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BENTHOS STUDIES IN FEEDING GROUNDS OF WESTERN GRAY WHALES OFF THE NORTHEAST COAST OF SAKHALIN ISLAND (RUSSIA), 2002-2010

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ABSTRACT

This paper reports the Western Gray Whales (WGW) food supply distribution patterns in two feeding grounds off the Northeast coast of Sakhalin: Piltun (PFA) and Offshore (OFA) feeding areas in 2002-2010. Whale distribution and photo-ID studies registered changes in WGW distribution and abundance in the Piltun and Offshore feeding areas in 2002-2010. To explain these year-to-year differences, potential correlations with benthic data were investigated. The basic food resources for WGW in the PFA are small benthic animals – amphipods (*Monoporeia affinis*) and sand lance fish (*Ammodytes hexapterus)*. Results show that differences in amphipod biomass in the Piltun area between years were statistically significant. Results also show that sand lance were an additional food source for gray whales in the northern part of PFA in water depths >20 m during 2004-2005 and 2010 when there was a greater frequency of occurrence of sand lance than during other years. According to statistical analysis, whales in this area fed more often in spots where frequency of occurrence of sand lance was highest. Food benthos biomass in the deep-water OFA was stable during 2002-2010, and no long time variations were observed; whales fed in a depth range of 41-61 m during all years in a zone of high abundance of ampeliscid *Ampelisca eschrichti* amphipods.

KEY WORDS: WESTERN GRAY WHALE, RUSSIA, SAKHALIN, FEEDING GROUNDS, FOOD/PREY, BENTHOS, OIL-GAS PROJECT.

INTRODUCTION

Gray whales feed primarily on benthic and epibenthic invertebrates. The critically endangered, western population of gray whales that inhabits the northeast coast of Sakhalin Island, near the Sakhalin-1 and Sakhalin-2 oil and gas projects, utilizes two main feeding areas during the ice-free season: a nearshore feeding area adjacent to Piltun Bay, and an offshore area, east-northeast of Niyskiy Bay (Figure 1). This population also utilizes an intermediate area, adjacent to Chayvo

Bay, but less intensively than the other two areas. Studies of benthos food resources are essential for an adequate understanding of the ecology of the western gray whales, so that changes in their distribution and behaviour can be interpreted, and to provide information for adaptive management of mitigation and conservation programmes.

Since 2002, benthos studies have been conducted annually by an industry-sponsored research and monitoring programme offshore Sakhalin Island. These studies have focused on the Piltun and Offshore feeding areas and on the intermediate area adjacent to Chayvo Bay (Chayvo feeding subarea), and have thus far provided a medium-term dataset of resource characteristics against which other components of the multidisciplinary programme (e.g. distribution and photo-ID surveys) can be compared.

This paper reviews the Western Gray Whales' food supply distribution patterns in feeding grounds off the Northeast coast of Sakhalin in 2002-2010. Methods of field studies and benthos distribution patterns in 2001-2003 and 2004-2008 were published earlier (Fadeev, 2007; 2009).

RESULTS AND DISCUSSION

Piltun feeding area

Crustaceans (amphipods and isopods) are believed to be the most important food resource for WGWs in the Piltun area. Despite the frequent occurrence of crustaceans in the Piltun area, the percentage of these animals in total benthos biomass varied considerably, mainly with depth. Based on data from 2002–2010, the overall proportion of crustaceans in the macrobenthos biomass in Piltun feeding area was 40–75% at depths of 5–10 m and only 3–10% at depths of 26–30 m.

Various orders within the crustacean group were distributed differently with respect to depth; three patterns were noticed: (1) amphipods and isopods had a maximum biomass at depths of 5–15 m, decreasing sharply at depths >20 m; (2) cumaceans biomass reflected the opposite pattern: lower biomass in shallower depths, and increasing in biomass in depths >20 m; and (3) decapods biomass was low at all depths and varied only slightly.

