Variations in Vertical Distribution of the Young of Two Commercial Bivalve Species Depending on Some Factors

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Abstract   The results of a long-term study of vertical distribution of the two main fouling species on scallop collectors of Japanese design—Japanese scallop, *Mizuhopecten (= Patinopecten) yessoensis*, and Pacific mussel, *Mytilus trossulus*—installed along the Primorsky Krai coast, Sea of Japan (East Sea), are presented in this article. The mussel, associated with Japanese scallop, is in fact its food competitor, which reduces its survival and growth rates. Settlement of scallop larvae begins earlier in shallow waters, i.e. in areas, where upper horizons are wormed up faster. A significant similarity in vertical distribution of juvenile scallop between stations is observed. The positive correlation between depth and vertical distribution of juvenile scallop is recorded most frequently in years with a high water temperature in June; for mussel, this relationship is always negative. Both climatic characteristics of year and position of the station exert influence on the depth of the maximum abundance of the young of the studied mollusks. Exposing scallop collectors at the optimum horizon, 9.5–15 m, promotes increase in the abundance of *M. yessoensis* and reduction in the abundance of *M. trossulus*.

Keywords: *Japanese scallop, pacific mussel, vertical distribution of juveniles, climate*

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1. Introduction

Cultivation of bivalves is highly demanded in maritime countries [1,2,3], and many countries of the Asia-Pacific region (especially China) have achieved great success in this promising industry [4,5,6,7]. In these countries, the major portion of aquaculture products is grown in the natural environment after collecting ―wild‖ larvae on artificial substrates. However scallop collectors attract not only larvae of cultivated species, but also their competitors and predators [8,9,10]. Competitors have a similar feeding spectrum to that of the cultivated species [8,11], while predators use this species as food [9,10]. The abundance of *M. trossulus* on the scallops collectors, placed at a horizon of 0.5–6.0 m in Amur Bay (Sea of Japan) in the summer 1999, reached 7,425.0–3,578.0 ind./m2 that caused complete mortality of *M. yessoensis* in the autumn [12]. As a result of the negative impact from associated species, the output of commercial production declines [13,14,15], and to increase profits, aquaculturists have to struggle against fouling by using biological [13,15,16,17] or chemical methods [18]; otherwise, collectors are hauled up to the surface and the cultivated animals are manually picked from the collectors and relocated to cages for subsequent on-growing [1,2]. According to my unpublished observations, covering the collectors and cages with an antifouling paint, containing polyvinyl chloride, in order to decrease the number of foulers caused mortality among cultured mollusks,

whereas introduction of the sea urchin *Strongylocentrotus nudus* into scallop cages resulted in destruction of the cages. Predatory gastropods are also of little use as a measure against unnecessary foulers. After being introduced in collectors and cages, juvenile predatory gastropods *Nucella heyseana* first killed mussels *Mytilus trossulus* and then switched to scallops *M. yessoensis* [19]. Manipulations over a cultured species weaken its immunity that often causes a mass mortality [20,21,22] or slower growth [20]. However, the technology of rearing larvae under artificial conditions is even more difficult, as they should be fed with specially grown microalgae, and there they grow worse than in the sea [23,24]. After the larvae settle, collectors are submerged into the sea, where larvae of competing and predatory species settle on them in turn. At the same time, larvae of invertebrates, settling on substrates, manifest their own environmental preferences, which result in their different spatial distribution over the substrate [25]. This colonization of ecological niches facilitates existence of invertebrates. Distribution of larvae depends on abiotic factors [26,27], and thus vertical distribution of juveniles on collectors also varies depending on climatic features of year [28]. Many researchers have reported climate changes in the recent years [29-33], and these changes can have an effect on vertical distribution of juveniles over artificial substrate. However, publications on this issue are lacking.

The goal of the present study is to investigate vertical distribution of two main fouling species on scallop collectors and its variability under the effect of abiotic factors.

2. Materials and Methods

2.1. Determination of Time for Exposing the Collectors

This research was conducted in coastal waters of the southern Far East of Russia (Figure 1). In order to determine terms of exposing the scallop collectors, the time of beginning of Japanese scallop spawning was recorded. It was determined by studying the gonadal index. In 1977–1990, each ten days from the middle May till the end of June, 25–30 specimens of *M. yessoensis* were caught in Minonosok Inlet (St. 1) by means of SCUBA; their total weight, the weight of soft tissues, muscle, and gonads were measured with the accuracy of ±0.02. Similar works were conducted in Kit Inlet (St. 15) from early June to early July, 1985–1987. The gonadal index in scallops was determined according to the method by Ito and co-authors [34]. The time of onset of spawning in molluscs was registered as the abrupt decrease of gonadal index (by 9–12%) in females. A week after spawning, plankton samples were collected with an Apschtein plankton net every two or three days in 1977–1990 and in 1995 and 1996 from the horizon of 0–10 m at the stations 1–3 in Minonosok Inlet (St. 1); in 1985–1988, in Kit Inlet (St. 15); in 1989, in Vladimir Bay (St. 16); and in 1999, in Amur Bay (St. 14). The mesh size of the plankton net was 100 μm. The plankton samples were fixed in 4% formaldehyde solution. Larva were counted and measured in a Bogorov chamber under a microscope; the number of larvae was calculated per 1 м3. Annually, 8–11 samples were taken from each of the stations. Along with plankton sampling, the water temperature was measured at three horizons (0, 5, and 10 m).

2.2. Study of Artificial Substrates

After scallop larvae reached 250 μm in length (the stage of settling), strings of bag collectors of Japanese design, attached to a caproic cord at 0.5-meter intervals, were submerged at 12 stations in the northwestern Posyet Bay in 1978–1982, 1985, 1988 and 1989, and in Minonosok Inlet in 1990–2014 (Figure 1, St. 1). The major part of these collectors was installed on the bottom. In total, collectors covered a horizon of 0–26 m. In 1988–1990, on the day of collection of plankton samples, pairs of strings of collectors were placed at a distance of 60 m from each other at the farm in Minonosok Inlet. Collectors were installed also in the Stark Strait off Popov Island (Figure 1, St. 13) in 1984–1985, in Kit Inlet (St. 15) in 1985–1988, in Vladimir Bay (St. 16) in 1988–1989, and in Amur Bay (St. 14) in 1999–2000. After juvenile scallops reached 8–10 mm in shell height, a part of collectors were lifted to the surface. Japanese scallops and Pacific mussels were picked from the substrate, and live and dead individuals were counted. The level of reproduction of these molluscs was found as a sum of live and dead individuals. The obtained results were expressed per 1 m^2 by dividing the values of counts by 1.44 m^2, which is the standard area of the scallop collectors. The shell height of 30–50 live and dead molluscs from each collector was measured to an accuracy of ±0.1 mm by using a caliper. The time of settlement of *M. yessoensis* larvae on collectors in 1978–1980 was determined by counting the number of daily rings on the shells of five individuals, collected from the top, middle, and bottom horizons, under microscope.

2.3. Climate Observations

To study the degree of abiotic factors' influence on reproduction of *M. yessoensis* and *M. trossulus*, we used daily values of water temperature and salinity, sea level, rainfall, wind speed and direction in 1977–2014, provided by the Posyet Meteorological Station (42°39'N, 130°48'E).

For *M. yessoensis* and the *M. trossulus* in Posyet Bay, spawning and the pelagic period last mainly in June, and thus the studies of dynamics of the climatic factors were based on data collected within this month. The values of Solar activity expressed in Wolf numbers were taken from the NOAA USA official website. The standard error of the mean for the sea surface temperature in June was calculated for each year. Duration of ice period was analyzed only in Minonosok Inlet (Figure 1, St. 1). For this reason, the mean and the standard error of the mean were not calculated. Duration of the ice period for the studied period varied from 94 to 127 days.

2.4. Statistical Processing of the Material

The degree of climate's influence on vertical distribution and reproduction of the investigated invertebrates was determined through a statistical comparison of the dynamics of climatic parameters to the dynamics of their abundance. Pearson's correlation analysis was used to evaluate relationships between the depth and abundance of juveniles and also between their vertical distributions in the investigated areas. The obtained data on dynamics in the number of juveniles and climatic factors were transformed by using the following formula: log (x+1). Standard error (SE) was found for all mean values. Vertical distribution of juveniles, the depth at which their number was the maximum, quantitative changes in duration of ice period, the mean sea surface temperature in June, the standard error of the mean sea surface temperature in June, the average sea level in June, the average amount of precipitations in June, the average wind speed in June, the average wind direction in June, the average sea surface salinity in June, the average Solar activity in Wolf' numbers, and the average shell height in *M. yessoensis* on September 23 of each year were assessed through non-metric multi-dimensional scaling (nMDS) ordination. The quantitative changes in dynamics of the abundance of *M. yessoensis* and *M. trossulus* (1977–2014) in Minonosok Inlet, and biotic and abiotic factors (1977–2014) were analyzed the same way. The patterns of ordinations were interpreted in relation to changes in the values of the environmental characteristic. The statistical processing of the materials was carried out in STATISTICA 6 (StatSoft Inc., Tulsa, Oklahoma, USA). The values of regression analysis were tested at α=0.05.

3. Results

Japanese scallop. Processing of plankton samples showed that larvae of both species are present in the plankton in June. And the maximum number of scallop larvae is usually registered 15 days earlier than that of mussel larvae. After counting the total number of daily

