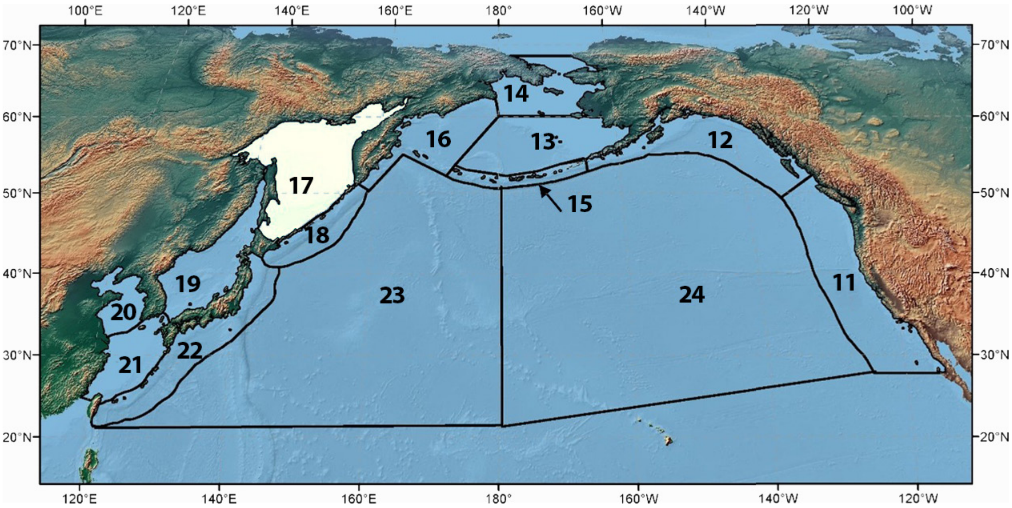


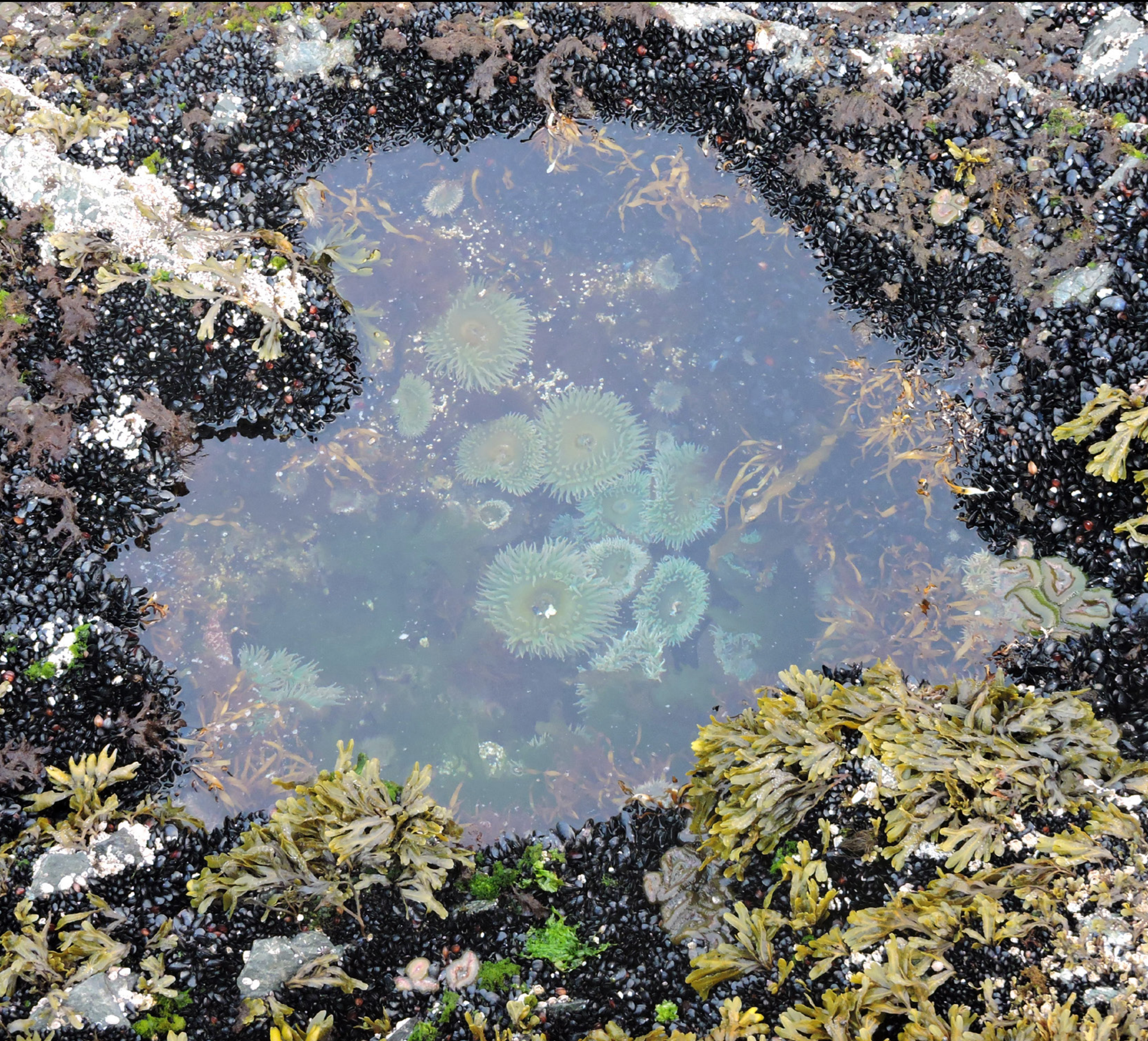
PICES

Regional Report for PICES Region:

17

PICES SPECIAL PUBLICATION 7

Marine Ecosystems of the North Pacific Ocean 2009–2016



PICES North Pacific Ecosystem Status Report, Region 17
(Sea of Okhotsk)

Yury Zuenko
Pacific Scientific Research Fisheries Center
Vladivostok, Russia

Contributors: S.Y. Glebova[1], A.L. Figurkin[1], L.S. Muktepavel[1], V.I. Matveev[1], E.P. Dulepova[1], E.E. Ovsiannikov[1], S.V. Loboda[1], N.L. Aseeva[1], A.O. Zolotov[1], A.Y. Dubinina[2], V.N. Koblikov[1], A.V. Lysenko[1], V. Nadtochii, N. Kolpakov, M.V. Simokon[1], L.T. Kovekovdova[1]

[1]Pacific branch of the Russian Res. Inst. of Fisheries and Oceanography (TINRO), Vladivostok, Russia

[2]Sakhalin branch of the Russian Res. Inst. of Fisheries and Oceanography, Yuzhno-Sakhalinsk, Russia

1. Highlight

- Environmental regime of the Okhotsk Sea changes recently toward warming, mostly because of changes of its heat exchange with atmosphere, that is realized in rising water temperature, lowering ice cover, and weakening geostrophic currents.
- Tendency to decreasing of dissolved oxygen content occurs in the lower part of the intermediate layer of the Okhotsk Sea, whereas slight increasing of oxygen content is observed in the subsurface layer and upper part of the intermediate layer because of weakening and shallowing of slope convection in conditions of warmer winters and lower ice cover.
- Spring bloom intensity (by satellite data on Chlorophyll *a* concentration at the sea surface) in the central Okhotsk Sea decreased sharply in the 2000s and remains recently at the relatively low level. This is a consequence of the weaker winter convection resulting in a reduction in the nutrient supply to the euphotic zone, although the mean annual concentrations of Chlorophyll *a* are rather stable.
- Total zooplankton biomass decreased in the 2000s and continues to decrease, although the abundance of large-sized predatory species of plankton has increased recently.
- Stocks of mass species of fish and invertebrates varied without visible dependence on changes in feeding conditions. Their changes are determined mainly by conditions of reproduction, with species-specific relationships: the stock fluctuations for the most abundant species – walleye pollock are generated by intra-population mechanisms, the stocks of some mass long-living species are stable notwithstanding of environmental changes.
- Recent changes in the macroecosystem of the Okhotsk Sea under the climate change to warming correspond to the conception of productivity decreasing and increasing of efficiency of the ecosystem functioning.

2. Introduction

PICES Region 17 corresponds to the Okhotsk Sea, one of the so-called Far-Eastern Seas – the marginal seas of the western North Pacific (Figure R17-1). It is connected with the ocean by dozens of deep Kuril Straits and with the neighbor marginal sea by two shallow straits. One of the largest rivers in the world, the Amur/Hēilóngjiāng flows into its western part and discharges about 350 km^3 of fresh water annually.

