BENTHOS STUDIES IN FEEDING GROUNDS OF THE OKHOTSK-KOREAN GRAY WHALE POPULATION IN 2007

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Feeding whale near Chayvo Lagoon (Photo by Yu. M. Yakovlev)

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RESEARCH REPORT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TEXT PHOTOGRAPHS

INTRODUCTION

General information[1]. We know that two independent gray whale (*Eschrichtius robustus*) populations (LeDuc et al. 2002) reside in the Pacific Ocean: the eastern or California–Chukotka population, which reached a size of about 18,000 animals in 2001 (Rugh et al. 1999; Le Boeuf et al. 2000; Rugh et al. 2005), and the western Pacific or Korean–Okhotsk population, numbering about 120 animals (Cooke et al. 2007, Yakovlev et al. 2007, Yakovlev and Tyurneva 2008).

After commercial whaling decreased in the 1940's, the eastern gray whale population increased to approximately 26,000 individuals by 1998 (Rugh et al. 1999) and since fell back to approximately 18,000 individuals (likely its carrying capacity) by 2001 (Rugh et al. 2005). Although an increase in the death rate, a low birth rate, and deterioration of the physical condition of some animals were observed in the eastern population in 1999 and 2000 (Moore et al. 2001), the status of the population was considered reasonably stable due to its large size (LeBoeuf et al. 2000).

In contrast to the eastern population, the Korean-Okhotsk (or western) gray whale population has probably never been large, and according to some estimates did not exceed 2,000–2,500 individuals at its peak (Berzin 1974; Yablokov and Bogoslovskaya 1984). Many years of whaling brought the population to near extinction, and it was only in the early 1970's that gray whales began to be sighted off northeastern Sakhalin (Berzin 1974; Brownell and Chun 1977; Blokhin et al. 1985). A 40-year ban on whaling (beginning in the 1960's) failed to produce a substantial recovery of the western population. For several years, the whale population was estimated to be between 120 and 250 individuals; more recent estimates have indicated a total population towards the lower end of this range (Cooke et al. 2006, 2007; Yakovlev et al. 2007, Yakovlev and Tyurneva 2008). In 2007, IBM photographed 131 individuals (Yakovlev and Tyurneva 2008).

It has been suggested that there are fewer than 50 remaining individuals capable of reproduction (Weller et al. 2001). Because of low reproduction rates, genetic uniqueness (LeDuc et al. 2002), and low total population (Weller et al. 2000; Vladimirov 2000), the Korean–Okhotsk gray whale has been classified as critically endangered on the IUCN List of

[1] Because more detailed information about the history of benthos studies, data on benthos distribution in the Eastern Sakhalin area, and the feeding of the California-Chukotka gray whale population is available in the report Kusakin, O.G., Sobolevskii, E.I., and Blokhin, S.A., 2001, Review of Benthos Research Literature for the Northeast Sakhalin Shelf. Interim Report of IBM DVO RAN and TINRO, Vladivostok, the present authors did not attempt a literature review herein. Published works are cited by us when discussing our findings and in other

Threatened Species (USFWS 1997; Hilton-Taylor 2000), and has been placed in category I of the Russian Federation Red Book (2000).

The startup of offshore commercial oil and gas development on the eastern Sakhalin Shelf in the mid-1990's necessitated comprehensive study of the Okhotsk-Korean gray whale population to assess possible anthropogenic impacts on the population and to develop mitigation measures (Berzin and Vladimirov 1996; Vladimirov 2000). Following the joint declaration of the Gore–Chernomyrdin Commission "On Measures to Ensure Biodiversity Conservation in the Sakhalin Island Area" dated 7 February 1997, the Russian and American parties prepared a joint "Okhotsk–Korean Gray Whale Population Monitoring and Research Program" in 1998, which was approved by the Russian State Committee on Environmental Protection (Goskomekologiya) and the U. S. Fish and Wildlife Service (Weller et al. 2001). The program proposed multidisciplinary studies of the Okhotsk–Korean population during the whales' feeding season off eastern Sakhalin: abundance and distribution surveys, acoustic studies, and a study of benthos as the key component in the diet of gray whales.

In 2001, 10 diving transects were sampled in the northeastern Sakhalin coastal zone in an area from Niyskiy Bay in the south to Tront Bay in the north. Four transects were sampled in the Piltun gray whale feeding area – the area seaward of Piltun Bay. It was demonstrated that at depths of 5 to 15 m, this area is characterized by a great abundance of forage benthos, primarily amphipods and isopods (Fadeev 2002).

For many years, the Piltun Area was considered to be the only gray whale feeding location off the east coast of Sakhalin Island, although small groups of animals were sometimes sighted further from shore (Sobolevsky 1999; Miyashita et al. 2001). On 10 September 2001, however, observers M. Maminov and Y. Yakovlev working aboard a seismic research support ship en route to refueling observed seven gray whales feeding seaward from Chayvo Bay. Subsequent aerial and ship-based surveys of the area resulted in the discovery of a second gray whale feeding area, referred to as the "Offshore area" (Maminov and Yakovlev 2002). This area is located on a traverse from the middle of Chayvo Bay to southern Niyskiy Bay, at a distance of 20–45 km from the latter in depths of 30–50 m. Whales were observed to feed here from September through November 2001 (Blokhin et al. 2002) in numbers ranging from 48 to 83 individuals. In subsequent years, whales continued to use this area, although the numbers in 2003-2004 were lower than those in 2001-2002

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necessary circumstances. Also, the above cited report (Kusakin et al. 2001) is available on the Internet at www.sakhalinenergy.com.

(Blokhin et al. 2003, 2004), while numbers in 2005-2006 were intermediate (Vladimirov et al., 2006, 2007).

A proposal was developed in 2002 for a comprehensive study of gray whales in the Piltun shallow-water feeding area, in the deeper-water Offshore area and in control areas where gray whales are not observed feeding. The fieldwork for the study was done in 2002–2007 during expeditions on the marine tug *Nevel'skoy* and the research vessel *Akademik Oparin*. The studies included gray whale prey/benthos surveys.

The first data obtained in 2002 on the benthos composition and distribution indicated that gray whales feed in the Offshore area where it is dominated by ampeliscid amphipods (Fadeev 2003, 2004, 2005, 2006, 2007). Amphipods of the genus *Ampelisca* are the most widespread and best-known food item in eastern gray whale feeding locations (Zimushko and Lenskaya 1970; Blokhin and Pavlyuchkov 1999; Bogoslovskaya 1996; Zenkovich 1937; Kusakin et al. 2001; Jones and Swartz 2002; Nerini 1984; Oliver et al. 1983, 1984). In comparision, the feeding grounds of the Piltun Area are dominated by epibenthic amphipods that differ from ampeliscid amphipods in both ecology and their diet (Sobolevsky et al. 2000; Fadeev 2007).

The objective of this survey during 2007 was to continue studies of the distribution and status of benthos in the Piltun and Offshore feeding areas, and at other sites where whales were observed to be feeding in 2007, to further our understanding of gray whale distribution and movement in response to prey availability.

This work was perfromed under the Okhotsk-Korean Gray Whale Population Monitoring and Research Program funded by the Sakhalin II project (operated by Sakhalin Energy Investment Company Ltd. (SEIC) and Sakhalin-1 project (operated by Exxon Neftegas Ltd. (ENL)).

<u>Tasks of the study.</u> This report was prepared based on the results of benthos studies conducted in July–October 2007 by an expedition of the Marine Biology Institute of the Far East Branch of the Russian Academy of Sciences on the research vessel *Akademik Oparin.*

The tasks of the study were:

- conduct benthos studies in the Piltun and Offshore whale feeding areas by collecting bottom grab samples using stations of the 2002 network;
- study benthos in the near-shore zone (to a depth of 12 m) of the Piltun traverse using diving equipment and underwater videography;
- investigate the benthos composition at gray whale feeding sites;

- obtain information on the species composition and abundance (colony density and biomass) of individual taxonomic groups and common species of benthos from analysis of macrobenthos collections;
- assess the composition and abundance of macrobenthos in the whale feeding areas and outside the feeding zones;
- perform a morphometric analysis of the common species of amphipods and isopods to assess the size distributions;
- obtain data on the hydrology and particle size distribution of sediments in feeding grounds and at feeding sites of gray whales as factors that may influence production and composition of macrobenthos;
- compare the benthos distributions in the Piltun and Offshore areas based on materials for 2007 and 2006, 2002.

MATERIALS AND METHODS

1. Materials and Methods for Field Studies

1.1. Material

<u>Research team and study period.</u> Field work for this 2007 survey was performed by a team from the Marine Biology Institute of the Far East Branch, Russian Academy of Sciences, aboard the research vessel *Akademik Oparin* from July 19 to October 10, 2007. The team included an underwater videographer from the DVO RAN Pacific Geographical Institute.

<u>Background to survey design and site selection in 2007.</u> The selection of sampling sites was based on results of previous surveys:

1. The stations sampled during 2007 were again based on those sampled during 2002, with collection of grab samples in the Piltun, Intermediate, and Offshore areas (Fig. 1).
2. In contrast to 2002-2003, gray whales were not recorded in the Offshore area during July and August 2004–2005. A few whales were observed feeding there only in September. Photo identification work in 2003, 2004, 2005, 2006 and 2007, showed that there were 35, 8, 7, 33 and 70 individual gray whales in the Offshore feeding area during those years respectively (Yakovlev and Tyurneva 2004, 2005, 2006, 2008; Yakovlev et al 2007). More benthic sampling was conducted at whale

feeding sites in the Offshore area in 2007, compared to 2004-2006, due to recent increased use by whales of the Offshore area.

3. In 2004-2005, whales were observed atypically feeding in deeper waters (>15 m) in the northern Piltun area. Sampling at these whale feeding locations determined that whales may have been feeding on concentrations of sand lance during these years. In 2007, samples were collected at these same sites where whales were no longer feeding to characterize the benthos present.
4. During 2006, whales were observed regularly feeding near Chayvo Bay, prompting increased sampling at whale feeding locations area during 2007.

<u>Characteristics of field collections</u>. Two basic gray whale feeding areas were studied in 2007: 1) Piltun Feeding Area (coastal zone from Odoptu Bay to southern Piltun Bay) and 2) Offshore Feeding Area (30–45 km from the coast from middle Chayvo Bay to southern Niyskiy Bay). Also investigated in 2006-2007 was an small local area in the vicinity of Chayvo Bay 40 km from the inlet to Piltun lagoon at locations where gray whales were observed feeding.

A consistent approach was used in planning the locations of benthos stations in both areas in 2007 and 2002-2006. During planning of the studies in 2002, the waters of the Piltun area were divided into 60 sectors of equal area making up five blocks corresponding to the aerial survey sectors. Within each sector, the locations of the stations were determined according to a random number table in 2002-2007 (60 stations). The accuracy of vessel positioning in 2007 relative to the 2002 stations in the Piltun area was affected by weather and navigational conditions and was 198±21 (SE) m on average; this is regarded as satisfactory.

In 2002 and 2003, the Offshore survey area was divided into 36 sectors (four blocks), each of about 115 sq km. There were 36 stations. The individual sectors in the Offshore area have a larger area than those in the Piltun area. In 2003, gray whales were observed further east outside of the Offshore sampling grid (Maminov 2004), and therefore the 2004-2007 station grid in the Offshore area was expanded eastward (48 stations). The 2002 network of stations was repeated in its entirety in 2007. The accuracy of 2007 vessel positioning relative to 2002 stations averaged 280±38 m.

The locations of benthos sampling stations in 2007 are shown in Figure 1. Grab samples were collected from 209 stations (Table 1 and 2). In addition to sampling at grid benthos stations (108 stations) collections of benthos (89 stations, 274 samples) and epibenthos and plankton (95 samples) were made where gray whales were observed feeding. The following samples were taken to study the characteristics of bottom sediments: 229 samples to determine sediment particle size, 60 samples to determine concentrations of heavy metals and petroleum hydrocarbons, and 30 samples to determine the organic content of the sediment.

Table 1. Samples Collected in 2007.

Area	van Veen Grab	Diving collections	Epibenthic net	Bongo plankton net
	Stations/samples	Stations/samples	samples	samples
Piltun area	60/180	12/48	0	0
Offshore area	48/144	0	0	0
Intermediate area	12/36	0	0	0
Whale feeding sites	89/274	20/64	35	60
Total	**209/634**	**32/112**	**35**	**60**

Table 2. Stations by Depth in Piltun area for 2001–2007.

Depth Range	Number of Stations						
	2007	2006	2005	2004	2003	2002	2001
1 - 5 m	14*	5*	6*	6*	0	0	5*
6 -10 m	18*	6*	7*	7*	10	0	5*
11-15 m	20	16	15	6	19	16	5*
16-20 m	18	14	12	13	7	13	5*
21-25 m	17	14	27	14	12	18	5*
26-30 m	14	13	15	13	10	11	5*
31-35 m	3	3	5	5	5	2	0
Total	104	74	87	64	63	60	30

Note: * denotes diving collections.

In 2001 and 2003, the sections of the Piltun area with the highest prey biomass were at depths up to 15–20 m. Therefore, benthos grab collections were made from a Zodiac boat on three traverses at depths of 3–15 m and by dives very close to the diving traverses of 2001 and 2003. Dives were made at depths of 3-12 m in 2005-2007.

A small Sigsby trawl was used to collect benthos material in the shallow-water near-shore stations in the Piltun Area in 2007. Trawling was performed from a Zodiac boat, and coordinates of the trawling start and end points were recorded by GPS.

In 2007, benthos collections were taken at seven stations in the Piltun area (with the highest prey biomass) at the start (last 10 days of July) and end of the expedition (first 10 days of October) to study the size distribution and assess the growth rates of common amphipod and isopod species.

The micro- and mesodistributions of forage macrobenthos were studied by taking 5-10 consecutive bottom grab samples as the vessel drifted at three stations in the Piltun area. The position of each bottom grab sampler at the moment of contact with the seabed was recorded by GPS.

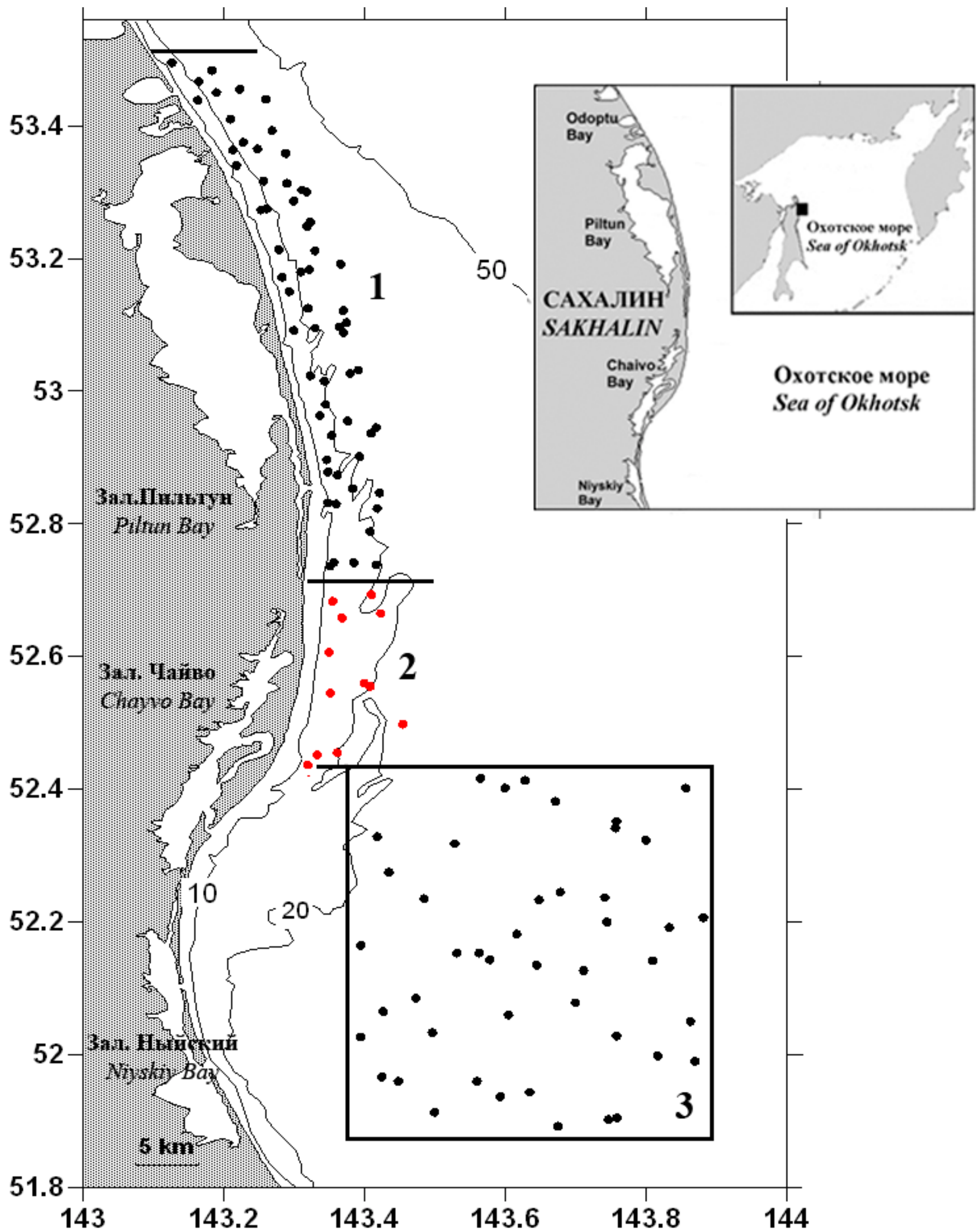

Figure 1. Locations of bottom grab sample stations in 2002 and 2007.

1 – Piltun Feeding Area
2 – Intermediate Area
3 – Offshore Feeding Area

1.2. Field Work Methods

All benthos samples taken from the expedition vessel were obtained using a van Veen bottom grab sampler (grab area 0.2 m^2, weight 57 kg). Three replicate samples were taken at each station. Before the start of grab sampling, an underwater video recording was made of the water column and the sediment surface at each station to obtain information on plankton in the water column and of epibenthos in the bottom water layers.

An epibenthic net with an area of 0.25 m^2 was used to collect samples of epibenthos, and a double Bongo net (0.1 m^2) was used for plankton. The location was determined by GPSMAP 76C, and the water depth was recorded, along with the water surface and bottom temperatures and salinities. Water temperature and salinity were recorded using a MultiLine P4 hydrologic probe (Germany) at depths to 20 m, and a Valeport SV EXTRA probe (England) at depths greater than 20 m; this probe included sensors for pressure, temperature, electrical conductivity, and dissolved oxygen concentration.

Aboard the ship, all the macrobenthos samples were washed through a sequence of three sieves: 5 mm (to remove coarse bottom fractions and large animals, such as sand dollars and molluscs), followed by 1 mm, and 0.5 mm sieve sizes, and fixed with 4% formalin. After 10 days all the benthos and epibenthos samples were transferred to 75% alcohol.

The washed (non fixed) benthos samples were photographed with an Olympus C-1060 digital camera.

To analyze the particle size distribution and the concentrations of petroleum hydrocarbons and heavy metals, surface sediment samples were taken using a Teflon pipe sampler. The samples were placed in plastic packets and dishes and kept in a cooler until analysis at an onshore laboratory.

2. Laboratory Analysis of Materials

2.1. Analysis of Particle Size Distribution of Bottom Sediments

The particle size distribution of bottom sediments was analyzed at the Shelf Problems Laboratory of Far East State University (DVGU) using two standard Russian methods, screen and aerometric, to determine percentages of the following size fractions (in mm): greater than 10; 10–5; 5–2; 2–1; 1–0.5; 0.5–0.25; 0.25–0.1; 0.1–0.05; 0.05–0.01; 0.01–0.005, and less than 0.005 (Petelin 1967). The methods are summarised as follows:

The moisture content (W) and specific gravity of the sediment samples were determined by the standard Russian method (Petelin 1967). Then the sediment sample was dried and sifted through a set of mesh sizes of 10, 5, 2 and 1 mm. The sediment fractions remaining on the screens and the fraction passing through the 1 mm screen were weighed. The sediment sample was transferred to a 1000 cm^3 flask, which was then filled with distilled water (approx. 300 ml). The sediment–water mixture was allowed to stand for one day, after which 1 cm^3 of 25% ammonia solution was added to the sample flask and boiled for 1 hour before cooling to room temperature. The suspension was poured into a 1-liter glass cylinder through a 0.1 mm sieve. The soil particles retained on the 0.1 mm sieve were dried, sifted through a set of screens with mesh sizes 0.5, 0.25, and 0.1 mm, and then weighed separately. The remaining suspension was agitated for one minute until all sediment was stirred up from the bottom of the cylinder. An areometer was introduced, and readings were taken one minute after agitation stopped (for the –0.05 mm fraction), after 30 minutes (for the –0.01 mm fraction), and after 3 hours (for the –0.005 mm fraction).

Sediment groups and types were determined according to the classification presented in Table 3.

Table 3. Sediment Classification System (Bezrukov and Lisitsyn 1960; Shepard 1976).

Sediment group	Types of sediments	Abbreviation in text	Predominant particle size, mm	Md, mm
Coarsely clastic (psephites)	Pebbles	Peb	>10	
Coarsely clastic (psephites)	Gravel: coarse medium fine	 Grc Grm Grf	 10-5 5-2 2-1	
Sandy (psammites)	Sand: coarse medium fine	 Sc Sm Sf	 1-0,5 0,5-0,25 0,25-0,1	 1-0,5 0,5-0,25 0,25-0,1
Silt (silts)	Coarse silts Fine silt silt	Ac Af	0,1-0,05 0,05-0,01	0,1-0,05 0,05-0,01
Clay (pelites)	Coarse pelite	Pec	<0,01	0,01-0,005

Note: "Md, mm" is the median diameter of the soil particles in mm. Numbers in the column are the range of values for the given type of sediment.

2.2. Analysis of Benthos Samples

The macrobenthos content of sediment samples was examined to determine species composition and quantitative characteristics (biomass and count for each species and for individual taxonomic groups, and total biomass and count of macrobenthos in the sample). All animals were sorted. Large organisms were counted visually, and small ones were counted with an MBS-10 binocular microscope. The gross weight of large benthic organisms was determined with a VLKT-100 electronic scale accurate to 10 mg, while the gross weight of small organisms was determined on a torsion scale accurate to 1 mg. Before weighing, the organisms were dried on filter paper for one minute.

The specific biomass per square meter was calculated based on the capture area of the sampler and rounded to 0.01 g. The average biomass error also was determined with the same precision. The colony density of organisms per square meter was calculated and rounded to the nearest whole number.

For colonial animals (*Hydroidea, Bryozoa, Spongia*), the number of individual colonies was counted; when it was not possible to determine the number of colonies clearly (because of fragmentation or aggregation of colonies, etc.), the number was indicated by a question mark "?" in the table. Taxonomic identification of the sample collections was done by qualified taxonomists[2] who had many years of experience with the relevant animal group. If the species was represented only by juvenile individuals (young without clear taxonomic features) so that it was difficult to identify the species, the designation *sp. juv.* was used for the taxon name. The rate of occurrence (incidence) of species in sandy bottom sediments was assessed by determining the species incidence frequency (P, %), which is the percentage ratio of the number of quantitative samples containing the species to the total number of quantitative samples taken in the area. This parameter partly reflects the availability of the prey to the consumer species.

The communities were described using traditional single-factor methods as well as methods of multidimensional statistical analysis, including classification and ordination methods (Afifi and Eyzen 1982) using the statistical software package Statistica 6.0 (Borovikov 2001) and Primer v5 (Clarke and Gorley 2001). The primary basis for the analysis was a tetragonal data matrix in the form of a list of benthic species for each station, with quantitative characteristics of the species. The Bray–Curtis similarity coefficient for each pair of samples was calculated based on the data matrix. Dendrograms were constructed

[2] The following colleagues from IBM DVO RAN and ZIN RAN took part in taxonomic identification of the major macrobenthos groups: Cand. L. L. Budnikova (amphipods), Cand. M. V. Malyutina (isopods), Cand. G. M. Kamanev (bivalve molluscs), Cand. V. V. Gul'bin (gastropods), Cand. E. V. Bagaveeva (polychaetes), Cand. S. F. Chaplygina (hydrozoa), Cand. V. N. Romanov (ascidians), Cand. A. V. Chernyshov (nemertini).

using the mean-link method (Clarke and Green 1988; UNEP 1995). Empirically, the quantitative characteristics of benthos abundance (number of individuals and biomass) typically do not follow a normal distribution. Therefore, to compare samplings using parametric criteria, the source data were transformed based on the nature of the empirical distribution (Elliott 1977).

The entropic index of sediments (H_s) was calculated based on the Shannon Diversity Index (H) using the formula: $H_s = -\sum p_i \times (\ln p_i)$: where p_i is the proportion of the i-th fraction in the sediment and n is the number of granulometry fractions in the analysis. This measure is independent of the type of sediment particle-size distribution function and is determined solely by the number of the particle-size ranges in the analysis and the selected scale of fraction sizes. The normalized sorting index (H_s/H_{max}, where $H_{max} = \ln n$) ranges from 0 (ideally graded sediments) to 1 (absolutely non-graded).

Standard procedures for the SURFER 7 cartographic system (Surface Mapping System) were used to construct distribution maps of bottom-sediment and water-column parameters, pollutant concentrations, and indices of quantitative abundance of macrobenthos. The cartographic system was used only for illustrating the general nature of the parameter distributions in the study area. Therefore, the “simple planar surface” version of the polynomial regression method was used to calculate isolines. This method is good for identifying large-scale trends in spatial distributions of data. This method has been described in detail (Draper and Smith 1981). The procedure for obtaining, processing, and analyzing samples was consistent with generally accepted methods (Bilyard and Becker 1987).

RESULTS AND DISCUSSION

3. Characteristics of Water Column and Bottom Sediments

3.1. Water Temperature and Salinity

The water surface and bottom temperature and salinity were measured in the waters studied at benthos sample collection points during the period from July 22 to October 5, 2007. The spatial distribution of bottom temperature and salinity is shown in Figure 2 for the Piltun Area.

Water temperature. In September 2007, the surface water temperature in the Piltun Area varied from 1.8 to 14.1°C, and the bottom water temperature varied from 5.8 to 13.7°C. Bottom water temperature averaged 10.4±0.29°C. Surface water temperatures in the Piltun area were consistent between 2005-2006 and 2007 (Table 4).

Table 4. Surface Water Temperatures (°C) in the Areas.