rings on scallop shells, we made a conclusion that earlier settlement of scallop larvae starts in shallow, faster warmed waters, i.e. in the upper horizons. However at certain stations (Figure 1, St. 2, in 1979), settlement began with middle horizons; at St. 5 in 1979 and at St. 6 in 1980, settlement started in lower horizons. Later on, scallop larvae settled on the stations 3 and 6, which are close to the deep-water aggregations of scallop.
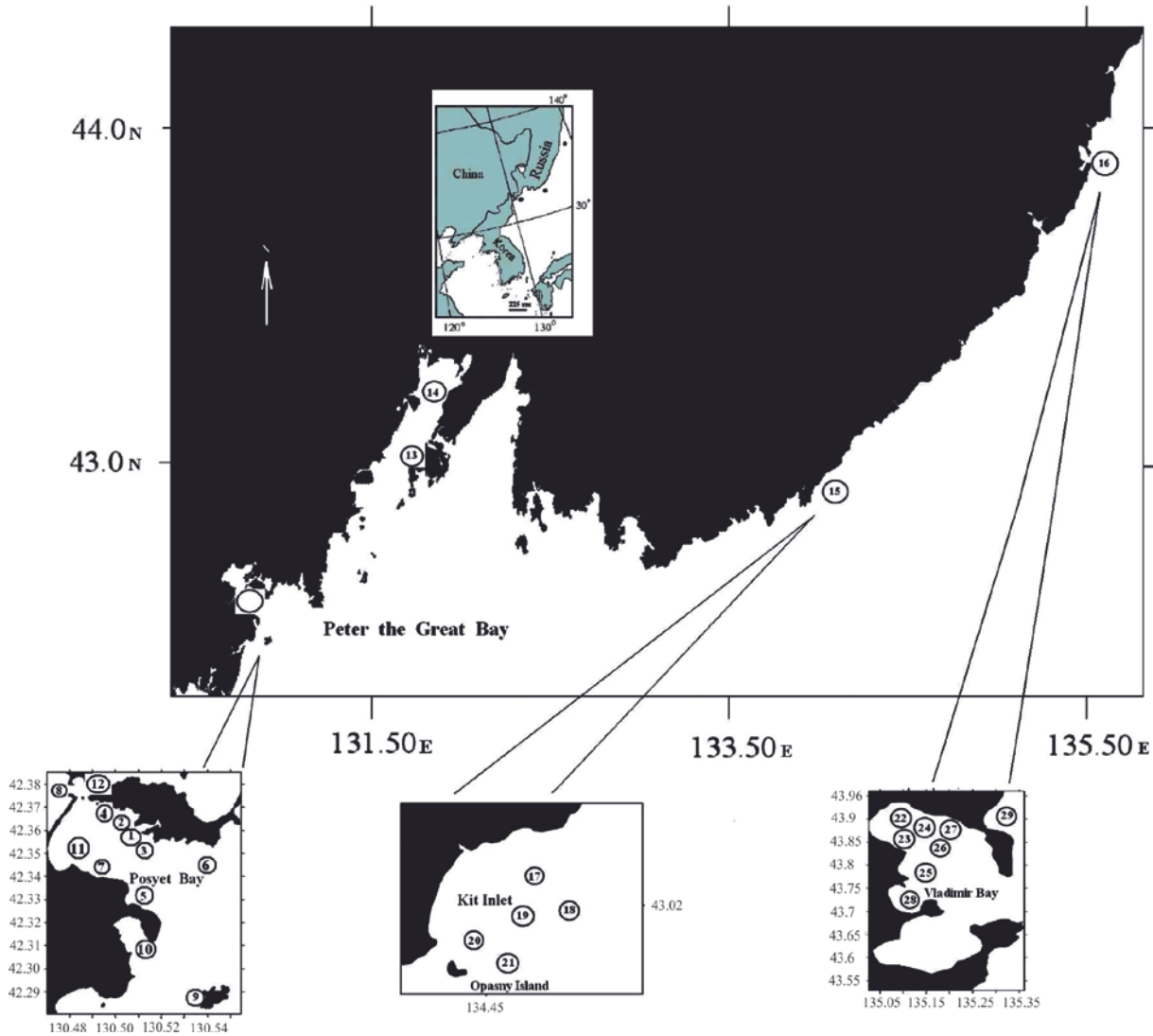

Figure 1. Study area showing sampling stations and sites of deployment of scallop's collectors in Primorsky Krai

Table 1. Interrelation of vertical distribution of animal and depth in Posyet Bay (N = 12). The bold type are emphasize of authentic interrelations.

| Species of bivalvia	Time of investigation	Abundance of juveniles, ind./m2	R	P
Japanese scallop	197S	69.0	0.430	0.022
--<<--	1979	327,0	0.657	0.000
--<<--	1980	22?0	0.201	0.326
~«—	1982	259.0	-0.201	0.226
--<<--	1983	1087,0	-0.473	0.167
--<<--	1984	193.0	0.200	0.704
--<<--	1985	109.0	-0.670	0.002
--<<--	1989	95.0	0.539	0.017
Pacific mussel	1978	118.0	-0.778	0.000
--<<--	1979	110.0	-0.899	0.000
--<<--	1980	1816.0	-0.825	0.000
--<<--	1981	908.0	-0.806	0.005
--<<--	1982	949.0	-0.783	0.000
--<<--	1983	1479.0	-0.855	0.002
--<<--	1984	1037.0	-0.486	0.329
--<<--	1989	399.0	-0.531	0.357

Within the first two years of observations (1978–1979) a significant positive relationship between the depth and abundance of juvenile scallops was observed within the horizon 0–16 m in the Posyet Bay (R = 0.430 and 0.657, respectively) (Table 1). In 1980, the reliably determined horizon of this relationship rose to 13 m; in 1982, up to

11.5 m. There is a weak positive relationship between this horizon and the water surface temperature in June: R = 0.41. In those years (1980 and 1982), scallop larvae were scarce and preferred settling in the upper horizon (Figure 2A). In 1985 and 1989, significant relationships between vertical distribution of juveniles and depth (0–16) appeared again, and they were both positive and negative (Table 1). In 1990–2014, the maximum abundance of juveniles was observed at the depth of 12.0 m in 50% of cases; however it rose higher after cold winters. In 1997 and 2001, the maximum number of juveniles was recorded at the depth of 7.5 m; in 2008 and 2012, at 9.5 m. In 2003, the maximum abundance of juveniles was observed at 12.5 m; in 2014, at 12 m.
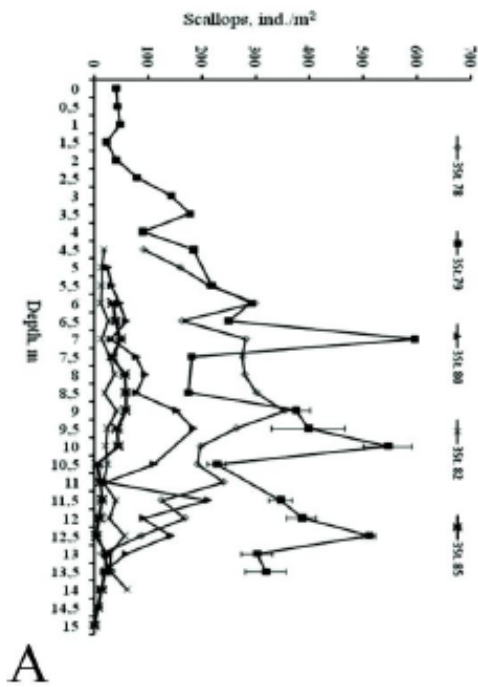
Figure 2A. Vertical distribution of juveniles of the Japanese scallop at Cape Nizmeny (Posyet Bay) in different years.
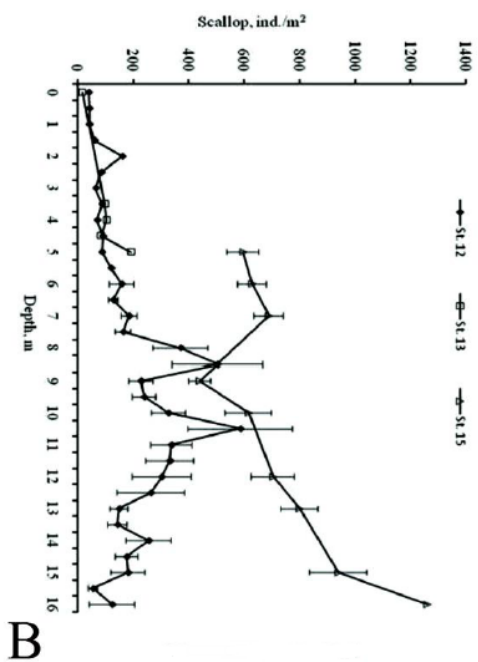
Figure 2B. Average of vertical distribution of juveniles of the Japanese scallop on collectors in Posyet Bay, Strait of Stark and Kit Inlet
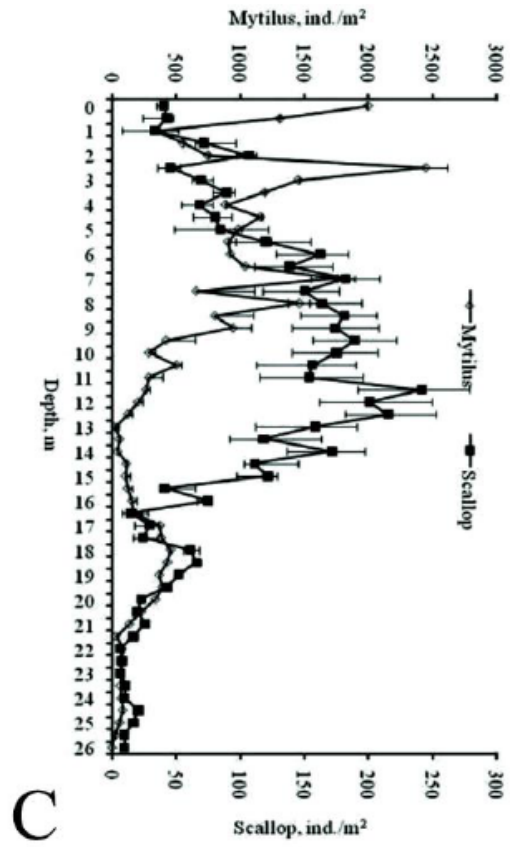
Figure 2C. Average of vertical distribution of juveniles of the Japanese scallop and of the Pacific mussel in Posyet Bay
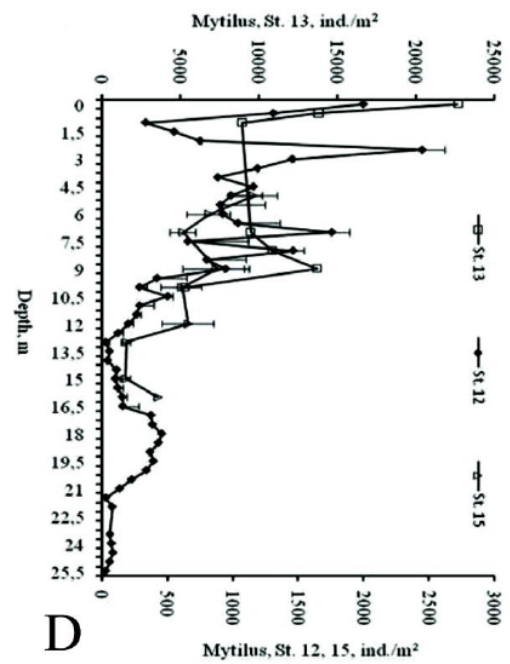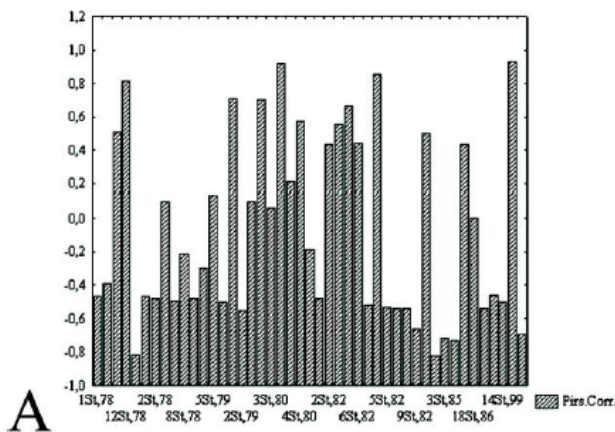
Figure 2D. Average of vertical distribution of juveniles of the Pacific mussel in Posyet Bay, Strait of Stark and Kit Inlet

Apparently, the active hydrodynamics in the open Kit Inlet (St. 15) cause the optimum horizon for larval settlement to lower deeper than that in Posyet Bay (Figure 2B). In the horizon 4.5–16.0 m in Kit Inlet, we found no significant positive relationship between the depth and the juvenile scallop abundance (R = 0.433, p = 0.233), and all the stations showed a significant similarity in distribution of juveniles. At three of the five stations, the highest

abundance was recorded at the depth of 12 m. Pelagic larvae were also located deeper than 10 m. In the horizon 0–20 m, their number was 1.5–2.0 times as large as that in the layer 0–10 m. A comparison of the vertical distribution of juvenile scallop in three areas situated far from one another in successive years showed some similarities between the Starka Strait (St. 13), and Kit Inlet (St. 15): R = 0.798; p = 0.412 (Figure 2B). In Vladimira Bay (St. 16), the number of juvenile scallops on the collectors, placed within the horizon 0–9 m, was observed to increase 6 times from the surface to the bottom.