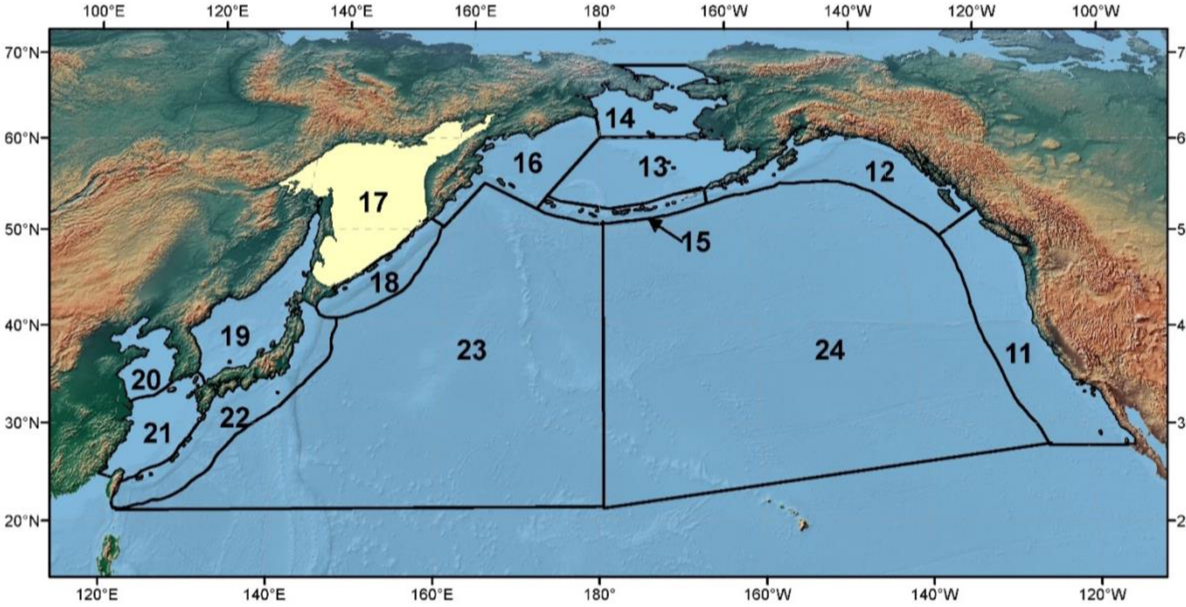


Figure R17-1. The PICES biogeographical regions and naming convention for the North Pacific Ocean with the area discussed in this report highlighted.

Though the sea was discovered for science by Chinese and Dutch travelers, it was explored mainly by Russian and Japanese scientists. The Russians started their exploration in the middle of 17th century from a small village named Okhotsk on the northwestern coast that was founded at the mouth of the Okhota River (the name is consonant with the Russian word “hunting”) – and this village gave the name for the whole sea. Mapping of the region was finished in the middle 19th century when the strait between Sakhalin Island and mainland was described in detail.

The region is located in moderate latitudes but falls deeply into the continent, that’s why it is distinguished by severe winters, when the sea surface is covered by ice, sometimes up to 96 %. Such phenomena as the high-density bottom shelf water forming in the process of ice freezing and slope convection of this water, typical for high latitudes, are quite usual for the northern Okhotsk Sea. On the other hand, waters of subtropic origin enter into the southern part of the sea. The sea is also distinguished by a large tidal range, with the highest tides up to 13 m in the Penzhinskaya Guba Bay in its northern tip. Strong tidal currents provide active vertical mixing on shelves and particularly in the Kuril Straits that totally distorts the water structure in local areas of mixing. Although the region is located closely to the continental centers of atmosphere action, as Siberian High in winter and Far-Eastern Low in summer, variability of its thermal regime depends mostly on intensity and shape of the high pressure center in the North Pacific that determines the tracks of cyclones in winter and the summer monsoon strength. Recently a considerable warming is observed here, both in winter and summer seasons.

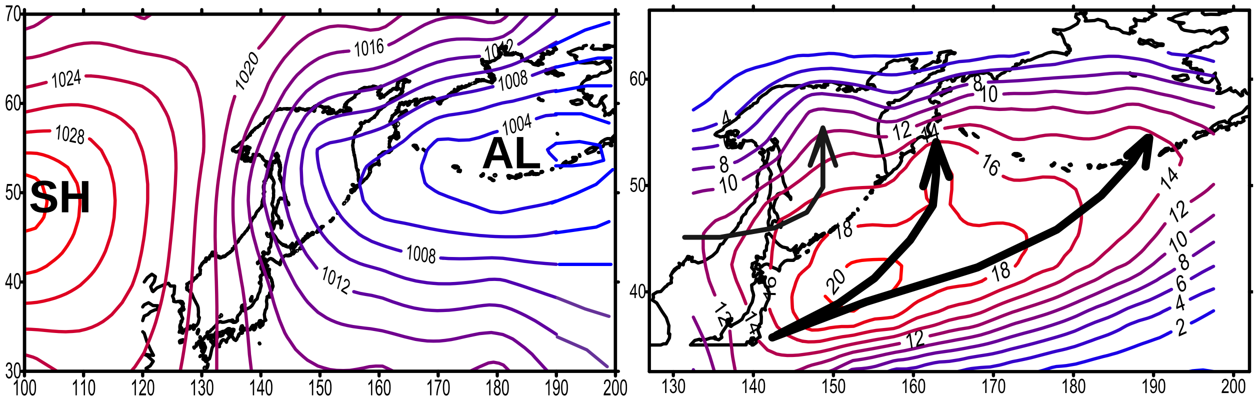
The oceanographic features of the region are rather favorable for photosynthesis because of good nutrient supply that supports high abundance of zooplankton, mainly large-sized copepods and euphausiids. The rich forage base maintains the habitat for huge commercial resources, including both local populations, as pollock, herring, capelin, flounders, halibuts, crabs and also subtropical species that come to the Okhotsk Sea in summer for feeding, such as sardine and saury. Pacific salmon use the forage resources of the sea during their anadromous and catadromous migrations. Marine mammals and birds dwell in the sea in mass and whales, in particular orcas, have increased their abundance considerably in recent times.

The region is important for the Russian and international fisheries, first of all for pollock, herring, and crabs, switching from one target species to another following the features of their biology. The sea ice is a real problem for winter fisheries, explaining the concentration of fishing vessels in the natural channel of the open water at West Kamchatka. On the other hand, the fisheries from ice, both commercial and amateur, is possible along all coasts of the sea. The region is distinguished by the lack of coastal processing of harvest because of the scarce population, so the catches are processed mainly aboard processor vessels and transported to the ports outside the sea. The sea is rich by mineral resources, as well, as natural gas and oil that are extracted from the seabed, mainly on the shelf of Sakhalin Island. The latter circumstance is important for the sea nature protection, including the protection of commercial resources for fishery.

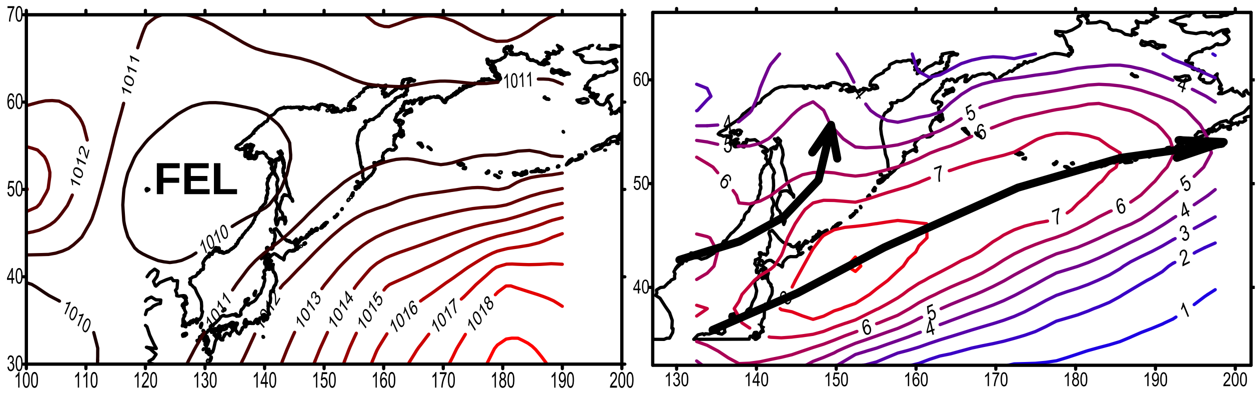
3. Atmosphere

Contributors: Svetlana Glebova

The atmospheric pressure field over the Okhotsk Sea has principally different patterns in winter and summer seasons that determines its monsoon climate. In fall-winter, the atmosphere conditions here are formed by interaction of the Aleutian Low and Siberian High (Figure R17-2), so northern winds prevail (winter monsoon). Cyclones pass eastward mostly along the atmosphere front located outside the Okhotsk Sea though some of them can reach Kamchatka Peninsula and transfer relatively warm air into the northeastern Okhotsk Sea. Other cyclones come from the mainland directly to the western Okhotsk Sea, but they are weak and their influence is much weaker. In spring-summer, the region of the Okhotsk Sea is under influence of the Hawaiian High and depressions of low pressure over the continent, with one of them (Far-Eastern Low) located at its western vicinity (Figure R17- 3). Number of cyclones (and storms) is lower in summer and they usually do not influence much on the atmospheric conditions over the Okhotsk Sea is this season.