In 2010, as in 2008-2009, the proportion of crustaceans in the overall biomass was >65% at depths of 11–15 m, decreasing to <5% at 26–30 m. Spots of high biomass at depths greater than 20 m consists of cumaceans and large *Saduria entomon* isopods, an important WGW food source. Shallow-water accumulations consist mainly of amphipods and isopods. The spatial distribution of amphipod biomass in the Piltun feeding area showed similar trends in 2002-2010; zones of maximum biomass were associated with the shallow, and the amphipod distribution has a distinctly aggregated nature. In 2010, areas of high amphipod biomass increased in size, extending from the northern to the southern parts of the Piltun Area.

Year-to-year changes in amphipod biomass. The data used for analysis of year-to-year changes in amphipod biomass consisted of data collected in 2002-2010 from 192 grid and feeding point stations located in the Piltun feeding area. These stations represent a subset of the entire set of

grid stations and are located in the Piltun coastal area at depths of up to 15 m, i.e., depths of maximum amphipod concentration.

All these stations are classified as high-calorie Crustacea – amphipods and isopods, and located in summer-autumn feeding areas for gray whales. Over 50-65% of the total amphipods biomass is comprised of five species: *Monoporeia affinis, Eogammarus schmidti, Anisogammarus pugettensis, Anonyx nugax,* and *Eohaustorius eous*. These species have large body size (more than 5-6 mm) and high frequency of occurrence (60-90%) in summer. Results of single-factor dispersion analysis allow us to reject a hypothesis on homogeneity of groups, i.e., they show the presence of statistically significant differences in mean total amphipod biomass throughout years (one-way ANOVA: df=8; F=3.6; p=0.001). Figure 2 shows differences in mean total amphipod biomass. As follows from the picture, the amphipod biomass decreased from the maximum values in 2002 (115.5 ±19.6 g/m^2) and in 2003 (113.8 ±14.2 g/m^2) to minimum values in 2006 (52.6±7.4 g/m^2).

Fisher LSD Test and Mann-Whitney U-test were used to confirm yearly differences in mean biomass (Borovikov 2001). Calculations in both tests show nearly identical results; principal deviations refer to assessment of difference significance levels (Table 1). The key results of the statistical analysis are as follows:

- There was not a statistically significant difference in mean amphipod biomass between years 2002 to 2005 (LSD multiple comparison, P>0.05).
- Mean amphipod biomass in 2006 was significantly lower compared to 2002-2005, 2007, and 2009-2010 and was not statistically significantly different from the 2008 values.
- Mean amphipod biomass in 2007-2010 was significantly lower compared to 2002-2003; amphipod biomass in 2008 was significantly lower compared to 2002-2005.

There is only one difference in the results of the Fisher LSD Test and Mann-Whitney U-test: The Mann-Whitney U-test shows 2009 and 2010 mean amphipod biomass to be higher than in 2008 (p=0.016), whereas Fisher LSD Test suggests there is no statistically significant difference between 2008 and 2009-2010 (p>0.05). However, if we correct the Mann-U alpha level for the number of analyses conducted on a single dataset (i.e., Bonferonni correction to alpha = 0.05/8 = 0.006; a standard procedure to guard against committing a Type I error in multiple comparisons), we conclude the Mann-U comparison between 2008 and 2009-2010 is not statistically significant. Note, the Fisher LSD test does not need an alpha correction factor because it essentially acts as a single test (i.e, alpha = 0.05). Other year-to-year comparisons that the Mann-U test found to be marginally significant (i.e., 0.05 > P > 0.006) will also become non-significant if we correct alpha (despite the LSD test continuing to show them as significant), a result that is symptomatic of non-parametric tests like Mann-U being less powerful than parametric tests like ANOVA and Fisher LSD (Zar 1984). In short, statistical inference should be based on the Fisher LSD results shown in Table 1; significant Mann-U results that align with significant Fisher LSD results gives confidence that these results indicate a true effect.

Thus, based on the results of the analyses, multi-year changes in amphipod biomass in the shallow waters of Piltun area represent a statistically significant biomass decrease in 2006 compared to 2002-2005. The rise in amphipod biomass observed in 2007-2010 has not yet reached the maximum biomass values of 2002-2003 (statistically significant differences still remain). The 2009-2010 amphipod biomass levels, which constitutes the main feeding component for gray whales in the Piltun area, were comparable with 2004-2005 levels (no statistically significant differences in biomass values).