As a rule, a significant similarity in the vertical distribution of juvenile scallop between stations in Posyet Bay was frequently registered in 1978–1982; at St. 4, it was highly significant within three years. Until 1980, a positive correlation between the depth and vertical distribution of juveniles in Posyet Bay was registered in 39.0% of cases (Figure 3A). Since 1980, the frequency of positive relationship has risen to 46.2%. The positive correlation was observed most frequently in 1979–1982 (Figure 3A), when the average water temperature in June was higher than the mean annual temperature (17.08 and 16.67°C, respectively). A significant influence of climate on vertical distribution of juveniles is confirmed by nMDS analysis. It divided all the available material into two groups, which, as a rule, differ in the time of study (Figure 3B).


Figure 3A. Pearson coefficients correlation between vertical distribution of juveniles of the Japanese scallop and depth at Primorsky Territory in different years
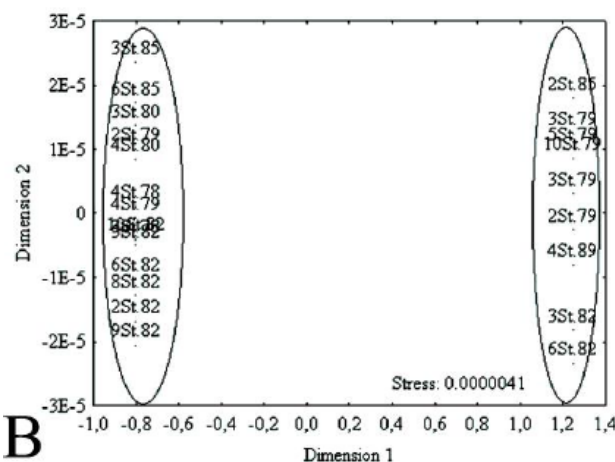
Figure 3B. No meric MDS analysis of vertical distribution of juveniles of the Japanese scallop in Posyet Bay in different years. Ellipses are limited of data with similar indicators
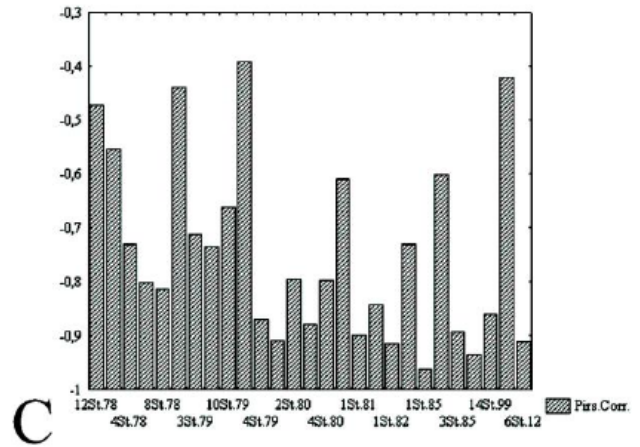
Figure 3C. Pearson coefficients correlation between vertical distribution of juveniles of the Pacific mussel and depth at Primorsky Krai in different years
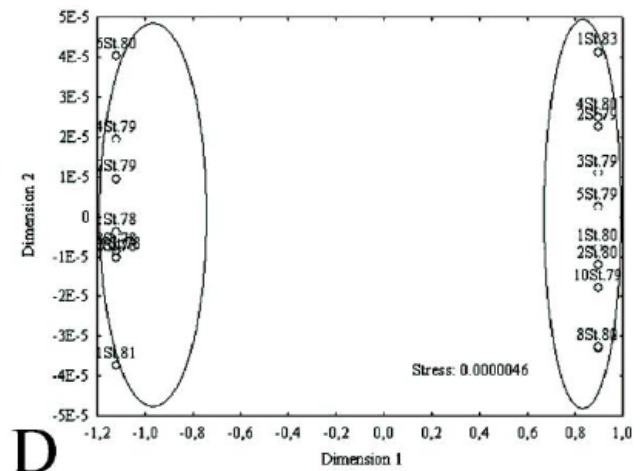
Figure 3D. No metric MDS analysis of vertical distribution of juveniles of the Pacific mussel in Posyet Bay in different years. Ellipses are limited of data with similar indicators

In half-closed Minonosok Inlet (St. 1), due to the insignificant mixing of water in June of some years (1987, 1993, and 1997), the temperature gradient between the surface and the bottom reached 6°C, and the near-bottom temperature dropped below 10°C. In these years, there were practically no juveniles on the collectors located at a depth of 13–14 m. On the collectors located at the depth of 11.5 m in the mouth of this Inlet, scallop abundance was already 1.3 times as high as that at 9.5 m. In more open St. 6, the thermocline is less pronounced because of mixing, and juvenile scallops occurred at the maximum depth of collectors, 26 m; however, after 16 m the number of juveniles decreased abruptly (Figure 2C).

A significant negative relationship between the depth and the number of juveniles at some shallow-water stations (Figure 3A) may occur due to an abrupt decline in the number of juveniles on lower collectors. A comparison of these observations to the type of bottom soil suggests that a muddy bottom can become the cause of poor larval settlement on lower collectors. Typically, larvae poorly settle on substrates at one and a half meters above the muddy bottom. At a solid bottom, the increase in the number of juveniles in the lower horizon occurred in 44.4% of cases; while for collectors put on a soft bottom, this number grew only in 25.0% of cases. The relationship between productivity of year and depth of the maximum

number of juveniles at St. 1 is insignificant (R = 0.252, p = 0.299), while as St. 2 and St. 3 this relationship is weakly negative (R = -0.213, p = 0.685 and R = -0.227, p=0.665, respectively).
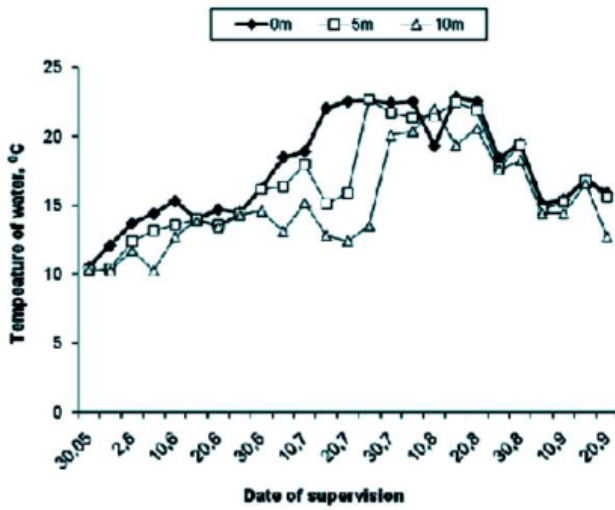

Figure 4A. Temperature of water at three horizon's in semi-closed Inlet in Posyet Bay in 1995
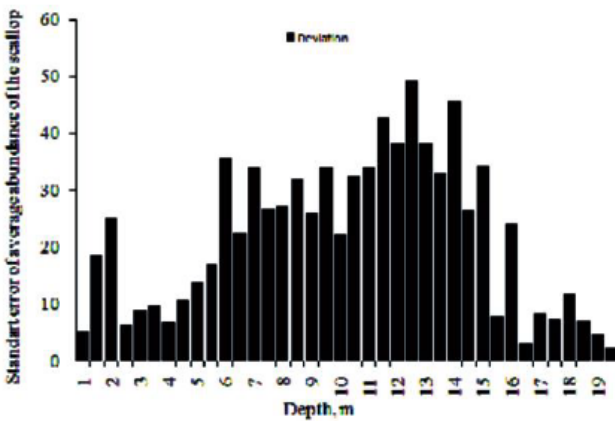

Figure 4B. Standard error (SE) at many years average of vertical distribution of juveniles of the Japanese scallop in Posyet Bay

Vertical distribution of juveniles depends also on orography of the shore. The most of the stations (55.6 %) in Posyet Bay, at which a positive relationship between abundance of juveniles and depth is recorded, are open to southeast winds prevailing in summer (St. 3, 4, 5, 6, 7 and

11). In inlets sheltered from these winds, the surface layer is carried away, and cold waters rise to the surface. As a result, the temperature at the surface is sometimes lower than that at the depth of 5 m and even 10 m (Figure 4A). This causes a negative relationship between depth of the maximum number of juveniles and wind speed at St. 2 (R = -0.6374; p = 0.174). Due to the appearance of stratification at closed stations, thermotaxis of larvae results in a negative relationship between vertical distribution and depth (Figure 3A).
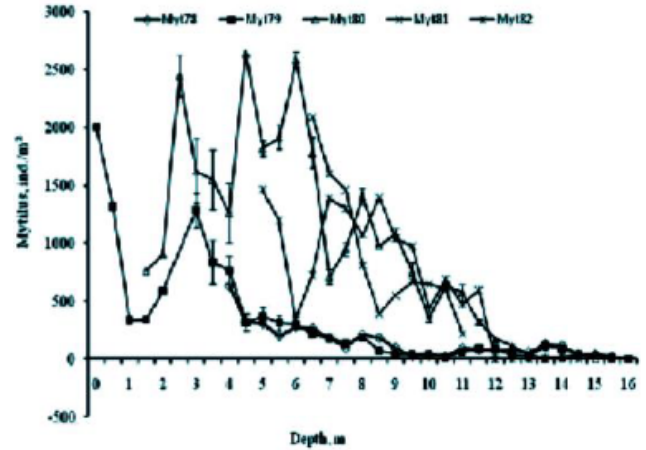

Figure 4C. Vertical distribution of the Paccific mussel during five years in Posyet Bay
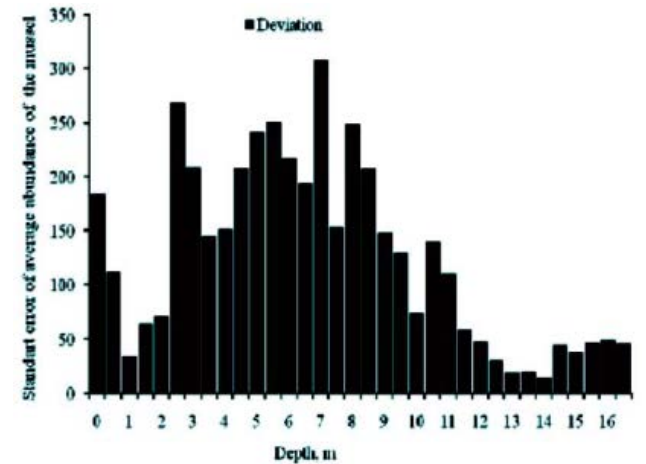

Figure 4D. Standard error (SE) at many years average of vertical distribution of juveniles of the Pacific mussel in Posyet Bay

Table 2. Pearson's coefficient of correlation between average vertical distribution of juvenile of the Japanese scallop (A) and Pacific mussel (B) at several stations in different years in Posyet Bay (N = 12). The bold type are emphasize of authentic interrelations.