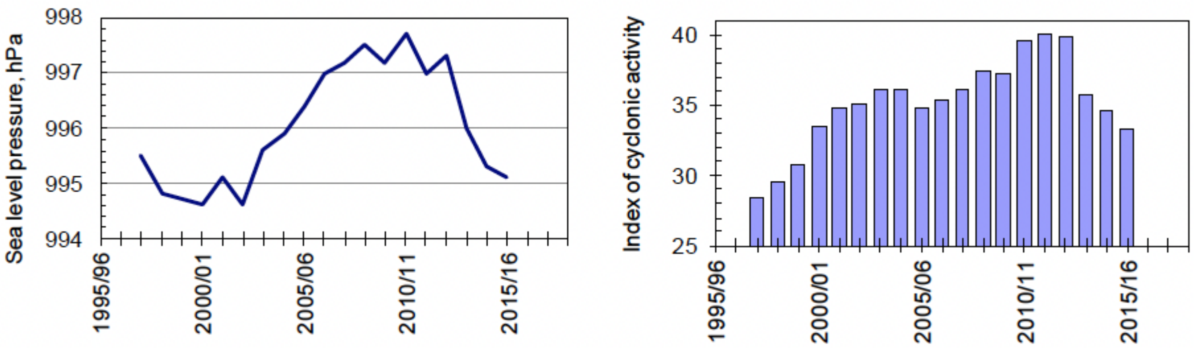


[Figure R17-2] Mean air pressure at the sea surface averaged for October-March of 1995-2016 (left) and mean number of cyclones for 5x5^{o} squares in this period (right). SH – Siberian High; AL – Aleutian Low; main paths of cyclones are shown.

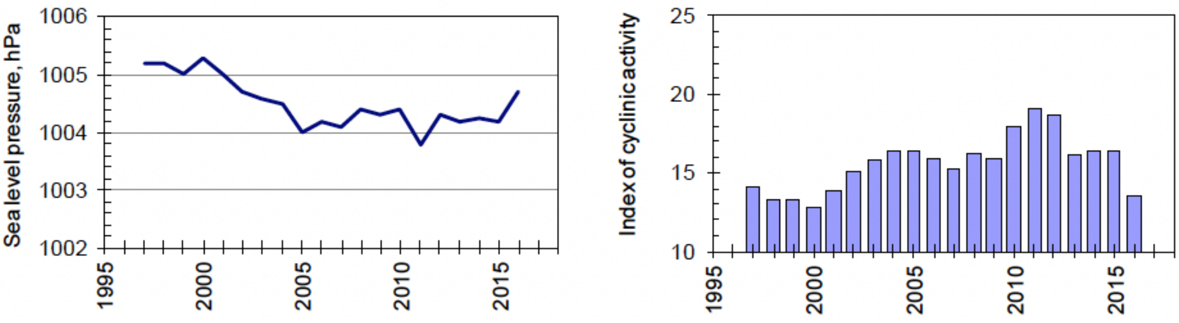


[Figure R17-3] Mean air pressure at the sea surface averaged for April-September of 1995-2015 (left) and mean number of cyclones for 5x5^{o} squares in this period (right). FEL – Far-Eastern Low; main paths of cyclones are shown.

The location and activity of the atmosphere action centers change from year to year causing interannual variability of atmospheric conditions. Although the Aleutian Low has a tendency to weakening in the last two decades, it has shifted westward providing more frequent meridional tracks of winter cyclones (Figure R17-4). Coming over the Okhotsk Sea, winter cyclones caused weakening of northern winds or even changing the wind direction to southern points. In both cases, the winter monsoon became weaker, and weather warmed. The most frequent and strong winter cyclones were observed over the Okhotsk Sea in the 2008-2013. On the contrary, the summer Far-Eastern Low had a tendency to strengthening (though it also shifted westward) and the cyclones coming from the mainland to the Okhotsk Sea became stronger, in particular in the 2010-2012, and caused strengthening of southern winds (Figure R17-5). The stronger summer monsoon was a possible reason of warmer conditions in the northern Okhotsk Sea in the 2007-2014.



[Figure R17-4] Interannual changes of atmospheric pressure in the centre of the Aleutian Low and index of cyclonic activity over the Okhotsk Sea (squared number of closed isobars per cyclone), averaged for October-March. Both are smoothed by 5-year smoothing

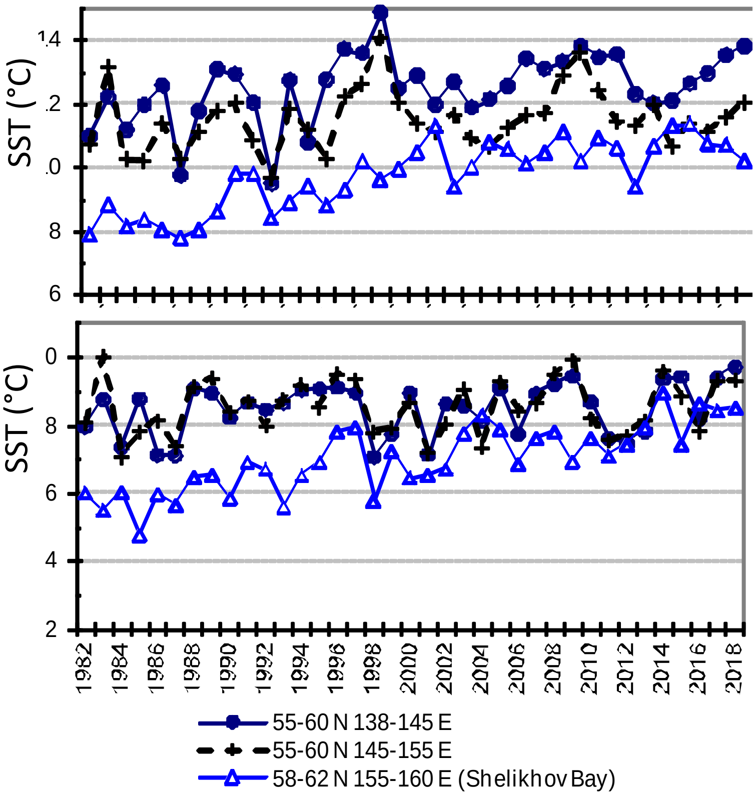


[Figure R17-5] Interannual changes of atmospheric pressure in the centre of the Far-Eastern Low and index of cyclonic activity over the Okhotsk Sea (squared number of closed isobars per cyclone), averaged for April-September. Both are smoothed by 5-year smoothing

4. Physical Ocean

Contributors: Alexander Figurkin, Larisa Muktepavel

4. 1. Water temperature, salinity and density

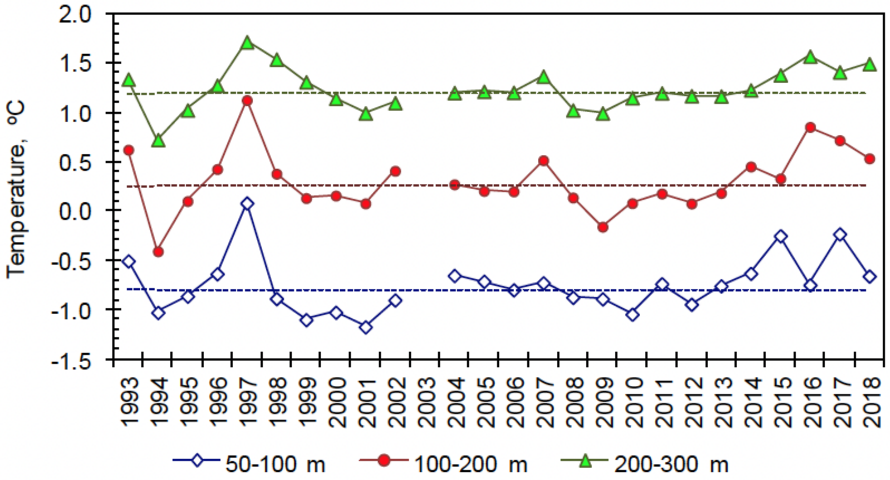


Thermohaline conditions in the Okhotsk Sea are determined mainly by two processes: winter cooling and water exchange with the Pacific Ocean. Both are highly variable under influence of atmospheric conditions. In the period since 2004-present, the atmospheric conditions over the North Pacific were distinguished by strong heat transfer to the high latitudes with cyclones in fall-winter, with abnormally warm winters with low ice conditions prevailing in the Okhotsk Sea in the period 2009-2015. The rate of summer warming of the sea surface became higher, too, and positive SST anomalies were usual for the Okhotsk Sea in this period in summer and September-October (Figure R17-6). Annual mean SST over the entire Okhotsk Sea has significant positive trend in the last three decades, the highest in the Shelikhov Bay.