Results of the benthos studies suggest that the sand lance *Ammodytes hexapterus* may be an occasional food source for gray whales. The sand lance accumulations in the northern Piltun area (depths greater than 20 m) were located 5-7 km from the shallow-water areas of the coastal amphipod complex (depth less than 15-20 m); however, gray whales can cover this distance in 1-1.5 hours, and so coastal areas with amphipod dominance and the deeper-water areas with sand lance dominance could easily be foraged by the same whales within short periods of time.

The average sand lance biomass in the Piltun area at the whale feeding locations was lower in 2009 and 2008 (8.8±3.7 g/m^2 and 12.9±5.4 g/m^2, respectively) than in 2007 (27.7±12.1 g/m^2). In the northern part of the Piltun area, the frequency of occurrence of sand lance decreased from 40-60% in 2005 to 20-25% in 2006-2007, and 8-12% in 2008-2009. In 2010 the sand lance frequency of occurrence in the northern part of the Piltun Area increased to 20%. During field observations two gray whale feeding locations were identified. Sand lance biomass at these feeding sites was 66 and 78 g/m^2. Considering the higher biomass numbers, and relative contribution of sand lance to the overall biomass, we may assume that in 2010 sand lance schools recovered in the northern part of the area to levels similar to 2006-2007, although the small sample size precludes robust statistical analyses.

Cluster analysis was used to examine differences in the composition and quantitative abundance of taxonomic groups at different locations. Three complexes were identified in the Piltun area; the Amphipods complex dominated at whale feeding sites. The Amphipods complex included 34 amphipod species, the most abundant of which were *Monoporeia affinis, Eogammarus schmidti, Eohaustorius eous eous* and *Anisogammarus pugettensis*. Amphipods (90.2 ±18.5 g/m^2) constituted 92% of the total biomass in this complex, which also included isopods and bivalve molluscs.

Summarizing the analysis of the distribution of macrobenthos complexes, we note that there are two complexes that cover most area offshore the Piltun Bay, i.e., a shallow-water, coastal amphipod complex with a high proportion of prey organisms by biomass, and a deeper-water sand dollar complex with a low proportion of prey organisms by biomass. The provisional boundary between the complexes lies at depths of about 20 m.

Chayvo feeding subarea

The occurrence of the amphipod complex to the south of Piltun Bay, as far as Chayvo Bay, has been known since 2001, when it was also noted that the biomass of amphipods is significantly lower there than in the Piltun area. In 2001, the average amphipod biomass at whale feeding sites in the 10-15 m range was 35.7±9.8 g/m^2, in 2006 it was 41.1±7.9 g/m^2, in 2007 it was 51.3±8.6 g/m^2, in 2008 it was 47.6±9.6 g/m^2 and in 2009 it was 61.4±13.6 g/m^2, respectively. Amphipod biomass at feeding locations in the Chayvo Subarea did not change significantly in 2010 (57.8±9.4 g/m^2) compared to previous years.

Vessel-based observation and photo-ID data recorded no more than 5-7 gray whales feeding in the Chayvo area at any one time. This may indicate that this small area with relatively low prey biomass may be of secondary importance as feeding habitat compared to the Piltun and Offshore feeding areas.

Offshore feeding area

The spatial distribution of benthos biomass in the Offshore area was similar in 2002-2010; the proportion of amphipod biomass in total benthos biomass of the Offshore feeding area increased with distance from shore toward deeper waters. This pattern also reflected a gradual increase in the proportion of silt-pelite fractions in the seabed deposits. Other groups (sea anemones, bivalve molluscs, cumaceans and sand dollars) that made up the remainder of the biomass had patchy distribution.

The ampeliscid *Ampelisca eschrichti* biomass at WGW feeding sites averaged 366.3±168.3 g/m^2 in 2005, 329.4±143.8 g/m^2 in 2006, 516±140.1 g/m^2 in 2007 and 523±148.5 g/m^2 in 2008. The average ampeliscid biomass at whale feeding sites in 2009 and 2010 was 507.7±59.3 g/m^2 and 423.4±103.5 g/m^2 respectively, indicating that gray whales forage in the Offshore area primarily at sites with ampeliscid biomass of more than 300 g/m^2. No major year-to-year variations were observed when comparing data for the whole Offshore area for all years between 2002 and 2010; forage benthos biomass in the Offshore feeding area was stable and differences in average amphipod biomass were not statistically different. WGW fed in a depth range of 41-61 m, in a zone of high abundance of amphipod *Ampelisca eschrichti*. In contrast to the dominant amphipod species in the Piltun area, the ampeliscids live in tubes attached to the substrate in areas with strong bottom currents.