A	1978	1979	1980	1981	1982	1983	1985
1979	-0.313						
1980	-0.029	-0.275					
1981	-0.292	-0.034	-0.627				
1982	-0.086	-0.233	-0.496	0,764			
1983	-0.067	-0,772	0.136	0.277	0,468		
1985	-0.512	0.370	-0.230	-0.064	0.232	-0.348	
1989	0.492	-0.722	0.071	0.370	0.259	0.610	-0,809
B							
1979	0,833						
1980	0,808	0.738					
1981	-0.013	0.349	0.347				
1982	0.658	0.362	0,776	0.148			
1983	0.732	0.598	0.617	0.281	0.629		
1985	0.669	0.510	0.730	0.344	0,902	0.574	

In the upper 4-meter layer, the conditions for settlement of scallop larvae are more stable than those in the horizon 6.0–15.0 m (Figure 4B). This is probably can be explained by more similar temperature conditions at the surface due to the water mixing. A cluster analysis of vertical distribution of juveniles for some years shows similarity both between stations within one year and between years at the same station (Figure 5A). The similarity between stations is observed more frequently in years with close levels of reproduction and, hence, with similar climatic conditions (Figure 5A). The results of the study of larvae's settlement on the collectors exposed at various times also support the thesis about influence of climatic parameters on vertical distribution of juveniles. The similarity is observed more frequently on collectors exposed simultaneously (Figure 5B, C, D). Significant positive relationships of average values of vertical distribution of juveniles in Posyet Bay were found between 1979 and 1982, between 1980 and 1989, and also between 1981 and 1989 (Table 2).
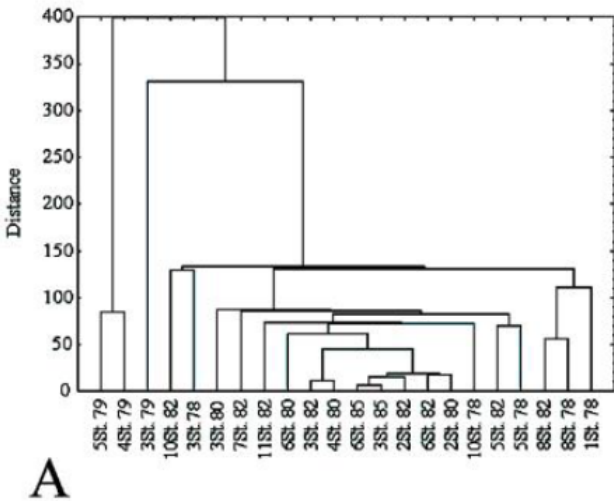
Figure 5A. Cluster analysis of vertical distribution of juveniles of the Japanese scallop on the common horizon at all stations in Posyet Bay
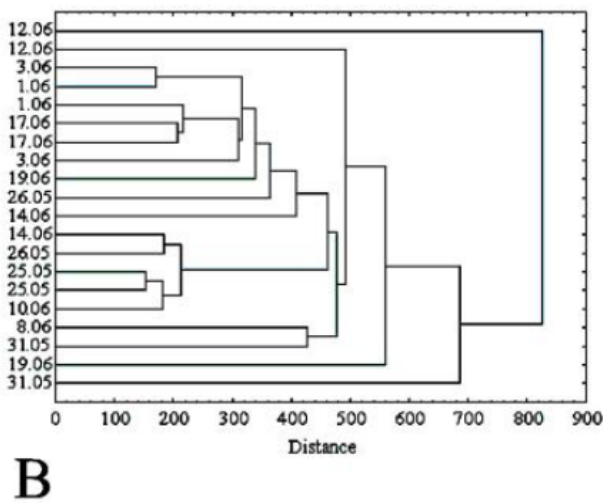
Figure 5B. Cluster analysis of vertical distribution of juveniles of the Japanese scallop on collectors, settling in Minonosok Inlet of Posyet Bay in 1988

In highly productive years, the abundance of juveniles is more than 200 ind./m^2 starting from 8 m of depth; from 10 to 15 m, it exceeds the abundance of Pacific mussel. At greater depths, scallop larvae rarely colonize artificial substrates, and the predominance of mussel starts from 15 to 25.5 m (Figure 2B). Consequently, the best horizon for collecting and on-growing of scallop larvae is a depth of 10–15 m.
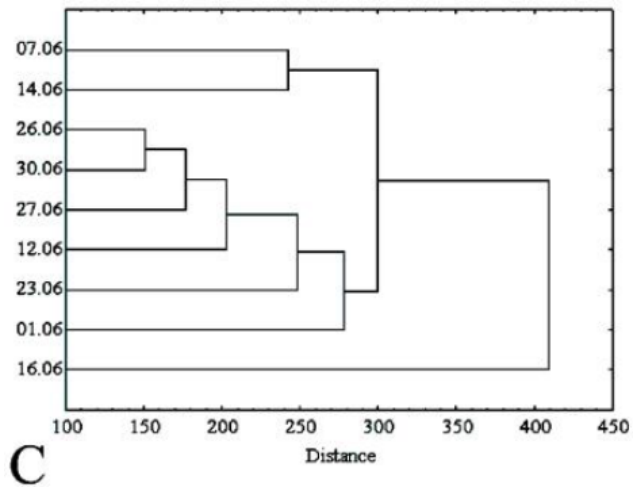
Figure 5C. Cluster analysis of vertical distribution of juveniles of the Japanese scallop on collectors, settling in Minonosok Inlet of Posyet Bay in 1989
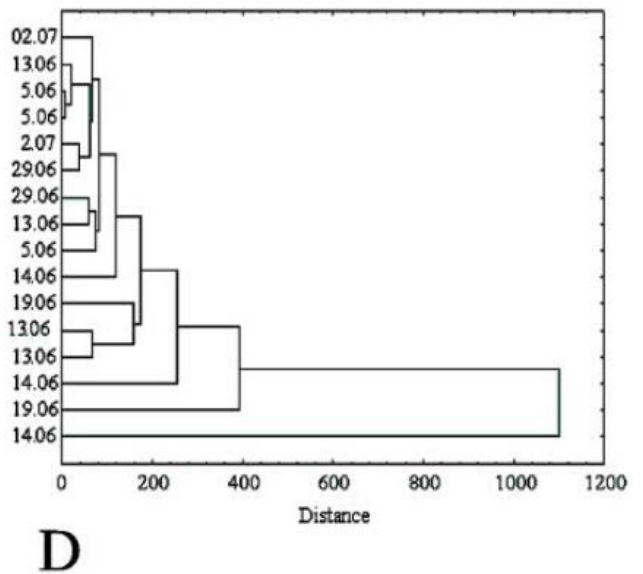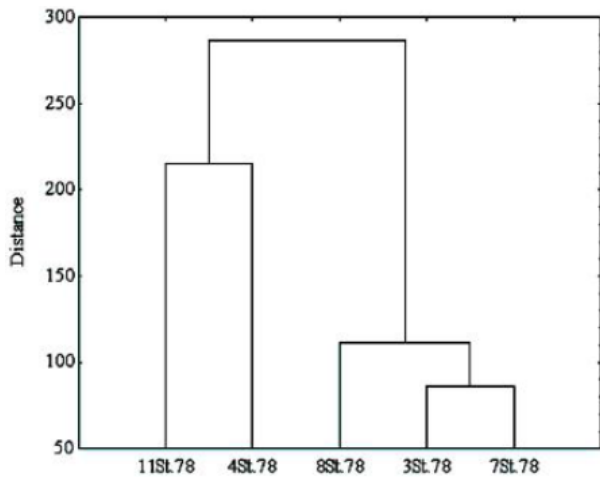
Figure 5D. Cluster analysis of vertical distribution of juveniles of the Japanese scallop on collectors, settling in Minonosok Inlet of Posyet Bay in 1990
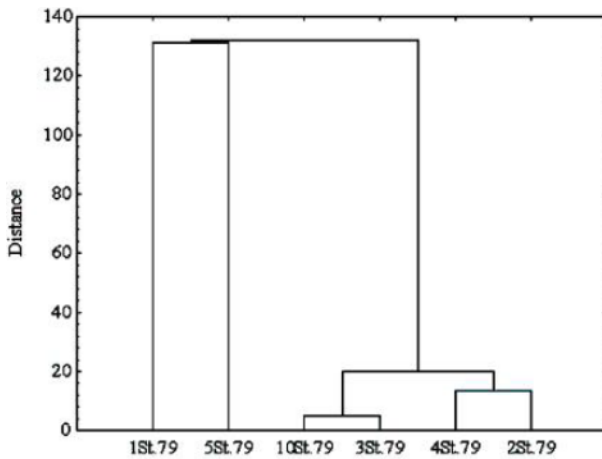
Pacific mussel. The study of vertical distribution of juvenile *M. trossulus* showed that it negatively correlated with depth, and an insignificant correlation was observed only in two years, 1984 and 1989 (Table 1). The most significant negative correlation was observed in 1979 and 1980 off Baklany Rock (Figure 1, St. 4) (R = -0.946 and -0.910, respectively); in 1981, in Minonosok Inlet (St.1); and in 1985, off Cape Degera (St. 6) and Cape Nizmenny (St. 3) (R = -0.927; -0.962 and -0.921, respectively) (Figure 3C). In spite of the differences in level of mussel reproduction for three years of observation, the vertical distributions of juveniles in Posyet Bay was similar (Figure 4C). A similar tendency was observed in the Starka Strait (St. 13), as well as in Kit Inlet (St. 15)

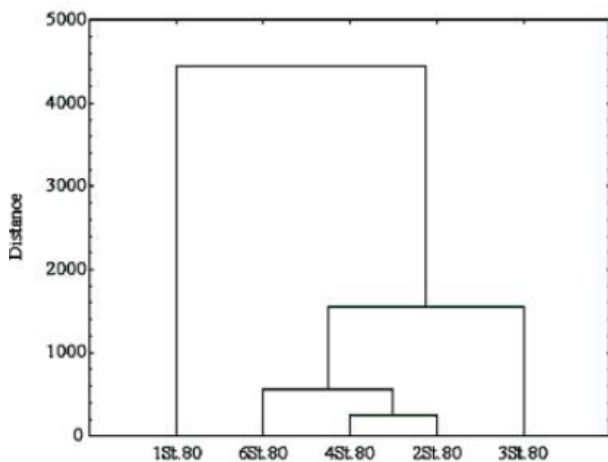(Figure 2D), but it was more smoothed due to the significant mixing of water.

