INTERANNUAL VARIATIONS IN BENTHIC FORAMINIFERA ASSEMBLAGES UNDER MARICULTURE SITES IN ALEKSEEV BAY (POPOV ISLAND, THE SEA OF JAPAN)

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Modern benthic foraminiferal assemblages in Alekseev Bay (Popov island), the Sea of Japan were studied during mariculture farming of Japanese scallop (*Mizuhopecten yessoensis*) and after its liquidation. Results of foraminiferal analysis pursued in period from 1985 to 2007 years show gradual changes in assemblage composition – increase of species richness from 86 to 107, number of agglutinated species from 2-3 up to 5-13 species and their distribution area under the mariculture. The most dominant families are Elphidiidae (*Cribroelphidium frigidum*, *Protelphidium asterotuberculatum*, *Elphidium advenum depressulum)*, Discorbidae (*Buccella frigida)* .The most abundant agglutinated families are Trochamminidae и Ataxophragmiidae (*Trochammina inflata, Eggerella advena*).

Key words: mariculture, benthic foraminifera, assemblages, ecosystem recovery, the Sea of Japan.

I. INTRODUCTION

Humankind has been damaging the seas for decades by discharging pollutants into the water, destroying coastal ecosystems and overexploiting marine organisms. Aquafarming is known to change ecological condition of bays and coves, especially if it is done by bivalve outboard method. There are many research papers about changes in ecological structure of benthic communities in the conditions of mariculture in different marine ecosystems [1,2,3,4]. Suspended organic matter is reduced due to filtering processes by cultivated shellfish, thereby the concentration of fecal metabolites at the bottom is increased, which leads not only to its siltation, but also to the accumulation of organic matter in the soil [5]. This in turn leads to the bacterial growth, oxygen deficit, macrobenthos total abundance and number of species reduction, meiofauna population density increase [6]. Similar changes have occurred in the composition and distribution of benthic foraminifera in the Alekseev Bay studied under scallop farming over 10 years (1978-1988 years) and in the years after mariculture facilities removal [7,8,9]. Benthic foraminifera is a large group of protozoa with the body protected by shell. They are widely distributed in marine basins and found at all latitudes and depths of the oceans from the intertidal zone to the ultra depths. Among meiobenthic animals foraminifera may predominate both in number and biomass in many marine ecosystems, making it possible to work with relatively small samples to get statistically significant results [10]. Benthic foraminifera are a particularly useful group for environmental biomonitoring because they are highly sensitive to environmental perturbations [10, 11, 12].