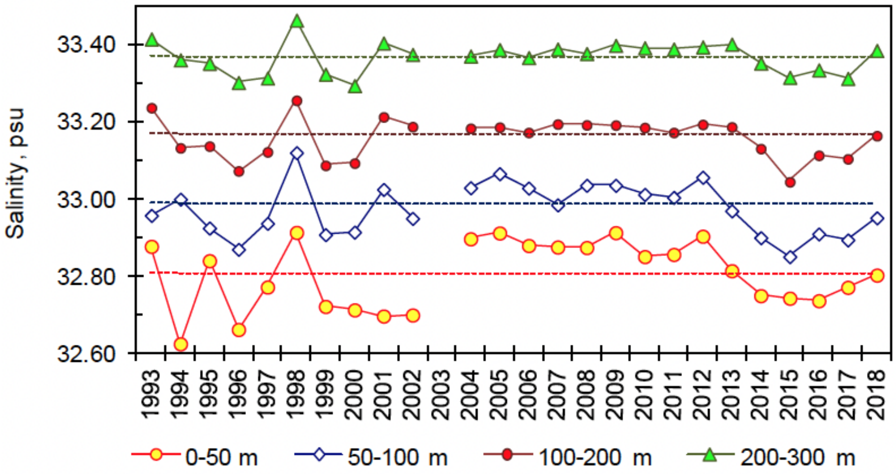
[Figure R17-6] Interannual variations of the sea surface temperature in certain areas of the Okhotsk Sea averaged for July-August (top panel) and September-November (bottom panel)

In the subsurface layer, formed in the process of winter convection, the tendency to warming is not significant, with exception of the last years (Figure R17-7). Salinity in the subsurface layer decreases quickly after 2012 (Figure R17-8), and the upper layer of the low-saline water (<32.8 ‰) becomes thicker: in the northeastern part of the sea it was 20-30 m in springs of 2004-2009 but 50-70 m in springs of 2013-2017 (Figure R17-9). These salinity variations are similar with those in the Pacific waters at northern Kuril Islands (where salinity in the subsurface layer is higher in 0.2-0.3 ‰) that means that they have a common nature.

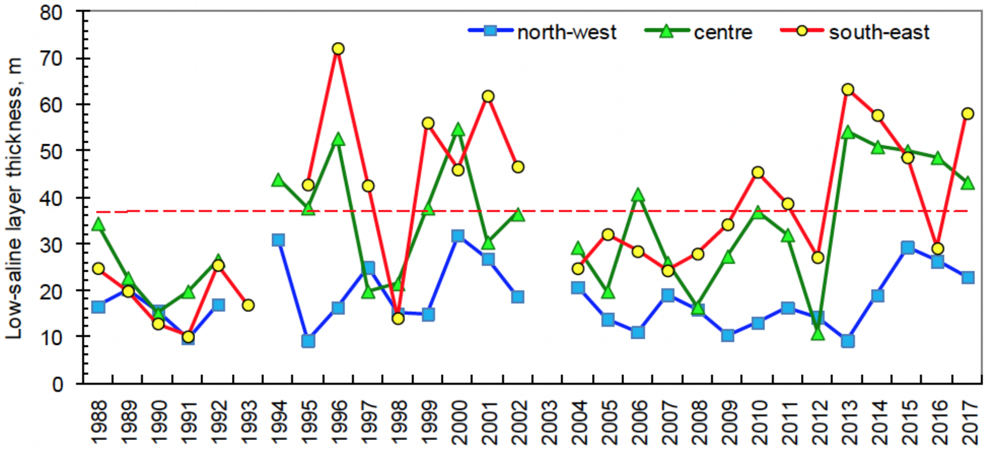
However, the water temperature in spring (April-May) has no positive trend. Since 2004, considerable negative anomalies (mostly from -0.5 to -1.0°) of temperature prevailed both at the sea surface and in the subsurface layer, despite warm winters in this period, though previously the spring conditions depended strongly on the ice cover in preceding winters. This phenomenon could be caused by strong heat losses from the sea surface uncovered by ice in conditions of higher cyclonic activity.



[Figure R17-7] Variations of water temperature in the layers 50-100, 100-200 and 200-300 meters within the area 51-60° N 140-160° E in April-May relative to its mean values (dotted lines)

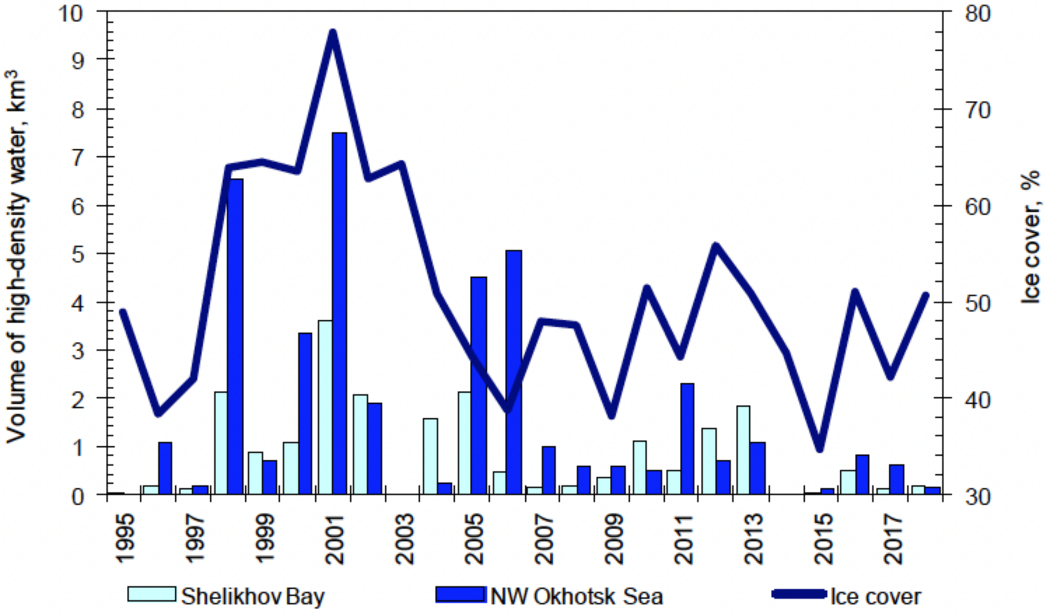


[Figure R17-8] Variations of salinity in the in the layers 0-50, 50-100, 100-200 and 200-300 meters within the area 51-60° N 140-160° E in April-May relative to its mean values (dotted lines)

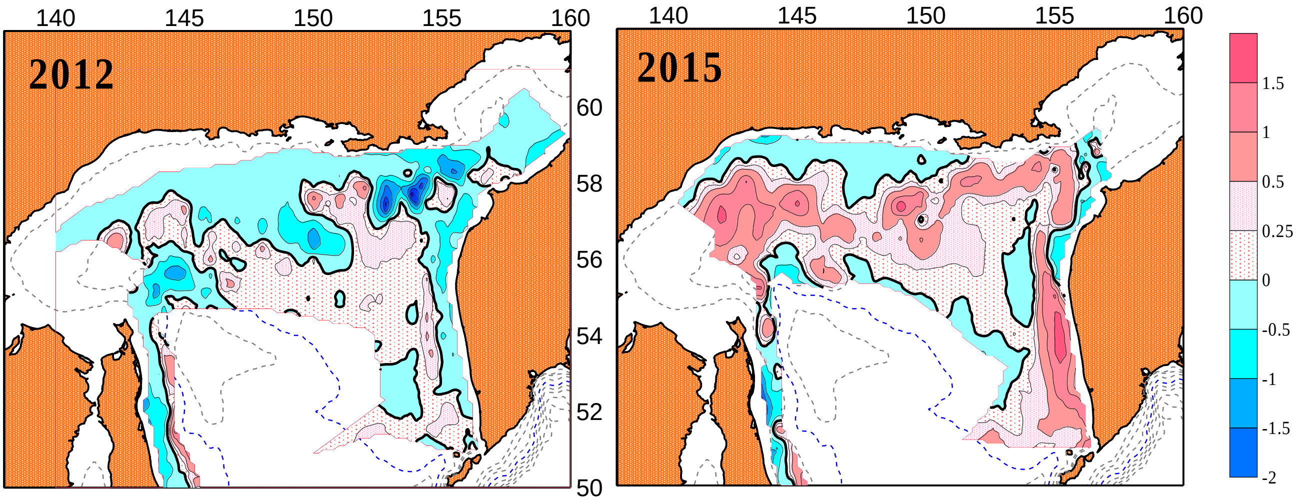


[Figure R17-9] Thickness of the upper low-saline layer with salinity below 32.8 ‰ in April-May averaged for the northwestern (55-59° N 140-146° E), central (56-59° N 146-155° E), and southeastern (51-56° N 153-156° E) areas of the northern Okhotsk Sea. The mean value for the southeastern area (at West Kamchatka) is shown by dotted line