E

Figure 5E. Cluster analysis of vertical distribution of juveniles of the Pacific mussel in Posyet Bay in 1978
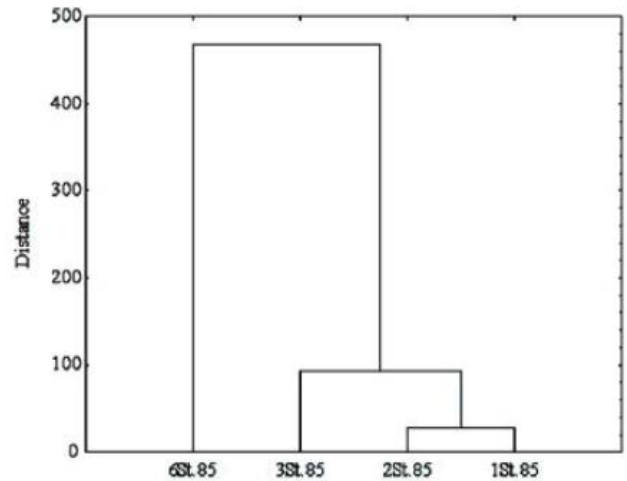

F

Figure 5F. Cluster analysis of vertical distribution of juveniles of the Pacific mussel in Posyet Bay in 1979
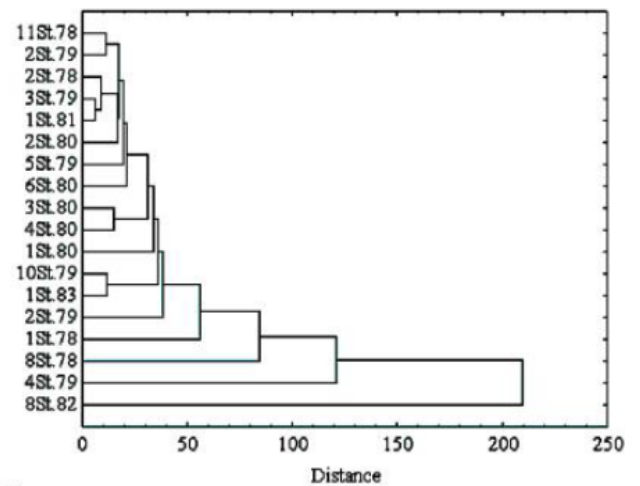

G

Figure 5G. Cluster analysis of vertical distribution of juveniles of the Pacific mussel in Posyet Bay in 1980
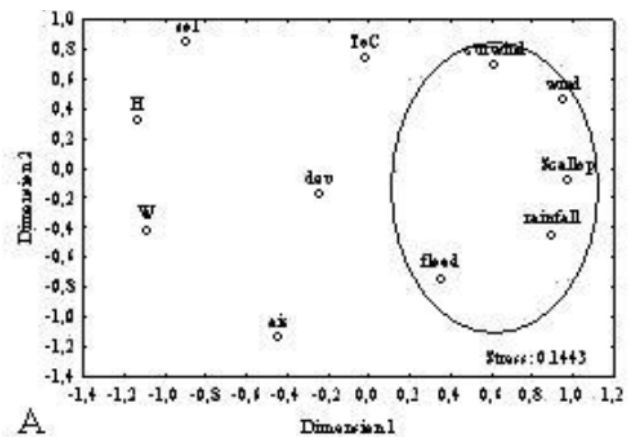

H

Figure 5H. Cluster analysis of vertical distribution of juveniles of the Pacific mussel in Posyet Bay in 1985

I

Figure 5I. Cluster analysis of vertical distribution of juveniles of the Pacific mussel at all stations in Posyet Bay

A

Figure 6A. Not metric MDS analysis of climate factors, influencing on reproduction of the Japanese scallops in Posyet Bay in 1977-2014. Tem - temperature on a water surface,°C, dev – standart error of average temperature on a water surface, flood - tide height, m, ais - duration of the ice period, day, w – average annual solar activity in Volf's numbers, H - shell height of juvenile of the Japanese scallops on September, 23 of each year, wind – average speed of a wind, m/sec, curwind - average direction of a wind, °, sol - salinity on a water surface, psu, rainfall – deposits, mm. Ellipses are limited of data with similar indicators
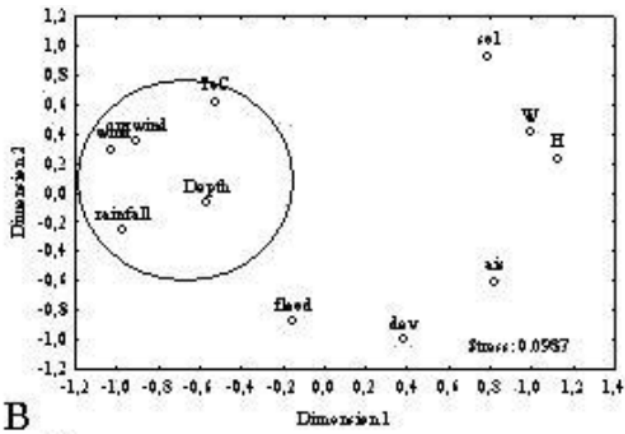
Figure 6B. Not metric MDS analysis of factors, influencing on depth of the maximum number of the Japanese scallops in Posyet Bay on station 1 in 1978-2014. Tem - temperature on a water surface,°C, dev – standart error of average temperature on a water surface, flood - tide height, m, ais - duration of the ice period, day, w – average annual solar activity in Volf's numbers, H - shell height of juvenile of the Japanese scallops on September, 23 of each year, mm, wind – average speed of a wind, m/sec, curwind - average direction of a wind,°, sol - salinity on a water surface, psu, rainfall – deposits, mm. Ellipses are limited of data with similar indicators
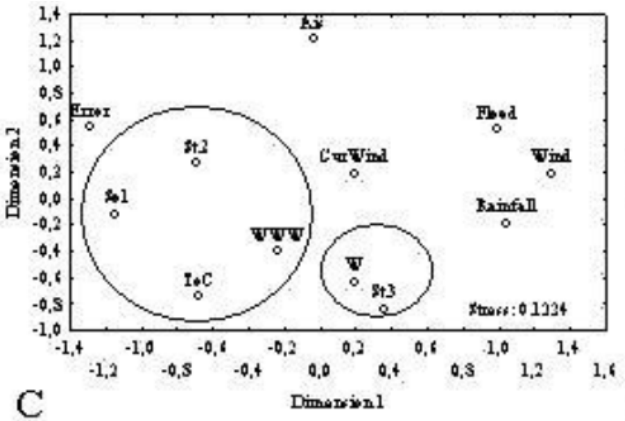
Figure 6C. Not metric MDS analysis of factors, influencing on depth of the maximum number of the Japanese scallops in Posyet Bay on station 2 and station 3 in 1978-1989. Tem - temperature on a water surface, °C, dev – standart error of average temperature on a water surface, flood - tide height, m, ais - duration of the ice period, day, w – average annual solar activity in Volf's numbers, www - average annual solar activity in Volf's numbers in previous year, wind – average speed of a wind, m/sec, curwind - average direction of a wind, °, sol - salinity on a water surface, rainfall – deposits, mm. Ellipses are limited of data with similar indicators.

Figure 6D. Cluster analysis of climate parameters are influensed on reproduction of the Japanese scallops in Posyet Bay in 1977-2014

Figure 7A. Not metric MDS factors, influencing on vertical distribution of juveniles of the Japanese scallops at Posyet Bay in 1978-1989. W - speed of a wind, m/sec, CW - wind direction, °, F - height of tides, m, T - temperature on a water surface, °C. Ellipses are limited of data with similar indicators.

Figure 7B. Not metric MDS factors, influencing on vertical distribution of juveniles of the Pacific mussel at Posyet Bay in 1978-1985. W - speed of a wind, m/sec, CW - w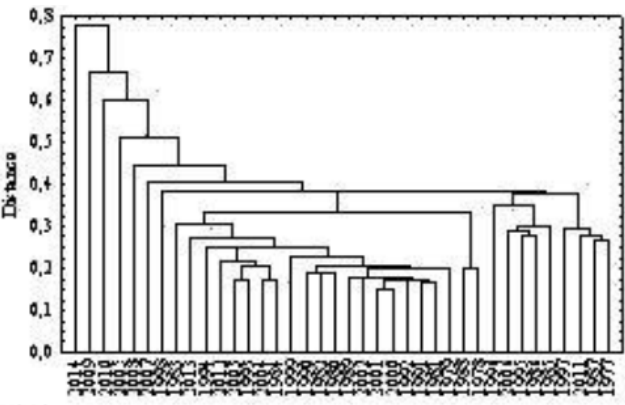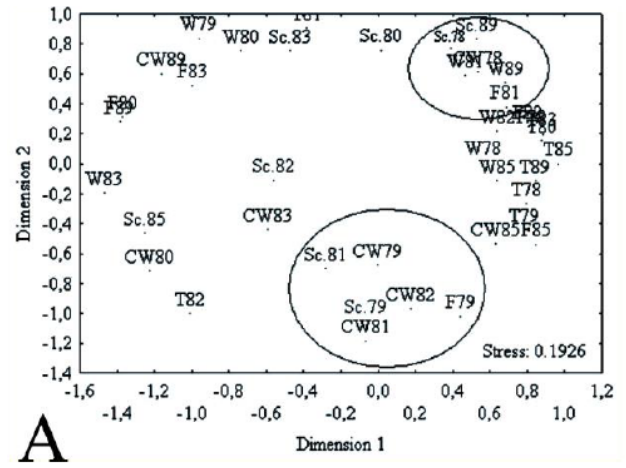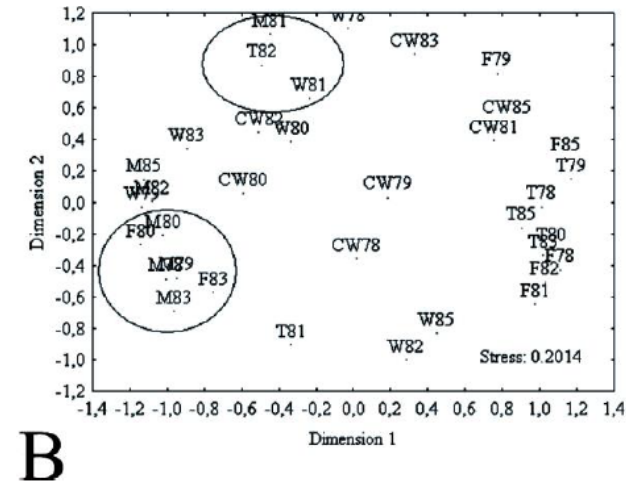ind direction, F - height of tides, m, T - Temperature on a water surface °C. Ellipses are limited of data with similar indicators