Cluster analysis of biota in the Offshore feeding area identified four complexes: the sand dollar complex (Complex I), the cumacean and amphipod complex (Complex II), the ampeliscid amphipod complex with bivalve mollusks, and sea anemones (Complex III), and the ampeliscid amphipod complex (Complex IV). The last (Complex IV) occupied the largest part of the study area and is considered of greater importance to the feeding of gray whales (Figure 3).

In 2010, as in previous years, benthos at the feeding sites had composition and structure consistent with the *Ampelisca eschrichti* complex IV and the *A. eschrichti* + Bivalvia + Actinia complex III. A complex dominated by the ampeliscid amphipod *Ampelisca eschrichti*, occurring in the eastern part of the Offshore area, had an average biomass of 644±145 g/m^2, of which 79%

(or 510 g/m^2) comprised biomass of the dominant group – amphipods. The complex comprised 35 amphipod species, of which 14 species were found only in the Offshore area. *A. eschrichti* was distinctly dominant in regard to frequency of occurrence, colony density and biomass. The ampeliscid colony density and biomass in the area are comparable to, and in some cases exceed, those of other highly productive areas of the North Pacific.

Year-to-year changes in whale distribution and forage benthos in the Piltun and Offshore feeding areas

The purpose of this section 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 WGW in 2002-2010

- 2002-2003 – whales fed in both (Piltun and Offshore) feeding 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.
- 2004-2005 – whales fed primarily in the Piltun area; the number of photo-identified whales 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.
- 2006 – whales fed in both the Piltun and Offshore areas; the number of photo-identified whales 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.
- 2007-2009 – whales fed in both areas; the number of photo-identified whales 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 subarea had a small number of foraging whales.
- 2010 – whales fed in both the Piltun and Offshore areas. In the shallow littoral areas of the Piltun Area the whales foraged along the entire coast from north to south. A small number of foraging whales were observed in the northern part at depths > 20 m.

Principal trends in variation of forage benthos abundance in 2002-2010

Offshore feeding area

Biomass of forage benthos was stable, and no major year-to-year variations were observed; whales fed in a depth range of 41-61m every year in a zone of high abundance of major prey: amphipods *Ampelisca eschrichti*.

Piltun feeding area

- 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 in waters >20 m in the northern part of the Piltun area 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.
- 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 Piltun Feeding area declined by 50% from the 2005 level; in the northern part of the Piltun Feeding area, the frequency of occurrence of the sand lance decreased from 40-60% to 20-25%.
- The decrease in abundance of amphipods and sand lance in 2006 coincided with the appearance of foraging whales in the Chayvo subarea and an increase in the number of whales in the Offshore area. It is notable that whales began feeding in the Chayvo subarea at sites with biomass of about 40 g/m^2 when the biomass of amphipods in the southern Piltun area dropped to approximately this level.
- 2007-2009 – amphipod biomass increased in the shallow-water zone of the Piltun area. In 2008-2009 amphipod *M. affinis* was dominant in the southern and central part of the area Piltun area; its biomass there in 2007-2009 was higher than in 2006 but did not reach the maximum levels of previous years.
- In 2007-2009, sand lance abundance at deeper-water sites in the northern part of the area remained at the low level of 2006. In 2009, the frequency of occurrence, biomass and the spatial distribution of sand lance in the Piltun area were similar to those of 2008. There have been sporadic finds while the concentrations in the northern part of the area is absent.
- In 2010, areas with high amphipod biomass increased in size, extending from the northern to the southern parts of the Piltun Area. At depths of 10-12 m amphipod biomass in the WGW foraging area increased 20-100 g/m^2 over 2009 and in certain places reached 180-205 g/m^2.
- An increase in the abundance of the amphipod *M. affinis* in the south Piltun area 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.

