examples of other coastal areas confirm this. For example, in the port of Marseille (Mediterranean) pollution of the water with hydrocarbons, organic matter and industrial sewage, does not prevent pelagic larvae of bottom invertebrates from penetrating there from clean waters of high sea (Gilet, 1960). In the harbors of Los Angeles and Long Beach (California, Pacific) one may observe the formation of rich fouling communities on buoys in the water column over heavily polluted sites of the bottom inhabited by highly pauperized communities (Abbott *et al*., 1973). The generalization of the world' s literature data for different estuaries and bays (Mileikovsky, 1976) has revealed that, as a rule, in the water mass (except for thin surface and bottom layers and sites closely adjoining the sources of pollution), pollutants' concentrations are sometimes below harmful and lethal levels. In addition, polluted coastal waters do not usually spread very far, and larvae distributed throughout the water column have a chance to survive.

Conclusion

Our studies have displayed, that the concentrations of pollutants in shallow bays of Peter the Great Bay are by far higher than permissible levels. At the same time, the larval plankton was great in density and rich enough in species diversity. There are no any considerable variations in meroplankton abundance between rather clean and considerably polluted waters.

Rather high number of pelagic larvae even over extremely polluted bottom areas testifies to the high reproductive potential of contaminated areas and that if they are purified either naturally or by humans the degraded bottom communities will recover.

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