The climatic characteristics of year in Posyet Bay influence the vertical distribution probably in a similar way, and a nMDS analysis showed a quite clear division of our materials into two areas. Data of 1980 and 1982 got mainly in the left area, and those of 1978 and 1979 got in the right area (Figure 3D). The middle layer, 2.5–8.5 m (Figure 4D), appeared to be the most changeable horizon for juveniles, and in the nearest years a similarity in vertical distribution of juveniles between stations is observed (Figure 5E-I). The highest similarity was found between 1978, 1979, and 1983. In 1980 and 1983, tide height exerted the most considerable influence on this process; in 1981, wind speed in June (Figure 7B). Sea surface temperature and tide height in June have the most substantial effect on mussel reproduction at St. 1 (Figure 8A). The same is confirmed by long-term observations over abundance of juveniles on the mussel collectors placed within the horizon 0–4 m and on scallop collectors located in the horizon 7.5–12 m. During a cold summer, the abundance of mussel increased at the water surface and decreased at a depth (Figure 8B).
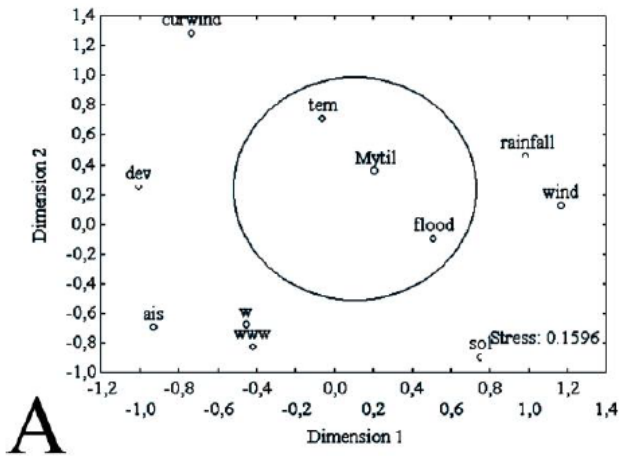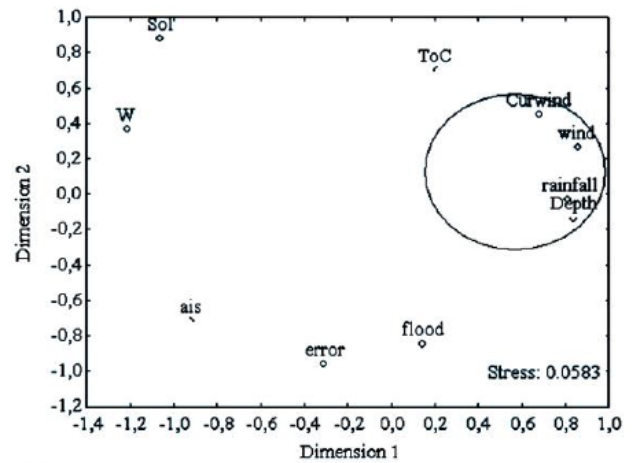
Figure 8A. Not metric MDS factors, influencing on the reproduction of the Pacific mussel in Posyet Bay in 1977-2014. Tem - temperature on a water surface, °C, dev – standart error of average temperature on a water surface, flood - tide height, m, ais - duration of the ice period, day, w – average annual solar activity in Volf's numbers, www - average annual solar activity in Volf's numbers in previous year, wind – average speed of a wind, m/sec, curwind - average direction of a wind, °, sol - salinity on a water surface, psu, rainfall – deposits, mm. Ellipses are limited of data with similar indicators.
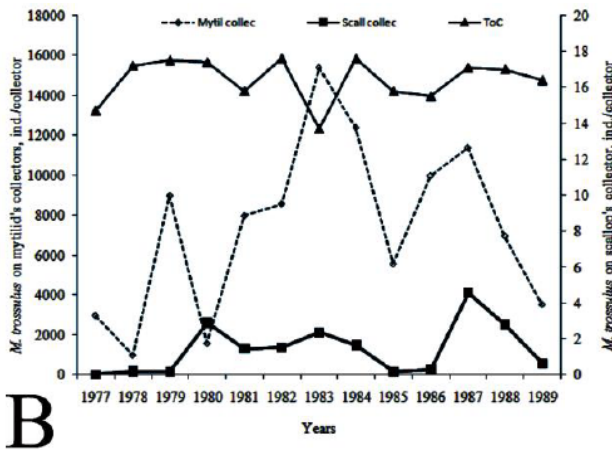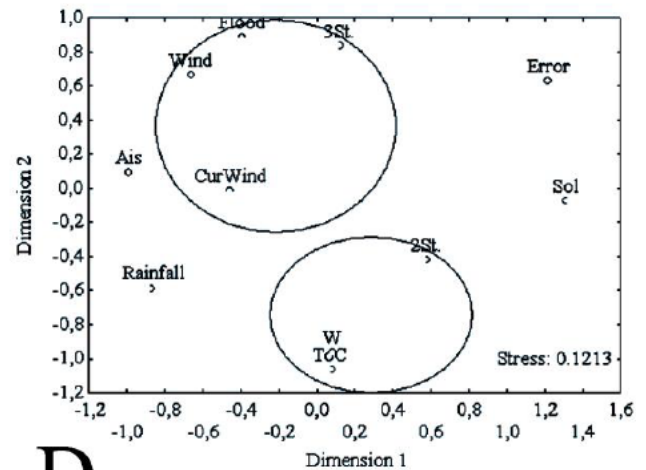

Figure 8B. Quantity of juvenile of the Pacific mussels on mussel and scallops collectors and temperature on a water surface in Posyet Bay

In half-closed Minonosok Inlet (St. 1), the depth of the maximum number is influenced mostly by precipitations and by wind speed and direction (Figure 8C). The long-term observations in this Inlet showed that the depth of the maximum number of mussels on scallop collectors, installed in Minonosok Inlet, is 7.5 m in 36 % of cases. In more open Klykov Inlet (St. 2), Solar activity in Wolf's numbers and sea surface temperature in June have the most pronounced effect on the depth of the maximum number of mussels; and at the even more open station at Cape Nizmeny (St.3), these factors are wind speed and direction and also tide height in June (Figure 8D). In Vladimir Bay (St. 16), a 13-fold decrease in the number of juveniles from the surface to the bottom was recorded for the collectors installed in the horizon 0–9 m. However the insignificant number of mussel juveniles there allows exposing scallop collectors even at the surface. A weak correlation is observed between the vertical distribution of juvenile scallops and juvenile mussels within the horizon 0–26 m (R = 0.329, p <0.05) (Figure 2C) that facilitates the search of the optimum horizon for scallop collectors.

Figure 8C. MDS factors defining depth of maximum number of the Pacific mussel on station 1 in Posyet Bay in 1978-2014. T°C - temperature on a water surface,°C, error – standart error of average temperature on a water surface, flood - tide height, m, ais - duration of the ice period, day, W – average annual solar activity in Volf's numbers, www - average annual solar activity in Volf's numbers in previous year, wind – average speed of a wind, m/sec, curwind - average direction of a wind, °, sol - salinity on a water surface, psu, rainfall – deposits, mm. Ellipses are limited of data with similar indicators.

Figure 8D. Not metric MDS factors, influencing on the depth of maximal quantity of juvenile of the Pacific mussel on station 2 and station 3 in Posyet Bay in 1978-1989. Tem - temperature on a water surface, °C, Error – standart error of average temperature on a water surface, Flood - tide height, m, Ais - duration of the ice period, day, W – average annual solar activity in Volf's numbers, WWW - average annual solar activity in Volf's numbers in previous year, Wind – average speed of a wind, m/sec, Curwind - average direction of a wind, °, Sol - salinity on a water surface, psu, Rainfall – deposits, mm. Ellipses are limited of data with similar indicators.

4. Discussion

The investigated species of bivalve molluscs show various temperature preferences that results in the difference in time of the beginning of spawning and its duration [35], and, as a consequence, their larvae have different time for attachment to a substrate. Mussel larvae manifest positive phototaxis [36], and thus most of them occur at the surface [10]. When settling on the same collector, the two studied species occupy different parts of

it [25]; but if this collector is positioned at the surface, abundant settling of mussel causes a high mortality among scallop [12]. In order to reduce scallop mortality, it is necessary to know vertical preferences of juveniles of both molluscs. Vertical distribution of juveniles can be judged to some extent by their location in the plankton. An analysis of the dedicated literature shows that larvae of bivalves make daily vertical migrations [37, 38, 39, 40]. In Lake Saroma (Hokkaido, Japan), *M. yessoensis* larvae concentrate in upper horizons during high tides and in lower horizons during low tides. During daytime, they keep at a depth of 6–12 m; before sunset, they rise to the layer 0–3 m; at night, they are found at the surface [37]. Vertical migration of larva of many species is complicated by different phototaxis in the course of ontogenesis. Early larvae manifest positive phototaxis, whereas late larvae do negative phototaxis [41,42,43]. Movements of larva are influenced by weight of the shell. Larvae smaller than 120 μm do not lower below the thermocline, while those larger than 170 μm do not experience the thermocline effect [44]. The similar results were obtained by Manuel et al. [45]. Turbulent mixing also has an effect on distribution of larva in plankton [46]. This mixing arises under the influence of dynamic factors, which are most frequently wind- or tide-induced [47]. In mixed waters, larvae are distributed evenly above the water column of 40–50 m [48]; in stratified waters, scallop larvae migrate above the thermocline [49], but in spite of the abundance of food in the upper 10-meter layer, they aggregate deeper [48]. Larvae in plankton behave as active particles. They occur below the thermocline enough frequently and stay in one place in spite of currents induced by upwelling and downwelling [26]. Though behavior of larvae is species-specific [50], many of them move to hyponeuston, and in case of pollution of this zone a threat to existence of bottom biocenoses there arises [51].

Food availability can have the same effect on vertical distribution of larvae as water turbulence does; nevertheless, under the conditions of stratification during day hours, vertical distribution of veligers is not related with water chlorophyll [39]. Availability of food is one of the major factors that influence development of larvae and juveniles. In case of a low food concentration, water turbulence increases the probability of contacts between larvae and food particles [39]. For Japanese scallop, the necessary concentration of suspension is 11.0 mg.l-1, whereas for Pacific mussel it is 2.5 mg.l-1. These values of seston biomass are typical for bays of the Sea of Japan [52]; in the surface layer of bays they vary from 2.4 to 5.0 mg.l-1 and reach 10.0 mg.l-1 in the near-bottom layer. Probably for this reason mussel settles and grows best in the layer 0–5 m, while scallop does in the near-bottom layer [53]. At the shallow-water stations, concentration of foods is highest at a depth of 9–10 m [14,54,55]; however the largest number of Japanese scallops is observed in horizon 9–16 m, where the concentration of its main competitors (Pacific mussel and Akazara scallop *Chlamys nipponensis*) and predators (seastar *Asterias amurensis*) is also lower [10].

Interspecific competition has a greater effect on the rate of scallop growth than concentration of food. According to our observations over collectors in Kit Inlet (St. 15), the total biomass of yearling scallop was maximum at the depth of 12 m (2,664.0 g); at the depth of 15 m, where the

mussel abundance was lower, this scallop biomass was higher than that at 9 m of depth (1,890.7 and 1,072.5 g, respectively). The high growth rate in scallop at the depth of 15 m can be related with the fact that the ATP content in the phytoplankton of the size group 3.0–15.0 μm was lowest at the depth of 10 m and highest at the depth of 20 m [56]. Phytoplankton needs biogenic elements, which come mostly from terrigenous material brought by rivers. In summer, the value of primary production was limited rather by the concentration of biogenic elements such as nitrates, which depend on river runoff, than by light [55]. For this reason, to increase mollusks' growth rate, farms are frequently situated in estuaries of major rivers [57]. However, if rivers are heavily turbid, the optimum conditions for settling and survival of larvae begin deeper than 30 m [58]. The increase in abundance of larvae with depth at the stations with hard bottom may be associated to a reduction of water flow velocity near uneven bottom surface and to a higher illuminance [59].