The warm winters in the last decade have drastic consequences for production of the high density waters on the northern Okhotsk Sea shelf. This water mass with low temperature and high salinity is produced in the process of ice freezing. It sinks to the bottom and then moves to the intermediate layer by slope convection. The total volume of this Bottom Shelf water mass with $\sigma_\theta >$ 26.8 is calculated over the whole shelf on the data of spring surveys, using a 15x20 km grid (Figure R17-10). The volume variations correlate strongly with the mean ice cover in January-April (r = 0.70). The ice cover decreased from 3.2-7.8$\cdot$10^3 km^3 in the 1998-2002 to 1.2$\cdot$10^3 km^3 on average in the 2004-2015. It was totally absent after the winters of 2007-2009, 2011, and 2014-2015, when big positive anomalies were observed at the bottom of the northern shelf (Figure R17-11). So far as the slope convection makes a cooling and ventilation effect on the intermediate layer, its cessation causes warming and deoxygenation of this layer (Table R17-1).



[Figure R17-10] Volume of the Bottom Shelf water mass with $\sigma_\theta >$ 26.8 in the northwestern (54-59° N 138-153° E) and northeastern (54-62° N 153-160° E) Okhotsk Sea in May (no data for 2003) *vs* the average ice cover of the Okhotsk Sea in January-April.

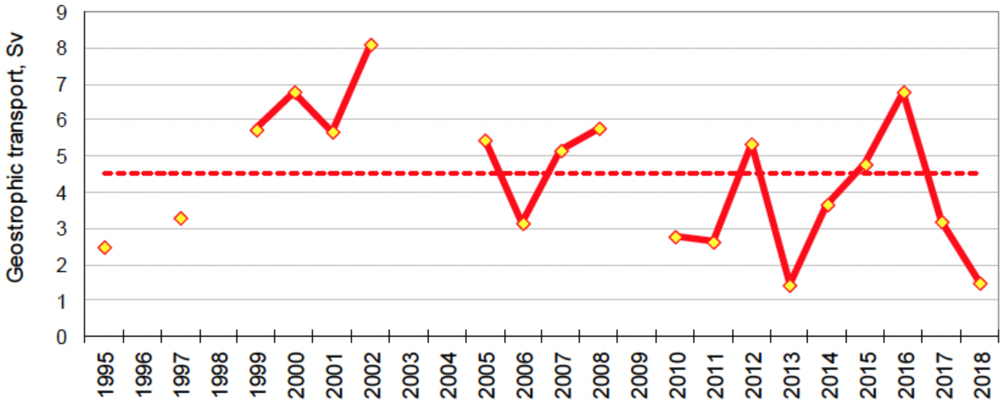


[Figure R17-11] Temperature anomalies at the bottom on shelf in April-May after the winters with high (2012) and zero (2015) production of the Bottom Shelf Water with $\sigma_\theta >$ 26.8 (2015)

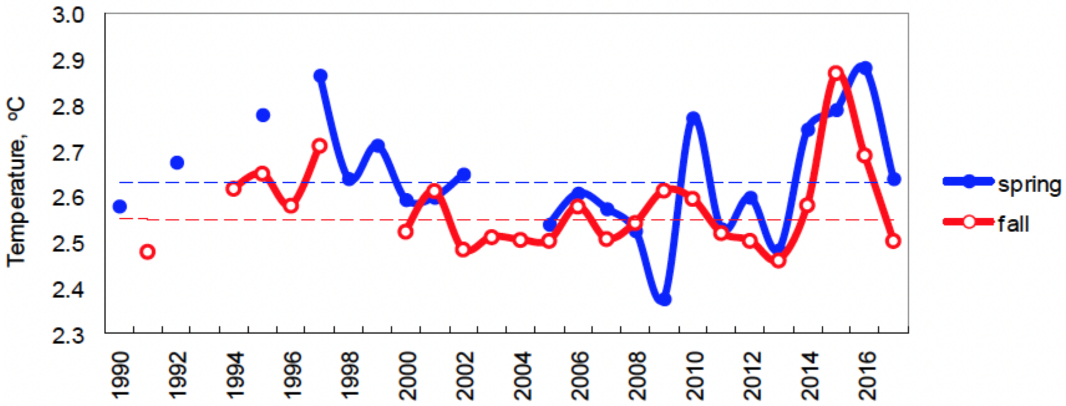
[Table R17-1] Modern trends of the water temperature and dissolved oxygen content changes in the intermediate layer of the Okhotsk Sea (by isopycnal surfaces) in the last 25 years, by areas

Area	26.8 σ_θ		27.0 σ_θ	
	Temperature, °C per decade	Oxygen, mL/L per decade	Temperature, °C per decade	Oxygen, mL/L per decade
45-50 N 145-150 E	+0.01	-0.14	+0.07	-0.14
Kuril Is.-50 N 150-155 E	+0.02	-0.08	+0.04	-0.07
50-55 N 150-155 E	+0.01	-0.13	+0.06	-0.10
50-55 N 145-150 E	+0.20	-0.14	+0.16	-0.12

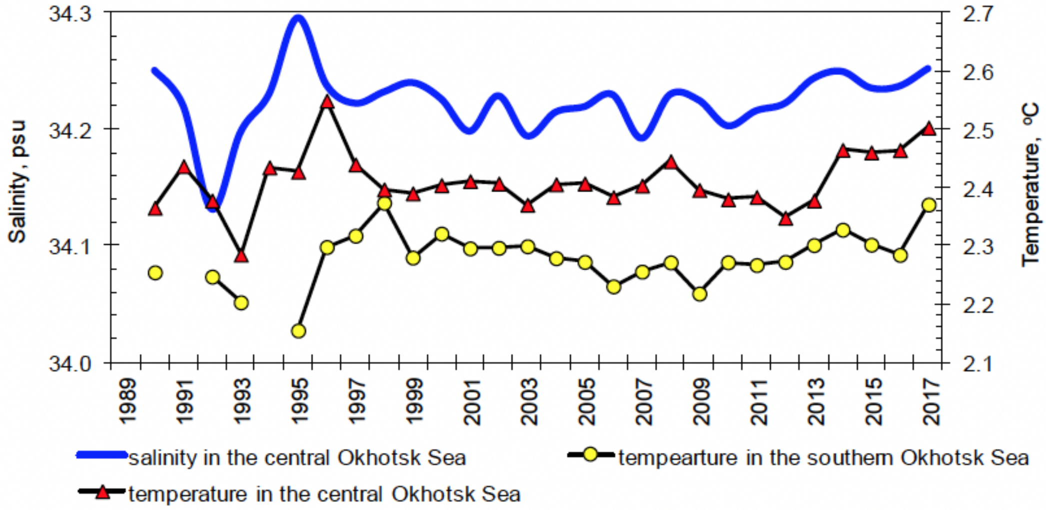
The main current of the Okhotsk Sea – the West-Kamchatka Current (that brings to the northern Okhotsk Sea the water of Pacific origin which entered through the northern Kuril Straits) has weakened in the last two decades, as could be seen by its geostrophic transport (Figure R17-12). Previously this relatively warm current became stronger in the years with cold winters, possibly compensating the outflow from the Okhotsk Sea through the southern Kuril Straits driven by strong winter monsoon. Fluctuations of the warm water transport by this current had no significant effect for the thermal conditions in the surface and subsurface layers in the northern Okhotsk Sea. On the other hand, the temperature in the core of the intermediate water and in its deeper portion had lowered in 2000-2015 and went up only in the last years that coincided in general with dynamics of the warm Pacific water flow (Figures R17-13, 14). However, this lowering had begun earlier than the West-Kamchatka Current weakening.