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 showed that the lowest bottom temperatures for the period 2004-2010 occurred in 2010. 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 and Coyle 1991). Whether the few degrees centigrade of temperature differences in the Piltun area has affected amphipod life cycle is not known. 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 2007-2010 amphipod collections is completed.

Important climate parameters such as sea ice dynamics can also impact coastal biota. Ice conditions varied substantially in the Piltun area during 2004-2010. Figure 4 indicates the position of the ice edge during the first ten days of June each year. According to these satellite 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 2007-2010, ice remained near the Chayvo lagoon, but there was open coastal water from the Piltun lagoon northward.

Ice cover could affect the abundance of *Monoporeia affinis* through influence on hydrological processes and on primary production (i.e., food for benthos). 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 et 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 et al. 1989). A sharp increase in growth rates of *M. affinis* has been shown to follow the spring bloom of phytoplankton in the Baltic Sea, where nutrients availability affected growth to a greater degree than temperature (Lehtonen 1996; Lehtonen and Andersin 1998).

The lowest abundance of *M. affinis*, the most likely principal component of WGW 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 (Figure 4).

CONCLUSION

Piltun Feeding Area The spatial distribution of amphipod biomass along the coast of the Piltun feeding area showed similar trends in 2002-2010; zones of maximum biomass were associated with the coastal waters, and the amphipod distribution has a distinctly aggregated nature. In 2010,

areas of high amphipod biomass increased in size, extending from the northern to the southern parts of the Piltun Area.

Multi-year changes in amphipod biomass in the shallow waters of Piltun area represent a statistically significant biomass decrease in 2006 compared to 2002-2005. Amphipod biomass rise observed in 2007-2010 has not yet reached the maximum biomass values of 2002-2003 (statistically significant differences still remain). In 2009-2010, amphipod biomass, the main feeding component for gray whales in the Piltun area, reached the level of 2004-2005 (no statistically significant differences in biomass values).

In the northern part of the Piltun area (depth > 20 m), a substantial decrease in sand lance frequency of occurrence was observed, from 40-60% in 2005 to 20-25% in 2006-2007, and 8-12% in 2008-2009. In 2010, sand lance frequency of occurrence in the northern part of the Piltun Area increased to 20%. Sand lance biomass at gray whale foraging spots was 66 and 78 g/m^2. Considering the higher biomass numbers, and relative contribution of sand lance to the overall biomass, we may assume that in 2010 sand lance schools recovered in the northern part of the area to levels similar to 2006-2007. This is evidenced by both the increase in the frequency of sand lance encounters and the increase in the area of their schools.

<u>Offshore feeding area</u>. The average benthos biomass in 2010 was 578.6±123.3 g/m^2. The biomass of amphipods was 206.2±53.7 g/m^2 in 2010 compared to 183.9±66.2 g/m^2 in 2009. Year-to-year differences in average amphipod biomass were not statistically significant. The spatial distribution of benthos biomass was similar in 2010 and 2006-2009. The proportion of amphipod biomass in total benthos biomass of the Offshore feeding area increased with distance from shore toward deeper waters. As in previous years in the Offshore feeding area, in 2010 the whales fed in the areas with amphipod biomass greater than 300 g/m^2.