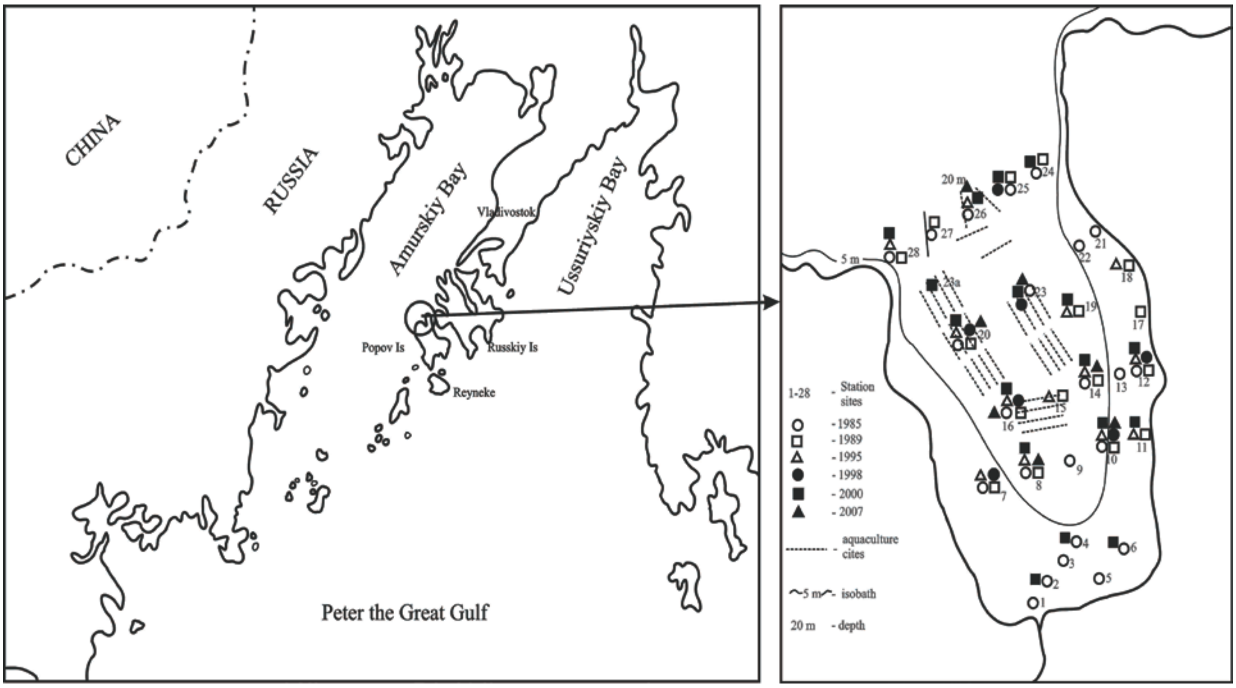

Fig. 1. Schematic map of the study area and the location of sampling stations collected in period of 1985-2007.

II. MATERIAL AND METHODS

Undisturbed sediment samples were collected at 28 stations in Alekseev Bay in August-September 2000 (17 stations) and in August 2007 (7 stations) at water depth from 0.5 to 20 m (Fig.1). Samples were taken at each station (2-3 sample per station) with 5-cm core sampler by SCUBA diver at 1-2 cm sediment depth. Simultaneously organic matter and granulometry analyses were collected. Samples for TOC were frozen immediately until laboratory treatment. For faunal analysis, samples were stored in a solution of Ethanol (70%) and Rose Bengal. After 24-hours samples were washed through 63-mµ sieve and dried at 80ºC. Foraminifers were separated from residue by floatation method [13] using carbon tetrachloride(CCl_4). Foraminifera were selected using binocular microscope. The total assemblage (living and dead) were picked and identified following the generic classification of Loeblich and Tappan [14]. Scanning electron micrographs were taken on selected species at SEM EVO 50. Several parameters linked to the assemblages were calculated indicating the foraminiferal density (FD, defined as the total number of individuals in a sample per square meter of the bottom), the species richness defined as the total number of species in each station, the number of species with agglutinated and secreted tests and the specific diversity indexes were determined using Shannon-Weaver and Fisher indexes [15, 16].

Sediments were classified based on the dominant diameter of silt, sand, gravel, pebbles and biogenic particles present in the samples. Total content of particles different in size were determined using traditional nomenclature of particles [17]. The degree of bottom siltation was determined by calculating the average value of the fraction (<0.25 mm) for silt and pelites of different granularity present in the sample. The total organic carbon in dry sediment was determined by dichromate oxidation [18].

III. RESULTS

Alekseev Bay (Peter the Great Bay, Japan Sea) is positioned in the north-western coast of the Popov island laying between high, steep, rocky headlands (Fig. 1). Its length is 1250 m, width - 700 m, an area of 0.9 km^2. The bay is half-closed and communicates with the Amur Bay by wind-driven waves. The bay's shores, are elevated and bordered by narrow sand and pebble beaches, rocky placers or boulders, with the exception of the coast of its summit (inner part) [19]. The top of the bay is relatively shallow (1 to 3 m depth), the depth increases to 9-10 m in the middle, and then uniformly increases to 15-20m towards the bay's exit. The water temperature in the bay significantly changes depending on the season. On the surface, it goes above 0 in mid-March, reaching a maximum (+ 23-24ºS) in the upper mid-August. In late November - early December, the water temperature drops below 0°C. Minimum temperature (-2ºS) recorded in January and February, which is the same as at a depth of 10-15 m in March. The salinity in the bay varies slightly (30-32 ‰). The difference in salinity between the surface and bottom layers of water at the outlet from the bay is less than 2 ‰.