Characteristic	Piltun area					Offshore area		
	Aug.2007	Sep.2007	Sep.2006	Aug.2005	Sep.2005	Sep.2007	Sep.2006	Sep.2005
Average	7.39	11.1	11.03	8.08	11.77	11.19	10.5	12.2
Standard deviation	0.47	0.3	0.16	0.52	0.12	0.31	0.18	0.11
Minimum	1.8	5.8	6.78	0.5	9	5.6	8.52	11
Maximum	14.1	13.7	14.39	13.0	14.1	13.5	13.04	13
Observations	73	44	60	34	64	38	48	37

A spot of colder water observed in the northern Piltun area in 2001–2006 might be due to persistent upwelling of deep waters in the area (Krasavtsev et al. 2000; Rutenko 2006). According to data of 2006-2007 field studies, upwelling has different durations and surface water temperature and salinity characteristics in the study area. Upwelling areas may range 5 to 40 km from shore, depending on the development phase. The most typical spatial distribution of pronounced upwelling with a surface water temperature of 2ºC is in the order of 25 km (Borisov et al., 2008).

A detailed analysis of the distribution of water temperature and salinity in August-September 2004-2005 in the Piltun Area was performed by staff members of the Pacific Oceanographic Institute (POI) of the Russian Academy of Sciences Far East Branch (DVO RAN) (Borisov et al., 2005; Kruglov et al., 2006).

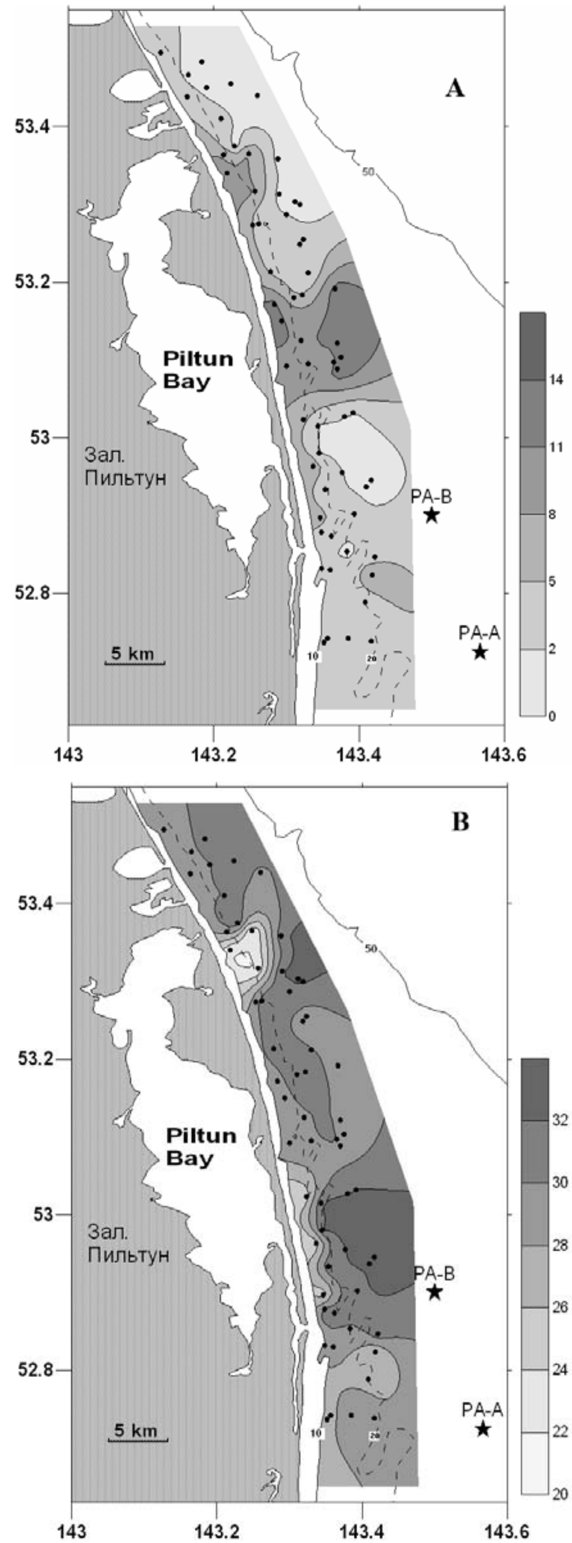

Figure 2. Distribution of bottom water temperature (A – T °C) and salinity (B - S, %) in the Piltun Area during the study period in 2007.

Their analysis showed that the thermohaline characteristics of the water are quite different between August and September. Average characteristics for August:

1. The temperature in the relatively mixed near-shore zone was 5.5–8 °C, and salinity was 28–30 psu. Shelf water was located within the 20-m isobath.
2. The shelf water front was located in an area where depths were 20–30 m, with a sharper temperature differential of 1–8.4 °C and a salinity differential of 28–31.5 psu.
3. Sea of Okhotsk water with temperature of 0.5–8.6 °C and salinity of 28.7–32.6 psu were located beyond the 30-m isobath.

Average characteristics for September:

1. The area occupied by shelf water increased in September towards the 30 m isobath. In this area, shelf water between the 0 and 20 m isobaths had temperatures of 7.7–9.4 °C and salinities of 29.55–29.95 psu, while between the 20 and 30 m isobaths it was 6.3–9.2 °C and 30–31.2 psu.
2. Accordingly, the shelf front moved toward the 40-m isobath. The range of average temperatures of Okhotsk seawater during September was 3.0–9.2 °C, and average salinity was 30.2–32.3 psu.

In addition to changes in water temperature, substantial changes in hydrologic conditions have also been reported between years. According to F. F. Khrapchenkov (POI DVO RAN), bottom temperature was lower during the summer of 2006 in the Piltun Area than in 2004-2005. For example, the bottom water temperature in mid-August 2005 was about 2 degrees colder in the Offshore area and 4 degrees colder at Piltun Bay than in 2004. The temperature in 2006 was still colder (by 2-3 degrees) thoughout the coastal region.

In mid-August 2004, water with negative temperature was found only opposite the outlet from Piltun Bay at depths greater than 40 m. At the same time in 2005, waters with negative temperatures were observed along the entire coast beginning at a depth of 35 m. In 2006, the 0 and –1 °C isotherms in the area of the Piltun Bay mouth were even closer to the coast. A comparison of bottom water temperatures in September 2005 and 2006 shows that the bottom water temperature distributions were about the same in the Piltun feeding area. Along Chayvo Bay and southward, the strip of bottom water temperature above 8 degrees was not more than 10 km in 2006 compared to 30 km in 2005. In September 2005 there were practically no bottom waters with negative temperature, while in September 2006 such waters were observed south of Chayvo Bay and came within 20 km from the coast at Nabil Bay (Kruglov et al., 2006).

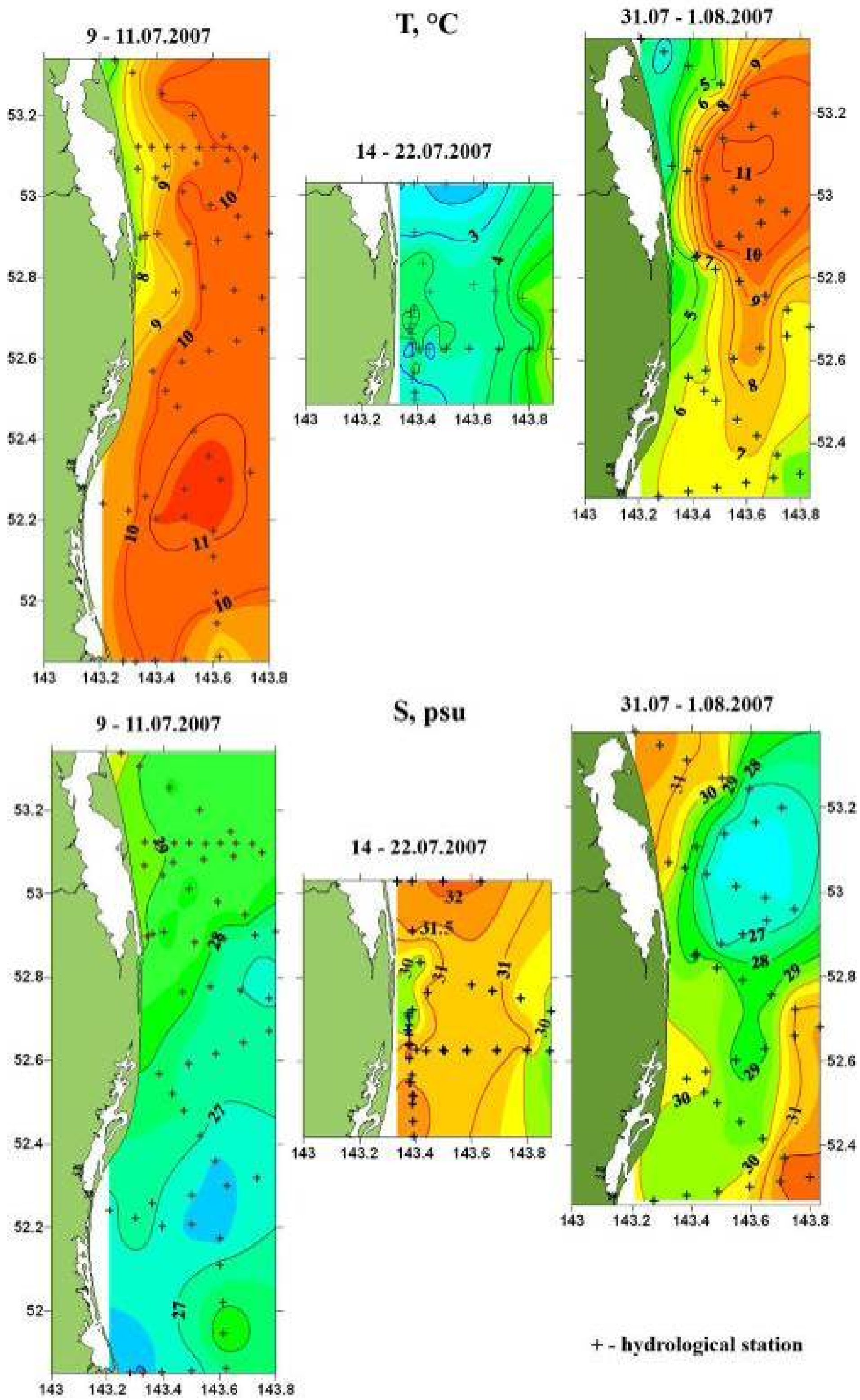

Figure 3. Sea surface water temperature (T, °C) and salinity (S, psu) variation in July 2007 (Borisov et al., 2008).

The development of cold, higher-density bottom water, which forms during the winter due to convection and salinization during ice formation, has principal influence on the hydrological conditions of the northeastern Sakhalin shelf, especially off Chayvo and Piltun Bays. The dynamics of ice formation depend on a number of factors: first, wind-induced mixing, especially under the effect of south and north winds, which promote upwelling and wind surges, respectively, along the coast; second, vertical and horizontal mixing due to tidal phenomena (the intensity of mixing increases during syzygial tides, when a complete breakdown of stratification is possible); and third, the dimensions and dynamics of the runoff lens of the Amur River, where the water temperature is higher and the salinity is lower than in the shelf waters of the Sea of Okhotsk.

The spatial and temporal variation of hydrological characteristics in the study area in 2007 was examined by staff members of the Pacific Oceanography Institute of DVO RAN (Borisov et al., 2008). A relatively even distribution of surface temperature (9-11ºC) and salinity (27-29 psu) was observed during July 9-11, 2007 (Fig. 3), although surface water temperature a little below 8ºC were recorded along the coast off Piltun Bay. Due to the synoptic situation over the Sea of Okhotsk in mid-July, there was a steady moderate to strong south wind that generated an upwelling zone along the coast in the region of Chayvo and Piltun bays, reaching 25-30 km from shore. The water temperature in the zone did not exceed 5ºC, and salinity was 30 psu. During the third ten-day period of July, after a deep cyclone had passed, primarily weak and northerly winds were observed. The result was that transformed Amur waters approached Piltun Bay again, and the surface water temperature rose to 9 – 11ºC, while salinity decreased to 27-29 psu; a temperature (8 - 6°C) and salinity (29–31 psu) front was recorded at the sea surface off Piltun Bay. Another front due to incipient upwelling was recorded northward from the mouth of Piltun Bay.

The synoptic situation over the Sea of Okhotsk again led to a steady moderate to strong south wind in the area during the second ten-day period in August. As a result, an upwelling zone formed again along the coast and extended from Nyyskiy Bay to the middle of Piltun Bay, and cold (below 5 degrees), salty (more than 31 psu) water again filled the coastal area. A new north-south temperature (5-10ºC) and salinity (32-29 psu) front formed due to upwelling. The coldest and saltiest water was found near the coast north of the outlet from Pitlun Bay (Fig. 4).

Hence the hydrological conditions in August 2007 differed substantially from the same period in 2006. Two extensive upwellings were recorded in the area in August lasting from a few days (early in the month) to a week (in mid-August). Consequently, there was a patch of cold water along Piltun Bay early in August, and along Piltun and Chayvo bays as far was Nyyskiy Bay during mid-August.

In late August and early September 2007, the homogeneous surface water layer, with a water temperature of 10-14°C and salinity below 30 psu, grew to 10-15 m depth; the temperature and salinity gap layer was 5-10 m deeper in 2007 than during the same months in 2006. The thickness of the homogeneous layer was influenced substantially by the tidal phase, and no water with a negative temperature was found.

As in 2005-2006, significant spatial and temporal variations in hydrological characteristics were recorded in the survey area. In contrast to 2006, the maximum surface water temperature range of 2 to 14.8°C along the coast was recorded in August, and salinity ranged from 27 to 32 psu. The bottom temperature ranged from 1 to 6°C, while salinity ranged from 29 to 33 psu; the water temperature was below 0°C beyond the 40-meter isobath in mid-August, and salinity was more than 32.5 psu. Frontal zones with significant temperature and salinity gradients (in a layer of 0-10 m) formed periodically in the area of Chayvo and Piltun bays throughout the period from July to September due to the development of upwelling.

Figure 5 shows the bottom temperature distribution in the Piltun Bay – Nyyskiy Bay area in July-August 2007. The bottom water temperature by mid-August 2007 was approximately the same as during the same period in 2006. Water with a temperature of 1 – 0°C was present along the Piltun Bay during the second half of July, and water with negative bottom temperatures moved away from the coast beyond the 40 – 50-meter isobaths in mid-August and even farther at the end of the month (Borisov et al., 2008).

Hence bottom temperatures lower than in 2004-2005 are the distinguishing feature of the hydrological regime in the coastal zone of the Piltun Area in 2006-2007.

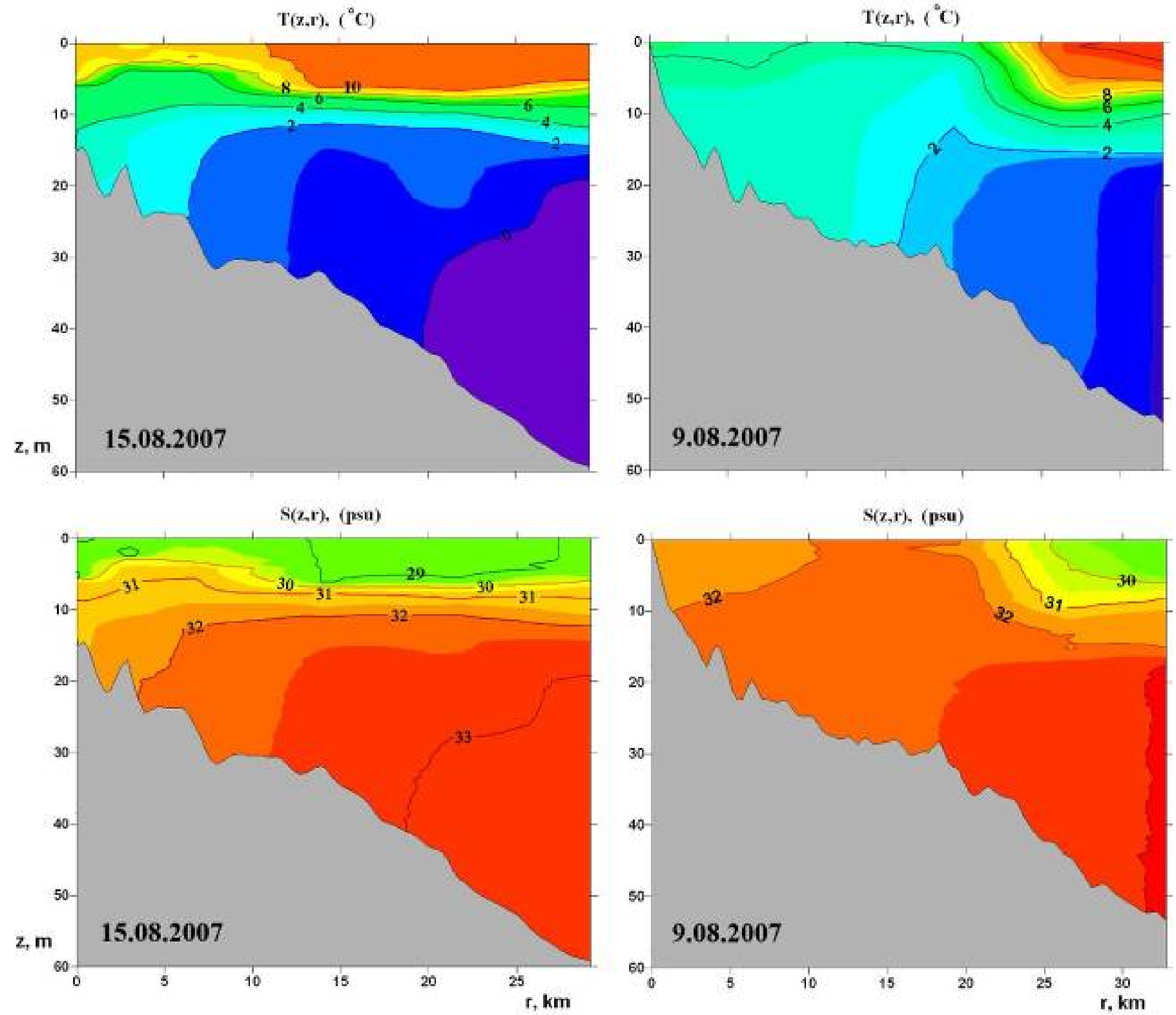

Figure 4. Temperature T(r,z) and salinity S(r,z) distribution on August 9 and 15, 2007, on a transect running east from the mouth of Piltun Bay (Borisov et al., 2008).

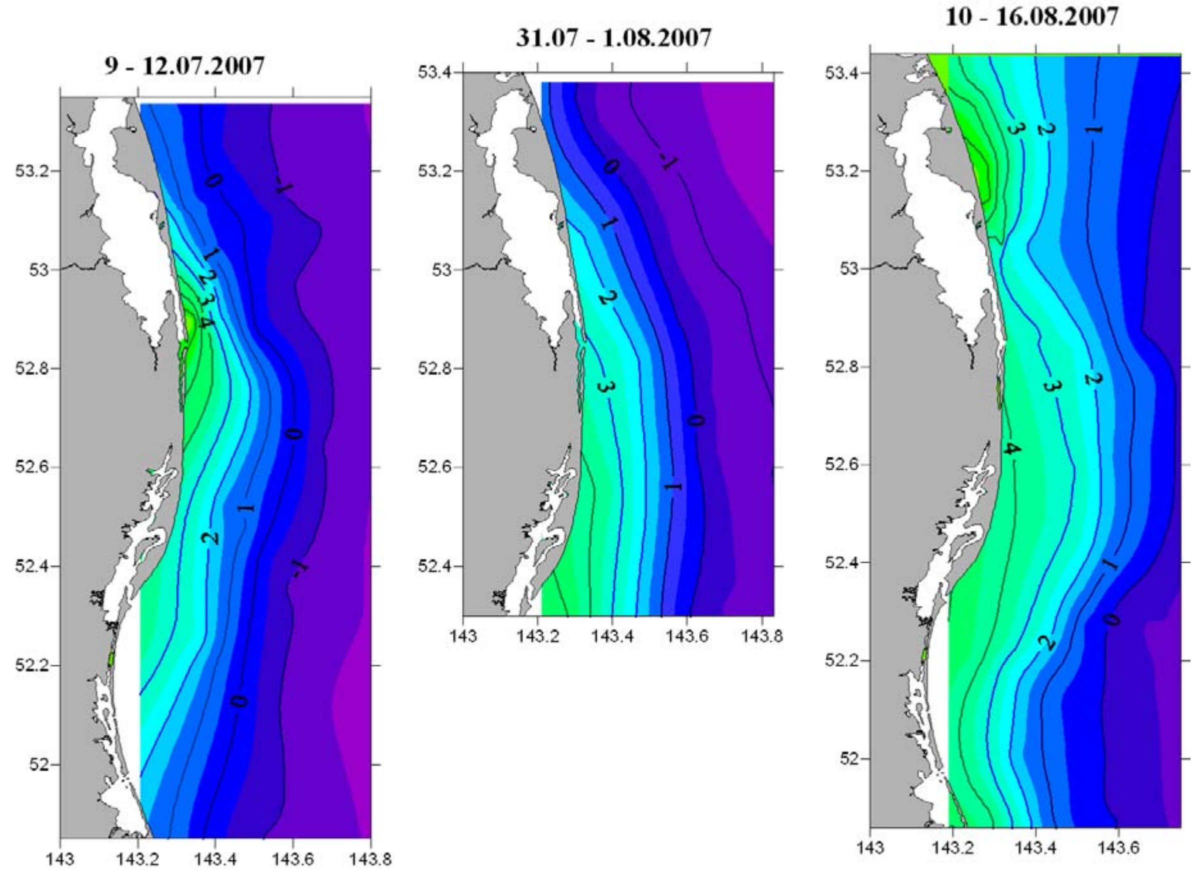

Figure 5. Bottom water temperature in July-August 2007 (Borisov et al., 2008).

3.2. Particle Size Distribution of Bottom Sediments in the Areas

The particle size distribution of bottom sediments was studied based on laboratory analyses of 210 sediment samples taken at benthos stations and whale feeding sites. The distributions of the main bottom sediment fractions (coarse silt; fine, medium, and coarse sand; and gravel) in the Piltun and Offshore areas are shown in Figures 6–7 and 8–9, respectively. The bottom sediments at most stations throughout the area are characterized by predominance of sandy (psammite) fractions. Of the 210 stations in all areas, 92% are predominately sands, while 7% have gravel–pebble soils containing some sands of various grain sizes. The proportion of the fine sand fraction exceeds 60% at most stations.

Piltun Area. Data for 2001–2006 showed that fine sandy soils predominate at depths up to 10–15 m throughout the area. With increasing depth, these are replaced by medium- and coarse-grained sands and areas with gravel–pebble soils containing some sands of varying grain size.

The 2007 data reconfirmed this spatial distribution. Fine sands predominated at 60% of the stations in this area, with medium sands predominating at 28% of the stations. Gravel–pebble bottoms, often containing some sands of various grain sizes, occur in patches at depths greater than 15–20 m. The highest proportion (more than 15%) of silt–pelite fraction in the sediment was observed in a local area at depths below 20 m in the channel area of Piltun Lagoon. The active hydrodynamics of the area probably promotes the transfer of fine soil fractions to greater depths (Fig. 7). Areas with elevated silt-pelite content are found both north and south of the lagoon outlet. This is consistent with hydrologists' data indicating that during low tides and upwelling, the current direction along the shoreline in the coastal zone of the Piltun Area can change direction from south to north.

Offshore Area. The depths in the Offshore area increase gradually from 20 to 70 m. The proportion of silt-pelite in the soil increases with water depth (Figure 9D). Overall, fine sands predominate at 85% of the stations in the Offshore area. Gravel soils and coarse-grained sands occur in patches.

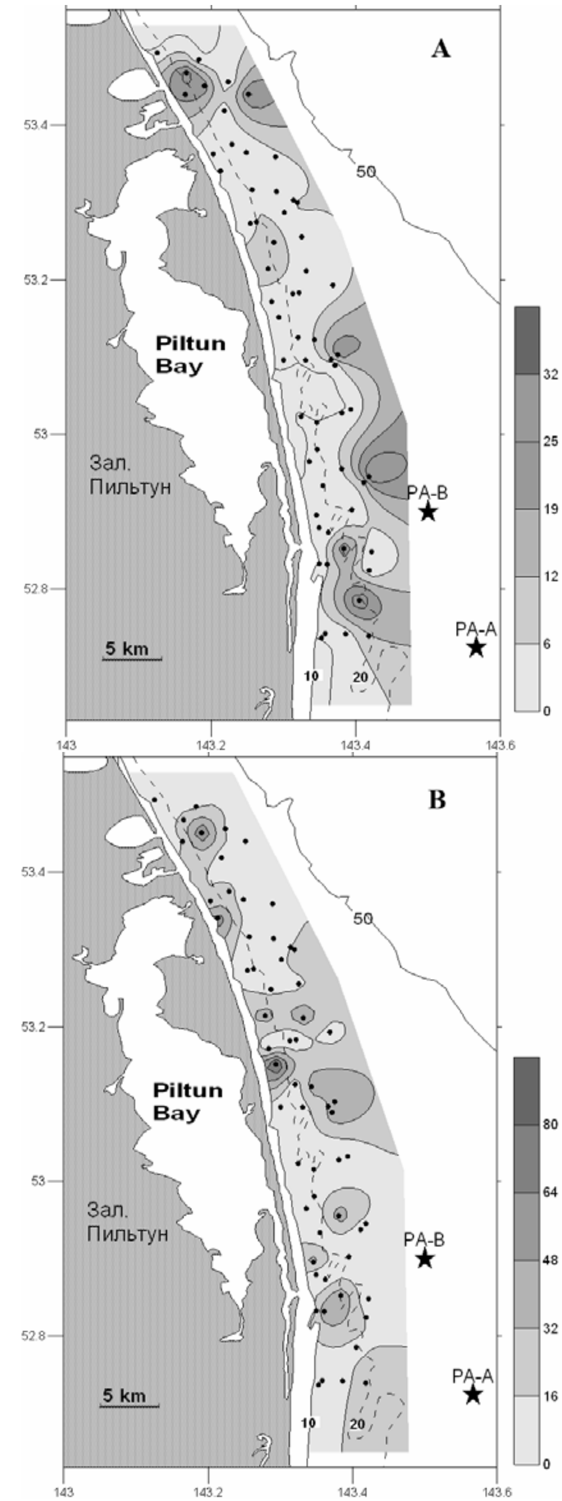

Figure 6. Distribution of sediment fractions (% of dry sediment weight) during 2007 in the Piltun area: coarse sand (A; 0.5 – 1 mm); medium sand (B; 0.25 – 0.5 mm).