The intensity of food consumption by mollusks grows along the water column [60] that increases the negative influence on competitors. For this reason, collectors and cages are placed in the horizon, where the abundance of competitors is lower. In many countries of the world, collectors and cages for scallop aquaculture are lowered to the depth of 12 m [61,62], 15 m [14,63,64], 18 m [65], and even to 20 m [54]. The horizon 15–20 m is better for cultivation of the scallop *Placopecten magellanicus* than a depth of 9–10 m [15,54]. The total biomass of competitor fouling depends on location of farm and always decreases with depth [15]. As the depth increases and the distance from shallow waters grows, the tendency of depletion of species composition and the decline in quantitative characteristics of fouling on hydrotechnical structures becomes growingly more evident [66].

In 1978–1979, the highest abundance of juvenile Pacific mussel in Posyet Bay was recorded at the shallow-water stations in Minonosok Inlet (St. 1) and off Cape Mramorny (St. 11); two peaks in the vertical distribution of abundance were observed: at the depths of 0 and 3.5 m [10]. The third peak of abundance, probably associated to the global warming, was recorded later at the depth of 7 m (Figure 2C). When larvae detect the optimum temperature for life, this apparently serves a trigger mechanism to settle, and thus, the optimum horizon for larval settlement may shift by 1–2 m depending on the hydrological characteristics of year [28]. A comparison of mussel population dynamics on mussel collectors installed in the horizon 0–4 m in 1977–1989 [67] to those on scallop collectors placed during the same period within the horizon 7.5–12 m [68] showed a negative relationship between the water surface temperature and the number of mussels on the mussel collectors (R = -0.231, p = 0.448) and a positive one on the scallop collectors (R = 0.199; p = 0.514). In case of high temperatures, larvae settle more preferably on scallop collectors than on mussel ones.

On the eastern coast of Korea, Japanese scallop larvae are distributed within five miles off the shoreline at a depth of 10–30 m, and their location depends much on temperature, currents, and wind factors; however, the density depends on location of sampling point and increases markedly during high tides [69]. Based on location of the sites of larvae's concentration, it is possible to judge about location of adult animals, as well as about

the population status of bottom groups [70]. The horizon, at which parental individuals are found, is most likely the optimum horizon for settling of scallop larva. After we set up an experiment with white spawners in Minonosok Inlet (St. 1), Posyet Bay, in 1982 [25], the most of albinos among juvenile Japanese scallop were registered on scallop collectors located in the horizon 7–10 m. Spawners for the experiment were caught at these depths also. It is probable that the wild scallop populations, living at various horizons, have also specific genotypes.

Since in warmer years the optimum temperature for life is recorded deeper, larvae reach greater depths when searching for it, and, consequently, a positive relationship is established between the depth and vertical distribution of juveniles. According to Razin [71] and Scarlato [72], Japanese scallop occurs at depths ranging from 0.5 to 80.0 m, but the largest aggregations are formed within 6–30 m of depth. There is an evident relationship between mass settlement of scallop and availability of soils suitable for life. In the sheltered bays of Primorsky Krai and in apices of bays of its deeply indented coast, the bottom soils are mainly liquid or clayey silts, whereas those suitable for scallop—muddy sand, sand, or pebbles—are distributed only in the near-shore zone. Thus, scallop in these waters forms the largest aggregations at 6–18 m [71]. In Primorsky Krai, according to O.A. Skarlato [73], it inhabits waters northward to Rudnaya Inlet, in Chikhacheva Bay, and off western Sakhalin Island; in the Sea of Okhotsk, waters of Aniva Bay, Busse Lagoon, and the area south of the Gulf of Patience. However, modern studies of Japanese scallop enable researchers to decrease its thermopathy, since the northern boundary of *M. yessoensis* aggregations on the mainland shifted up to Tabo Bay (51°37'N), and the depth of its habitat has reached 138 m [74].

5. Conclusion

The studied invertebrates have specific thermopathy, and, due to variations in water temperature with depth, each marine species has its own horizon of the highest preference [10]. The more southward the center of the species range is located, the later the species spawns, and the upper horizon its juveniles occupy. For successful reproduction of valuable marine organisms, it is necessary to know and use the pattern of spatial distribution of juveniles of not only cultivated but also competitive and predatory species. Thus, in order to optimize the process of Japanese scallop cultivation, collectors should be placed in the horizon of the minimum abundance of mussels, at a depth of 9–16 m [10]. Nevertheless the subsequent observations, which were conducted during the period of noticeable climate changes, allowed to narrow this horizon to 9.5–15 m.

Acknowledgements

References

[1] Burton, C.A., Mac Millan, J.T. and Learmouth, M.M. "Shellfish ranching in the UK", *Hydrobiologia,* 465, 1-5, 2001.

[2] Watanabe, T. "The present situation and problems of mariculture in Japan", *Plant. and Soil,* 89. 351-369. 1985.

[3] Xiang, J-H. "Mariculture-related environmantal concerns in th people's republic of China", *Ecological and Genetic Implication of Aquaculture Activities*, 6. 219-228. 2007.

[4] Focardi, S., Corsi, I., Franchi, E. "Safety issues and sustainable development of European aquaculture: new tools for environmentally sound aquaculture", *Aquaculture International*, 13 (1-2). 3-17. Mar. 2005.

[5] Http://www.pewoceans. org.

[6] Http://www.whoi.edu/sites/marineaquataskforce.

[7] Shi, H., Zheng, W., Zhang, X., Zhu, M., Ding, D. "Ecological-economic assesment of monoculture and integrated multi-trophic aquaculture in Sanggou Bay in China", *Aquaculture*, 410-411.172-178. Oct. 2013.

[8] Su, Z., Xiao, H., Yan, Y., Huang, L. "Effect of fouling organisms on food uptake and nutrient release of scallop (*Chlamys nobilis*, Reese) cultured in Daya Bay", *J. Oceanic Univ. Chin.* 7 (1). 93-96. Sept. 2008.

[9] Belogrudov, E.A. "About some features of settling of larvae on collectors and growth of juvenile scallops *Mizuhopecten yessoensis*, Jay and other animals in Posyet Bay (Sea of Japan)", in *Materials of the Soviet-Japanese Symposium on Marine Biology,* Vladivostok Academic Publishers, 7-8. 1974.

[10] Gabaev, D.D. "Spatfall larvae of bivalve mollusks and starfishs on collectors in the Posyet Bay (Japanese Sea)", *Sov J Mar Biol*, 4. 263-268. 1981.

[11] Silina, A.B., Ovsyannikova, I.I. "The Yezzo scallop and it epibiosis in bottom and hanging cultures in Alekseev Inlet (Sea of Japan)", *The Bulletin of the Russian Far East Malacological Society.* Vladivostok Academic Publishers, 4. 103-105. 2000.

[12] Gabaev, D.D., Taupek, N.J. and Kolotukhina, N.K. "Specificity of conditions of existence a trade invertebrate on artificial substrata in evtrofical Amur Bay (Sea of Japan)", *Rus J Ecology*, 36 (4). 370-377. 2005.

[13] Ross, K.A., Thorpe, J.P. and Brand, A.R. "Biological control of fouling in suspended scallop cultivation", *Aquaculture*, 229 (1-4). 99-116. Jan. 2004.

[14] 14. Guenther, J., Southgate, P.C.and deNys, R. "The effect of age and shell size on accumulation of fouling organisms on the Akoya pearl oyster *Pinctada fucata* (Gould)", *Aquaculture,* 253 (1-4). 366. Mar. 2006.

[15] Claereboudt, M.R., Bureau, D., Cŏté, J. and Himmelman, J.H. "Fouling development and its effect on the growth of juvenile giant scallops (*Placopecten magellanicus*) in suspended culture", *Aquaculture*, 121 (4). 327-342. Apr. 1994.

[16] Greene, J.K., Grizzle, R.E. "Successional development of fouling communities on open ocean aquaculture fish cages in the Western Gulf of Maine, USA", *Aquaculture,* 262 (2-4). 289. Febr. 2007.

[17] VanDolah, R.F., Wendt, P.H., Kuott, D.M. and Wenner, E.L. "Recruitment and community development of sessile fouling asemblages on the continental shelf off South Carolina, USA estuarine, coast" *Shelf Sci,* 26 (6). 679-699. 1988.

[18] 18. De Lorenzo, M.E., Pennington, P.L., Chung, K.W., Finnegan, M.C. and Fulton, M.H. "Effect of the antifouling compound, isgarol 1051, on a simulated estuarine salt marsh ecosystem", *Ecotoxicology*, 18 (2). 250-258. Febr. 2009.

[19] Gabaev, D.D., Kolotukhina N.K. "The effect of predation by *Nucella (Thais) heyseana* on population of Japanse scallop *Mizuhopecten yessoensis* (Jay)", *Russian Journal of Ecology*, 30 (2).133-135. 1999.

[20] Belvin, S., Tremblay, R., Roussy, M. and McGladdery, S.E. "Inoculation experiments to understand mass mortalities in sea scallop, *Placopecten magellanicus*", *Journal of Shellfish Research,* 27 (2). 251-260. Apr. 2008.

[21] Gabaev, D.D. "Effect of fouling on thr Yezzo scallop *Mizuhopecten yessoensis* (Jay) in Peter the Great Bay (Sea of Japan)", *Oceanology*, 53 (2). 183-191. Mar. 2013.

[22] Oh, B.S., Jung, Ch.K., Kwon, M-G. and Lee, J.S. "The effect of Yellow Soil on Mortality of Korean scallops, *Patinopecten yessoensis* at Indor Tank", *Korean J. Malacology,* 26 (3). 179-183. Sep. 2010.

[23] Marti´nez, G., Aquilera, C. and Mettifogo, L. "Interractive effects of diet and temperature on reproductive conditioning of *Argopecten puppuratus* broadstock", *Aquaculture,* 183 (1-2). 149-159. Mar. 2000.

[24] Robert, R., Gérard, A. "Bivalve hatchery technology: the current situation for the Pacific oyster *Crassostrea gigas* and the scallop *Pecten maximus* in France", *Aquat. Living Resource,* 12 (2). 121-130. Jan. 1999.

[25] Gabaev, D. D. "Biological substantiation of new methods cultivation of some trade bivalve molluscs in Primorye", *Ph.D. thesis*, 1-129. 1989.

[26] Shanks, A.L., Brinr, L. "Upwelling, downwelling, and cross-shelf transport of bivalve larvae: test of a hypothesis", *Mar Ecol Prog Ser,* 302 (4). 1-12. Nov. 2005.