This work is a result of long term research of benthic foraminifera composition and distribution in Alekseev bay (1978-1988), where for 10 years scallops were grown in cages, the young scallops were seeded over large areas, and in the last year mussels were also farmed in this area [4,7]. Creating populations of farmed aquatic organisms has led to ecosystem deterioration. It is known that the spatial and quantitative distribution of benthic foraminifera is closely related to the type of sediment, which is inhabited by animals [4, 20]. The ratio of bottom sediments siltation in the period used in mariculture Alekseev (1985) is 60%. After 12 years after the removal of the farm (2000), this figure fell to 39%. The granulometry results for sediments collected in 2007, also showed a decrease siltation of bottom sediments on the same stations for all years of study up to 34%. It also revealed a decrease in the C_{org} in sediments from 4-5% (1985) down to 0.9% (2000) and 1.2% (2007).

Significant changes occurred in foraminiferal assemblages in 12 years after the liquidation of the marine farm (2000). Species composition was changed: number of species increased, some species disappeared and many other species became widespread. There were 107 species belonging to 47 genera and 21 families. The most abundant families are the Elphidiidae, Discorbidae, Trochamminidae and Ataxophragmiidae. They were joined by representatives of other families - *Buliminella elegantissima* and *Cribrononion incertus* spread throughout the bay. The number of agglutinated species has risen up to 21. It should be noted that *Rotaliammina ochracea*, seen at certain stations before, has been found at almost all stations of the bay. *Ammoscalaria fluvialis*, *Ammotium inflatum*, *Glomospira gordialis*, *Siphonaperta macbeathi*, first appeared in the bay in 1998 also spread to several stations. The number of agglutinated forms at some stations increased to 13. In 1985 values of FD were 800±280 thousand ind/m^2 but comparing with years of mariculture (1989-1998) when the FD were gradually reduced, the average value of FD became 600±170 thousand ind/m^2 in 2000. The percentage of living individuals in assemblage averaged 32%, which was comparable with the data 1995 (30%) and 1998 (36%), but was higher than in 1985 (11%) and 1989 (24%). The values of species diversity indices ranged from 0.69 to 1.52 and from 2.58 to 21.48. The content of agglutinating foraminifera dropped to 30%. *C. frigidum* became the dominant species at most of the stations in the southern part of the bay. *T. inflata* - in the central part, as in 1998, while *P. asterotuberculatum* - towards the mouth of the bay and the mouth itself.

After 19 years after the scallop mariculture liquidation in Alekseev bay (2007) 104 species belonging to 43 genera of 20 families were found. 10 species are the most abundant: *Trochammina inflata, Eggerella advena, Quinqueloculina cf. quinquecarinata, Buccella frigida, Discorbis subaraucana, Cribroelphidium frigidum, Protelphidium asterotuberculatum,* *Elphidium advenum depressulum, Retroelphidium subgranulosum, Buliminella elegantissim*a (Fig. 2.). Secretion species dominanted. Agglutinated foraminifera ranged from 11 to 44%. The exception was the north-east part of the bay (station 23), where the greatest number of foraminifera (57%) with a sand wall were found at a depth of 13 m. The highest FD is also marked here. It was more than 2.5 million ind/m^2. Agglutinated species *E. advena* and *T. inflata* dominated and subdominated respectively. High FD values were also observed in two other areas of the bay at a depth of 7 and 5.5 meters (st. 14 and st. 20) more then 1 million ind/m^2. Species with calcareous wall were the most abundant. *C. frigidum* dominated at both stations, *P. asterotuberculatum* were subdominant at st. 20 and at the st. 14 with *C. frigidum* were dominant. *B. frigida* and *E. advenum depressulum* were subdominant. The percentage of living individual species in these stations was the lowest among all studied areas - 15% and 11% respectively. The lowest density (278 thousand ind/m^2) was at the mouth of the bay at a depth of 20 m (station 26) where inequigranular silts prevail in this area. The percentage of living species in the area was