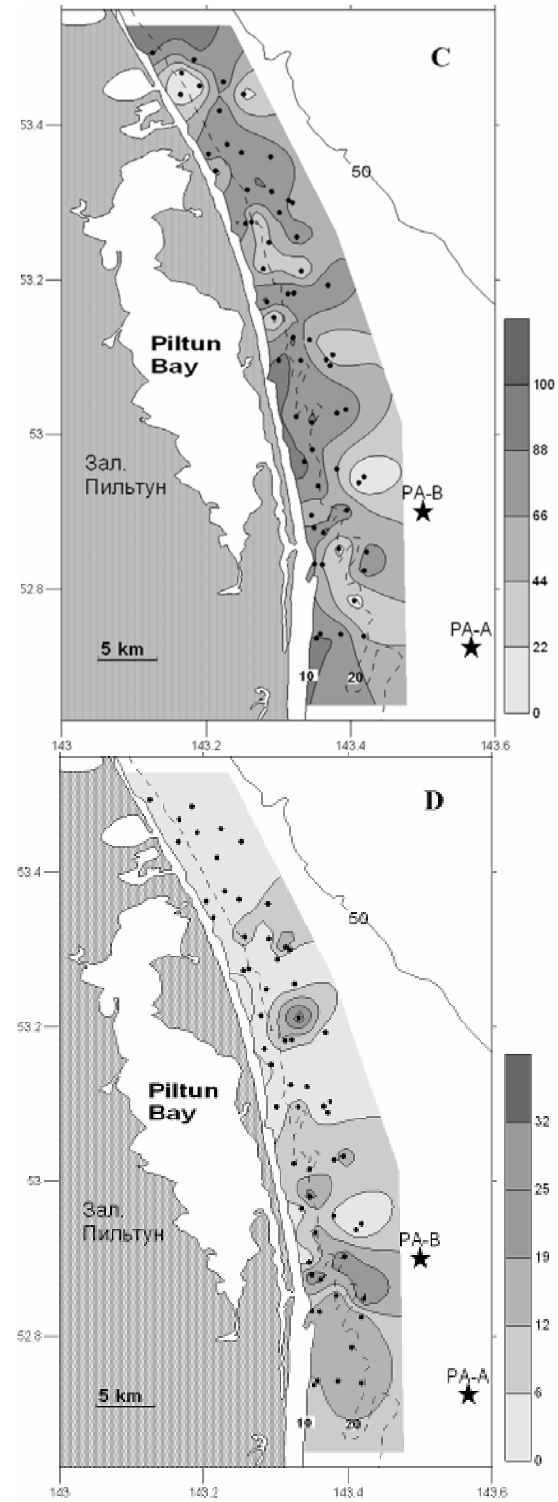

Figure 7. Distribution of sediment fractions (% of dry sediment weight) during 2007 in the Piltun area: fine sand (C; 0.1 – 0.25 mm); silt (D; < 0.1 mm).

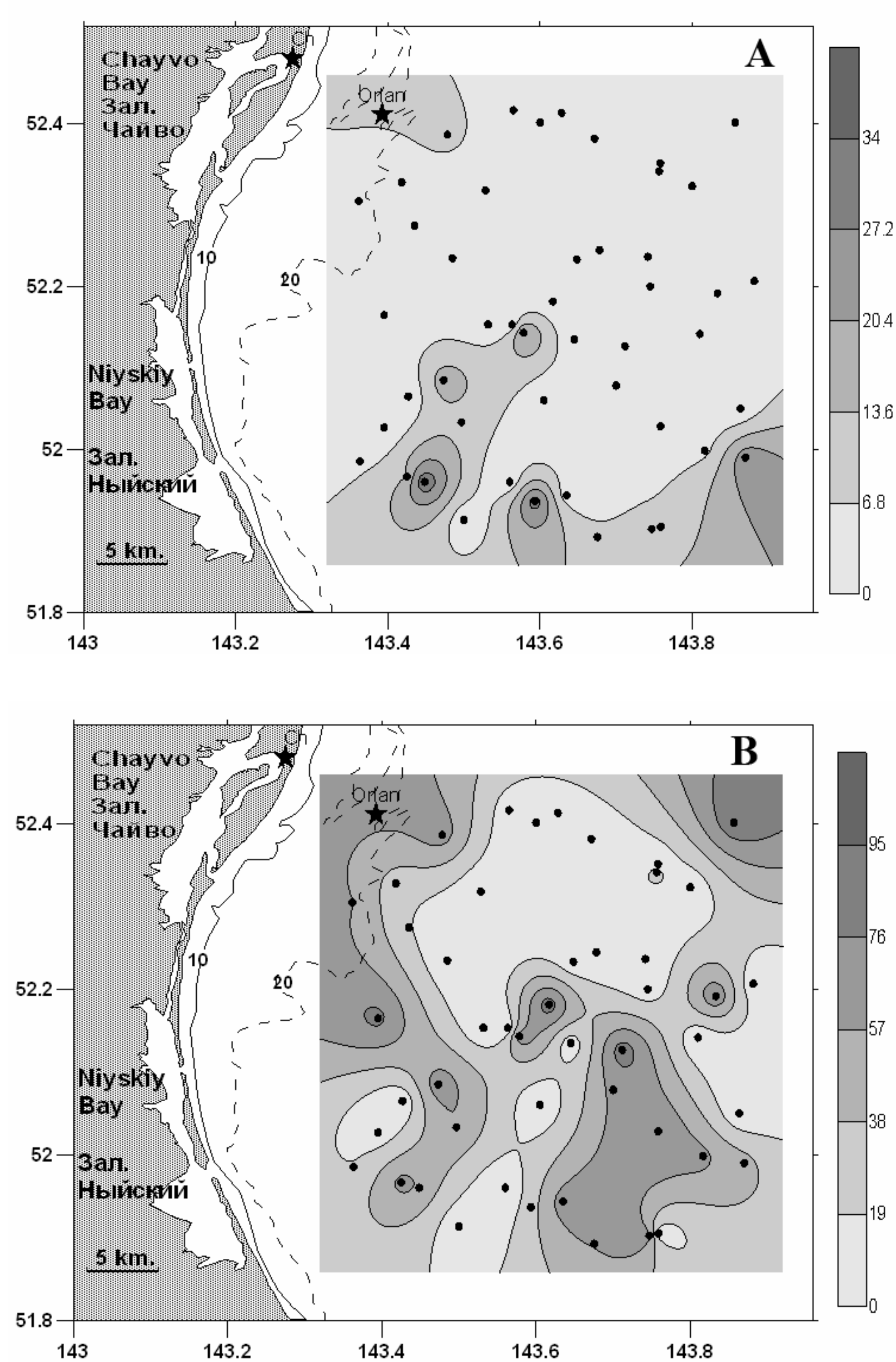

Figure 8. Distribution of bottom sediment fractions (% of dry sediment weight) during 2007 in the Offshore area: coarse sand (A; 0.5 – 1 mm); medium sand (B; 0.25 – 0.5 mm).

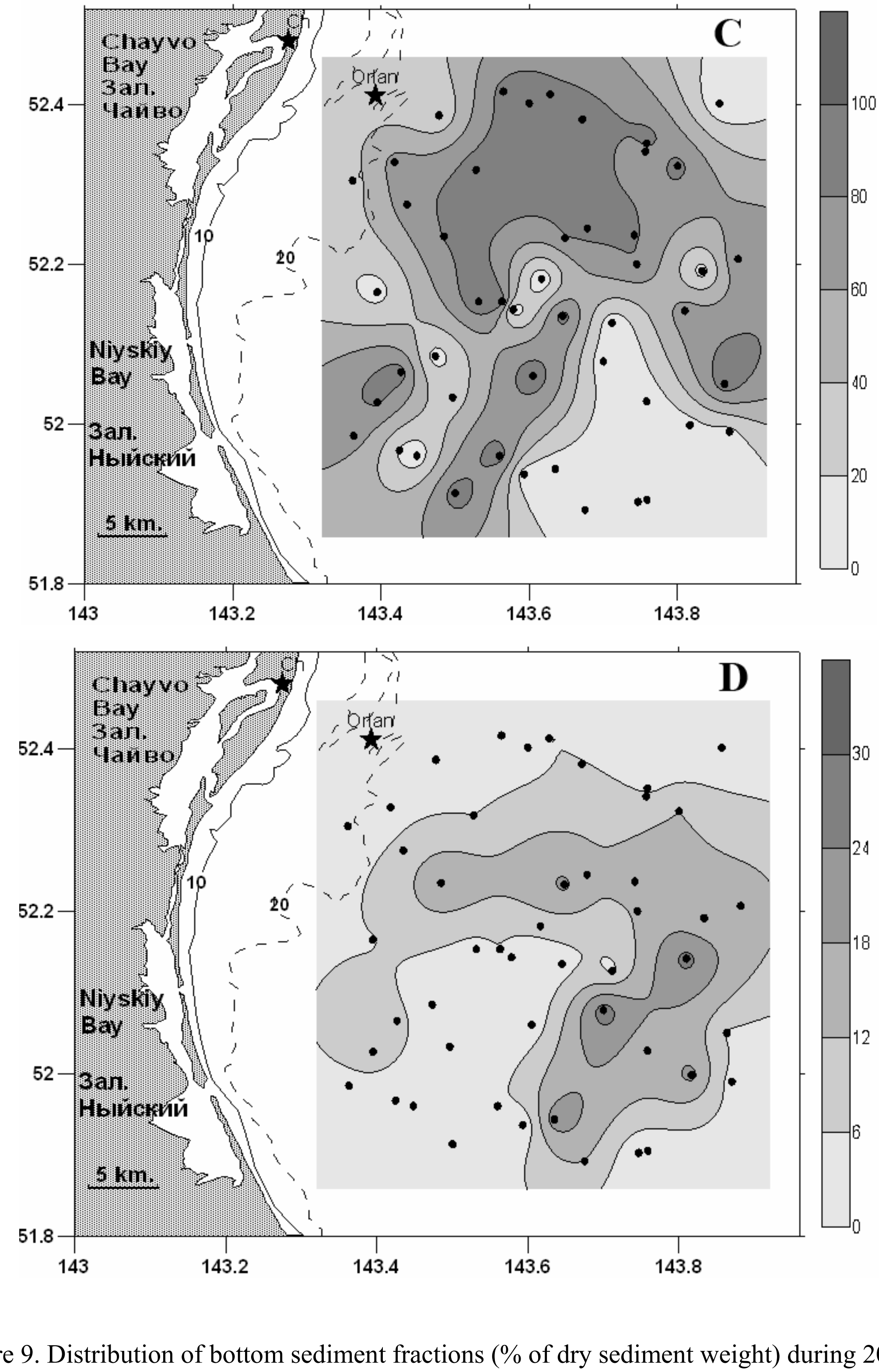

Figure 9. Distribution of bottom sediment fractions (% of dry sediment weight) during 2007 in the Offshore area: fine sand (C; 0.1 – 0.25 mm); silt (D; < 0.1 mm).

3.3. Classification of Stations According to Similarity of Particle Size Distribution

Data on the 10-fraction compositions of bottom sediments at stations in the Piltun and Offshore areas and at whale feeding sites have been grouped (classified) by cluster analysis procedures (Ward's clustering method, Euclidean distance). Dendrograms are shown in Figure 10.

It follows from the dendrograms that three groups of stations (A, B, C) can be distinguished according to particle size distribution. Table 5 provides average characteristics for each sediment group for the Piltun and Offshore areas based on data from 2002–2006. No *group D* sediments were found in 2005–2007. This group includes sediment in which fine sand and silt are prevalent. The stations of the group occupy small areas of the seabed in the Offshore area at depths greater than 65 m.

Group A consists of stations where the 0.1–0.25 mm fraction (fine sand) predominates. According to 2001–2006 data, the proportion of this fraction varies from 60 to 96% of dry sediment weight in sediments of the Piltun area. The normalized entropic index of sediment sorting averages 0.35 for the coastal zone from Odoptu Bay to southern Piltun Bay (an ideally sorted sediment has a value of 0). The average depth at which this sediment group occurs in the Piltun area is 19 m. ***Group B*** includes stations where the soil is predominately medium-grained sand with up to 20% coarse sand. The entropic index of sorting varies from 0.6 to 0.74. The average depth of the sediments of this group in the Piltun area is 22 m. ***Group C*** comprises stations without clear dominance of any one fraction. The soil is gravel mixed with sand fractions. The major fractions are 0.5–1.0 mm (coarse sand) and 1.0–2.0 mm (small gravel). The entropic index of sorting varies from 0.79 to 0.87 (absolutely ungraded sediment has a value of 1). The average depth of this group of stations in the Piltun area is 26 m.

Hence ***group A*** is well-sorted fine-grained sands, ***group B*** comprises medium-sorted sands of varying grain size (a mixture of fine and medium sands), and ***group C*** corresponds to poorly sorted gravel soils containing some sands of varying grain size, pebbles, and shell detritus. The sediment groupings in the Piltun area from 2007 data are in good agreement with the sediment analysis based on the 2002–2006 data (Table 5).

Table 5. Characteristics of Sediment Groups in Piltun and Offshore Areas.

Sediment group	Sediment fractions						H_s	H_s/H_{max}	Code
	Peb	Grav	Sand coarse	Sand med	Sand fine	Aleu+Pel			
Piltun area, 2007 data									
A	0	0.74	0.49	5.40	**83.92**	9.45	0.61	0.35	Sf
B	0	4.71	7.51	45.95	39.54	2.29	1.2	0.7	Sfm
C	3.52	41.1	23.23	15.66	14	2.49	1.42	0.81	Gr+Sc
Piltun area, 2006 data									
A	0	0.7	0.71	3.84	**90.36**	4.39	0.42	0.26	Sf
B	0	6.73	9.17	34.97	47.84	1.29	1.18	0.73	Sfm
C	1.88	38.83	24.98	18.13	15.5	0.68	1.42	0.79	Gr+Sc
Piltun area, 2005 Data (Fadeev, 2006)									
A	0	4.1	5.07	12.25	**74.48**	4.1	0.89	0.55	Sf
B	0	9.75	29.04	**54.2**	4.72	2.29	1.15	0.71	Smc
C	6.1	36.15	22.02	20.48	11.68	3.57	1.57	0.87	Gr+Scm
Piltun area, 2004 data (Fadeev 2005)									
A	0	0.52	1.56	19.6	**72.89**	5.45	0.8	0.5	Sf
B	0.00	10.69	20.65	**56.76**	7.82	4.08	1.21	0.75	Smc
C	8.56	49.16	24.08	10.16	5.00	3.04	1.39	0.78	Gr+Scm
Piltun area, 2003 data (Fadeev, 2004)									
A	0.83	1.98	2.12	10.93	**75.48**	8.66	0.87	0.48	Sf
B	0	4.81	13.61	**63.85**	17.12	0.6	1.04	0.64	Smf
C	5.01	44.3	20.28	16.8	11.88	1.74	1.46	0.81	Gr+Scmf
Piltun area, 2002 data (Fadeev, 2002)									
A	0.39	1.21	0.77	11.41	**84.52**	1.7	0.57	0.32	Sf
B	0.26	8.11	9.64	**47.81**	32.64	1.54	1.23	0.68	Smf
C	1.05	37.28	14.81	17.49	25.96	3.41	1.47	0.82	Gr+Sfmc
Offshore area, 2007 data									
A	0	0.62	1.00	7.18	**83.61**	7.65	0.55	0.33	Sf
B	0	2.55	8.81	**68.1**	13.46	7.19	0.95	0.5	Sm
C	2.3	34.13	20.48	27.43	13.71	2.54	1.52	0.82	Gr+Scm
Offshore area, 2006 data									
A	0	0.39	0.5	1.96	**94.39**	2.76	0.27	0.17	Sf
B	0	0.71	1.14	2.84	**76.56**	18.75	0.71	0.44	Sf+Al
C	3.28	22.72	14.34	28.8	29.96	0.9	1.49	0.83	Sfc+Gr
Offshore area, 2005 data (Fadeev, 2006)									
A	0	0.75	1.01	10.38	**82.67**	5.19	0.63	0.39	Sf
B	0	2.87	2.6	19.31	**66**	9.22	1.01	0.63	Sfc
C	5.32	30.93	11.73	18.32	29.38	4.32	1.58	0.88	Gr+Sfmc
Offshore area, 2004 data (Fadeev, 2005)									
A	0.00	0.65	1.32	3.68	**88.14**	6.21	0.5	0.31	Sf
B	0.00	0.29	1.06	21.41	**71.22**	6.02	0.8	0.5	Sfm
C	7.40	28.06	5.08	19.76	25.14	14.56	1.65	0.92	Gr+Sf
D	0.00	0.35	0.55	3.30	**67.60**	28.20	0.78	0.49	Sf+Al
Offshore area, 2002 data (Fadeev, 2003)									
A	0.71	2.74	2.4	15.65	**75.4**	3.1	0.83	0.47	Sf
B	0.31	3.49	5.41	**52.03**	37.55	1.21	1.05	0.59	Smf
C	0.44	18.49	21.83	36.69	20.66	1.89	1.44	0.8	Gr+Scmf

Notes for Tables 5 and 6: for abbreviations of sediment fractions, see Table 3. H_s is the entropic index of sediment sorting, and H_s/H_{max} is the normalized entropic index of sorting. **Boldface** indicates the dominant seidment fractions; values for major sediment fractions in the absence of a predominant fraction are shaded.

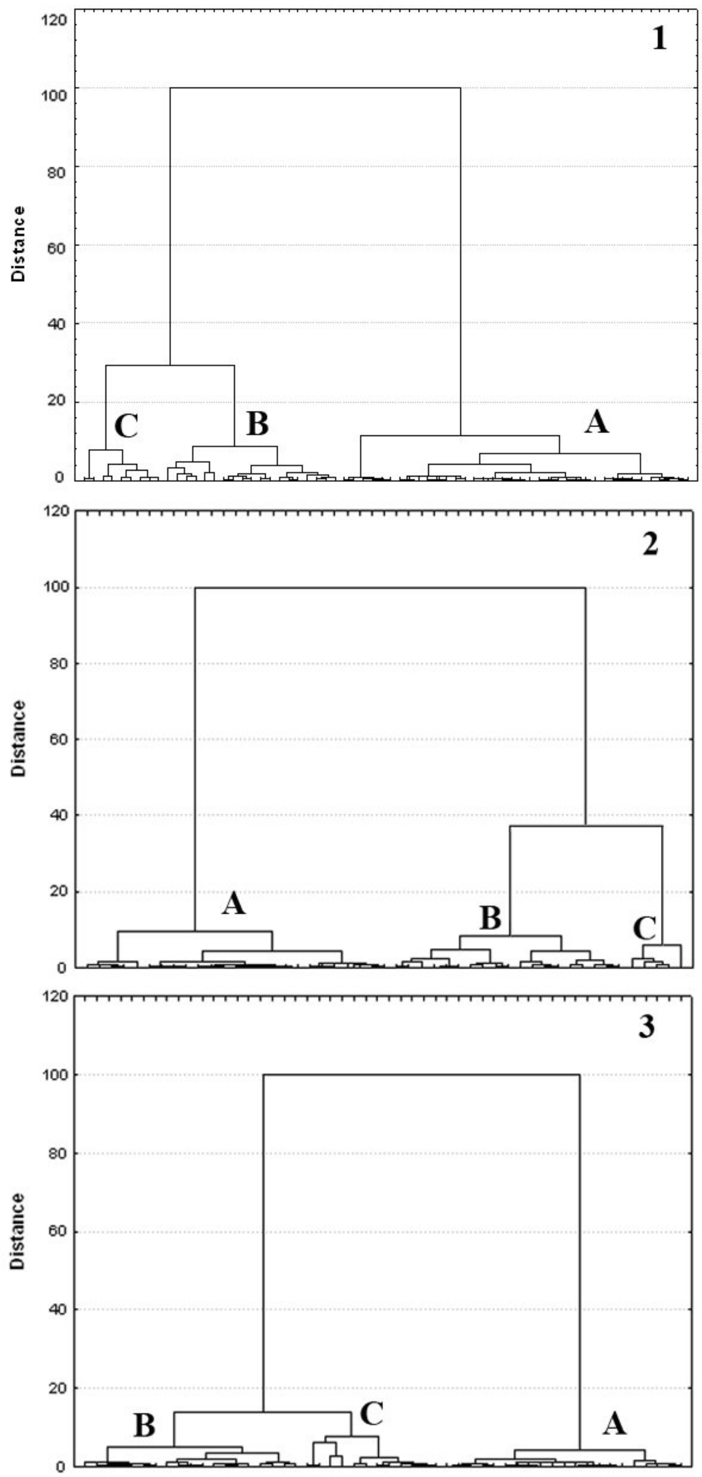

Figure 10. Classification of benthic stations in 2007 by 10-fraction sediment composition in the areas. 1 – Piltun area; 2 – Offshore area; 3 – Benthic stations in gray whale feeding points; A, B. C – types of bottom sediment

3.4. Particle Size Distribution of Bottom Sediments at Gray Whale Feeding Sites

The sediment composition at gray whale feeding sites in the Piltun and Offshore areas was studied from data obtained in 2001–2006 (Fadeev 2007). In 2001, sediments were sampled at nine gray whale feeding sites in the Piltun feeding area. The average depth of the feeding sites was 9±0.9 m. The analysis showed that the sediments at the feeding sites were fine-grained sands in all cases (proportion of 0.1–0.25 mm fraction ranging from 73.9 to 94.3%); i.e., sediments classified as group A.

In 2002, bottom sediments were sampled at 46 whale feeding sites: 21 stations in the Piltun area (average depth 12±0.7 m) and 25 stations in the Offshore area (average depth 41±0.9 m). Sandy sediments were prevalent at all the feeding sites in the Piltun area; fine-grained sands predominated at 53% of the stations, medium sands at 38%, while mixed fine and medium sands were found at 9% of the stations. In 2006 medium sands and mixed fine–medium sands predominated at 36% of the stations, while 12% of the stations had fine and coarse sands. In 2007, sediment samples were taken at 51 whale feeding sites: 12 stations in the Piltun area (average depth 18.6±1.6 m) and 39 stations in the Offshore area (average depth 50.8±0.9 m). Well-sorted fine sands (sediment group A) were prevalent at all gray whale feeding sites in both areas. About 15% of the whale feeding sites had medium-sorted mixed sandy soils (medium and fine sands). A small number of whale feeding sites in the Offshore area had a fine sandy soil mixed with silt fraction (up to 25%) (sediment group D).

Table 6. Characteristics of Sediment Groups at Whale Feeding Sites.

Sediment group	Sediment fractions						H_s	H_s/H_{max}	Code
	Peb	Grav	Sand coarse	Sand med	Sand fine	Aleu+Pel			
Whale feeding sites (2007 stations)									
A	0	0.23	0.77	5.28	**87.55**	6.16	0.43	0.31	Sf
B	0	1.69	8.85	**71.66**	10.4	7.4	0.74	0.46	Sm
C	0	7.37	12.13	44.81	26.67	9.01	1.42	0.85	Smfcк
Whale feeding sites (2006 stations)									
A	0	0.44	0.35	1.32	**90.48**	7.41	0.37	0.23	Sf
B	0	0	0.59	**87.7**	11,45	0.3	0.41	0.3	Sm
C	0	11.45	9.1	48.05	31.3	0.1	1.19	0.74	Smf+Gr

4. Benthos Composition and Quantitative Distribution in the Areas

Benthos studies were conducted in the Piltun and Offshore areas in 2002–2007 and in the Intermediate area only in 2002 and 2007.

4.1. Piltun Area

There were 60 stations in this area during the 2002 expedition, at depths of 11 to 35 m (181 bottom grab samples, average depth 20.4±0.8 m). In 2003, there were 63 stations at depths of 8 to 33 m (189 bottom grab samples, average collection depth 18.7±0.9 m); ten of the stations that year were between 8 and 10 m. There were a total of 64 stations in the Piltun area in 2004: 51 stations were sampled from the vessel at depths of 11 to 35 m, and 13 stations were sampled from a zodiac at depths of 3 to 10 m. In 2005 there were 72 stations (229 samples) at which samples were taken from the *Oparin* and 15 dive stations (60 samples) at depths of 3–12 m. Most of the vessel stations in 2006 were in the same locations as the 2005 stations. During the 2006 field season, samples were collected at 60 bottom grab stations (180 samples) and 14 diving stations (56 samples).

The station locations in 2007 was the same as the 2002 stations; samples were collected at 60 bottom grab stations (180 samples) from the vessel and 12 diving stations (48 samples) from the Zodiac. Figure 11 shows the station locations.

4.1.1. Quantitative abundance and distribution of benthos

Total benthos biomass. The 2001 and 2002 data showed similar trends in the distribution of total benthos biomass in the Piltun area: an increase in total biomass with depth was recorded throughout the area. The increase in total biomass with depth was primarily a function of increasing biomass of the sand dollar *Echinarachnius parma*, which comprised 61 to 70% of the total biomass of the area, increasing to 85–95 % at depths of 25–30 m. The proportion of other groups in the total biomass was significantly lower: crustaceans, 9–17%; bivalve molluscs, 8–13%; and isopods, 4–5%. The proportion of key WGW forage benthos (amphipods and isopods) to the total biomass decreased with depth: from 40–59% at 5–15 m to 1–4% at 20–30 m.

In 2003 and 2004, the average benthos biomass in the Piltun area at depths of 8–30 m (minimum collection depth, 8 m) was more than 500 g/m^2, with a colony density of more than 6000 individ./m^2. Once again, the sand dollar *E. parma* comprised the largest proportion (70%) of the benthos biomass; the proportion of sand dollars in the total benthos biomass increased with depth, from 20% at 15 m to 95% at 25–30 m. The biomass of amphipods decreased from

146 g/m^2 (74% of total benthos biomass) at depths of 8–11 m to 9 g/m^2 (1.2% of total benthos biomass) at 26–30 m. The sharpest changes in the quantitative abundance of benthos were observed between 15 and 20 m.

In 2005, average benthos biomass in the region was 392.4±63.3 g/m^2, which was not significantly different from the 2004 data (501.2±93.8) (Fadeev, 2005, 2006). In 2006, the average benthos biomass in the Piltun area was 434.3± 64.5 g/m^2, which was not significantly different from 2004 and 2005.

The average total benthos biomass in the Piltun Area in 2007 was 448.5±87.1 g/m^2 and showed no statistically significant differences from 2004, 2005 and 2006 data. In 2007, as in previous years, sand dollars accounted for most – 71% - of total biomass, and the proportion was as high as 84% at depths greater that 20 m. The quantitative abundance of the principal forage benthos components – amphipods and isopods – decreased from 80 g/m^2 (65% of total benthos biomass) at 11-15 m to 28 g/m^2 (4%) in the depth range of 26-30 m.