[27] Diagle, P.M., Metaxas A. "Vertical distribution of the marine invertebrate larvae in response to thermal stratification in the laboratory", *J. Exp. Mar. Biol. Ecol,* 409. 89-98. Sept. 2011.

[28] Gabaev, D.D. "Laws of settling on collectors of some invertebrate in Posyet Bay", *Biology of shelf zones of the World ocean, The thes SU Conf.* Vladivostok Academic Publishers, 54-55. 1982.

[29] Scavia, D., Field, J., Boesch, D., Buddemeier, R., Burkett, V., et al. "Climate change impacts on U.S. coastal and marine ecosystems", *Estuaries*, 25. 149-164. 2002.

[30] Drinkwater, K.F., Mueter, F., Friendland, K.D., Taylor, M., Hunt Jr, G.L., Hare, J. and Melle, W. "Recent climate forcing and physical oceanographic changes in Northern Hemisphere regions: A review and comparison of four marine ecosystems", *Progress in Oceanology,* 81.10-28. Apr. 2009.

[31] Belkin, I. "Rapid warming of large marine ecosystems", *Progress in Oceanography*, 81. 207-213. 2009.

[32] Belkin, I., Cornillon, P., Sherman, K. "Fronts in large ecosystems", *Progress in Oceanography,* 81. 223-236. 2009.

[33] Byrne, M. "Impact of ocean warming and ocean acidification on marine invetebrate life history stages: Vulnerability and potential for persistence in a changing ocean", *Oceanography and Marine Biology: An Annual Review,* 49:1-42. 2011.

[34] Ito, S., Kanno, H. and Takahashi, K. "Some problems on culture of the scallop in Mutsu Bay", *Bulletin of Marine Biological Station Asamushi*, 15 (2). 89-100. 1975.

[35] Kasyanov, V.L., Medvedeva, L.A., Jakovlev, S.N. and Jakovlev, J.M. "Reproduction of echinodermata and bivalvia molluscs", Moskow Academic Publishers, 1980. 1-135.

[36] Kasyanov, V.L, Krjuchkova, G.A, Kulikova, V.A, and Medvedeva, L.A. "The larvae of the marine bivalve molluscs and echinodermata", Moskow Academic Publishers,. 1983. 1-200

[37] Maru, K., Obara, A., Kikuchi, K. and Okesaku, H. "Studies on the ecology of the scallop *Patinopecten yessoensis* (Jay). On the diurnal vertical distribution of scallop larvae", *Ibid*, 15. 33-37. 1973.

[38] Heritage, G.D., Bourne, N. "Pacific oyster breeding in British Columbia", *Fish. Mar. Serv. Tech. Report*, 882. 1-140. 1977.

[39] Raby, D., Lagadeuc, Y., Dodson, J. and Mingelfier, M. "Relationship between feeding and vertical distribution of bivalve larvae in stratified and mixed waters", *Mar. Ecol. Prog. Series.* 103(3). 275-284. Jan. 1994.

[40] Revkov, N.K., Shalyapin, V.K. "Features of vertical distribution of larvae *Mytilus galloprovincialis* and formation of settlements of a mussel in Black Sea", *Ecology of Marine*. 48. 58-62. 1999.

[41] *Bayne B.* "Primary and secondary settlement in *Mytilus edulis* L. (Mollusca)", *J. of Animal Ecology,* 33 (3). 513-523. 1964.

[42] Milejkovsky, C.A. "Ecology and behaviour of larvae of mussels during them stay in a plankton", *Trade bivalve molluscs-mussels and their role in ecosystems*, Leningrad Academic Publishers, 86-87. 1979.

[43] *Peteltihina T.S.* "Cultivation of mussels in Barents Sea", *Biology and cultivation molluscs. The collection of proceedings,* Moskow ASJFO. 60-67. 1987.

[44] Gallager, S.M., Mainiel, J.L., Manning, D.A. and O'Dor, R.K. "Ontogenetic changes in the vertical distribution of scallop, *Placopecten magellanicus*, larvae in 9 m deep mesocosms as a function of light, food, and temperature", in *9 th International Pectinid Workshop*, Nanaimo, B.C., Canada, 1. 38-44. 1994.

[45] Manuel, J.L., Pearse, C.M., Manning, D.A. and O'Dor, R.K. "The response of sea scallop (*Placopecten magellanicus*) veligers to a weak thermocline in 9-m deep mesocosms", *Marine Biology*, 137 (1). 169-175. Aug. 2000.

[46] Pearce, C.M., Gallager, S.M., Manuel, J.L., Manning, D.A., O'Dor, R.K. and Bourget E. "Settlement of larvae of the giant scallop, *Placopecten magellanicus*, in 9 m deep mesocosms as a function of temperature stratification, depth, food, and substratum", *Marine Biology*, 124 (4). 693-706. Sept. 1996.

[47] Konev, V.B. "A hydrochemical sketch of Pallada Bay in Posyet Bay. Primorye territorial administration on hydrometeorology. A bureau of calculations and inquiries." *Vladivostok. PMGMS.* 1990. 1-249.

[48] Tremblay, M.J., Sinclair, M. "Sea scallop larvae *Placopecten magellanicus* on Georges Bank: vertical distribution in relation to water column stratification and food", *Mar. Ecol. Progr. Series,* 61. 1-15. Mar. 1990 A.

[49] Tremblay, M.J., Sinclair, M. "Diel vertical migration of sea scallop larvae *Placopecten magellanicus* in a shallow embayment", *Mar. Ecol. Progr. Series,* 67. 19-25. Sep. 1990 B.

[50] Ma, H., Grassle, J.P. and Chant, R.J. "Vertical distribution of bivalve larvae along a cross-shelf transect during summer upwelling and downwelling", *Marine Biology*, 149 (5). 1123-1138. Aug. 2006.

[51] Shuvalov, V.S. "Character of vertical distribution of larvae of bottom invertebrate", *Laws of distribution and ecology of the coastal biochenosis,* Leningrad Academic Publishers, 32-34. 1978.

[52] Kolganova, T.N., Hrushkova N.G. "To an estimation of a forage reserve of the Yezzo scallops in to lagoon Busse (Island of Sakhalin)", *The thes SU Conf.* Vladivostok PJSFO, 171. 1983.

[53] Kuznetsova, I.A. "The characteristic of a food of the Yezzo scallops and edible mussels in conditions of mariculture", *Biology of objects of mariculture. Biology and cultivation invertebrates and seaweeds.* Moskow Academic Publishers, 65-69. 1987.

[54] Fréchette, M., Gaudet, M. and Vigneau, S. "Estimating optimal population density for intermediate culture of scallops in spat collector bags", *Aquaculture*, 183 (1-2). 105-124. Mar. 2000.

[55] Zvalinsky, V.I, Lobanov, V.B, Zaharkov, S.P. and Tishchenko, P. J. "A chlorophyll, the slowed down fluorescence and primary production in a northwest part Sea of Japan in the autumn of 2000", *Oceanology,* 46 (1). 23-32. Jan. 2006.

[56] Gordienko, A.P., Yerokhin, V.E. and Chaida, V.G. "Research of a forage reserve of mussels in Kandalaksha Bay", *Marine Ecology*, 47. 84-89. 1998.

[57] Moiseyev, P.A, Karpevich, A.F. and Romanycheva, O.D. "Marine aquaculture". *Moskow Agrapromizdat*, 1985. 1-253.

[58] Pereladov, M.V. "To a question on the factors defining survival rate of larvae mussels at settling, and about several structure of biotop the Black Sea mussel", *V th All-Union conference on trade invertebrate,* Moscow ASJFO, 132-134. 1990.

[59] Gabaev, D.D. "Through-cultivation of the trade bivalve molluscs", *Questions of Fishery*, 9(1) (33). 218-243. 2008.

[60] Soldatova, I.N., Reznichenko, O.G. and Tsihon-Lukanina, E.A. "Features of fouling installations of mariculture of the Sea scallop", *Oceanology*, 25 (3). 513-518. 1985.

[61] Naidu, K.S., Scaplen, R. "Settlement and survival of the gigant scallop, *Placopecten magellanicus*, larvae on enclosed polyethylene film collectors", *FAO Technical Conference on Aquaculture E. Preprint Kyoto,* 5. 1976.

[62] Wallace, J.C., Reinsnes, T.G."Growth variation with age and water depth in the Iceland scallop (*Chlamys islandica*, Pectinidae)", *Aquaculture*, 41 (2). 141-146. Sept. 1984.

[63] Aoyama, T. "Culture and propagation of scallop on Mutsu Bay, Aomori Prefecture, and the observation system of the related environmental factors", *Bulletin of the Japanese Society Fisheri & Oceanography*, 50 (2). 179-180. 1986.

[64] Ovsyannikova, I.I. "Distribution of cirrifooting cancers on shell of the Yezzo scallops at cultivation in hanging culture", *Sov J Mar Biol*, 4. 71-76. 1989.

[65] Allen, D.M. "Biological aspects of the calico scallop *Argopecten gibbus*, determined by spat monitoring", *Nautilus*, 93 (4). 107-119. 1979.

[66] Kashin, I.A., Maslennikov, S.I. "Fouling of constructions for cultivation of the Yezzo scallops", *Sov J Mar Biol*, 4. 90-97. 1993.

[67] Gabaev, D.D., Kucherjavenko, A.V. and Shepel, N.A. "Anthropogenous evtrofication of Posyet Bay Sea of Japan by installations of mariculture", *Sov J Mar Biol*, 24 (1). 53-62. 1998.

[68] Gabaev, D.D. "Dynamics of the abundance of som bivalve species in Russian waters of the sea of Japan and its Prognosis", *Oceanology,* 49(2). 237-247. Apr. 2009.

[69] Park, Y.J.**,** Rhee, W.Y. "Spat collection and larvae distribution of the scallop, *Patinopecten yessoensis* (Jay) in the east sea of Korea", in *9 th International Pectinid Workshop,* Nanaimo, B.C., Canada. 1. 194. 1994.

[70] Sergeenko, V.A, Shpakova, T.A. and Kulikova, V.A. "Distribution and density of pelagian larvae of the Yezzo scallops (*Mizuhopecten yessoensis*) in the summer period in Aniva Bay (southern of Island Sakhalin)", *Works of SachSIIPO*, 7. 71-82. 2005.

[71] Razin, A.I. "Sea trade molluscs of southern of Primorski Territory", *Proceedings of PSIIFO,* 8. 1934. 1-110.

[72] Skarlato, O.A. "Bivalve molluscs of the Far East Seas USSR (group of Dysodonta). A determinant on fauna of the USSR", *Leningrad Academic Publishers,* 71. 1960. 1-150.

[73] Skarlato, O.A. "Folding molluscs of temperate waters of a northwest part of Pacific ocean", *Leningrad Academic Publishers,* 1981. 1-480.

[74] Dulenina, P.A, Dulenin, A.A. "Distribution, dimensional, age structure and growth of Yezzo scallops *Mizuhopecten yessoensis* (Bivalvia: Pectinidae) in the northwest parts of Tatar Strait", *Sov J Mar Biol*, 38 (4). 290-297. 2012.