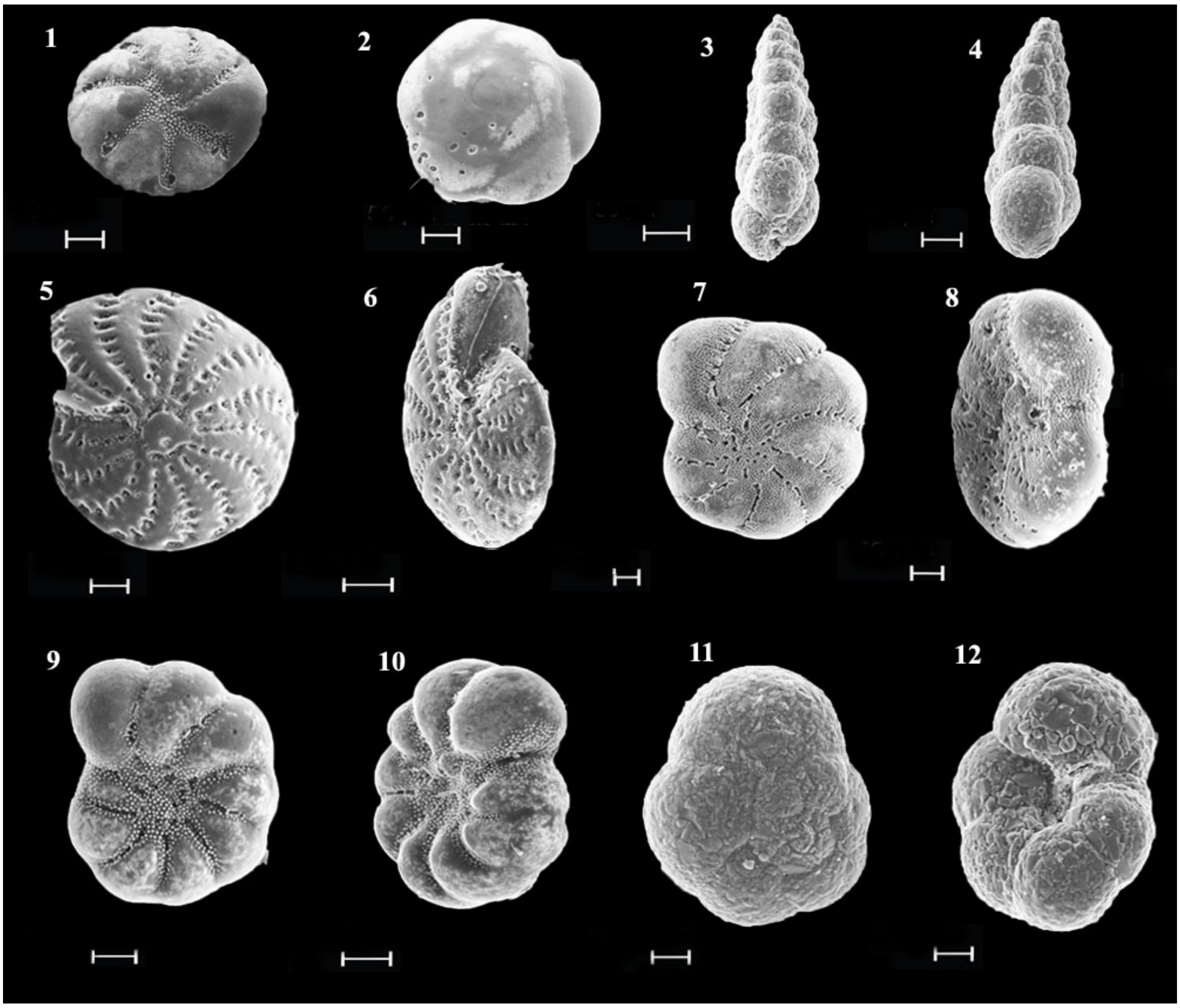

Fig.2. Electron images of representative foraminiferal species from Alekseev Bay: 1,2 – Buccella frigida; 3,4-Eggerella advena; 5,6-Elphidium advenum depressulum; 7,8 –Cribroelphidium frigidum; 9,10,- Protelphidium asterotuberculatum; 11,12 – Trochammina inflata, scale bar 50 µm.

the highest (46%). *P. asterotuberculatum* was dominant, while *E. advena was* subdominant. The FD was similar on the other stations in the eastern and western parts of the bay (stations 8, 10, 16), and ranged from 288 to 304 thousand ind/m^2. The highest number of agglutinating foraminifera in these areas was found at the station 10 (44%). *T. inflata* dominated, *C. frigidum* and *E. advena* were subdominant. *C. frigidum* prevailed at st. 8 and 16, *P. asterotuberculatum, T.*

inflata and *E. advena* were the second most present. The percentage of living species ranged from 18 to 32%.