Biomass of basic taxonomic groups and common benthos species. Crustaceans (amphipods, isopods, decapods. and cumaceans), bivalve molluscs, and marine worms are of greatest interest for assessing food supplies for gray whales in the study area.

Crustaceans (*Crustacea*). The main crustacean groups had high frequencies of occurrence in the 2007, with amphipods occurring in 90% of the samples and isopods in 58%, not substantially different from the 2006 data. Despite the frequent occurrence of crustaceans in the Piltun area, the percentage of these animals in benthos biomass varied considerably within the study area, and with depth. Based on data from 2001–2007, the overall proportion of crustaceans in the macrobenthos biomass in Piltun feeding area was 40–55% at depths of 5–10 m and only 3–10% at 26–30 m.

Three types of crustacean biomass changes were observed with increasing depth. (1) Amphipods and isopods had maximum biomass at 5–15 m, decreasing sharply at depths greater than 20 m; (2) The change in cumacean biomass was the opposite, being at minimum at depths less than 20 m and increased with depth; and (3) Decapod biomass was low at all depths and varied only slightly.

For 2007, the proportion of crustaceans in the overall biomass was 65% at depths of 11–15 m, decreasing to 4% at 26–30 m. Spots of high biomass at depths greater than 20 m consist of cumaceans and large *Saduria entomon* isopods. Amphipods have the strongest declining trend in proportion of benthos biomass with increasing depth (Table 7; Figures 12, 13). Some patchy areas of high crustacean biomass were observed in the coastal zone. The largest areas of crustacean accumulations were observed in the southern and northern portions of the area. These shallow-water accumulations consist of amphipods and isopods.

Table 7. Macrobenthos Biomass Distribution (g/m2) in the Piltun Area Based on Field Data from 2006 and 2007.

Depth	Depth								Entire area.		
	11–15 m		16–20 m		21–25 m		26–30 m				
	2007	2006	**2007**	2006	**2007**	2006	**2007**	2006	**2007**	2006	2002
Amphipoda	74.7	59.8	22.8	25.5	19.9	19.8	16.8	9.4	32.1±4.8	28.5±3.8	42.7±8.4
Isopoda	5.5	17.3	5.7	10.6	4.2	12.4	11.3	7.7	6.8±3.8	11.6±1.6	18.9±4.6
Bivalvia	32.9	6.4	21.4	19.6	54.5	32.2	34.4	56.2	35.9±5.6	30.1±7.1	40.4±8.8
Cumacea	1.2	0.3	0.8	0.3	2.4	0.4	19.5	9.1	7.3±3.9	2.7±1.1	7.1±3.5
Echinoidea	2	4.5	339.1	110	319	620	655	523	334±84	335±65	343±112
Polychaeta	6.6	4.1	11.4	4.6	8.7	3.2	8.2	9.1	8.7±3.2	5.3±1.2	12.1±7.1
Pisces	0.6	7.5	15.1	9.1	23.1	17.6	39.9	34.1	27.7±12.1	17.7±9.9	43.4±18.1
Totals	123.5	102.5	416.3	183.8	431.8	709.9	775.1	658.2	448.5±87.1	434.3±64.5	525±88.1

Isopods (*Isopoda*). In 2001, the proportion of isopods to the total macrobenthos biomass was 14.1% at depths of 5–10 m, and only 2.4% at 11–30 m. The average isopod biomass in 5-30 m was 25.0 g/m^2. The small isopod *Synidotea cinerea* (average body weight 0.02 g) was the most significant component of benthos biomass in the Piltun area. This isopod had the highest rate of occurrence of all macrobenthos species: 86% in the study areas at depths of 5–30 m. Maximum biomass values for this species were observed at depths less than 15 m. Only a few individuals of *S. cinerea* were encountered in deeper waters. The largest colony of *S. cinerea* (up to 5000 individ./m^2) was associated with tube mats of the sea worm *Onuphis shirikishinaiensis* (Photo 1A).

A larger isopod, *Saduria entomon* (body weight up to 5 g, average weight 2.1 g), was encountered much less frequently in the Piltun area (approximately 25% frequency of occurrence). However, this species can form large local accumulations that, together with other crustaceans, can be considered as potential prey for gray whales (Photo 1B). In contrast to *S. cinerea*, the biomass of *S. entomon* increases with depth. *S. entomon* had a 16% frequency of occurrence in the 2002 collections. The biomass of this species at depths of 11 to 30 m varied from 1.5 to 56 g/m^2.

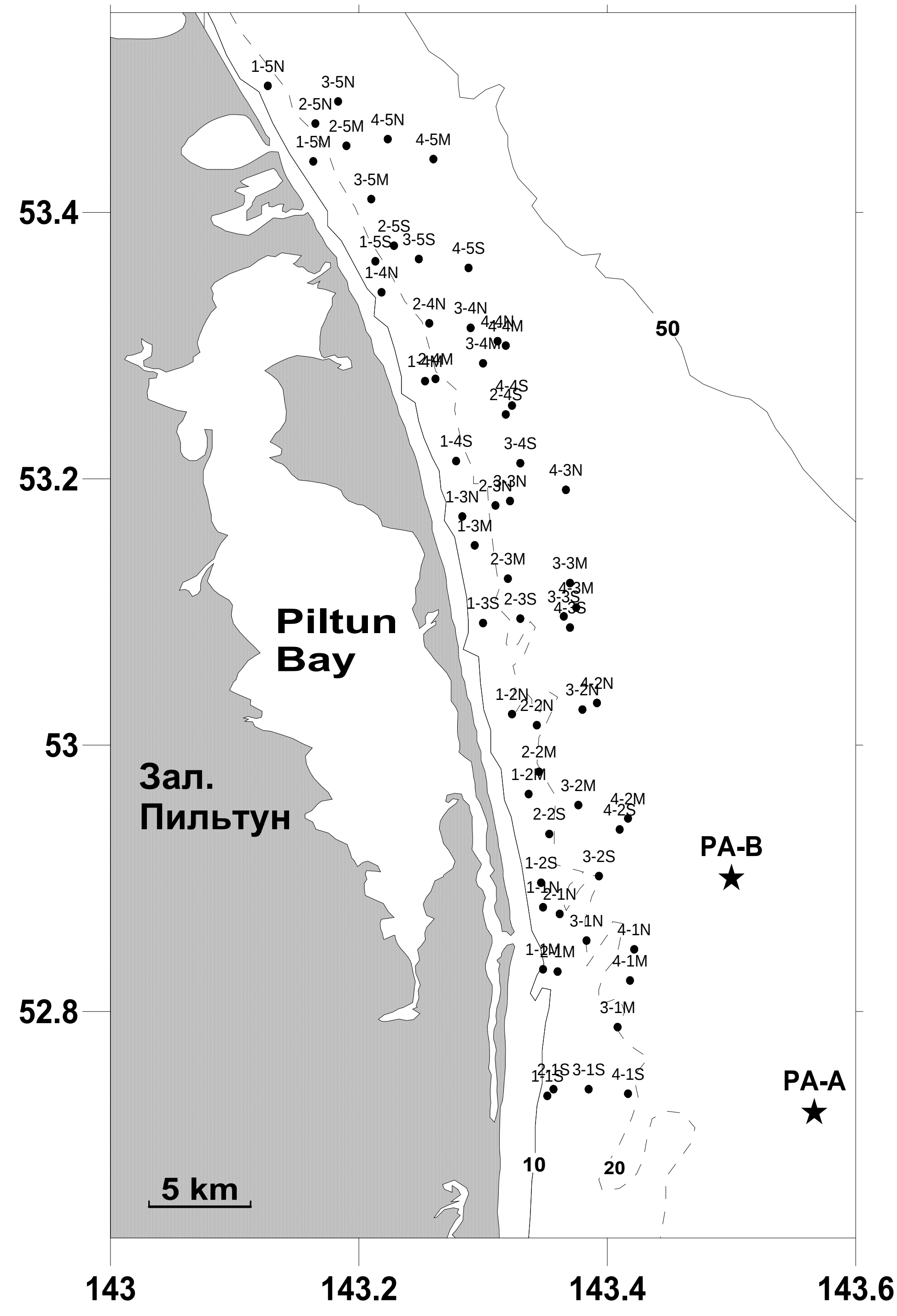

Figure 11. Locations of stations in the Piltun area in 2002 and 2007.

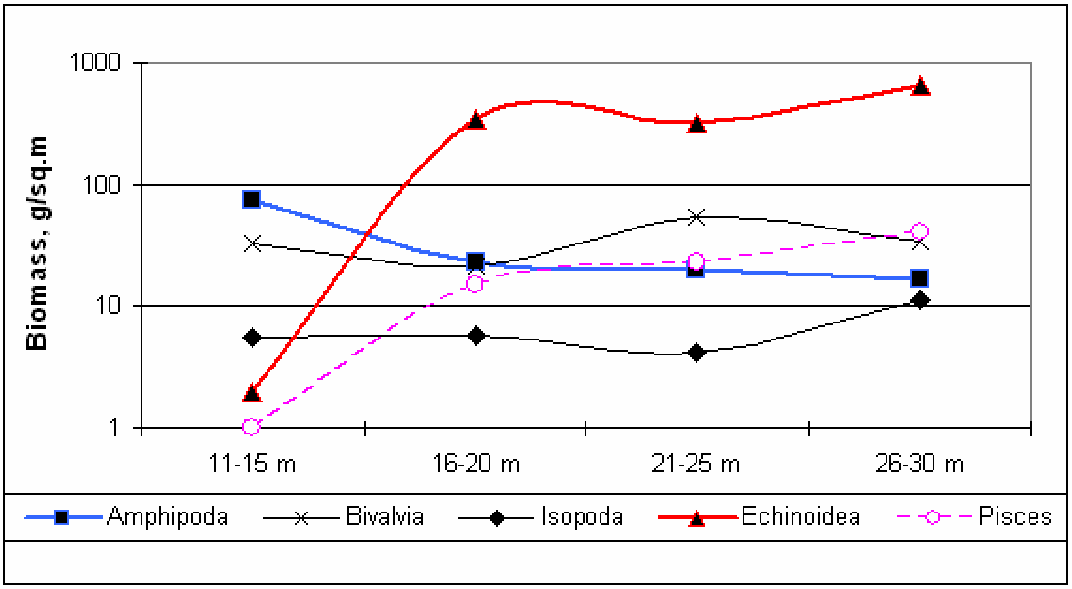

Figure 12. Variation in biomass (g/m2) of 5 benthos groups by depth in the Piltun area in 2007.

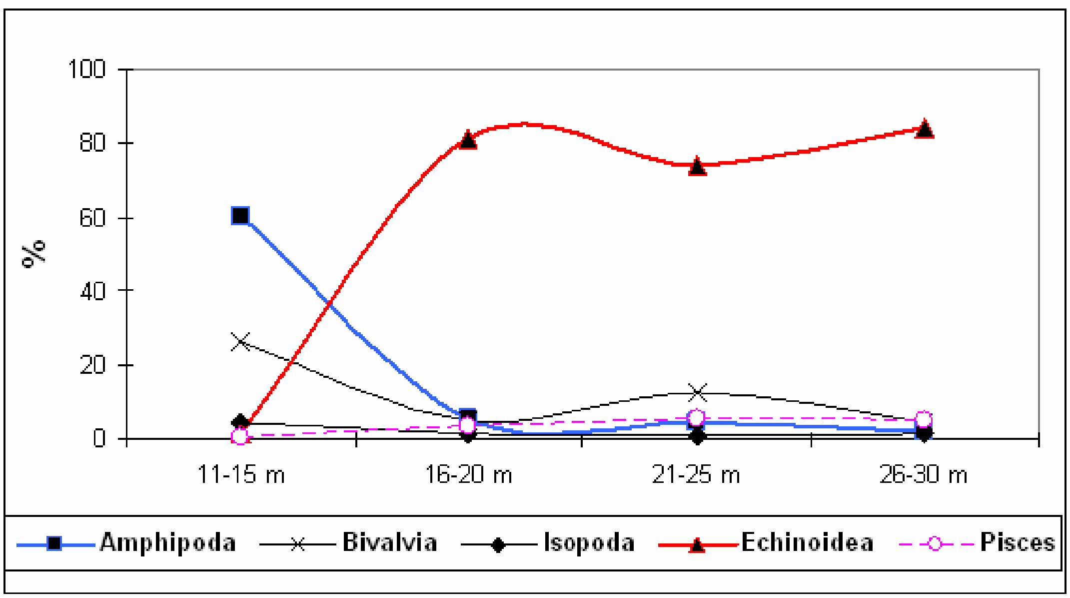

Figure 13. Variation in the proportions (%) of 5 benthos groups in the total benthos biomass by depth in the Piltun area in 2007.

The isopod distribution in the Piltun area in 2003 was distinctly patchy. This patchiness of isopod biomass distribution in the shallow zone was due to local accumulations of the small isopod *Synidotea cinerea*. The density of this species in the accumulations reached 3600 individ./m^2 with a biomass of 55 g/m^2. At depths greater than 15 m, areas of elevated isopod biomass were due to accumulations of the large isopod *Saduria entomon*. The biomass of this species in local accumulations reached 128 g/m^2 with a colony density of 75 individ./m^2. However, analysis of the spatial biomass distribution of this species indicated that such accumulations are rare and occupy a small area in the sand dollar zone. For example, accumulations of *Saduria entomon* with a biomass greater than 30 g/m^2 were observed at six stations in 2003. The isopods were present at each station in only one bottom grab sample out of three taken at the station. The other two samples at these stations were predominantly sand dollars with a biomass of up to 1200 g/m^2, with no isopods. The proportion of samples with isopod dominance in the biomass was only 6% at depths greater than 15–20 m in 2003 and less than 3% if bottom grab sample collections from 2002 are included. Despite the infrequent occurrence at depths greater than 15 m, there are local accumulations of large isopods.

Both of these isopods can be eaten by individual whales but do not constitute a constant food source.

The average isopod biomass in 2007 collections (6.8±3.8 g/m^2) was lower than in 2002 and 2006 (11.6±1.6 and 18.9±4.6 g/m^2, respectively). This decrease was due to the prevalence of young *Saduria entomon* (size class up to 25 mm) during the 2007 survey period. Moreover, no clear trend in variation of isopod biomass with increasing depth was observed (Table 7, Fig. 14). As in 2002-2006, the highest biomass (more than 45 g/m^2) of *Saduria entomon* were observed within local accumulations at depths greater than 20 m. The maximum biomass of this species in 2007 collections was 79 g/m^2 .

The spatial distribution of isopods in 2007 and 2006 was distinctly patchy. Distinct accumulation of isopod biomass was observed near the mouth of the Piltun lagoon in 2002 and in 2007 (Fig 14B). Only a slight accumulation of isopod biomass occurred near the mouth of the lagoon in 2006, while larger accumulations were recorded in the northen portion of the area (Fig 14A).

<u>Characteristics of the dominant isopod species</u>. The large isopod *Saduria entomon* is a brackish-water Pan-Arctic circumpolar species represented by relic populations in the boreal zone. It resides throughout a broad depth range: 0-44 m in the Arctic (Crimmon and Bray, 1962), and 1-270 m in the Baltic Sea (Jarvekulg 1979). According to published data, the

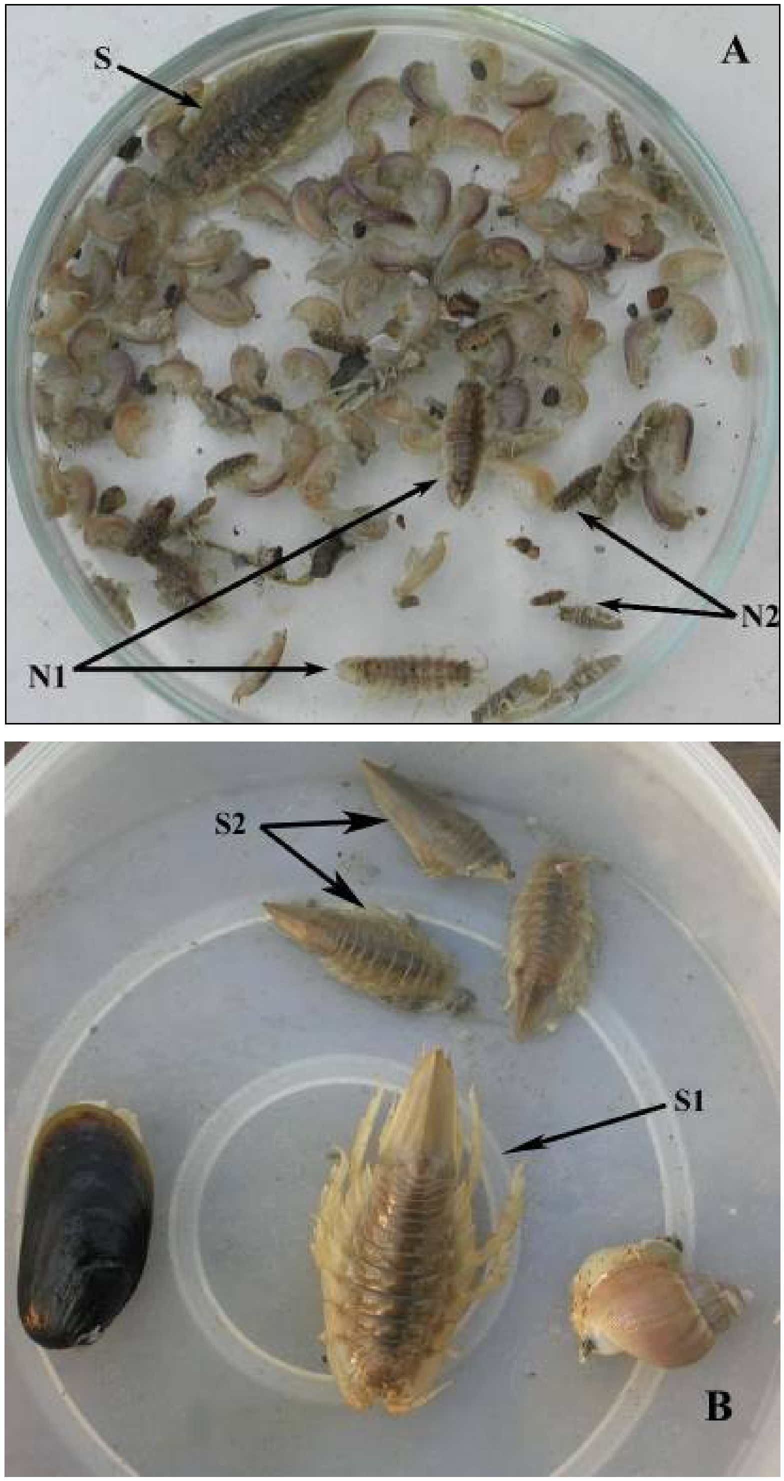

Photo 1. A) Isopod *Saduria entomon* (S), adult (N1) and young (N2) individuals of the isopod *Synidotea cinerea* from bottom grab sample. B) Young (S2) and adult (S1) individuals of the isopod *Saduria entomon* (depth 25 m) from the sand dollar zone.

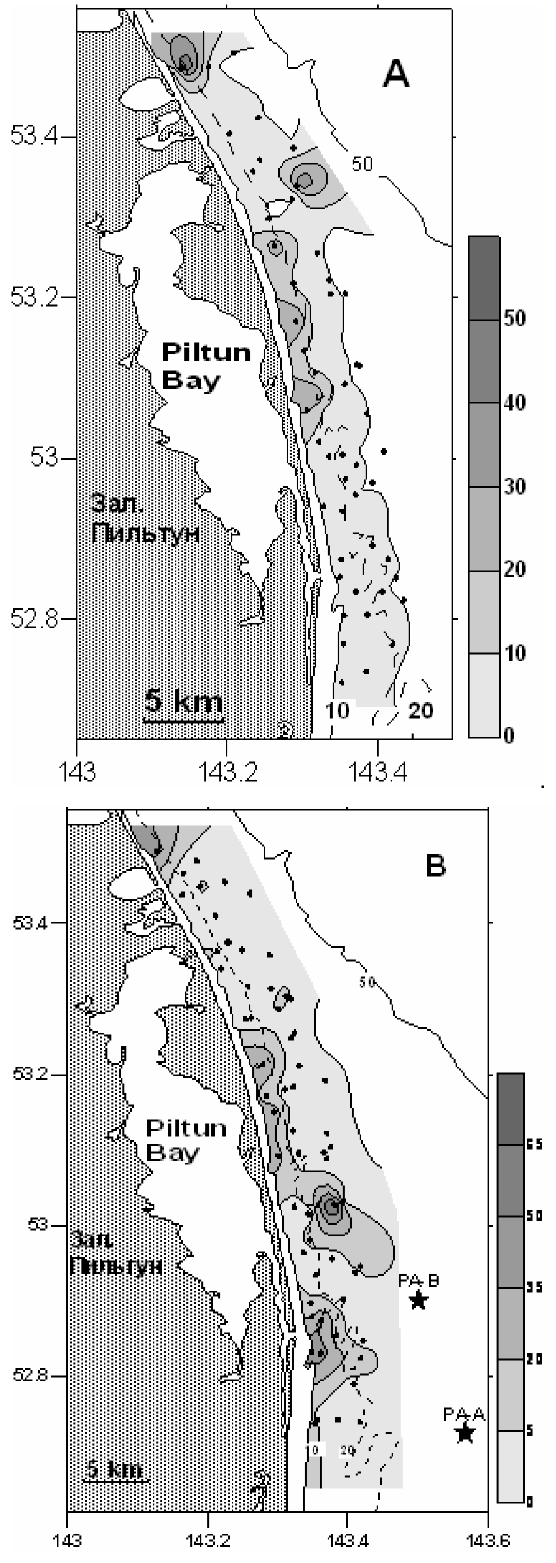

Figure 14. Isopod biomass distribution (g/m2) in the Piltun area according to materials from 2006 (A) and 2007 (B).

maximum habitat temperature in the Arctic and the seas of the Far East is 10 ºC (Crimmon and Bray 1962). The species reaches sexual maturity at the age of 3-4 years (Yarvekyulg 1979). It inhabits the lagoons of eastern Sakhalin and is encountered throughout the Piltun lagoon, where it is the only predator among the epibenthic invertebrates (Kafanov et al. 2003). This isopod is an active cannibal predator (Leonardsson 1991; Sparrevik and Leonardsson 1998), and its accumulations are temporary in nature.

Amphipods (*Amphipoda*). In 2001, all ten species of amphipods had frequencies of occurrence higher than 25% at depths of 5–30 m, and three species had a frequency of occurrence higher than 50% (*Eohaustorius eous eous – 81%; Grandifoxus longirostris – 75%; and Monoporeia affinis – 71%*). The average amphipod biomass for the Piltun feeding area at depths of 5–30 m was 114.1±15.7 g/m^2.

In 2002-2003 37 amphipod species were recorded. Of these, six species frequenc of occurrence (P) higher than 50%: *Eohaustorius eous eous (P = 100%), Pontoporeia affinis* (98%), *Grandifoxus longirostris* (86%), *Eogammarus schmidti* (81%), *Anisogammarus pugettensis* (78%), *and Westwoodilla sp*. (65%). The average amphipod biomass levels for the entire area were similar in 2002 and 2003 (42.7±9.6 g/m^2 and 54.6±8.7 g/m^2).

The average amphipod biomass in the Piltun area in 2005 was 38.8±7.2 g/m^2, which is lower but not significantly different to 2004 values of 47.4±7.7 g/m^2. The further decrease in average amphipod biomass for the Piltun area from 38.8±7.2 g/^{2} in 2005 to 28.5±3.8 g/m^2 in 2006 was due to a decrease in amphipod biomass at depths greater than 25 m (18.1 g/m^2 in 2005 and 9.4 g/m^2 in 2006). The decrease in amphipod biomass at these depths has no decisive effect on the food supply for gray whales in the Piltun area, since amphipods make up less than 2% of average benthos biomass at depths greater than 25 m and do not form significant accumulations.

The average amphipod biomass was 32.1±4.8 g/m^2 in 2007, which is higher than but not significantly different to that in 2006. As in 2005-2006, the average amphipod biomass in 2007 was about 6-9% of the total benthos biomass. More than 95% of amphipod biomass was due to two species: *Monoporeia affinis* (more than 60% of the total amphipod biomass) and *Eogammarus schmidti* (more than 30%). In 2007, amphipods accounted for 58% of benthos biomass at depths less than 15 m, and the proportion decreased to 1.5% at depths greater than 20 m.

Data for 2001-2007 show that the largest amphipod accumulations occurred in the near-shore zone of the Piltun area at depths less than 15-20 m. In 2007, the average amphipod biomass at depths of 15 m or less was 74.7±9.8 g/m^2, which is higher than but not significantly different to that in 2006 (59.8±11.8 g/m^2, Table 7).

The differences in amphipod biomass distribution between years are seen on Figure 15. The amphipod biomass distribution was more aggregated in 2006 than in 2007 and 2002. In 2006, local spots of elevated biomass (about 120 g/m^2) can be seen only in the northern parts of the area. It is noteworthy that this northern accumulation was not of *Monoporeia affinis,* as in all previous years, but of *Eogammarus schmidti*, which is usually the second-most predominant species. Another notable change in the spatial distribution of amphipods was the re-emergence of elevated amphipod biomass near the mouth of the Piltun lagoon in 2007 after a decline in 2006. Such areas are distinctive in the southern Piltun area (the waters off the outlet from Piltun lagoon) in the 2002 and 2007 charts (Fig. 15).

In September 2006, the average amphipod biomass in 11-15 m depth in the southern Piltun area was 33.5 g/m^2. In 2005, in the same area in similar depths, the average amphipod biomass sometimes reached 69.4 g/m^2. Differences in average biomass numbers at the same stations in 2005 and 2006 may have been due to a number of factors. In 2005, in the area's southern section, sampling was performed in July, i.e., at the beginning of the feeding season, while in 2006 samples were collected in September, i.e., at the end of the feeding season. Despite the different sample collection periods, the average size of mature *M. affinis* individuals was 11.62±0.14 mm (max = 15.9 mm) in 2005 and 12.66±0.18 mm (max = 15.8 mm) in 2006. The proportion of *M. affinis* in biomass in the northern part of the area in 2006, as in the southern part, was lower than the figures for previous years. Most of the biomass was accounted for by *Eogammarus schmidti.*

A description of hydrologic regime provided in section 3.1 of this report indicates that near-bottom water temperatures in the southern sections of the Piltun area were lower in 2006 than in 2004 and 2005. In addition, satellite observation data, indicate that ice conditions were more difficult in 2006 than in 2004 and 2005 (Fig. 33). Thus near-bottom temperatures and longer sea ice cover might have limited amphipod production during 2006 in the Piltun area. The probable effect of the water temperature and ice conditions on amphipods productivity is considered in more details in Section 4.6.