[Figure R17-12] Geostrophic transport of the West-Kamchatka Current in the layer 0-1000 m through the latitudinal section along 51-52° N, eastward from 150° E (1 Sv = 10^6 m^3/s)



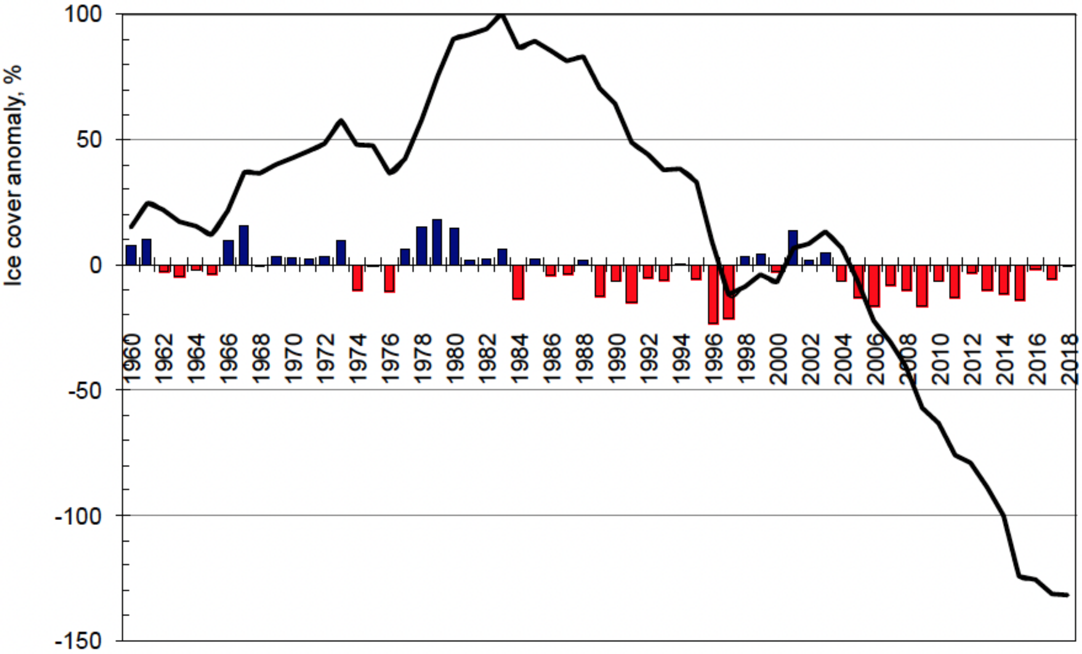
[Figure R17-13] Interannual variations of the maximum temperature in the intermediate layer at western Kamchatka (50-53° N, eastward from 150° E) in April-May and September-November and its mean values



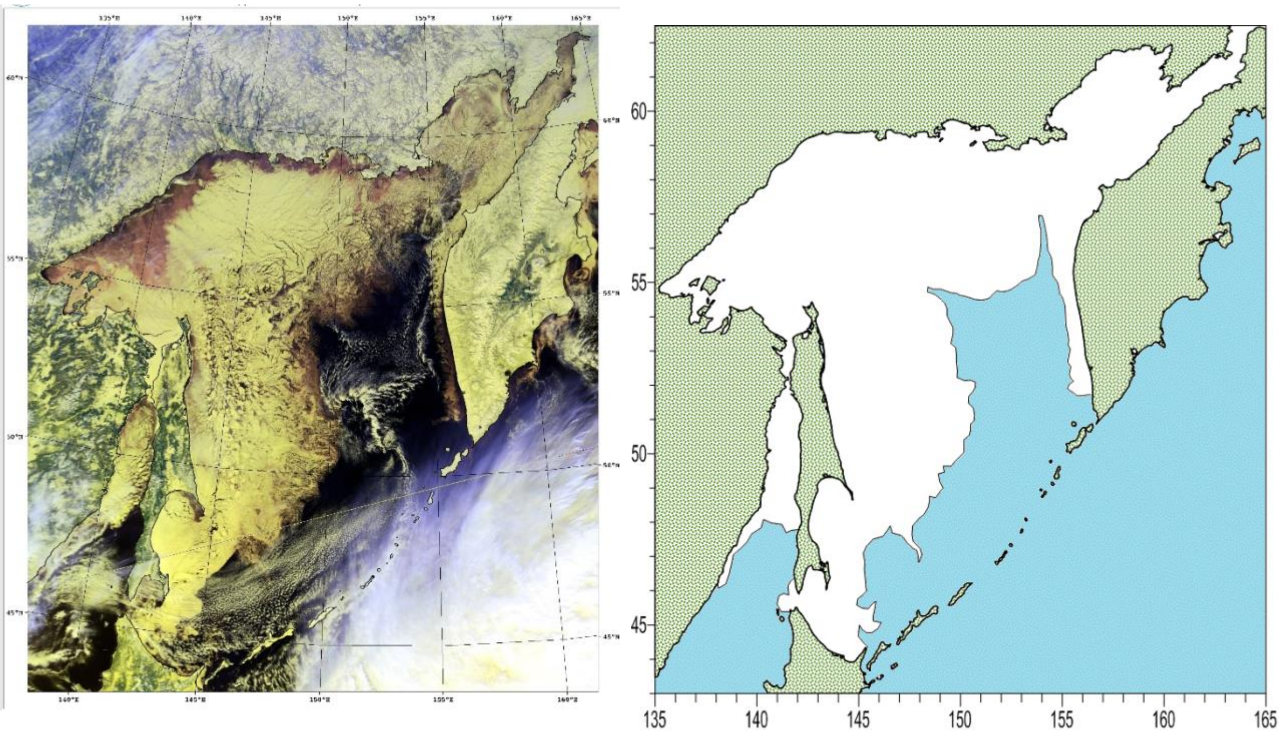
[Figure R17-14] Variations of annual temperature and salinity in the layer 800-1000 m in the deep-water basins in the central (47°30-51°00 N 145-154° E) and southern (44°00-47°30 N 144-152° E) Okhotsk Sea

4. 2. Sea Ice

Lower than normal ice cover was observed in all winters since 2004 (Fig. R17-15). Moreover, ice cover has been declining in the Okhotsk Sea since 1984, corresponding with a tendency of winter weather warming (Shatilina and Anzhina, 2006; Muktepavel and Shatilina, 2009). The minimal ice cover (14-17 % below the mean climatic value) was formed in the winters of 2009, 2011, and 2015, was caused by anomalous northern position of the tropospheric frontal zone and unusually northern tracks of its cyclones. Even in the coldest winter of 2011-2012, the ice cover did not reach is normal level with about 80 % of the Okhotsk Sea occupied by ice (Fig. R17-16).

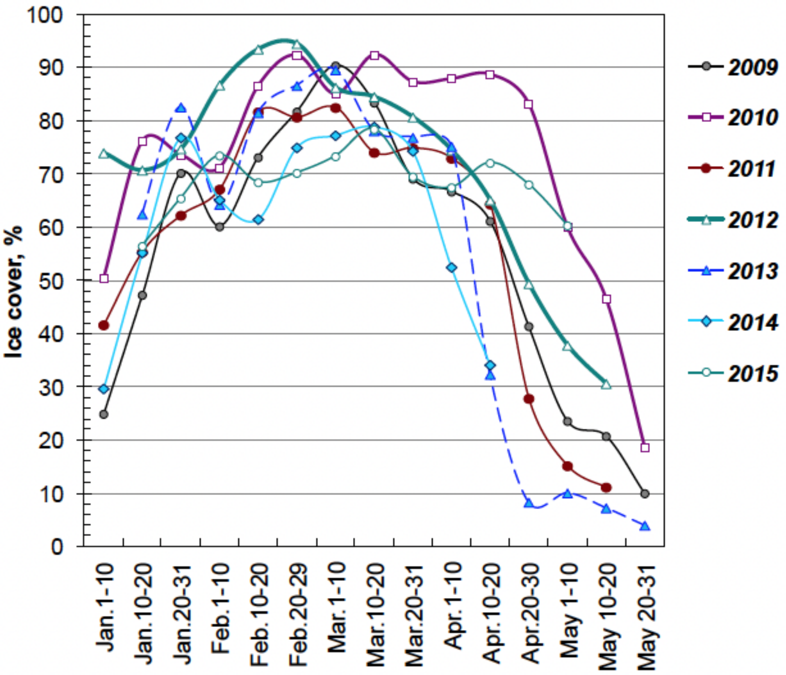


[Figure R17-15] Mean for January-May anomaly of the ice cover in the Okhotsk Sea, by years (bar), and its cumulative curve (black line).