IV. DISCUSSION

Results of the faunal analysis showed a gradual change in foraminiferal assemblages in the period from 1985 to 2007 as appeared in qualitative composition and distribution in the bottom sediments of the bay: increasing in species richness, structural reorganization of the assemblages, growing number of families and genera, agglutinated species and their distribution areas, increasing their numbers in the stations (from 2-3 to 5-10 species), which were previously located under the mariculture cages. Species richness also increased significantly at the stations as well where former mariculture cages were stationed. However FD decreased from year to year up until 2000, 12 years after the completion of marine farming, this figure increased to 600 thousand ind/m^2, and S increased to 107. In 2007 104 species were found at 7 stations and FD increased to 800 thousand ind/m^2, the number of live specimen increased by 2.5 times (from an average of 11% in 1985 to 28% in 2007) (Table. 1).

Table 1. Structural dynamics of foraminiferal assemblages in Alekseev Bay during 1985-2007.

Years	**1985**	**1989**	**1995**	**1998**	**2000**	**2007**
Species richness (S)	86	90	91	102	107	104
Number of families	15	20	20	19	21	20
Number of genus	35	42	41	41	47	43
Number of calcareous species	73	76	77	87	86	84
Number of agglutinated species	13	14	14	15	21	20
Average FD (thousand ind/m2)	800	400	300	200	600	800
Average percent of living individuals	11	26	30	36	32	28

The results of foraminiferal research allow us to recognize changes after 19 years after mariculture and shellfish cultivation in surveyed area levels of ecosystem. Granulometric structure of sediments gradually changed. The content of clay fractions in the soil at the same stations during 1985-2007 declined from an average of 64% (1985) to 39% (2000) and to 34% (2007). Apparently, this is one of the reasons that caused the structural reorganization in the foraminiferal assemblages. It showed in increasing species diversity, number of individual species, appearance of new species as well as a change of dominant and subdominant species of foraminifera. The area as well as FD of dominanated species of *C. frigidum, B. frigida* reduced after the mariculture farming. *T. inflata, E. advena, P. asterotuberculatum* become dominant and subdominant species at most stations in 2007, and prevailed only in a few stations in 1985 (Fig.3). There was a change in foraminiferal structure in 2000. *C. frigidum* and *B. frigida* were again widespread in many parts of the bay, which might be an indicator of the bottom sediments with a high degree of silting and high content of organic matter in sediments. There might be several reasons for this. Firstly, it could be due to the high content of C_{org} (0.2 - 1.4%) favorable for foraminifera fauna. Secondly, it could be due to increasing siltation (39%) of bottom sediments common to all stations as a result of intensive terrigenous runoff, intensified during the cyclonic activity in 1998-2000. According to the Department of long-term weather prediction, Far Eastern Regional Hydrometeorological Research Institute rainfall in these years was 2 times higher than the normal level, which resulted in an increase in the terrain runoff into the bay. This lead to an increase of nutrients.