In 2007 amphipod biomass increases in the shallow-water zone of the Piltun area. Amphipods biomass is higher for entire Piltun Area in 2007 (32.1±4.8 g/m^2) than in 2006 (28.5±3.8 g/m^2) but fails to reach the maximum levels of previous years (2004 - 47.4±7.7 g/m^2).

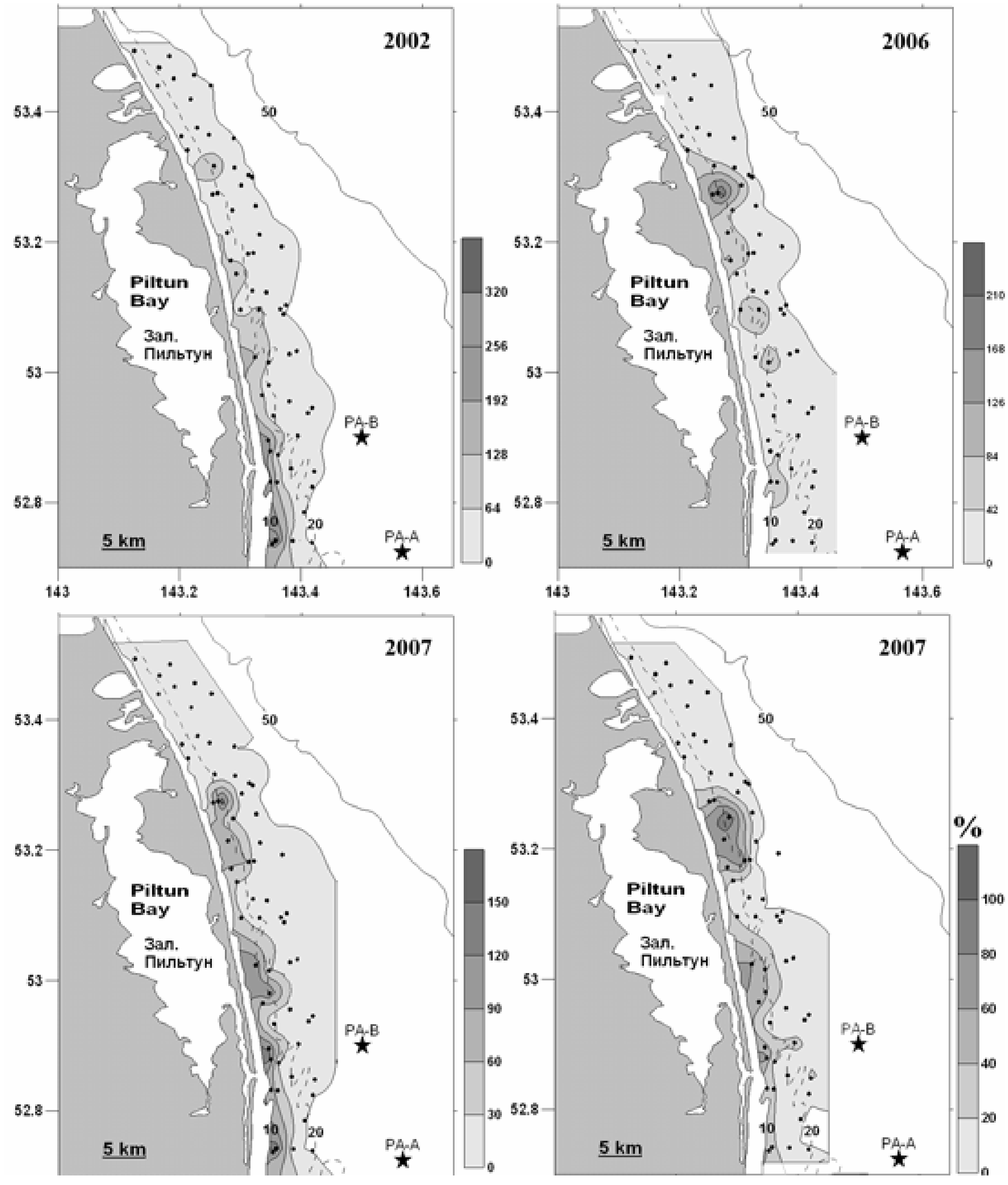

Figure 15. Amphipod biomass distribution (g/m2) in the Piltun area based in 2002 and 2006-2007, and the proportion of amphipods (%) in total benthos biomass in the Piltun area in 2007.

Characteristics of the dominant amphipod species. The amphipod *Monoporeia affinis* (= *Pontoporeia affinis*) is a brackish-water Pan-Arctic circumpolar species represented by relict populations in the boreal zone. It inhabits the northern arctic seas and lakes of Northern Europe and North America. It has been recorded in the Northern Pacific along the littoral of the Komandorskiye Islands, in freshened areas and relict lakes of the western part of the Bering Sea (the mouth of the Kamchatka River, the Anadyr liman, and lakes near the mouth of the Kamchatka River) and in the Amur liman and the Sea of Okhotsk.

In the Baltic Sea, it lives at depths of 0.5-300 m with salinity of 1.5-18‰ and temperatures up to 12.8ºC (Yarvekyulg 1979). Females are benthic forms and are covered in the soil throughout their life cycle. Males lead a pelagic life during the mating season. Mating occurs in October-December, and young appear in March or April. The males die soon after mating, and the females die after the young emerge from the incubating sac.

With respect to feeding type, it is a burrowing detritus feeder. In digging up the top layer of the bottom and stirring up the bottom sediment during feeding, *M. affinis* has a significant impact on bivalve mollusk juveniles (Segestrale 1973), meiobenthic animals (Olafsson and Elmgren 1991) and even zooplankton (Albertsson and Leonardsson 2001). It breeds in winter, and juveniles emerge from the hatching pouch in spring; individuals die after the first breeding (Jarvekulg 1979). In cold waters, the species reaches sexual maturity in the second year of life, while in warmer waters, it has a one-year life cycle (Segerstrale 1967). In the Baltic Sea, *M. affinis* is among the highly productive benthic species (Andersin et al. 1984).

Cumaceans (*Cumacea*). In 2001, the average biomass of cumaceans at depths of 5–30 m was 7.1±3.5 g/m^2. Their biomass displayed a pattern of increasing with depth. In the range of 11–15 m, average cumacean biomass was 5.3 g/m^2 and increased to 48.9 g/m^2 at a depth of 30 m. The highest cumacean colony density of 24,800 to 37,600 spec./m^2 with a biomass of 84 to 113 g/m^2 was observed at 30-32-m depths.

The average cumacean biomass for the entire area in 2003 was 1.7 g/m^2, which is comparabe to the 2004 data – 1.1 g/m^2 (Fadeev 2007).

Cumaceans had a high frequency of occurrence – more than 75% of all samples collected during 2006 and 2007 contained cumaceans. As previously, four cumacean species were observed in 2007 at depths up to 30 m: *Lamprops affinis, Lamprops quadriplicata, Diastylopsis dawsoni* and *Diastylis bidentata.* The first three species were encountered in small numbers at depths less than 15 m. Only *Diastylis bidentata* was encountered at all depths; it accounted for more than 98% of the total cumacean biomass. The average cumacean biomass for the entire area in 2007 was 7.3±3.9 g/m^2, which is not substantially different from the data from 2006 – 2.7±1.1 g/m^2. Cumacean biomass in 2006 and 2005 were lower than in 2002 – 10.9 g/m^2. However, it should be noted that the station layout in 2005-2006 differed from the 2002 layout. The 2007 collections performed according to the 2002 station layout demonstrate a similar level of cumacean biomass at depths greater than 20 m.

Bivalve molluscs *(Bivalvia).* In 2001, only three bivalve mollusc species had a frequency of occurrence higher than 25%: *Siliqua alta, Macoma lama* and *Tellina lutea*. The biomass of Bivalvia increased somewhat within the Piltun area from 5 m to 15 m, and then decreased at depths greater than 20 m. The average biomass of bivalve molluscs for the Piltun area (at depths of 11–30 m) was 103.2±25.15 g/m^2.

In 2002, the average biomass of bivalve molluscs (at depths of 11–30 m) was 40.36±8.81 g/m^2. In 2002, four species made up the basis of bivalve mollusc biomass: *Tellina lutea* (frequency of occurrence P = 56%), *Macoma lama* (P = 45%), *Siliqua alta* (P = 31%) and *Mactromeris polynyma* (P = 31%). Areas of elevated biomass had a patchy distribution and were associated with the southern, middle and northern parts of the area (Fadeev 2007).

Over the period 2002-2007, thirty species of bivalve molluscs were recorded. Of these, five species had average frequencies of occurrence higher than 25%: *Tellina lutea* (P = 60-71%), *Macoma lama (*P = 25-35%), *Siliqua alta* (P = 30-32%), *Mysella kurilensis (*P = 28-30%) and *Mactromeris polynyma* (P = 25-27%).

The average bivalve mollusc biomass in the Piltun area was 35.9±5.6 g/m^2 in 2007 and 30.1±7.1 g/m^2 in 2006 (Table 7). The bivalve mollusc biomass varies only slightly throughout the depth range studied (Figures 12 and 13).

Sand lance *Ammodytes hexapterus.* In 2002-2003, the frequency of occurrence of the sand lance in the Piltun area was 5-8%, with an average biomass of 4.6-6.2 g/m^2. The frequency of occurrence of the sand lance in 2004 was 15%, with an average biomass of 14.8±4.8 g/m^2. Within local accumulations, the sand lance biomass varied from 68 to 166 g/m^2, which amounted to 25 to 48% of the biomass in the samples.

The sand lance was encountered in small numbers throughout the Piltun area in 2004-2005, with the densest accumulations recorded in the northern and middle parts of the area. In 2005, when frequency of occurrence was 15% throughout the area, the frequency in the northern part was as high as 40-60%. Average biomass in 2005 was 16.3±4.4 g/m^2 for the Piltun area and reached 150 – 236 g/m^2 within local accumulations. Sand lance were observed in the Piltun area for the first time at depths greater than 10 m in 2001 and was considered potential prey of western gray whales in the Piltun area (Fadeev, 2002), since sand lance had previously been identified as prey of gray whales (Zimushko and Lenskaya, 1970).

Photo 2. Contents of two bottom grab samples at station 4-5M, 25 m (explanations are given in the text).

The sand lance is a temporary biota component at depths of 40 m or less. It breeds and the young feed there. The densest accumulations of the species in the Piltun area are associated with areas of sandy bottoms mixed with gravel at depths greater than 20 m

To assess the size of sand lace microaggregations, a series of 5 bottom bottom grab samples were collected at stations where they had accumulated in 2006-2007. The coordinates for each sample were registered by GPSMAP. The coordinates of mass appearances of the sand lance from the bottom were registered using an underwater TV camera. Photo 2 shows two consecutive bottom grab samples (out of a total of 5 collected) at station 4-5M, as the vessel drifted. The distance between each of 5 bottom grab sample was 50 m. Only sand dollars *E. parma* were present in the first grab sample (no photo shown), while urchins and a few sand lance were present in the second sample (shown in Photo 2A). In contrast, sand lance with biomass of more than 106 g/m^2 were present in the third sample (Photo 2B), while there are only sand dollars in the fourth and fifth samples. Based on the video survey of the bottom surface along the line on which the 5 grab samples were taken, the abundance of sand lance was estimated to be 1200-1400 m^2. If the sand lance biomass in grab sample (Photo 2B) is taken as the maximum, the total biomass in this area can be as high as 120-150 kg.

The average sand lance biomass in the Piltun area was similar in 2007 and in 2006 (Table 7). In the northern part of the Piltun area, a substantial decrease in frequency of occurrence of sand lance was observed from 40-60% in 2005 to 20-25% in 2006-2007. The causes may be related to a natural decline in numbers (according to published data, an eruption of sand lance typically lasts three or four years). Changes in the spatial distribution and abundance of the sand lance during the period 2004-2007 are illustrated in Figure 16.

The most distinct increase in frequency of occurrence and biomass of sand lance in the northern Piltun area was observed during 2004-2005. There was a concurrent decrease in the number of whales feeding in the Offshore area, and increase in the number of gray whales feeding at depths greater than 20 m in the northern Piltun area (Vladimirov et al., 2006; Yakovlev and Tyurneva, 2006). The appearance of an additional, accessible food supply, sand lance, in the northern Piltun area may have attracted feeding whales to the northern Piltun area, away from other feeding areas. Most of the sand lance accumulation in the northern Piltun area was 5-7 km from shallow-water coastal amphipod complex. Gray whales can cover this distance in 1-1.5 hours, allowing shallower-water areas with amphipod dominance and deeper-water areas with sand lance dominance to be used by the same individual WGWs on the same day.

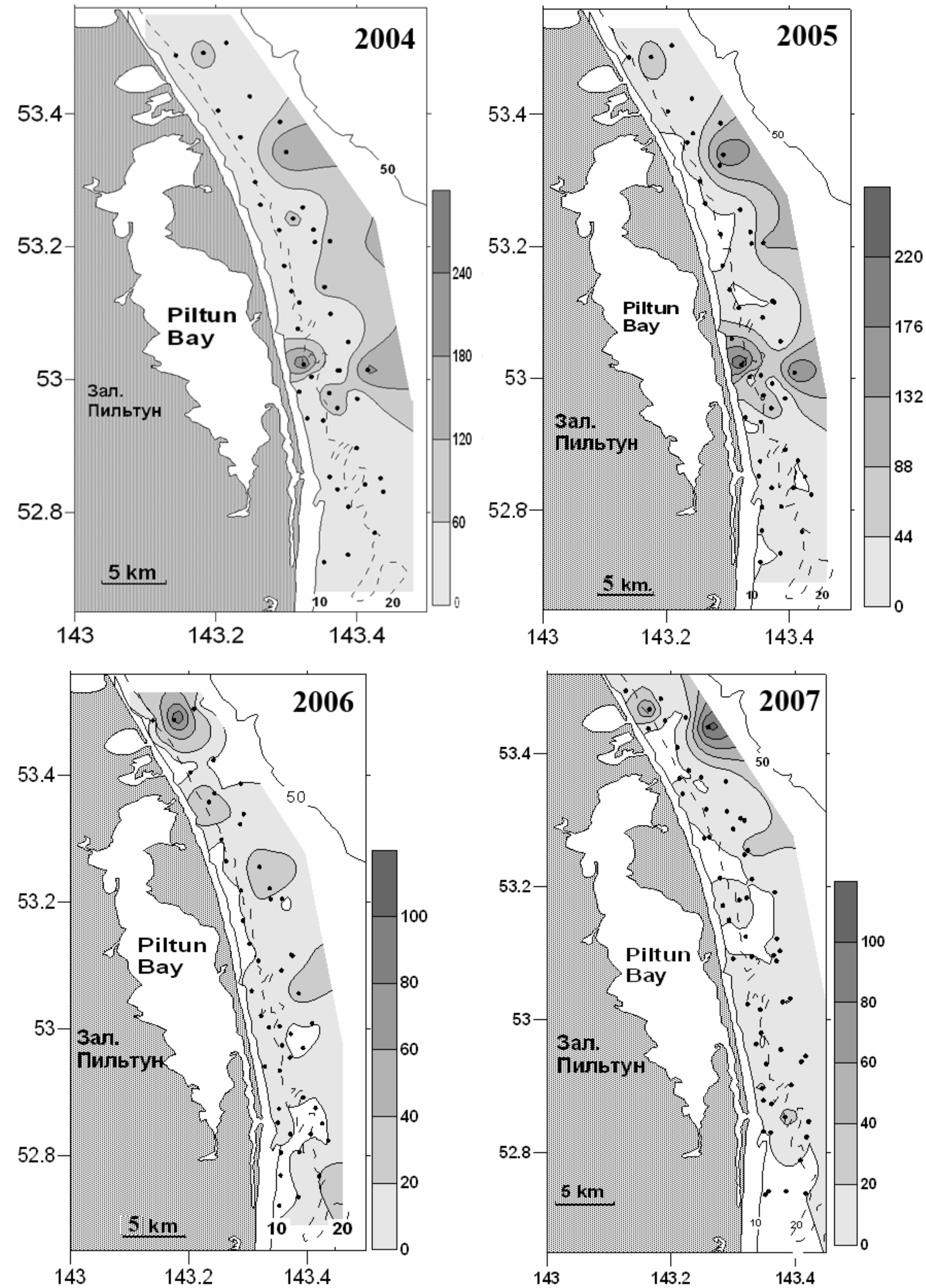

Figure 16. Sand lance biomass distribution in the Piltun area in 2002-2007.

4.1.2. Composition and Distribution of Benthos Complexes

Cluster analysis was used to identify irregularities in the benthos distribution – the 256 stations (2002-2006) were grouped according to the similarity of quantitative relationships among benthos taxonomic groups. The classification results are presented in a dendrogram (Fig. 18). Data from 2007 have been used to further define the boundaries of the complexes. The groups of stations with the greatest similarity within the groups in regard to benthos complexes are not, strictly speaking, biocenotics units. In further detailing, the complexes are further divided into a number of complexes that are smaller but have greater similarity of units within the groups – communities. Figure 17 shows the locations of stations assigned to each complex in the Piltun area. The benthos complexes differ in both the composition and the quantitative abundance of the taxonomic groups (Table 8).

Table 8. Composition of benthos complexes of the Piltun area.

Taxonomic group	*Amphipoda* complex		*Bivalvia* complex		*Echinoidea* complex	
	A, spec./m^2	B, (g/m^2)	A, spec./m^2	B, (g/m^2)	A, spec./m^2	B, (g/m^2)
Amphipoda	5283	**90,21**	1077	20,35	419	25,35
Bivalvia	74	17,56	377	**162,45**	67	46,32
Cumacea	120	1,58	74	0,68	1196	7,63
Decapoda	0	0	1	2,06	2	3,54
Echinoidea	1	1,34	10	30,52	167	**914,3**
Isopoda	312	18,47	254	11,71	16	20,52
*Pisces**	2	7,09	1	5,91	3	17,23
Polychaeta	66	2,57	79	14,79	90	24,54
Totals	2663	138,82	1874	248,47	1960	1059,43

Note: * - temporary community component.

The *Amphipoda* complex includes 68 stations at depths of 5 to 23 m (average depth 15 m) in the fine- and medium-grained sand zone. The complex is distributed in a belt-like pattern along the coast in the Piltun area (Figure 17). The average biomass of the complex (138.8 g/m^2) is made up primarily of amphipods – 65%; isopods – 13%; and bivalve molluscs – 13%. The complex includes 34 amphipod species with a total biomass of 90.2 ±18.5 g/m2 at a colony density of 5,280±1,300 spec./m^2. Four species have the greatest quantitative abundance: *Monoporeia affinis, Eogammarus schmidti, Eohaustorius eous eous* and *Anisogammarus pugettensis*. They account for 92% of the average biomass and colony density of amphipods in the complex. (Photo 3).

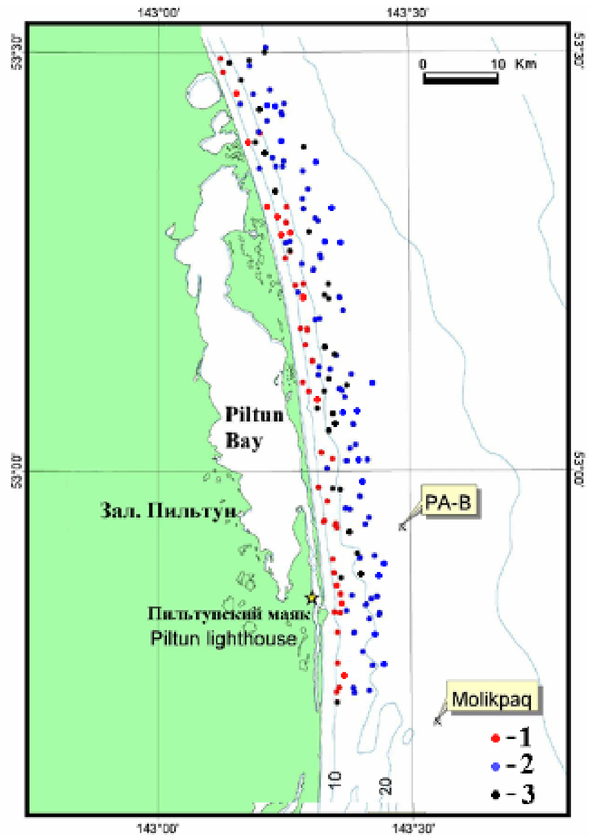

Figure 17. Distribution of complexes in the Piltun area based on 2002-2007 data.

Complex designations: 1 – amphipods; 2 – sand dollars; 3 – bivalve molluscs.

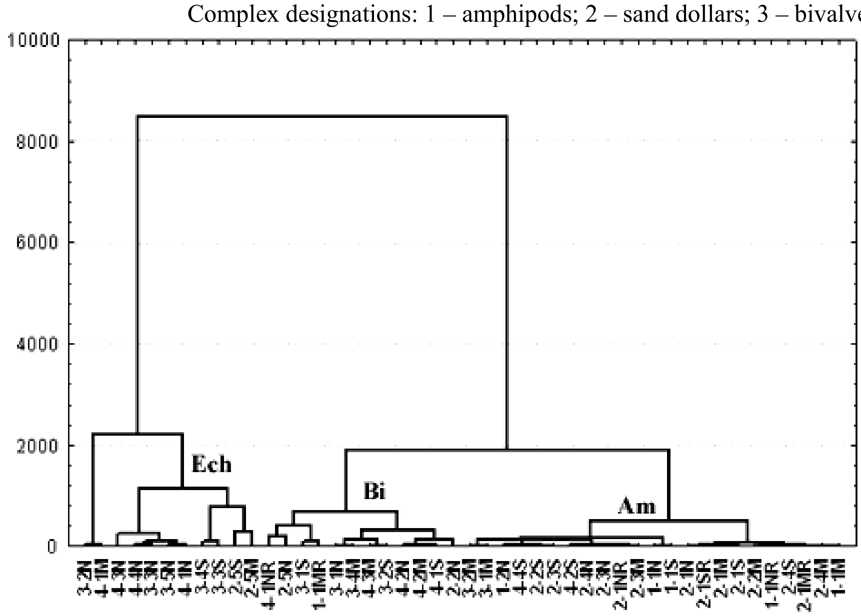

Figure 18. Dendrogram of the similarity of stations in the Piltun area based on collections from 2002-2007.

In dendrogram: Am – amphipod complex; Bi – bivalve mollusc complex; Ech –sand dollar complex.

Photo 3. Bottom grab sample (0.2 m^2) from the amphipod complex.

Photo 4. Bottom grab sample (0.2 m^2) from the sand dollar complex.

The *Amphipoda* complex of species, in turn, is dominated by *Monoporeia affinis*, which makes up 85% of biomass and 80% of colony density of the complex. Second in significance in the complex is the isopod group, represented by two species: *Synidotea cinerea* and *Saduria entomon*. The dominant species, *S. cinerea,* has a frequency of occurrence in the complex of 95%, and it accounts for 94% of the total isopod biomass. The complex includes 10 species of molluscs, of which five species have a frequency of occurrence greater than 50%: *Tellina lutea, Siliqua alta, Tridonta borealis, Liocyma fluctuosum* and *Macoma lama.* These species account for more than 95% of the biomass of bivalve molluscs (17 g/m^2).

Based on diving data from 2001, the bottom areas where similar compositions of amphipods and isopods dominate are located in the near-shore zone of the Piltun area at depths of 5-17 m (Fadeev 2007). The amphipods *Monoporeia affinis* had the greatest abundance in the coastal amphipod complex in 2001–2007.

The *Bivalvia* complex includes 48 stations at depths of 9 to 31 m (22 m on average) on fine sands and mixed gravel and sand bottoms. In contrast to the amphipod complex, it has a distinctly spotty distribution across the area (Figure 17). The composition of the complex includes 18 bivalve mollusc species with a biomass of 162.45± 53.4 g/m^2 at an average complex biomass of 248.5 g/m^2. Seven species have the highest frequency of occurrence: *Tellina lutea, Astarte arctica, Macoma lama, Tridonta borealis, Siliqua alta, Mysella kurilensis, Liocyma fluctuosum* and *Mactromeris polynyma*. They account for more than 98% of the total biomass of the complex. The bivalve mollusc complex is not homogeneous: *Tellina lutea* is dominant in the shallow areas, while *Astarte arctica* is dominant in deeper waters (deeper than 20-25 m). Within the complex, the total amphipod and isopod (primarily *Saduria entomon*) biomass can reach 50% of the biomass of molluscs.

The sand dollar *Echinarachnius parma* complex (Photo 4) has been described in detail based on materials from 2001-2004 (Fadeev 2007) and is not covered in this report.

Summarizing the analysis of the distribution of macrobenthos complexes based on materials from 2002-2007, we note that most of the sea bottom in the Piltun area is occupied by two complexes: a shallow-water coastal amphipod complex with a high proportion of forage components, and a deeper-water sand dollar complex with an extremely low proportion of prey in its biomass. The provisional boundary between the complexes lies at depths of about 20 m. No year-to-year changes were observed in the structure or spatial distribution of the complexes during the period 2002-2007.

4.2. Offshore area

4.2.1. Quantitative abundance and distribution of benthos

In the Offshore area in 2007, there were 48 stations (144 bottom grab samples) at depths from 19 to 62 m. The average depth in 2007 was 42.5±1.7 m; 42.1±1.7 m, n=48 in 2006; 42.5±1.7 m, n=48 in 2005; and 49.3±2.3 m, n=32 in 2004. Diagrams of station locations in the Offshore area are presented in Figures 19. In contrast to the diagrams of station locations in 2002, there was a full grid of stations (48 stations) throughout the Offshore area during the 2007 expedition.

Most of the Offshore area has sandy sediments: well-graded fine sand was recorded at 40 stations and differently-grained sand with mixtures of gravel and pebbles at eight stations. The proportion of the silt-pelite fraction is more than 20-26% of the dry sediment weight at a number of stations. Seventeen benthos taxonomic groups were recorded during 2007 in the Offshore area; they differed substantially in their frequency of occurrence (Table 9).

Table 9. Frequency of occurrence of benthos taxonomic groups in the Offshore area.