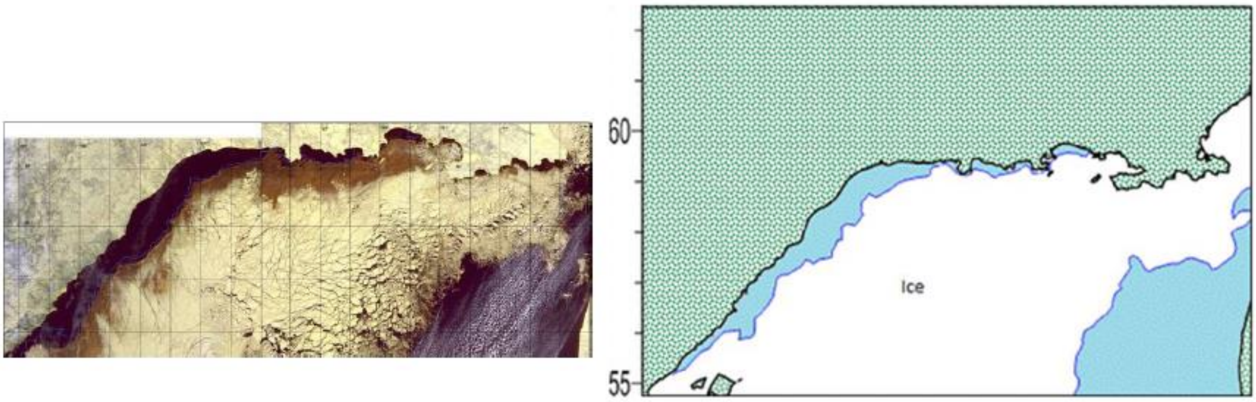
[Figure R17-16] The Okhotsk Sea ice cover image from the satellite NOAA-19 on March 11, 2012, and the ice edge decrypted from the images for March 10-11, 2012

For winter fisheries in the Okhotsk Sea, ice conditions in the area at West Kamchatka are crucially important. The ice cover in this area was lowered in the whole period 2009-2015, with its highest value in late February of 2012 (Figure R17-17). The winters of 2014 and 2015 were the least icy here as meridional tracks of cyclones passed to Kamchatka under the blocking effect of the strong Hawaiian High. The winters of 2011, 2013, and 2014 were distinguished by very early end of the heavy ice period – in late March.

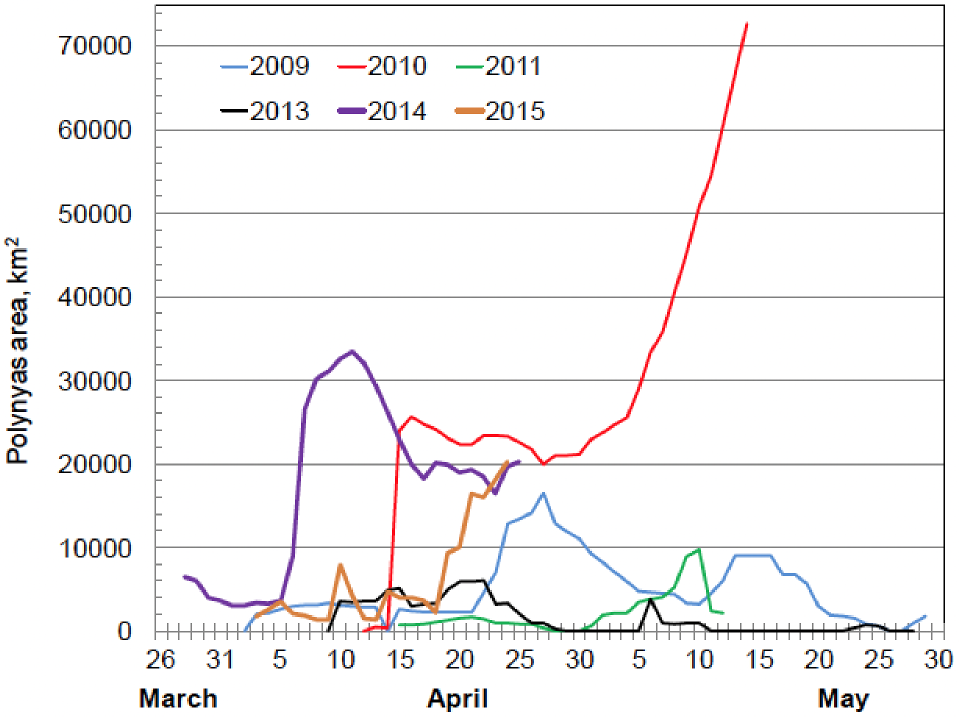


[Figure R17-17] Seasonal dynamics of the ice cover in the area at West Kamchatka (eastward from 153°30’ E, northward from 54°00’ N) for the 2009-2015.

Quasi-stationary polynyas along the northern and northwestern shores of the Okhotsk Sea caused by winter monsoon winds are crucially important for herring spawning – these ice-free water belts are necessary for earlier and successful spawning (Zavernin, 1972; Tyurnin, 1980; Muktepavel, 2006; Figure R17-18). Because of the weak winter monsoon in the 2009-2015, the polynyas formed relatively late – in late March – early April and were absent in 2012. However, after late forming they were relatively large and stable in 2010, 2014, and 2015 (Figure R17-19) – these years were quite favourable for the herring spawning, in spite of late terms.



[Figure R17-18] [FIGURE MISSING] The northwestern Okhotsk Sea ice cover image from the satellite AQUA on April 3, 2011(left), and the ice edge decrypted (right). Polynyas are visible along the northern and northwestern shores



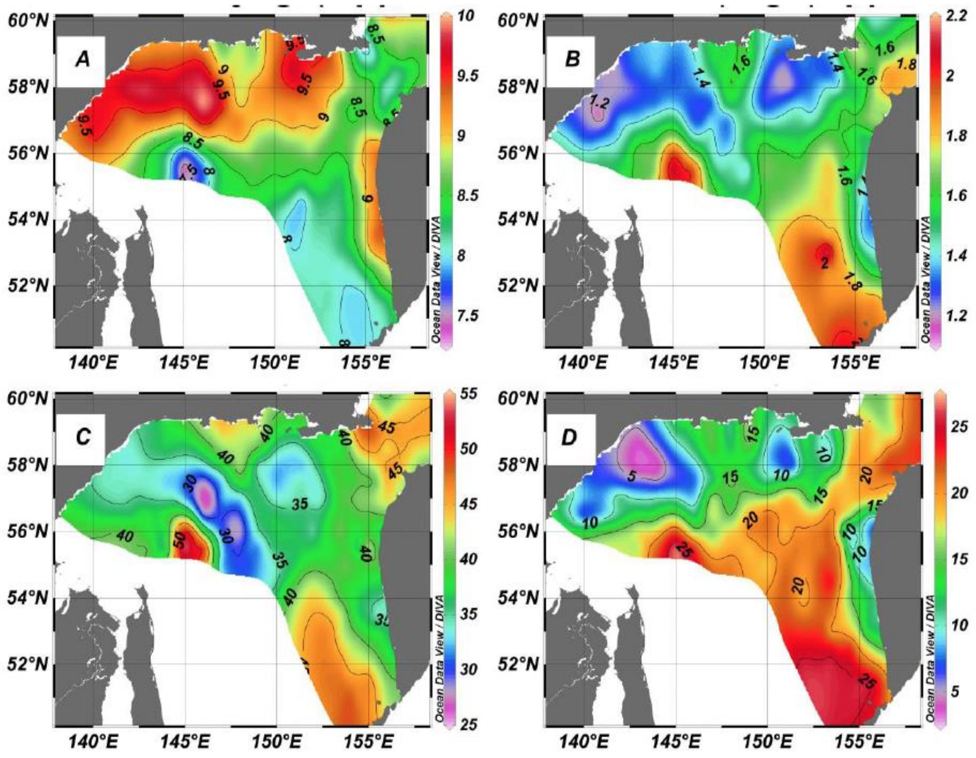
[Figure R17-19] Dynamics of the polynyas area at the northern shore of the Okhotsk Sea for the years 2009-2015. The polynyas were absent in 2012