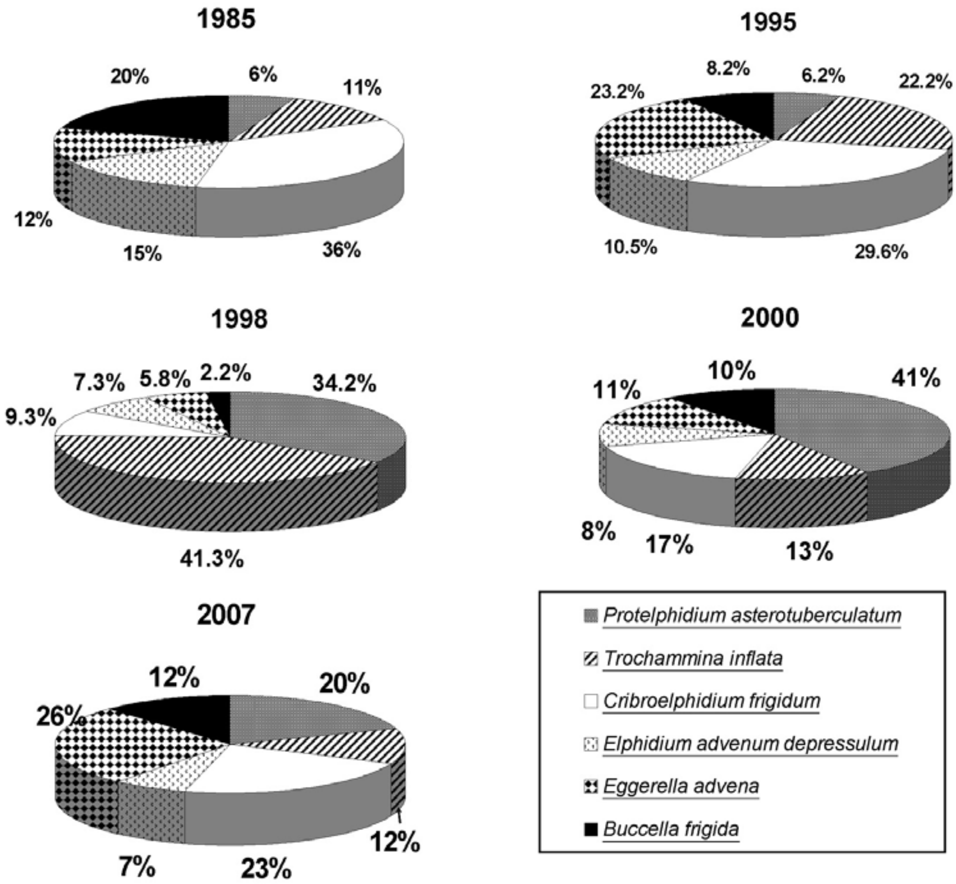

Fig.3. Percent ratio of the most representative species of Foraminifera in Alekseev Bay during 1985-2007.

Another reason for this change could be the disappearance of most groups of macrobenthos due to increased poaching in recent years. Visual observations by researchers from Marine Biology Institute and Pacific Oceanological Institute suggested that sea urchins, sea cucumbers, large clams, fish and even a few stars almost completely disappeared in Alekseev Bay. It could contribute to an increase in the number of meiobenthic animals [21]. Many researchers attribute spreading of meiofauna not only to sufficient food supply, but also as absence or reducing predation and competition for food among the macro- and meiofauna [11,22]. The structure of foraminiferal assemblages Alekseev Bay might be changed due to decreasing share of organic matter in the sediments from 4-5% in 1985 to 0.9-1.4% in 2000 and 2007. The expert opinions about the relationship between foraminiferal and other meiobenthos distribution of the share of organic matter in sediments differ. Some authors identified foraminifera distribution patterns by the content of organic matter in the sediment [24]. Many others have shown that the abundance of benthic organisms is not connected directly with concentration of total organic matter in the sediment [25]. However, all of them believe that the content of organic carbon in the sediments is an important factor controlling the number of foraminifera. Low concentrations, as well as extremely high ones, adversely affect their activity.

In coastal areas, which receive large amounts of organic matter, the number of common species can either decrease or increase, but species diversity is usually diminished. Other researchers also noted small number of species and low abundance of foraminifera directly in the areas of human impact. However, dramatic increase in species diversity was observed in few hundred meters of domestic waste [12]. Record values of FD of up to 6 million ind/ m^2in

Alekseev Bay were recorded during mariculture farming. We may conclude that after scallop mariculture was liquidated, foraminiferal assemblages changed significantly: foraminiferal diversity increased from year to year, FD decreased, percentage of living individuals in total assemblages increased and so did the number of agglutinated species (Table 1).

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