Frequency of Occurrence (P, %) of Taxonomic Groups, n=48							
P>50%		P = 25-50%		P = 10-25%		P<10%	
Group	P,%	Group	P,%	Group	P,%	Group	P,%
Amphipoda	96	*Gastropoda*	44	*Echinoidea*	21	*Bryozoa*	8
Polychaeta	83	*Nemertinea*	27	*Sipunculida*	19	*Hydroidea*	8
Bivalvia	73	*Decapoda*	27	*Caprellida*	17	*Pisces*	8
Cumacea	70			*Holoturoidea*	12	*Ophiuroidea*	5
Actinia	70			*Isopoda*	10		

As in 2002-2006, the groups with a frequency of occurrence greater than 50% were amphipods, cumaceans, bivalve molluscs, marine worms and sea anemones. Groups with lower frequencies of occurrence, such as sand dollars *E. parma* (P = 19%), nevertheless formed localized concentrations of biomass. For the Offshore area as a whole, these seventeen taxonomic groups accounted for more than 95% of the average total benthos biomass during 2007 – 654±60 g/m^2 (n=48). The quantitative abundance of benthos in the Offshore area in 2007 are given in Table 10.

Field data from 2007 and 2006 were collected under a similar sampling procedure (performed on 48 stations) and within similar calender timelines, thus reducing potential effects of temporal variability in the analysis of the data.

The average total benthos biomass was 489.4±60.5 g/m^2 in 2007 and 654.7±59.9 g/m^2 in 2006; these differences were not statistically significant.

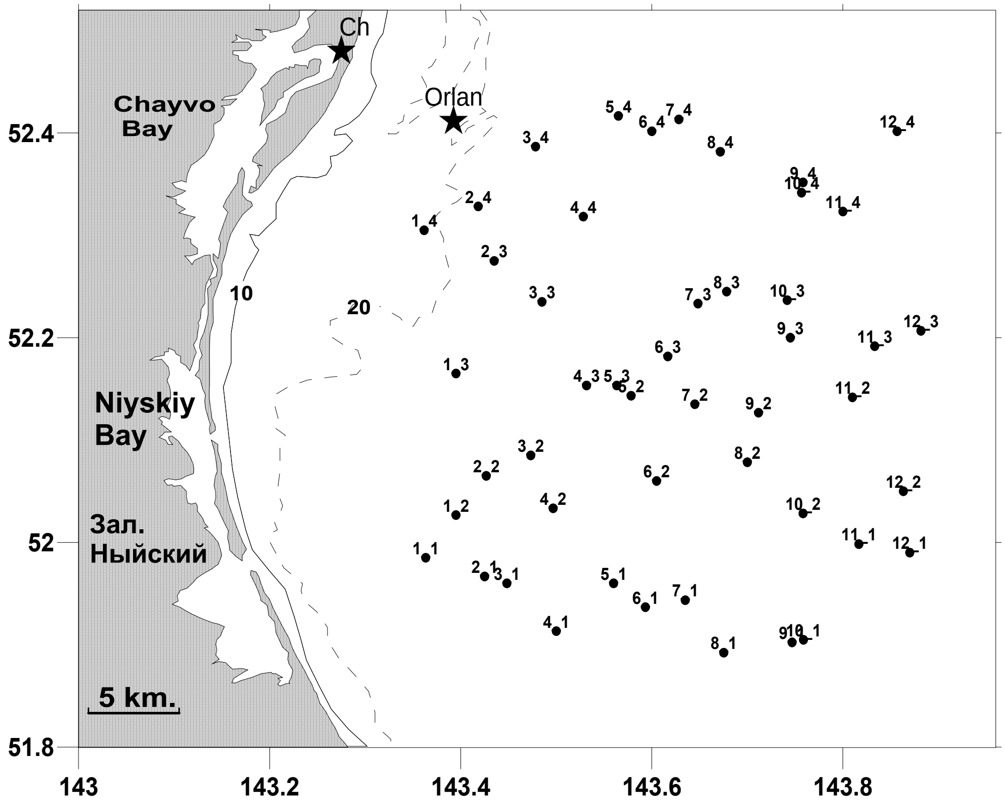

Figure 19. Diagram of station locations in the Offshore area in 2007.
The numbers indicate number station.

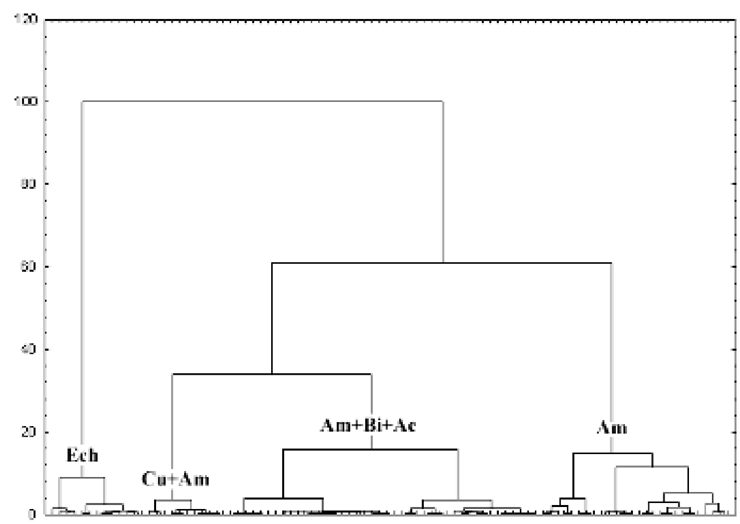

Figure 20. Dendrogram of the similarity of Offshore area stations in regard to benthos structure.

Table 10. Macrobenthos biomass (B, g/m2) in the Offshore area, 2006-2007.

Indicator	Taxonomic Group								Entire Area (Bsumm)	
	Amphipoda		*Actinia*		*Bivalvia*		*Echinoidea*			
	2007	2006	**2007**	2006	**2007**	2006	**2007**	2006	**2007**	2006
Average B	173.5	184.9	102.6	127.2	40.2	102.3	116.7	138.7	489.4	654.7
Standard deviation	58.6	29.6	24.4	21.9	9.2	24.8	42.5	46.2	60.5	59.9
Proportion, % of Bsumm	35	28.2	21	19.4	8	15.6	24	21.2	135	100
Minimum	0.3	0.9	0	0	0	0	0	0	92.4	92.4
Maximum	572.8	953.1	820.4	659.3	306.7	710.4	1192	1218	1642	1642
Number of stations	48	48	48	48	48	48	48	48	48	48

Notes: **Bsumm** is the average total benthos biomass, g/m^2

The biomass of the main groups (amphipods, bivalve molluscs, sea anemones and cumaceans) in 2007 was comparable to the 2006 data. The biomass of amphipods – the most important component in the diet of whales in the Offshore area – was 173.5±58.6 g/m^2 and 184.9±29.6 g/m^2 in 2007 and 2006, respectively. The year-to-year variations in the average amphipod biomass are statistically insignificant. Analysis of data from the central part of the Offshore area (20 stations), where benthic samples were taken in 2002-2004 and 2006-2007, shows that the differences between the years in the total biomass of benthos and the total biomass of the main prey item - *Ampelisca eschrichti* - were statistically insignificant.

The spatial distribution of benthos biomass was similar in 2007 and 2006. The biomass and the proportion of amphipods in the total benthos biomass of the Offshore area increases from shore toward deeper water (Figures 22, 23). A similar trend was observed in 2002-2005. The 2004 expedition succeeded for the first time in outlining the zone of the highest amphipod biomass levels. In moving eastward from the maximum biomass zone, there is a sharp decrease in the quantitative abundance of amphipods. There was also a gradual increase in the proportion of silt-pelite fractions in the seabed. The other groups (sea anemones, bivalve molluscs, cumaceans and sand dollars) that make up most of the remainder of the biomass had a patchy distribution.

Higher-biomass areas of these groups are on the edge of the amphipod mass development zone. The distribution of total benthic colony density is determined by the distribution of cumaceans and amphipods. Zones of high-density coincide with cumacean colonies in the eastern part of the area and with areas of amphipod mass development in the western part.

4.2.2. Composition and Distribution of Benthos Complexes in the Offshore area

During 2002-2004 (118 stations), three macrobenthos complexes were distinguished in the Offshore area: the sand dollar complex, the cumacean and amphipod complex, and the ampeliscid amphipod complex. The latter occupied the largest part of the study area and is considered of great importance to the feeding of gray whales (Fadeev, 2005).

All the stations of 2007 and 2002-2006 were grouped according to the similarity of quantitative relationships among benthos taxonomic groups. A similar approach was used in classifying the stations of the Piltun area (Section 4.1.3). The classification results are illustrated with a dendrogram (Figure 20). Based on materials from 2002-2007, four benthos complexes were distinguished in the Offshore area (Table 11).

I. A complex with dominance of sand dollars *Echinarachnius parma* was present mostly in the northern Offshore area (Fig 21). The average depth was 31.5±1.8 m (18 stations at depths of 18-47 m). Sand dollars are dominant at all stations, with an average biomass greater than 670 g/m^2 (more than 85% of the total biomass of the complex).

A similar complex was described in the Piltun area at depths greater than 20 m (Fadeev, 2007). According to Averintsev et al. (1979), there is a substantial subarctic-latitude occurrence of the sand dollar *Echinarachnius parma* in the area of northeastern Sakhalin Island at depths of 15-120 m. This site occupies an area of about 13,000 km^2, i.e., about 40% of the shelf area, off eastern Sakhalin. The *E. parma* community is associated with shallow sandy bottoms and silted sands, where bottom currents with sufficiently high speeds are present (Koblikov, 1983 a, b). As the current speed decreases southward along the eastern Sakhalin shelf and bottom silting increases, the sand dollars are replaced by other species. Mobile seston-feeders (sand dollar, etc.) settle primarily on sands and coarse silts, with an organic matter content of 0.5-1.0% and a concentration of suspended matter in the seabed water of about 20 mg/l (Kuznetsov, 1964). Significant bottom areas occupied by the *E. parma* community have been discovered on the western Kamchatka shelf (Neyman, 1988), and, as researchers note, the northern boundary of the *E. parma* area has advanced more than 20 miles to the north. They connect the cause of such changes with an indirect human impact – over-harvesting of the Kamchatka crab and flounder (which feed on the sand dollars), which has resulted in a disruption of the balance in the “predator-prey” system.

Table 11. Quantitative characteristics (B, g/m2) of macrobenthos complexes in the Offshore area.

Parameter	Taxonomic Group					Average total biomass (**Bsumm**)
	Amphipoda	*Actinia*	*Bivalvia*	*Echinoidea*	*Cumacea*	
1. Complex *Echinarachnius parma* (Ech)						
Average biomass	54,8	72,7	75,5	**674,9**	52,5	931,6
Standard deviation	20,4	32,3	36,5	125	26,1	162,2
Proportion in **Bsumm**, %	5	7	8	72	5	100%
2. Complex *Diastylis bidentata* + *Amphipoda* (Cu+Am)						
Average biomass	**131,6**	25,4	24	25,4	**230,7**	436,3
Standard deviation	34,7	14,9	11,4	14,1	35,4	62,9
Proportion in **Bsumm**, %	30	5	5	5	52	100%
3. Complex *Ampelisca eschrichti* + *Bivalvia* + *Actinia* (Am+Bi+Ac)						
Average biomass	**226**	**140**	**126,5**	0,8	42,2	522,3
Standard deviation	26,8	36,9	26,9	0,8	11,9	49,7
Proportion in **Bsumm**, %	43	26	24	0	8	100%
4. Complex *Ampelisca eschrichti* (Am)						
Average biomass	572,2	136,6	93,4	0	22,7	810,6
Standard deviation	64	35,7	22,8	0	6,1	98,3
Proportion in **Bsumm**, %	70	16	11	0	2	100%

Note: Abbreviated names of complexes used in Figure 21 are given in parentheses.

II. A complex dominated by cumacean *Diastylis bidentata* and amphipod *Ampelisca eschrichti.* The average depth of the 2007 stations where this complex occurred was 28.6±1.8 m (21 stations at depths of 24-31 m). The average total biomass of the complex in 2007 was 338±44 g/m^2, and the dominant species accounted for more than 80% of the biomass (cumaceans – 58%; and amphipods – 23%). The complex occurred in patches at depths of 24 to 31 m in the western part of the area, on fine-grained and mixed sands. Amphipod *A. eschrichti* was a subdominant species with a biomass of 131.6±34,7 g/m^2.

Data from 2002 were used to examine the relationship between the colony density of cumaceans *D. bidentata* and amphipods *A. eschrichti* in the Offshore area. The amphipod colony density decreased, and the cumacean colony density increased, as the depth increased (Fadeev 2003). Ampeliscid amphipods and cumaceans are seston-feeders and filter-feeders; i.e., both species obtain nutrition by filtering the seabed water. In areas of greatest abundance, their densities becomevery large: for cumaceans, up to 87,000 spec./m^2; and for amphipods, more than 31,000 spec./m^2. It could be expected that competition for food supplies would result in a spatial separation between accumulations of amphipod *A. eschrichti* and cumacean *D. bidentata*.

Analysis of benthos at gray whale feeding sites in the Offshore in 2002 indicated that the whales fed in areas where this complex was dominant in a number of cases (Fadeev 2003). Nevertheless, the possibility of gray whales using cumaceans in their diet remains unclear. It is known that there is a threshold amphipod body size (6-8 mm, according to: Rice and Wolman 1973; Nerini 1984), below which they cannot be used by WGW as a food source. If this value is valid for other crustaceans as well, it is worth noting that the cumaceans in the Offshore area are significantly smaller. Gray whales may prefer the high ampeliscid biomass content of this complex (based on data from 2002-2007, more than 130 g/m^2), selectively feeding the areas of this complex with ampeliscid pockets.

III. A complex with dominance of amphipod *A. eschrichti*, bivalve molluscs, and sea anemones. Photo 5 shows a portion of a bottom grab sample taken within the complex. The average depth was 37.1±2.2 m (49 stations in a range of 23-47 m). This complex occurred in patches on the edge of the ampeliscid complex, and had an average biomass of 622±48 g/m^2. Ampeliscids, bivalve molluscs, and sea anemones accounted for about 95% of the biomass of the complex. The complex included 18 recorded species of bivalve molluscs. Two species had the highest frequency of occurrence: *Serripes groenlandicus* (P>50%) and *Liocyma fluctuosum* (P>30%).

The dominant species in biomass of the complex – amphipods *Ampelisca eschrichti* and bivalve molluscs *S. groenlandicus* and *L. fluctuosum* – are seston-feeders and filter-feeders, and are associated with hydrodynamically active sections of the shelf. A high seston concentration in the seabed and the presence of steady bottom currents to facilitate seston transfer are necessary conditions for their existence. Actinians, which are classed as predators, also depend on currents to promote the transfer of larvae from existing sestonophage colonies to new areas, which lead to a patchy distribution.

IV. A complex dominated by amphipod *Ampelisca eschrichti* was indentified at 64 stations with an average depth of 52.6±1.9 m (range of 30-65 m). The complex occurred in the eastern part of the Offshore area. The average biomass was 644±145 g/m^2, and the biomass of the dominant group – amphipods – was more than 510 g/m^2 (79% of total biomass). The complex comprised 35 amphipod species, of which 14 species were found only in the Offshore area. One species – *A. eschrichti* – was distinctly dominant in regard to frequency of occurrence, colony density and biomass. Its biomass made up 95-100% of the total amphipod biomass at some stations. The maximum ampeliscid biomass had similar values in 2005 and 2006: 1,237 and 1,334 g/m^2, respectively, at 100% frequency of occurrence.

Data from 2007 and 2006 for the Offshore area (Table 10) support the conclusion that the quantitative abundance levels for *A. eschrichti* are high. The ampeliscid colony density and biomass in the area are comparable to, and in some cases exceed, the benthic values of other highly productive areas of the North Pacific (Kuznetsov, 1964; Koblikov, 1983 a, b, 1986; Makarov, 1937) and eastern gray whale feeding grounds (Stoker, 1981; Nerini and Oliver, 1983; Oliver et al., 1983; Dunham and Duffus, 2001, 2002). In contrast to the dominant species in the amphipod complex of the Piltun area, the ampeliscids live in tubes attached to the substrate in areas with significant bottom currents (Mills 1967; Wildish and Kristmans 1997).

The size composition of ampeliscids was analyzed on the basis of materials from 2001-2004. The average body length was 11.38±0.43 mm in 2001 (n = 210) and 13.78±0.31 mm in 2002 (n = 2015). More than 90% of the individuals had a body length ≥6 mm. The average body length in 2003 was 14.1±0.26 mm (n = 592), and the proportion of individuals larger than 6 mm was 96%. The distribution of ampeliscid body sizes was similar in 2003 and 2004. The average ampeliscid body length in 2004 was 13.91±0.41 mm (n = 610), and the proportion of individuals with body sizes larger than 6 mm was 83%. The average body length in 2007 was 13.83±0.15 mm (n = 1830), and the proportion of individuals with body sizes larger than 6 mm was 90%. Hence 83 to 96% of the amphipods had body sizes larger than 6 mm – i.e., were suitable prey for gray whales – in all the survey years in the Offshore area. The maximum size of individual ampeliscids in all the samples was 31.3 mm (2003 and 2007 samples). This value can be used as the “theoretical maximum linear size” of amplescids in the Offshore area for linear size calculations using the Bertalanfy equation.

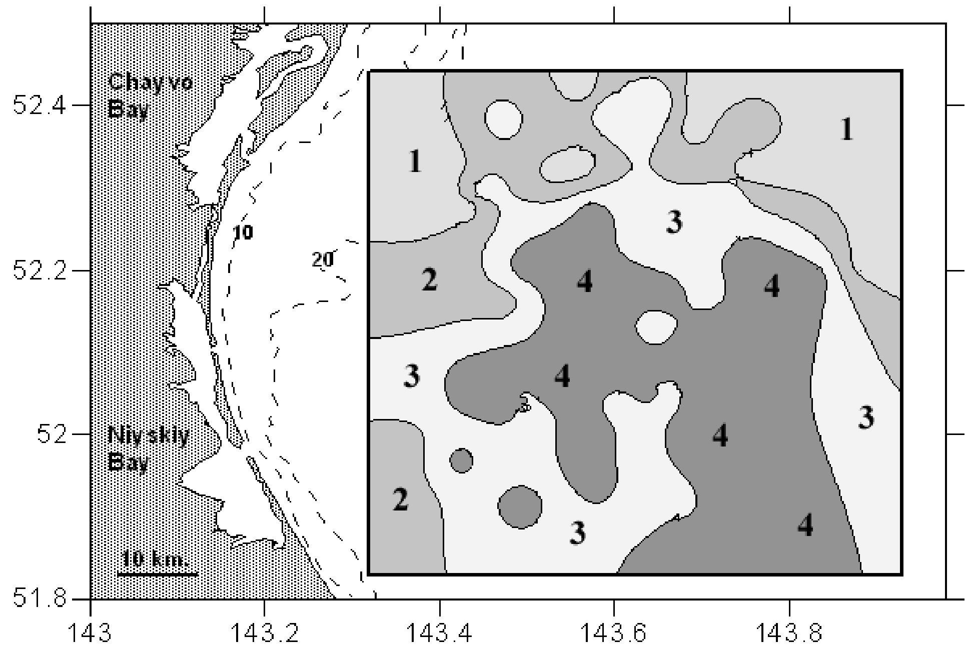

Figure 21. Distribution of benthic complexes in the Offshore area in 2004-2007. The numbers of the complexes are given in Table 11.

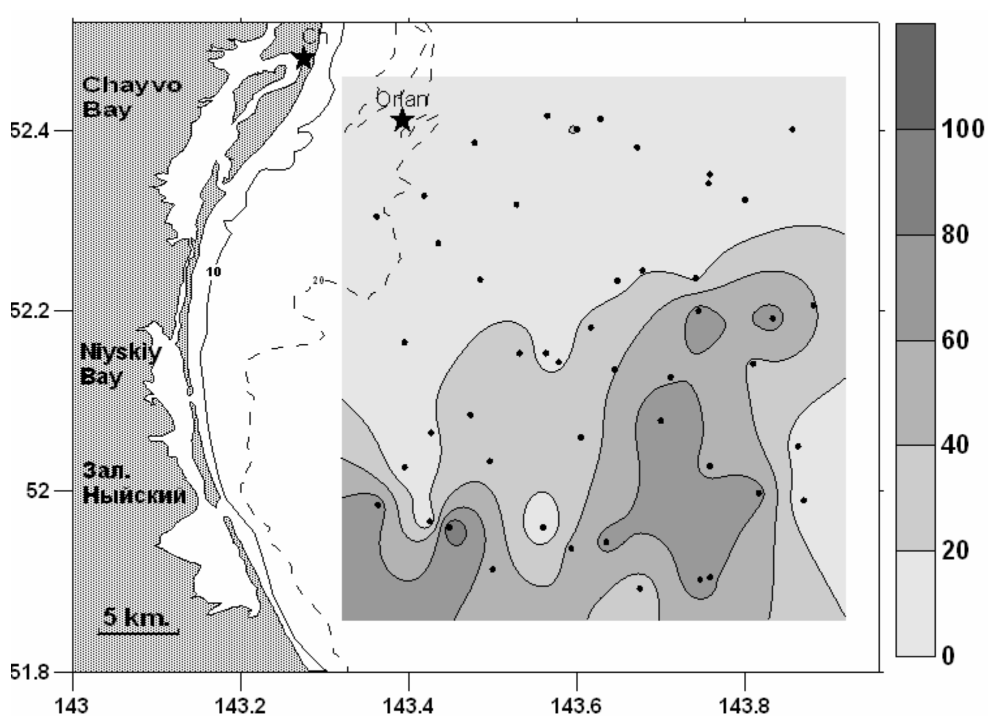

Figure 22. Proportion (%) of ampeliscid amphipods in total biomass of the Offshore area based on 2007 data.

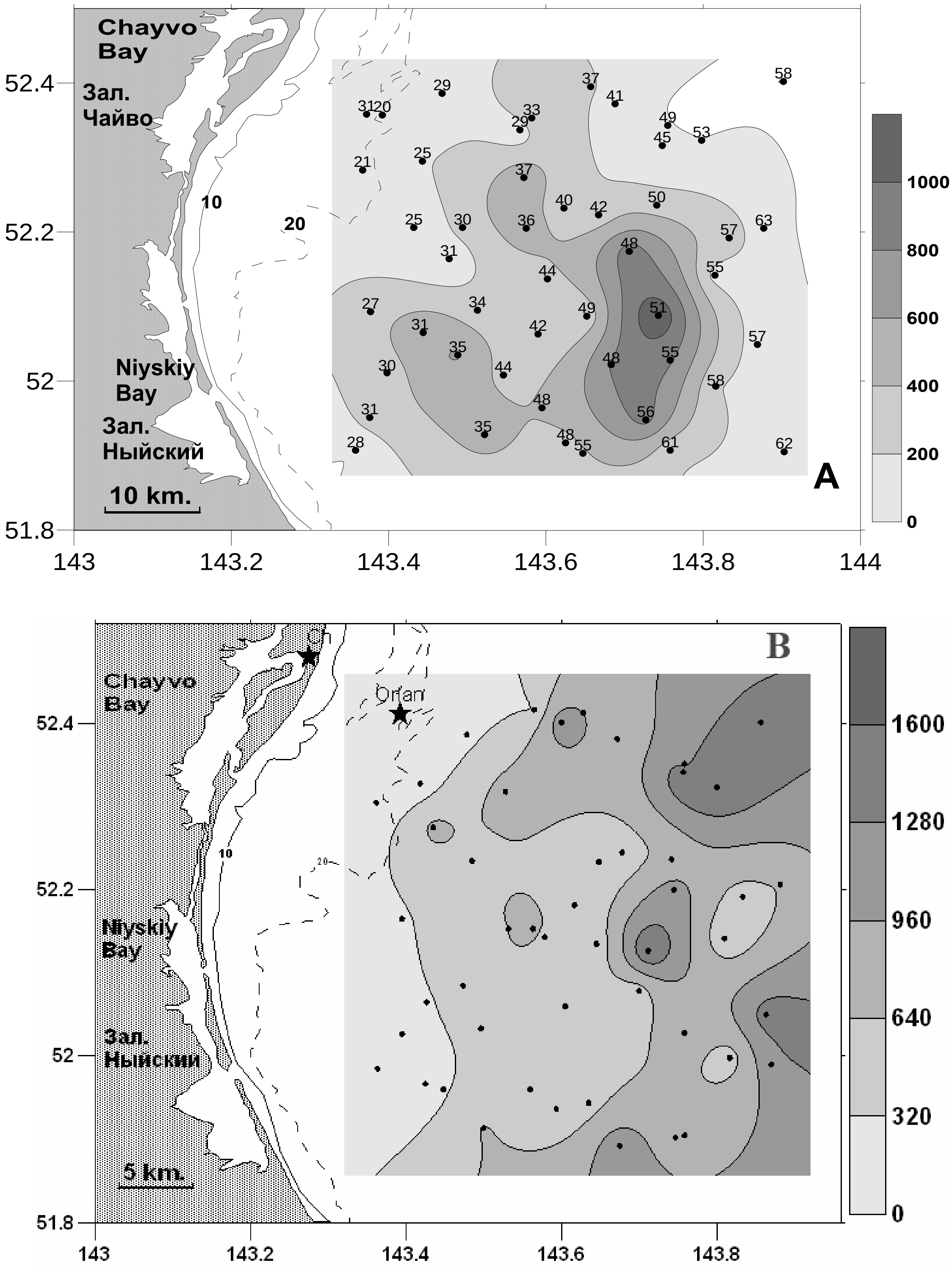

Figure 23. Ampeliscid amphipod biomass distribution (g/m2) in the Offshore area in 2006-2007 (A) and total benthos biomass in 2007 (B). In Figure A, the numbers indicate station depth.