<u>Year-to-year variations in forage benthos in the Piltun and Offshore areas</u>. Forage benthos biomass in the Offshore feeding area was stable during 2002-2010, and no major year-to-year variations were observed; whales fed in a depth range of 41- 61 m during all those years in a zone of high abundance of amphipods *Ampelisca eschrichti*. In the Piltun feeding area, the most notable changes in the abundance and spatial distribution of the dominant amphipod species, *Monoporeia affinis*, occurred in 2006 when the lowest biomass levels were observed. 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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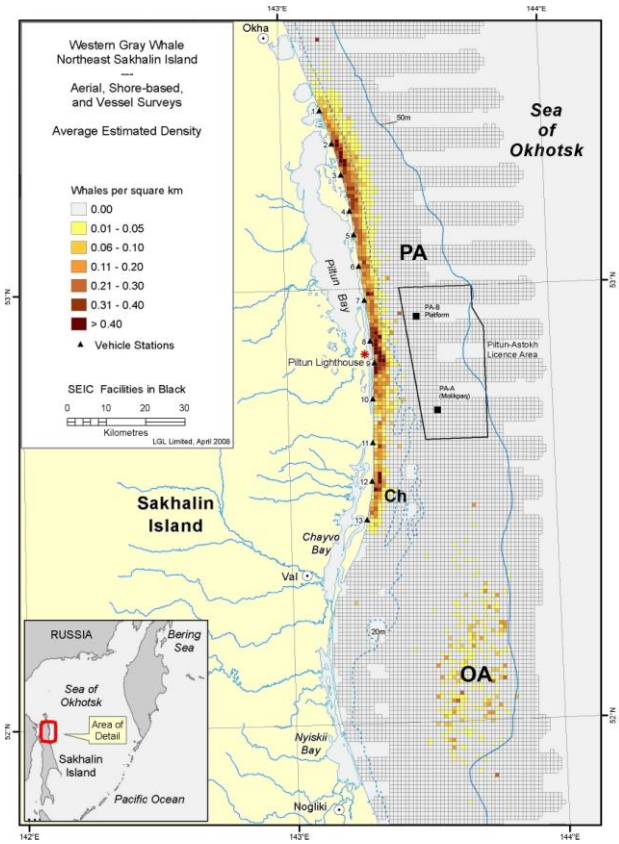

Figure 1. Locations of WGW feeding grounds off the northeast coast of Sakhalin Island. PA – Piltun Feeding Area, OA – Offshore Feeding Area, Ch – Chayvo Feeding Subarea.

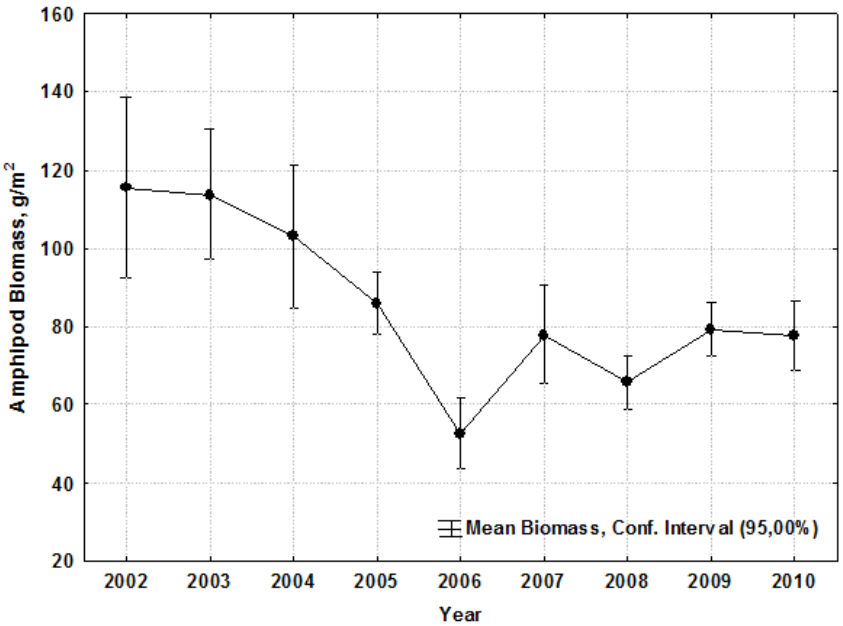

Figure 2. 2002–2010 changes in mean total amphipod biomass in Piltun area at depths < 15m.

Table 1. Fisher LSD Test and Mann-Whitney U-test results showing mean total amphipod biomass broken down by years.

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010
2002		**ns**	**ns**	**ns**	***	*	*	*	*
2003	**ns**		**ns**	**ns**	***	**	***	**	**
2004	**ns**	**ns**		**ns**	***	**ns**	**	**ns**	**ns**
2005	**ns**	**ns**	**ns**		**	**ns**	**	**ns**	**ns**
2006	***	***	***	***		*	**ns**	***	**
2007	*	*	**ns**	**ns**	**		**ns**	**ns**	**ns**
2008	***	***	*	*	**ns**	**ns**		*	*
2009	*	*	**ns**	**ns**	**	**ns**	**ns**		**ns**
2010	*	*	**ns**	**ns**	*	**ns**	**ns**	**ns**	

Legend: Top triangle – Mann-Whitney U-test results (alpha=0.007), bottom triangle – LSD test (alpha=0.05; one-way ANOVA: df=8; F=3.6; p=0.001).
Significance levels: ns = p>0.05, * = p<0.05, **= p<0.01, *** = p<0.001.