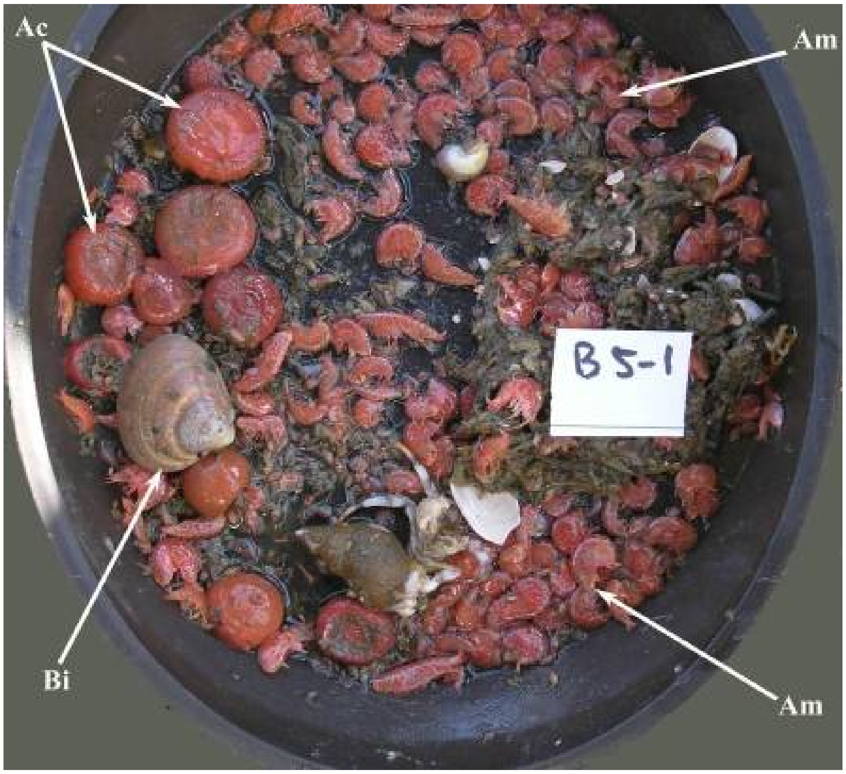

Photo 5. Bottom grab sample (0.2 m^2) from the ampeliscids (Am), bivalve molluscs (Bi) and actinia (Ac) complex

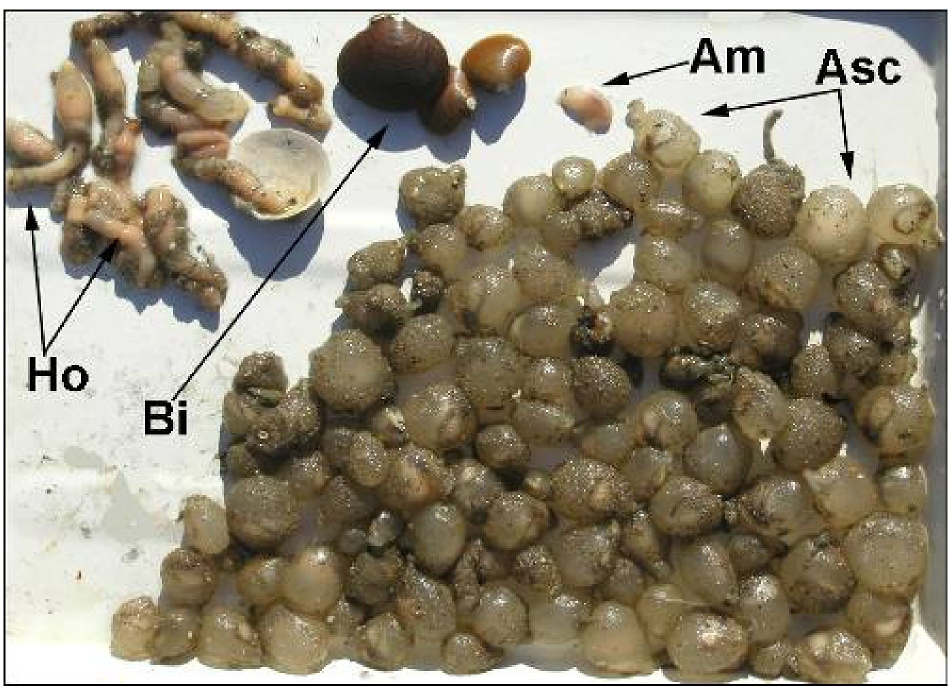

Photo 6. Bottom grab sample (0.2 m2) from ascidian complex.

Asc – ascidian; Am – amphipod; Bi – bivalve mollusc; Ho – holothurian.

4.3. Intermediate area

4.3.1. Quantitative abundance and distribution of benthos

Stations of the Intermediate area are located south of the Piltun area and cover waters from Chayvo Bay to the western boundary of the Offshore area. Figure 24 shows a chart of the stations sampled in 2002 and 2007. Bottom grab samples were collected at 12 stations (36 samples) in 2007 and at 13 stations (39 samples) in 2002, at depths from 8 to 24 m, with an average collection depth of 18.1±1.1 m. In 2007 the average benthos biomass for the Intermediate area was 426.2±106.1 g/m^2 (n=36). As in the Piltun area, substantial variations in benthos biomass were recorded with depth in the Intermediate area (Table 12). The biomass of amphipods decreased sharply from 93.4±15.3 g/m^2 at depths of ≤15 m to 5.4 g/m^2 at 25 m. Sand dollar biomass increased with the depth and reached maximum values (as much as 630 g/m^2) at depths greater than 15 m.

4.3.2. Benthic complexes

Analysis of the benthos composition indicates significant variations. Classification of the Intermediate stations according to benthos composition and biomass of individual groups identified 3 benthos complexes (Fig. 25):

1. A shallow-water complex (3 stations, average depth 11.3±2.0 m) with dominance of amphipods at an average biomass of 94.2±25.3 g/m^2. This complex included the same amphipod species as in the Piltun area at depths of ≤15 m, isopods *Synidotea cinerea* with biomass up to 60 g/m^2, and bivalve molluscs. Hence 2002 and 2007 data confirm the analysis of 2001 data that forage benthos also has a relatively high biomass south of Piltun Bay as far as Chayvo Bay (Fadeev, 2002). The amphipod complex includes stations In11, In12 and In22 (Fig. 24).

2. A complex dominated by individual ascidian *Pareugyrioides dalli* (4 stations, average depth 20±1.6 m). The complex occupied sections of the southern part of the Intermediate area (stations In32, In33, In4-3 and In5), and is a boundary complex with the Offshore area. The biomass of the dominant species averaged 110±59.5 g/m^2 (Photo 6), while cumaceans and polychaetes were found in small numbers.

3. A complex dominated by sand dollars *E. parma* at 6 stations, (average depth 18±1.4 m), including stations In13, In21, In23, In31, In41 and In42. Sand dollar biomass averaged 291.3±106.1 g/m^2.

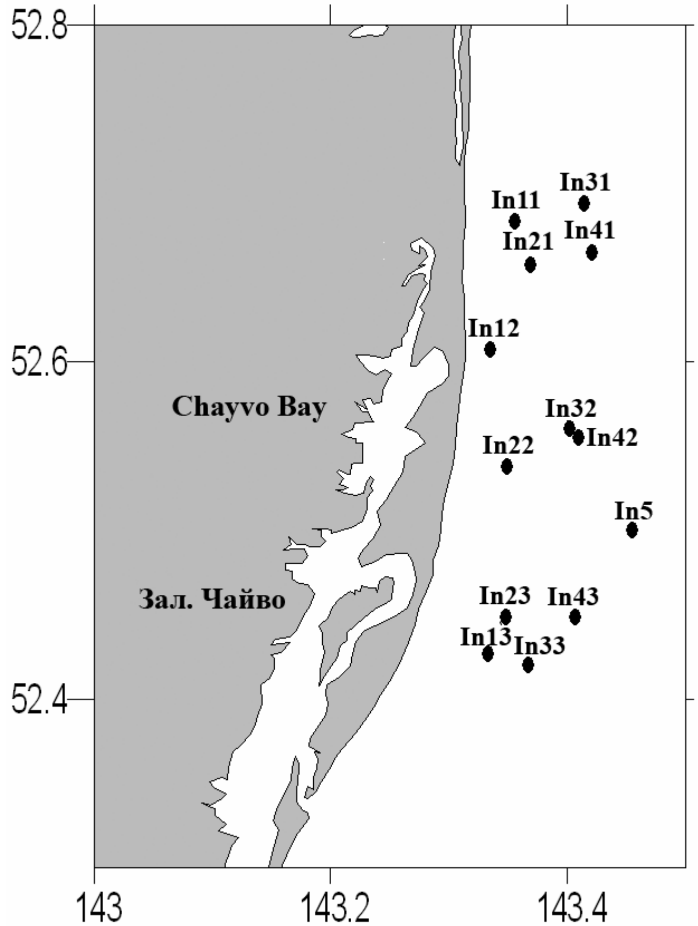

Figure 24. Locations of stations in the Intermediate area in 2002 and 2007.

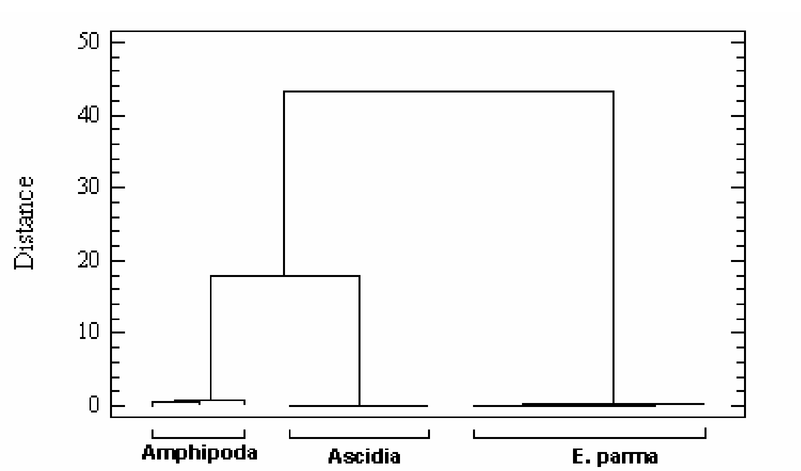

Figure 25. The faunal complexes of the Intermediate area.

Table 12. Distribution of macrobenthos biomass (g/m2) in the Intermediate area based, 2007 data

Group	Frequency of occurrence	Depth (m)			Average biomass	Standard deviation
		<15	16-20	21-25		
Amphipoda	100	93.4	13.7	5.4	37.6	12
Bivalvia	88	61.6	84.8	26.7	8.1	3.3
Polychaeta	88	1.6	6.9	17.5	17.8	7
Cumacea	84	9.3	8.9	4.3	11.8	6.5
Echinoidea	60	0	120.1	630.8	233.5	107.3
Isopoda	48	11	8.1	11.3	6.3	3.1
Ascidia	44	10.9	155.3	196.9	110.9	59.5
Total		**187.8**	**397.8**	**892.9**	**426.2**	

The latter two complexes are found in patches in areas with a complex bottom macrorelief and active hydrodynamics. Based on depth finder profiling data for the area of the complexes, the ascidian complex is associated with terrain elevations made up of sand of varying grain size mixed with shell detritus. The *E. parma* complex was more prevalent on flatter relief.

Sharp changes in the abundance of benthos were recorded in the coastal zone south of the Intermediate area (from Chayvo Bay to Niyskiy Bay). The average total benthos biomass there, according to 2002 data (3 stations), was 90.9 g/m^2, and amphipod biomass decreases to 3.7 g/m^2, while isopod biomass decreases to 5.9 g/m^2. A similar change in the abundance of benthos in the area from the middle part of Chayvo Bay to Niyskiy Bay was observed in the 2001 data (Fadeev, 2002).

4.4. Benthos at Gray Whale Feeding Sites

During 2007, 89 benthos stations (274 samples) at gray whale feeding sites were sampled: 30 in the Offshore area, 21 in the Chayvo Bay area, and 38 in the Piltun area.

As in previous years, photo-ID materials, data of vessel-based observations of the distribution of whales, and WGW distribution maps (plotted from the shore-based observations) were used in selecting the sites for samples in whale feeding areas. Figure 26 shows a planning diagram for collecting benthos samples based on the results of GPS recording of whale feeding sites during photo-ID studies.

4.4.1. Whale Feeding Sites in the Piltun Area

Bottom grab samples were first collected at 21 stations (average depth of the stations 19.5±1.5 m) at gray whale feeding sites in the Piltun area in 2001. The average benthos biomass was 234.4 g/m^2. Forage benthos – amphipods and isopods – made up more than 50% of the total biomass.

Twelve sites (average depth – 18.6±1,6 m) were studied in 2003. The average biomass of benthos at the feeding sites was 164.2 g/m^2, and amphipods and isopods made up 79% of the biomass. Most of the whales fed at depths of 20 m or less within the shallow-water amphipod complex in 2002 and 2003 (Fadeev, 2007).

In 2004, 50 whale feeding sites were studied in a depth range of 14-35 m (average depth – 23.5±0.9 m). The increase in the average feeding depth of the whales is due to the fact that the whales began using areas at depths greater than 20 m within the sand dollar complex in the northern part of the area.

In 2005, there were 74 whale feeding sites (average depth – 18.5±1.1 m). As in the previous years, most of the whales fed at depths of 20 m or less within the coastal amphipod complex. In the northern Piltun area, however, whales were observed feeding at greater depths during these years. The number of "deeper-water" whales in 2005 sometimes was as high as 40% of the number of whales in the norther Piltun area. Analysis of bottom grab samples from 2004-2005 collected at whale feeding sites at depths greater than 20 m demonstrated that the sand lance *Ammodytes hexapterus*, the amphipod *Eogammarus schmidti* and the isopod *Saduria entomon* had the highest frequency of occurrence and biomass in these samples.

An increase in the frequency of occurrence and biomass of the sand lance in the nothern Piltun area was seen most clearly from 2004 to 2005. There was a concurrent decline in the number of feeding whales in the Offshore area and an appearance of gray whales feeding at depths greater than 20 m in the northern Piltun area (Vladimirov et al., 2006; Yakovlev and Tyurneva, 2006). Data for 2003-2005 on sand lance distribution indicated that the Offshore area may be a secondary feeding area for the gray whales and used by them during periods of reduced biomass of forage benthos (excessive feeding, seasonal or year-to-year variations in biomass) in the primary feeding area – the Piltun area (Fadeev, 2006). Hence the appearance of an additional accessible food supply –sand lance – in the northern Piltun area in 2003-2005 may have prompted redistribution of the whales between the Piltun and Offshore areas. It must be mentioned that most of the sand lance accumulations in the northern Piltun area (depth greater than 20 m) are located 5-7 km from the areas occupied by the shallow-water coastal amphipod complex (depth less than 15-20 m). Gray whales can cover this distance in 1-1.5

hours, so that coastal areas with amphipod dominance and the deeper-water areas with sand lance dominance can be used by the same whales within short periods of time.

The average biomass of sand lance in the Piltun area had similar low values in 2007 and 2006 (Table 7), and a substantial decrease in the frequency of occurrence of the sand lance was observed in the northern part of the area (from 40-60% in 2005 to 20-25% in 2006-2007). Changes in the distribution of the sand lance in 2004-2007 are covered in section 4.1.1.

The decrease in sand lance abundance in the northern part of the area in 2006-2007 was accompanied by an increase in the number of whales feeding in the Offshore area. Based on photo-ID results for 2005, 2006 and 2007, 7, 33 and 70 individual gray whales, respectively, were observed in the Offshore area (Yakovlev and Tyurneva, 2006, 2008; Yakovlev et al 2007).

In addition to the main whale feeding areas in the southern and northern Piltun area (Fig. 27), feeding whales were observed every year during 2002-2007 in an area 16 km south of the entrance to Piltun Bay abreast of the Molikpaq Platform; this area was therefore studied in 2006-2007. The feeding ground has an area of about 16 km^2. The number of whales feeding in the area simultaneously was not usually more than 3-4; 7 whales were observed feeding there simultaneously only in 2004. The average total biomass of benthos at the whale feeding sites in this area was 57.9±7.5 g/m^2, of which amphipod biomass was 35.2±3.2 g/m^2 (60.7% of the total biomass). According to the composition and structure of benthos, the area can be classified as belonging to the coastal amphipod complex. The biomass of amphipods in the area in late August in 2005-2007 was more than 50 g/m^2.

4.4.2. Whale Feeding Sites in the Chayvo Bay Area

In 2006, the onshore observation team reported whale sightings throughout the field season in the Chayvo Bay near-shore zone. The largest densities of whales in this area were recorded in September 2006 and in August-September 2007 (Vladimirov et al 2007 and 2008). The Chayvo Bay near-shore zone is located approximately 40 km south of the Piltun lagoon. Vessel-based whale counts and photographic surveys were performed here in 2006-2007, and benthos samples were collected at whale feeding sites. In benthic station locations, underwater video surveys of the water column and bottom surface were conducted, and plankton (Bongo net) and epibenthos samples were collected.

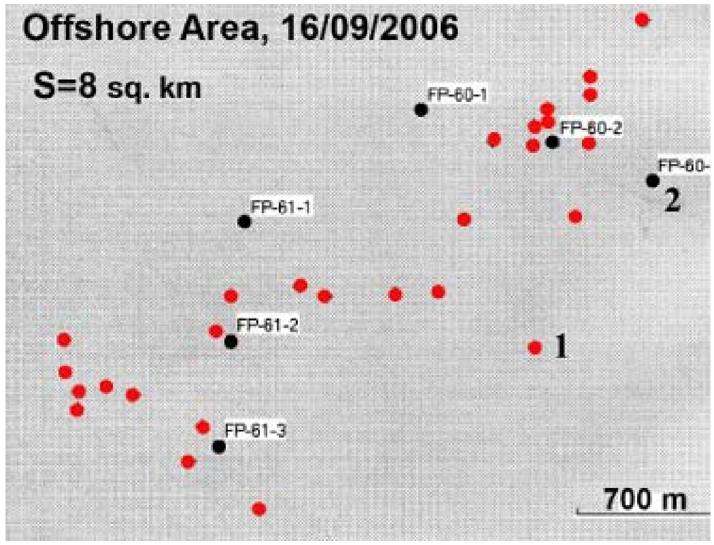

Figure 26. Planning diagram for collection of benthos samples at whale feeding sites based on photo-ID data.

1 – whale feeding sites based on photo-ID data; 2 – benthos sample collection sites.

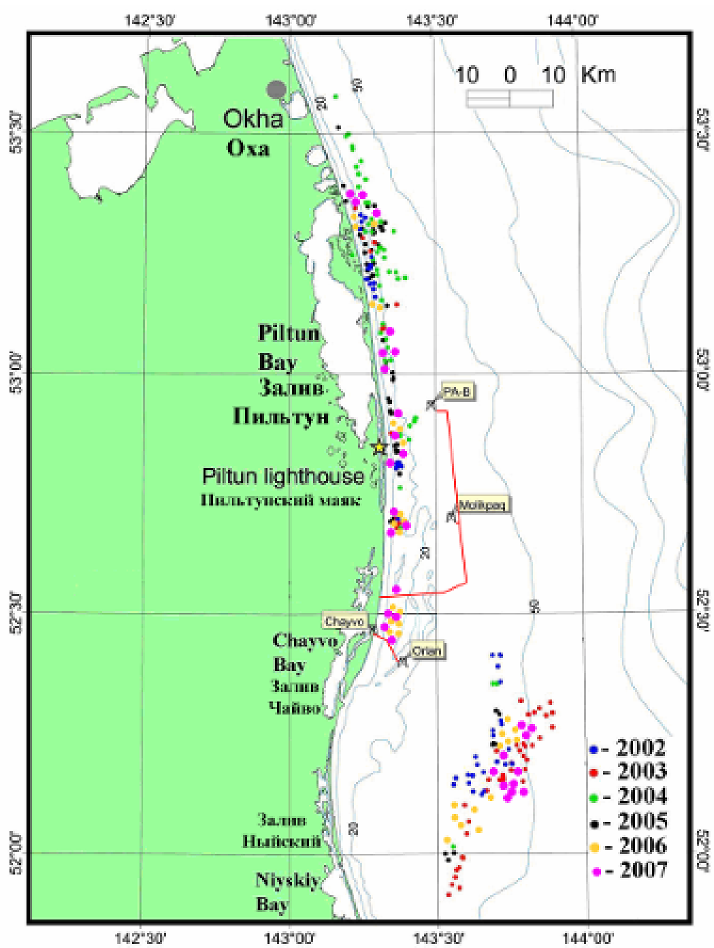

Figure 27. Chart of gray whale feeding sites studied in 2002-2007.

There were 32 bottom grab stations (103 samples) in 2006-2007 (Fig. 28). In addition, benthos samples were taken outside the whale feeding zone in the direction of the Orlan platform (sampling depth 18-22 m). Stations at whale feeding sites were located in depths of 10 to 15 m (average depth – 13.5 m) on well-graded fine and medium sand. Video records did not reveal any accumulations of plankton animals in the water column. Euphausiids, copepods, cumaceans and planktonic amphipod-hyperiids were found in insignificant numbers in samples of plankton and epibenthos (epibenthos net).

Benthos at the whale feeding sites was classified as belonging to coastal amphipod complex, which is also common at depths of ≤20 m or less in the Piltun area, and its species composition of amphipods, isopods and bivalve molluscs was with the same as the amphipod complex of the Piltun area (see section 4.2.1).

The occurrence of amphipod complex to the south of Piltun Bay, as far as Chayvo Bay, has been known since 2001 (Fadeev 2002), when it was also noted that the biomass of amphipods is significantly lower there than in the Piltun area. This observation was confirmed by the data of 2002 benthos stations in the Intermediate area (Section 4.3). In 2001, scuba diving benthos surveys were conducted along two transects over the range of depths from 5 m to 30 m; the whale feeding area sampled in 2006-2007 was located between these transects. In 2001, the average amphipod biomass in the 10-15 m range was 35.7±9.8 g/m^2, which is not significantly different from the biomass level in 2006 (41.1±7.9 g/m^2) and in 2007 (51.3±8.6 g/m^2, Fig. 29).

Thus, no amphipod biomass increase was observed in the Chayvo Bay area in 2006-2007. Although foraging whales were first observed in the Chayvo Bay area in 2006-2007, vessel-based observation and photo-ID data recorded no more than 5-7 gray whales feeding in the area at one time. It is likely that the whales' use of the small area with low relatively prey biomass near Chayvo in 2006-2007 is related to the decrease in amphipod and sand lance abundance in the Piltun area: the average amphipod biomass in the 11-15 m depth range was 69.4 g/m^2 in 2005 and 33.5 g/m^2 in 2006. Furthermore, there was a decrease in the frequency of occurrence and abundance of sand lance during 2006-2007, which had been aggressively used by whales during the 2004-2005 feeding seasons. These reductions in amphipod and sand lance abundance in the Piltun area in 2006-2007 may also be related to an increase in the number of whales feeding in the Offshore area in 2006-2007.

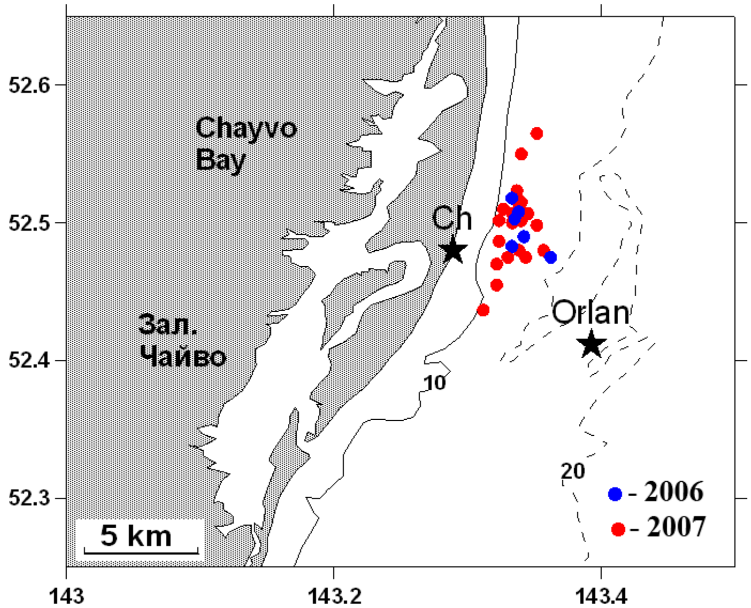

Figure 28. Chart of gray whale feeding sites in the Chayvo Bay area in 2006-2007.

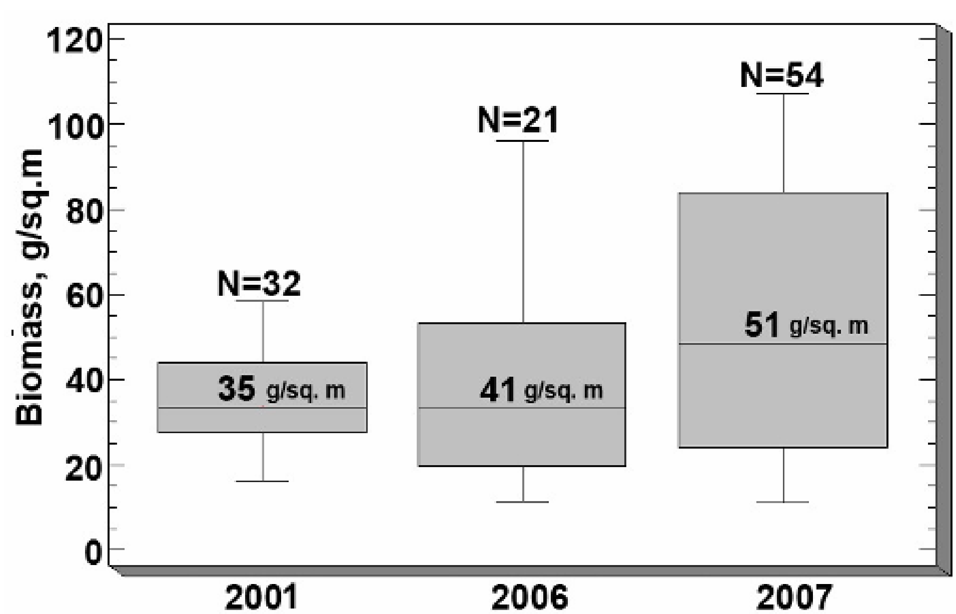

Figure 29. Amphipod biomass (g/m2) in the Chayvo Bay area in 2001, 2006 and 2007.

4.4.3. Whale Feeding Sites in the Offshore Area

Year-to-year variations in the number of feeding whales are typical of the Offshore area. According to the results of photographic identification studies in 2003, 2004, 2005, 2006 and 2007, there were 35, 8, 7, 33 and 70 individual gray whales, respectively, observed in the Offshore area (Yakovlev and Tyurneva 2004, 2005, 2006, 2008, Yakovlev et al. 2007).

In 2002-2003, 64 whale feeding sites were studied in the Offshore area, 3 sites in 2004, 8 sites in 2005, 14 sites in 2006, and 30 sites in 2007. During all these years, the whales fed in a rather narrow depth range, from 41 to 53 m, i.e., in a zone of high abundance of the amphipod *Ampelisca eschrichti* (Fig. 30). However, variation in densities of feeding whales in the Offshore area were not linked to variations in abundance of total benthos or the ampeliscid component.

The ampeliscid biomass at whale feeding sites averaged 366.3±168.3 g/m^2 in 2005 and 247.7±43 g/m^2 in 2006. The average ampeliscid biomass at whale feeding sites in 2007 was even higher: 516±140.1 g/m^2, indicating that gray whales forage in the Offshore area primarily at sites with ampeliscid biomass of 200-300 g/m^2 or more. Whales were observed foraging at a local site of maximum ampeliscid biomass (more than 600 g/m^2) in an area of great depths in 2007, for the first time in all the years of observations. Foraging of the whales at greater depths in 2007 may be due to an increase in the total number of whales (up to 70 individuals) in the Offshore feeding area

In 2006-2007, as in previous years, benthos at the feeding sites was consistent in composition and structure with the *Ampelisca eschrichti* complex and the *A. eschrichti* + *Bivalvia* + *Actinia* complex (Table 12). Whales fed at approximately the same sites in the Offshore area in 2007 as they did in 2002 and 2006 (Fig. 31); the distance between the some feeding points in different years was sometimes 1-3 km.