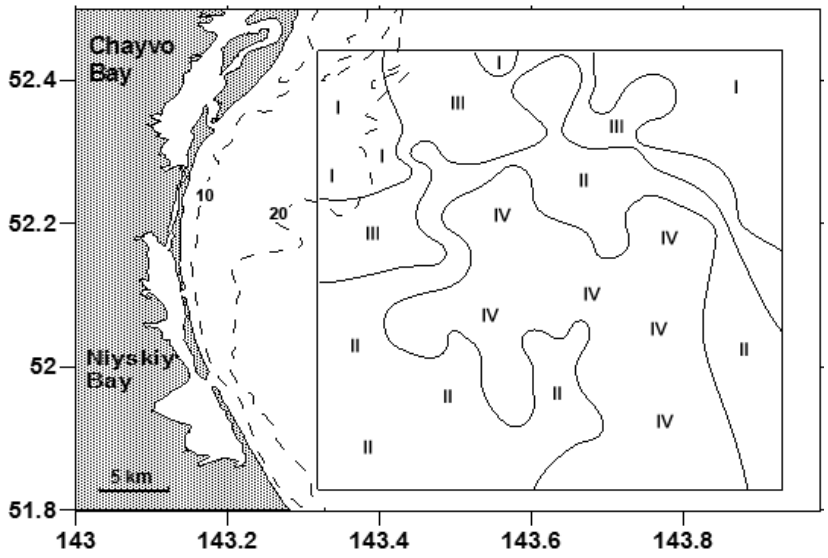

Figure 3. Distribution of benthic complexes in the Offshore feeding area. Numbers for the complexes are given in the text.

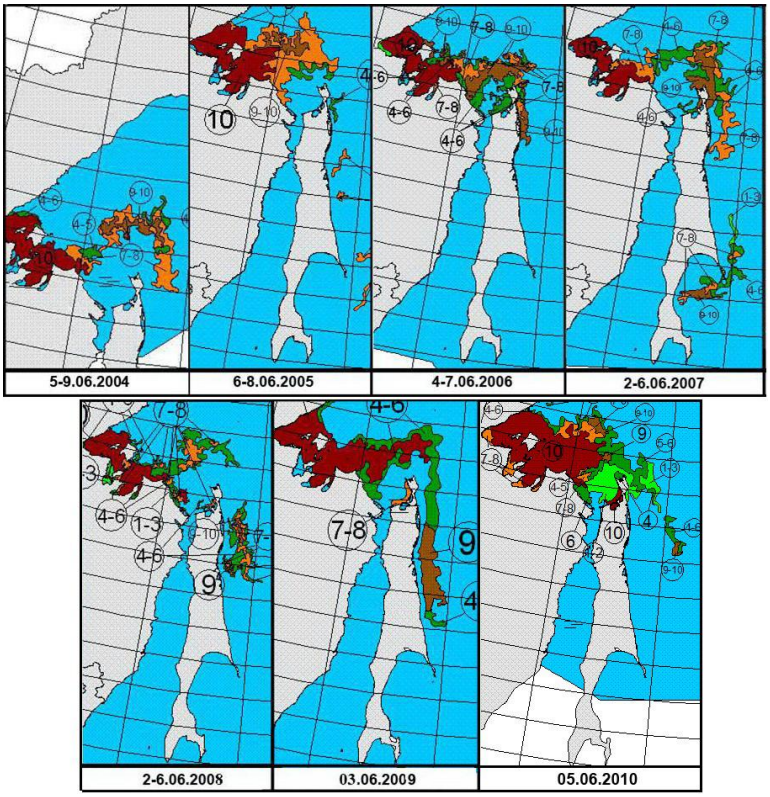

Figure 4. Locations of ice fields according to satellite monitoring data during the first ten days of June 2004-2010 of northeastern Sakhalin (http://www.aari.nw.ru).