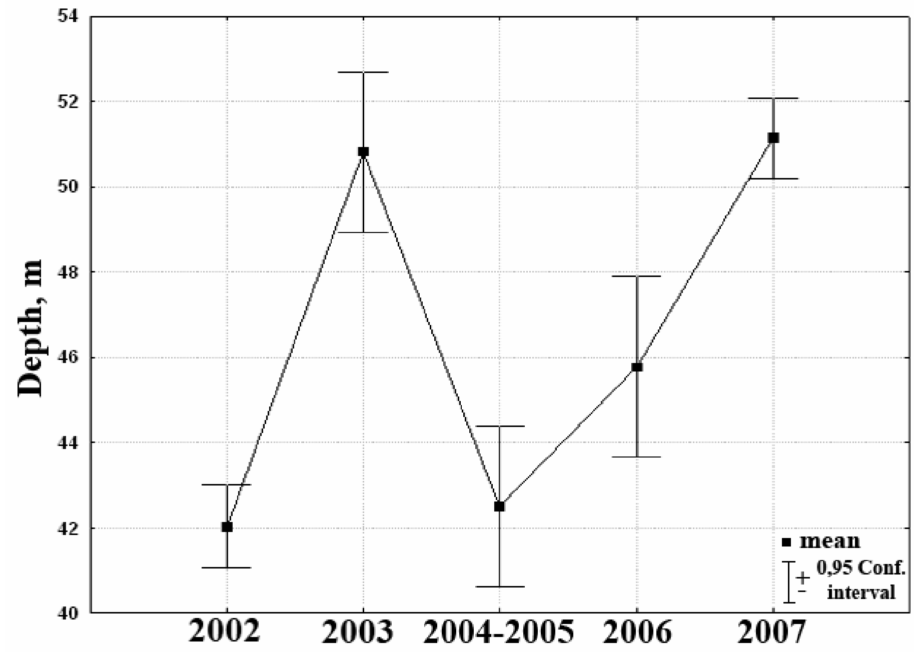

Figure 30. Distribution of average depths of whale feeding sites in the Offshore area by years.

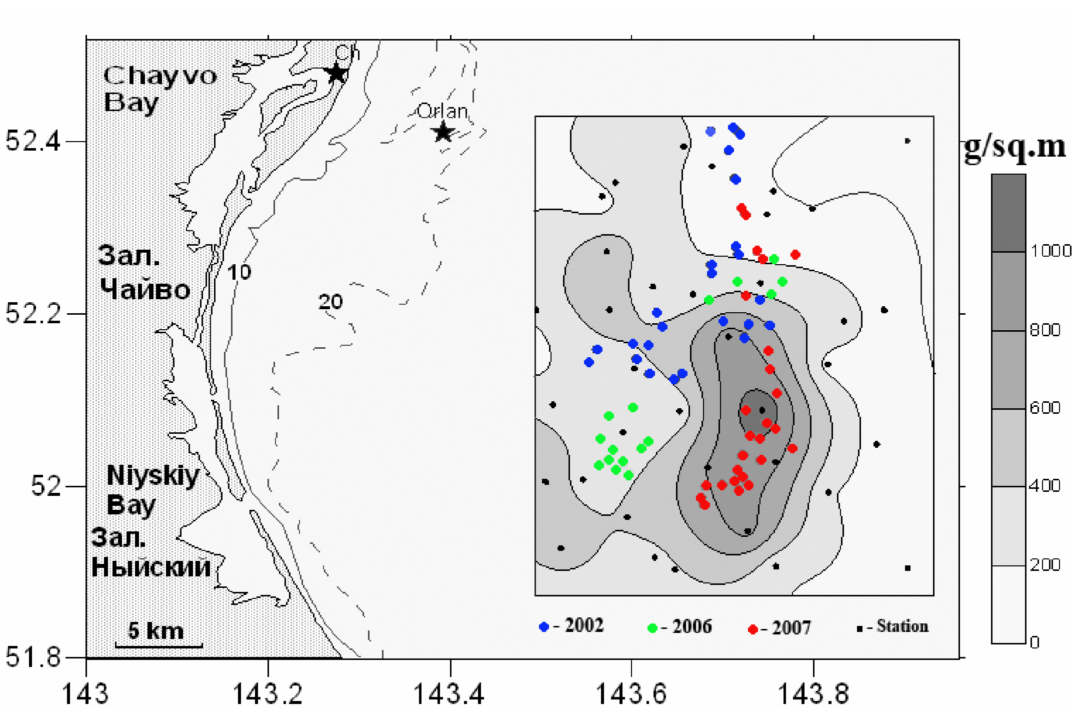

Figure 31. Chart of the distributionof biomass of the amphipod Ampelisca eschrichti (g/m2) и and whale feeding sites in the Offshore area in 2002, 2006 and 2007.

4.5. Stable carbon and nitrogen isotope ratios in sublittoral organisms

Stable isotope ratios of carbon and nitrogen were examined to identify potential sources of organic matter in trophic relationships supporting the production of benthic macrofauna in the Piltun and Offshore feeding areas on the northeastern Sakhalin shelf.

Analysis of the natural ratios of stable isotopes of carbon and nitrogen[3] has been widely used to investigate the sources and flows of organic matter in a wide variety of marine, fresh water and terrestrial ecosystems. In coastal marine ecosystems in the middle latitudes, carbon sources clearly differ in $\delta^{13}C$ levels: phytoplankton $\delta^{13}C$ values range -23 to -19‰; most benthic macrophytes and microalgae range -18 to -6‰; terrestrial plant material range -28 to -25‰. The ratios of $\delta^{13}C$ isotopes in organic material undergo very slight changes (about 1‰) from their origin in the food chain, from plants through herbivorous animals, to predators, which makes it possible to use $\delta^{13}C$ as a tracer of trophic relationships.

Nitrogen isotopes in organic matter, on the other hand, are subject to significant fractionation in the course of metabolic processes, which results in consistent ^{15}N enrichment (about 3.4‰) at each successive trophic level. This effect makes it possible to use $\delta^{15}N$ values to examine the nitrogen source of organic material, and the trophic status of organisms in the ecosystem. Planktonic and benthic plants in coastal marine ecosystems have similar nitrogen isotopic compositions, which makes it possible to determine the trophic levels of different animal species based on $\delta^{13}N$ values.

Samples of benthic invertebrates of 20 species from various taxonomic groups were collected in the Piltun and Offshore feeding areas and in the Piltun lagoon for isotope analysis in 2006.

The isotope analysis was performed at the Laboratory of Stable Isotopes of the Far East Geology Institute of DVO RAN using a system consisting of a FlashEA-1112 elemental analyzer, a ConFlo-III interface, and a MAT-253 isotopic mass spectrometer (ThermoQuest). The accuracy of the determination of $\delta^{13}C$ and $\delta^{15}N$ values was ±0.10‰.

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[3] The concentration of rarer stable ^{13}C and ^{15}N isotopes in organic material is generally determined in the form of ratios to the corresponding most common isotopes as the value of deviations δ promille from generally accepted international isotope composition standards:

for carbon – relative to V-PDB standard

$$\delta^{13}C\ (‰) = [(^{13}C/^{12}C_{sample} - {}^{13}C/^{12}C_{standard})/\ {}^{13}C/^{12}C_{standard}] \times 1000$$

(It should be mentioned that all organic objets in the biosphere have negative values of $\delta^{13}C$ due to lower ^{13}C content compared to the V-PDB standard of mineral origin);

for nitrogen – relataive to molecular nitrogen in the atmosphere

$$\delta^{15}N\ (‰) = [(^{15}N/^{14}N_{sample} - {}^{15}N/^{14}N_{standard})/\ {}^{15}N/^{14}N_{standard}] \times 1000.$$

Values of $\delta^{13}C$ from -19.5 to - 17.9‰ have been determined for various types of filter feeders feeding on suspended organic matter. The ascidian *Ascidia vegae* was poorer in ^{13}C ($\delta^{13}C$ -19.4±0.3‰) that the bivalve mollusc filter feeders (*Astarta, Musculus* and *Serripes*: $\delta^{13}C$ from -18.4 to -17.9‰). Bivalve mollusc gathering detritus eaters (*Leda, Megangulus*) do not differ substantially from bilvalve filter feeders in the isotopic composition of carbon (Fig. 32).

Determinations of $\delta^{13}C$ were performed previously[4] for the study area for suspended organic matter including phytoplankton (-22.4±0.3‰), and for total organic matter of bottom sediments (from -22.3 to -20.6‰). Invertebrates feeding directly on phytoplankton should have values of $\delta^{13}C$ closer to -21.4‰ (including ^{13}C enrichment by 1‰ in the course of assimilation of organic matter by heterotrophic organisms). All of the filter feeders collected from the Piltun and Offshore feeding areas were substantially richer in ^{13}C (by 3 - 4.5‰) than organic matter in the sediment and water column, which most probably indicates a contribution from resuspended microphytobenthos .

Values of $\delta^{15}N$ for most bivalve molluscs, ascidians and sand dollars (from 7.9 to 9.2‰) are typical of consumers of the second trophic level, which feed directly on microalgae. The bivalve mollusc *Astarta* displays higher values of $\delta^{15}N$ (10.5 to 13.7‰), which indicates a substantial proportion of heterotrophic zooplankton microorganisms in its diet. The holothurian *Chiridota* and the predatory gastropods *Buccinum*, which occupy a higher trophic level, have the highest values of $\delta^{13}C$ and $\delta^{15}N$.

Invertebrates that form significant local accumulations of zoobenthos biomass in the area – *Ampelisca* amphipods and *Diastylis* cumaceans – differ substantially from most of the animals we investigated with respect to the isotopic composition of carbon and nitrogen. These animals display the lowest values for $\delta^{13}C$ (from -20.8 to -22.0‰), indicating that they obtain their carbon either entirely from phytoplankton, or from a combination of terrigene organic matter, phytoplankton and microphytobenthos. They also displayed the lowest values for $\delta^{15}N$ (from 6.9 to 7.5‰) among the animals included in this study, suggesting the extremely low trophic status of these crusaceans. The isotopic characteristics obtained contradict the accepted view of *Ampelisca* amphipods and *Diastylis* cumaceans as omnivorous animals. Most species of Gammaridae amphipods and cumaceans in other coastal ecosystems display an omnivorous type of diet and, on the other hand, are significantly rich in ^{13}C and ^{15}N compared to filter feeders.

Several approaches can be used to explain this contradiction.

(1). Organic matter from shore, with low values of $\delta^{13}C$ and $\delta^{15}N$, plays a substantial role at the base of the food chain for amphipods and cumaceans.

(2). *Ampelisca eschrichti* and *Diastylis bidentata* are mass species in this area specializing in feeding on settling planktonic microalgae. (It should be mentioned, however, that other less common species of amphipods (*M. affinis, E. schmidti*) and isopods (*S. cinerea*) that we investigated from this area had lower values of $\delta^{13}C$).

(3) It is not impossible that the low values of $\delta^{13}C$ and $\delta^{15}N$ of omnivorous small crustaceans sampled in this study might be due to a small contribution to their diet from the microbial food chain, based on methane carbon, which is extremely poor in the ^{13}C isotope, of chemosynthesizing bacteria that develop in petroleum hydrocarbon seepage areas or are oxidized themselves by petroleum hydrocarbons. Thus amphipods and cumaceans display anomalously low values for $\delta^{13}C$, even in peripheral areas of the Pacific deep-water methane seeps.

Further study with a set of isotope and molecular marker methods (analysis of the aliphatic acid composition, analysis of the isotopic composition of individual molecular components of the organic matter of hydrobionts and bottom sediment) can help to resolve the issue of the original sources of local extremes of benthos biomass on the shelf of the Sea of Okhotsk.

[4] Data are received by an expedition of the Marine Biology Institute of the FEB RAS on the research vessel *Akademik Oparin* in 2003.

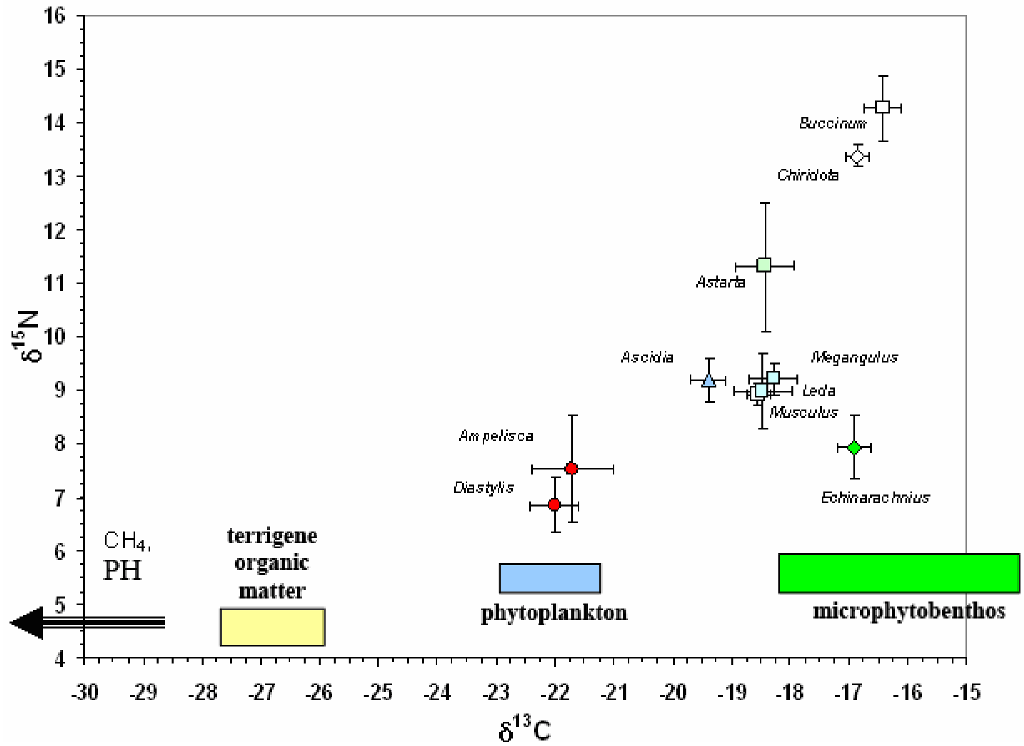

Figure 32. Distribution of mass benthos species of the Piltun and Offshore areas in coordinates of concentration values of stable isotopes δ13C and δ15N.

4.6. Comments for assessing year-to-year changes in forage benthos in the Piltun and Offshore areas

The purpose of this section is not a detailed, cross-spectrum analysis of the relationships between benthos and foraging whales. That exercise would require special analysis methods within the framework of a unified GIS. Rather, our task here is to compare the most notable trends in year-to-year changes in the distribution of foraging whales and forage benthos.

Principal trends in the distribution of whales in 2002-2007:

(1). 2002-2003 – whales fed in both areas; most of the whales in the Piltun area fed in the shallow-water zone at depths ≤ 20 m in the northern and southern parts of the area.

(2). 2004-2005 – whales fed primarily in the Piltun area; the number in the Offshore area was low– 8 (2004) and 7 (2005) individuals; whales fed in the Piltun area generally in the shallows at depths of ≤ 20 m, while in the northern part of the area, some whales (up to 40%) fed at depths greater than 20 m.

(3). 2006 – whales fed in both the Piltun and Offshore areas; the number in the Offshore area increased to 33 individuals; whales in the Piltun area fed along the entire coastline; the number of foraging whales declined sharply in the southern part of the area, as did the proportion of whales feeding at depths >20 m in the north. A small number of foraging whales appeared in the Chayvo Bay area.

(4). 2007 – whales fed in both areas; the number in the Offshore area increased to 70; the number of foraging whales in the southern Piltun area increased relative to 2006, while the number of whales feeding at depths > 20 m in the northern part of the area was very low. The Chayvo Bay area had a small number of foraging whales.

<u>Principal trends in variation of forage benthos abundance in 2002-2007</u>:

Offshore area: Biomass of forage benthos was stable, and no major year-to-year variations were observed; whales fed in a depth range of 41-53 m every year in a zone of high abundance of major prey: amphipods *Ampelisca eschrichti.*

Piltun area:

(1). 2004-2005 – areas with elevated amphipod biomass occur in the shallower-water part of the southern and northern Piltun area; *Monoporeia affinis* is dominant in biomass; there is an increase in the frequency of occurrence (to 40-60%) and biomass of the sand lance *Ammodytes hexapterus* in the northern part of the area.

The appearance of the sand lance coincided with a decrease in the number of whales in the Offshore area, and the appearance of foraging whales in the northern Piltun area at depths greater than 20 m.

(2). 2006 – the proportion of the amphipod *M. affinis* in the total biomass of forage benthos in the shallow-water zone decreased, and the biomass of this species at shallow-water stations in the southern part of the area declined by 50% from the 2005 level; in the northern part of the area, the frequency of occurrence of the sand lance decreased from 40-60% to 20-25%.

The decrease in abundance of amphipods and the sand lance coincided with the appearance of foraging whales in the Chayvo area and an increase in the number of whales in the Offshore area. It is notable that whales began feeding in the Chayvo area at sites with biomass of about 40 g/m^2 when the biomass of amphipods in the southern Piltun area dropped to this level.

(4). 2007 – amphipod biomass increased in the shallow-water zone of the Piltun area; *M. affinis* was dominant in the southern part of the area; its biomass there in 2007 was higher than in 2006 but did not reach the maximum levels of previous years; sand lance abundance in at deeper-water sites in the northern part of the area remained at the low level of 2006.

An increase in the abundance of the amphipod *M. affinis* in the south coincided with shore- and vessel-based observations of increases in the number of foraging whales in the southern section of the area; lone foraging whales were observed in deeper waters of the northern section.

During the period from 2002 to 2007, the most notable variations in the abundance and spatial distribution of the dominant amphipod species – *Monoporeia affinis* –were observed in 2006 and were preserved partially (in the northern part of the area) in 2007.

Changes in hydrology and sea ice cover in the Piltun area:

An analysis of the year-to-year dynamics of the hydrological regime in the Piltun area (Section 3) showed that the lowest near-bottom temperatures for the period 2004-2007 occurred in 2006-2007. Temperature is expected to affect amphipod breeding, growth, and feeding, resulting in changes to their life cycle duration. For example, the dominant species in the Piltun area, *Monoporeia affinis*, has a two-year life cycle in cold waters and a one-year life cycle in warmer waters (Segestrale, 1967). The amphipod *Ampelisca macrocephala,* which inhabits the Offshore area, lives for 5-6 years in the cold waters of the Bering Sea, but for only 2-3 years in the temperate waters of Denmark (Kannewoff, 1969; Highsmith, Coyle, 1991). The effect of hydrological features on the life cycle of mass amphipod species on the Sakhalin north-east shelf will be further assessed once current morphometric analysis of the 2005-2007 amphipod collections is completed.

Climate-forcing parameters such as sea ice dynamics can also impact coastal biota. Ice conditions varied substantially in the Piltun area during 2004-2006. Figure 33 indicates the position of the ice edge during the first ten days of June each year. According to these satellite monitoring data, the northeastern Sakhalin coastal zone was free of ice in June 2004 and 2005. However, the area was covered in 10-point ice almost to the mouth of the Piltun lagoon in early June 2006. In June 2007, ice remained near the Chayvo lagoon, but there was open coastal water from the Piltun lagoon northward.

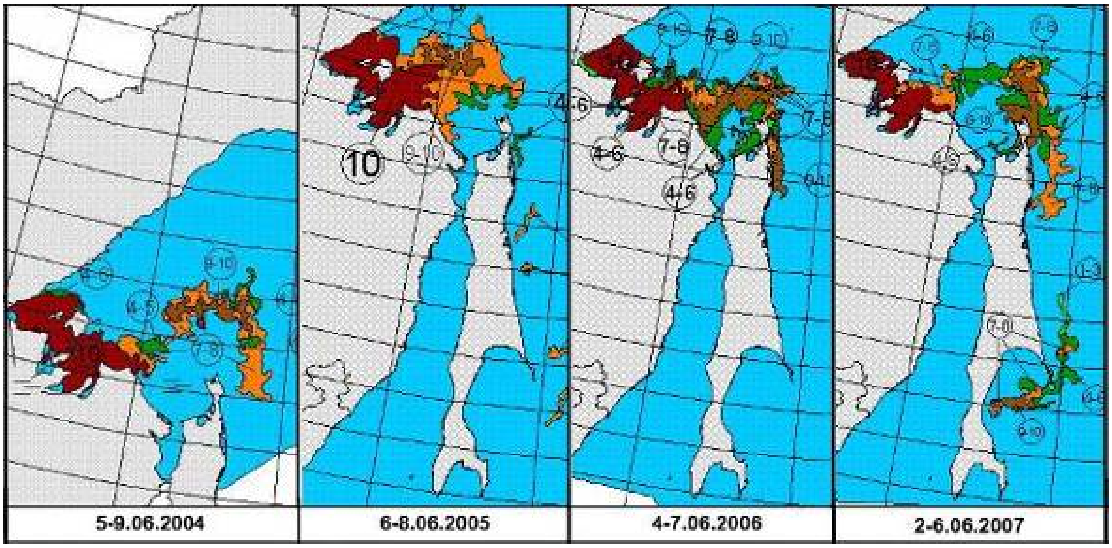

Figure 33. Locations of ice fields according to satellite monitoring data during the first ten days of June 2004-2007 of northeastern Sakhalin (http://www.aari.nw.ru).

Ice cover could affect the abundance of *Monoporeia affinis* through influence on hydrological processes and on primary production. Settled phytoplankton and detritus of phytoplanktonic origin have been reported to play an important role in the diet of this species (Sarvala, 1991; Van de Bund at al., 2001). In an environment with an ice regime, such as the northeast Sakhalin shelf and associated coastal bays and lagoons, the intensity and duration of spring bloom of phytoplankton may, as in similar environments, be influenced in part by light conditions when the water surface is free of ice (Schell at al., 1982); persistence of ice conditions could delay the spring bloom of phytoplankton, and this in turn could affect zooplankton productivity and fish that feed on plankton (Boytsov and Orlova 2004), as well as benthos (Fleeger, Shirley and Ziemann 1989). A sharp increase in growth rates of *M. affinis* has been shown to follow the spring bloom of phytopolankton in the Baltic Sea, where food supply affected growth to a greater degree than temperature (Lehtonen, 1996; Lehtonen, Andersin, 1998).

The lowest abundance of *M. affinis,* the most likely principal component of western gray whale diet, occurred in 2006. The distinguishing features of the hydrological and climatic conditions in 2006 were: (a) a decrease in the summer temperature of bottom waters, and (b) an anomalous ice cover duration (Fig. 33). We note that the two phemonena may be related. There are available data on the observed cooling of the climate of the Sea of Okhotsk (Volvenko 2004). Unfortunately, no data are available for phytoplankton productivity.

A slight and not statistically significant increase in *M. affinis* biomass in 2007 coincided with an earlier clearing of ice cover (Fig. 33).

CONCLUSION

1. Bottom grab collections of benthos taken during July 22 through October 5, 2006, in the coastal waters of northeastern Sakhalin in two gray whale feeding areas – the Piltun and Offshore areas – and an Intermediate area between the two feeding areas, served as material for the study. Bottom grab samples were collected using a standard grid (including 360 samples from 120 stations) and at whale feeding sites (including 274 samples from 89 stations). There were also 32 scuba diving stations (112 samples) at depths of 12 m or less in the whale feeding areas.

2. Analysis[5] of year-to-year variations in the bottom water temperature for the period from 2004 to 2007 in the section from Piltun Bay to Niyskiy Bay indicated that bottom temperatures in 2006-2007 were lower than in 2004-2005. Considerable spatial and temporal variation of hydrological characteristics was observed in the study area in 2005-2007. Frontal zones (in a layer of 0-10 m) with significant water temperature and salinity differentials formed as a result of the development of upwelling during the entire period of studies in the area of Chayvo and Piltun bays.

3. In 2007, the average total biomass of benthos in the **Piltun feeding area** was 448.5±87.1 g/m^2. As in previous years, most of the total biomass is accounted for by sand dollars (71% of total biomass on average, and up to 84% at depths greater than 20 m).

For the entire depth range studied in 2007, the average biomass of amphipods was 32.1±4.8 g/m^2, compared to 28.5±3.8 g/m^2 in 2006. More than 90% of the abundance of amphipods was due to 2 species: *Monoporeia affinis* (> 60% of total amphipod biomass) and *Eogammarus schmidti* (> 30%). The average biomass of amphipods at depths of 15 m or less was 74.7±9.8 g/m^2, which is not significantly different from the 2006 data (59.8±11.8 g/m^2). The distribution of amphipod biomass along the coast of the Piltun feeding area showed similar trends in 2002-2007; zones of maximum biomass were associated with the coastal waters, and the amphipod distribution has a distinctly aggregated nature. Sand lance abundance figures for

[5] The analysis has been conducted by F. F. Khrapchenkov, POI DVO RAN.

the northern part of the area in 2007 and 2006 have similar low values (frequency of occurrence 20-25% at biomass less than 20 g/m^2).

4. **Offshore feeding area.** The average benthos biomass in 2007 was 489.4±60.5 g/m^2 and 654.7±59.9 g/m^2 in 2006. The biomass of amphipods was 173.5±58.6 g/m^2 in 2007 and 184.9±29.6 g/m^2 in 2006. Year-to-year differences in average amphipod biomass were not statistically significant. The spatial distribution of benthos biomass was similar in 2007 and 2006. The proportion of amphipod biomass in total benthos biomass of the Offshore feeding area increased with distance from shore toward deeper waters.

5. **Study of macrobenthos trophic relationships in gray whale feeding areas.** Ratios of stable carbon and nitrogen isotopes indicated that phytoplankton and microphytobenthos are the likely main sources of organic material for mass zoobenthos production in the Piltun area

6. **Year-to-year variations in forage benthos in the Piltun and Offshore areas.** Forage benthos biomass in the Offshore feeding area was stable during 2002-2007, and no major year-to-year variations were observed; whales fed in a depth range of 41-53 m during all those years in a zone of high abundance of *Ampelisca eschrichti.* In the Piltun feeding area, the most notable changes in the abundance and spatial distribution of the dominant amphipod species, *Monoporeia affinis*, were observed in 2006. Hydrological and climatic conditions in summer 2006 were characterized by lower bottom temperatures compared to 2004-2005, and the anomalous duration of the ice cover.

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