5. Chemical Ocean

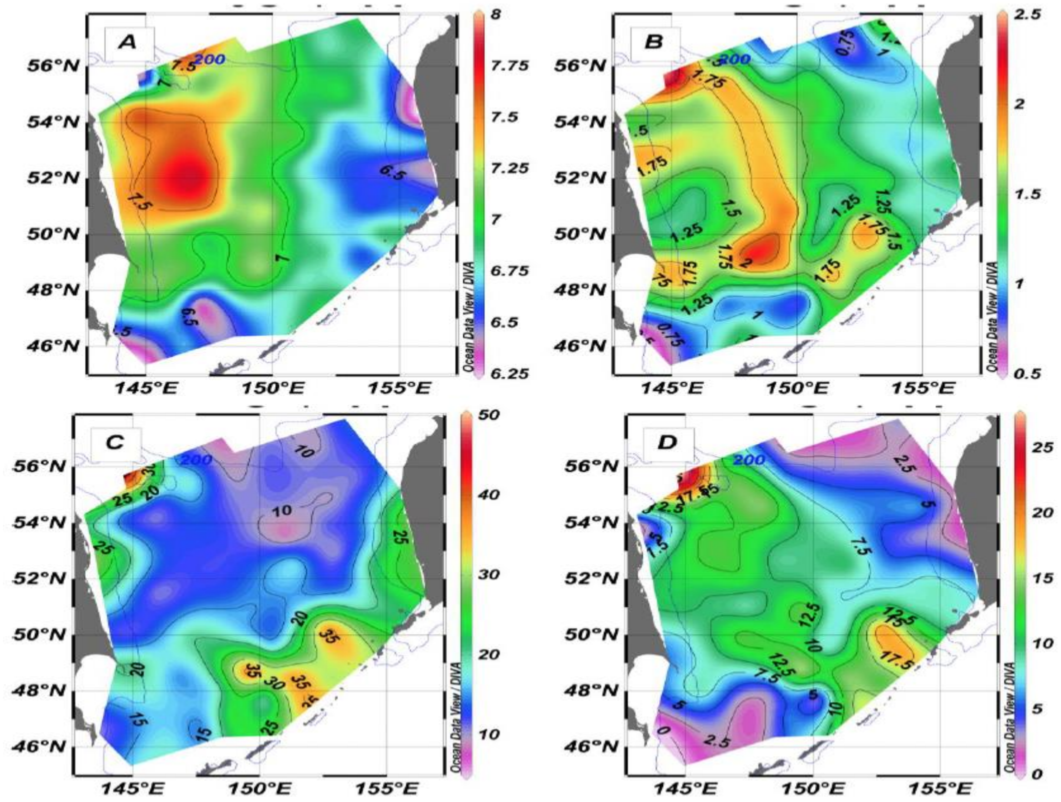
Contributors: Vladimir Matveev

The basic chemical parameters of the Okhotsk Sea waters are formed under influence of regional factors as the coastal and oceanic waters advection, convective and tidal mixing, and currents. Their variability, in particular the seasonal variability, is controlled by biogeochemical cycles which include the processes of the organic matter synthesis and decomposition that is accompanied by oxidation or recovery of biogenic elements (nitrate, phosphorus, and silicon) and release or consumption of dissolved oxygen. Photosynthesis occurs in the upper euphotic layer of the sea, mostly in spring when this layer has the necessary or nutrients. Decomposition is possible in any time and depth but is more active near the bottom where the organics concentration is the highest.

The period of the active photosynthesis is rather long in the Okhotsk Sea because of active processes of vertical mixing and very variable because of its vast area embracing different climatic zones. On average, light and nutrients condition are enough for photosynthesis there for 270 days of the year, and the process can continue all the year round in the waters at Kuril Islands with active tidal mixing. The maximal photosynthetic activity (or spring bloom) is observed in May-June, with exclusion of the areas at Hokkaido, southern Sakhalin and south-western Kamchatka where it happens in April, and at eastern and northern Sakhalin where it continues till July. In the process of the spring bloom the nutrients (salts of nitrogen, phosphorus and silicon) are consumed, and oxygen is produced in the upper layer (Figure R17- 20). It stops because of exhaustion of nutrients, and their low concentrations are observed in summer, when the oxygen content becomes lower, too, because of water warming. Autumn mixing stimulates nutrient upward flux and photosynthesis starts again, but less active in conditions of weak stratification and deeper – rather at the depth of pycnocline (20-50 m) than at the sea surface (Figure R17-21). In winter both nutrients and dissolved oxygen in the upper layer have the highest concentrations in their annual cycles.

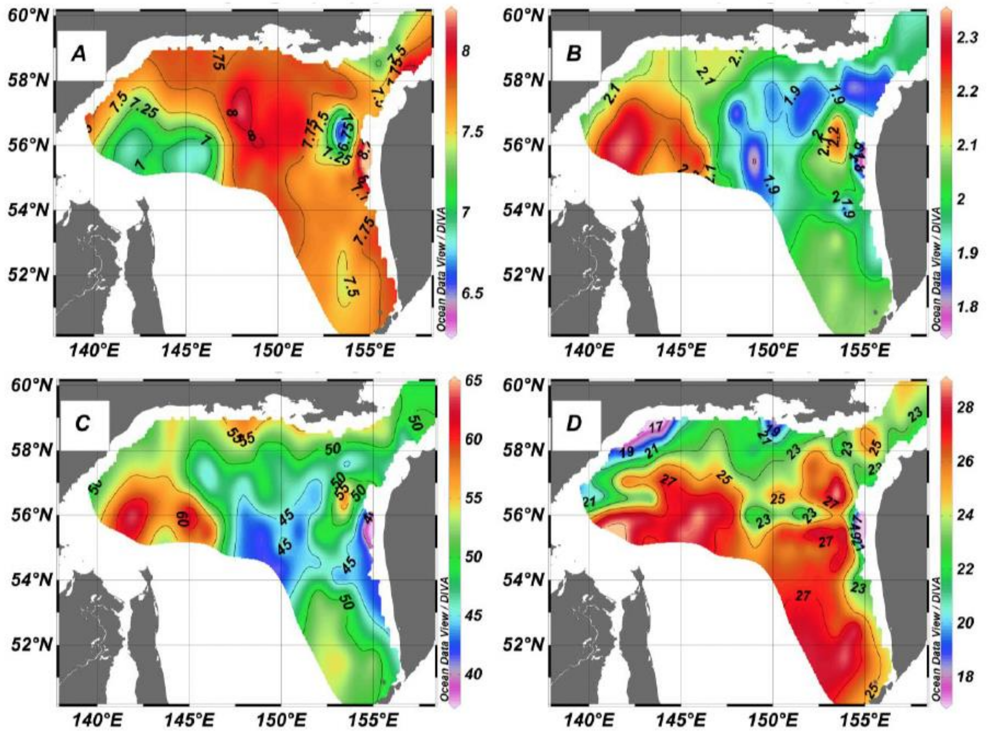


[Figure R17-20] Spatial distribution of dissolved oxygen (A, mL/L), phosphorus (B, μM/L), silicon (C, μM/L), and nitrate (D, μM/L) at the 10 m depth in April-May (averaged for 2008-2016).

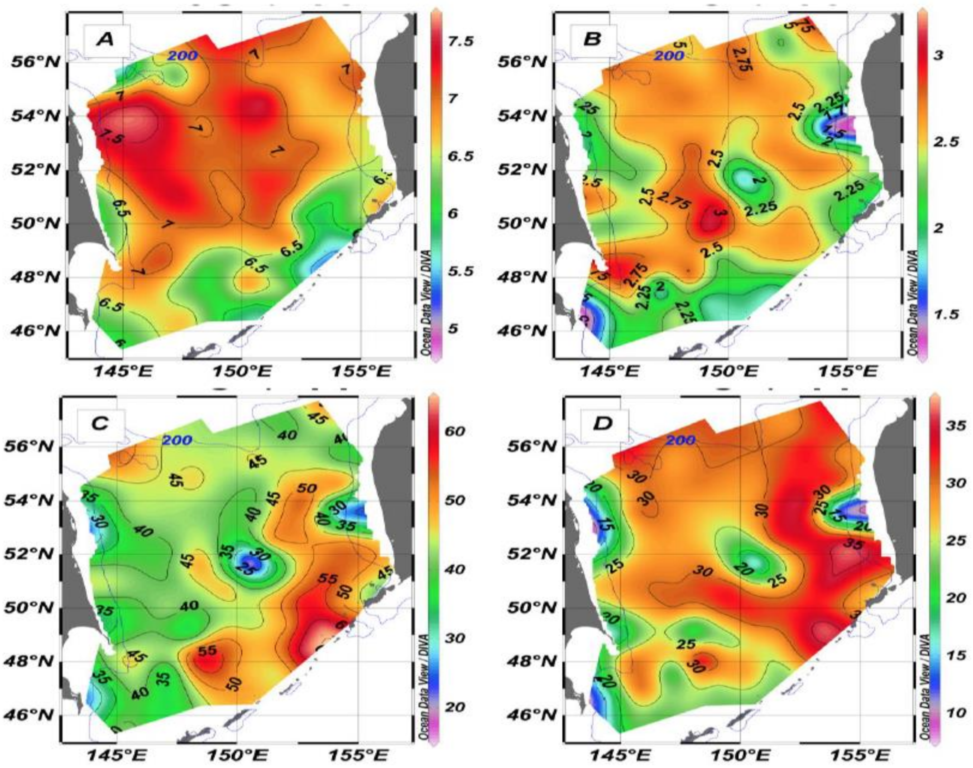


[Figure R17-21] Spatial distribution of dissolved oxygen (A, mL/L), phosphorus (B, μM/L), silicon (C, μM/L), and nitrate (D, μM/L) at the 10 m depth in October-November of 2017

Below the upper layer, dissolved oxygen content is significantly lower, nutrient concentrations are significantly higher and their seasonal variations are weaker. The spatial variability is determined mostly by water dynamics. For example, in the subsurface layer the oxygen content is lowered, and the nutrient concentrations are heightened in the areas of upwellings, as Kashevarov Bank (Figure R17-22). On the other hand, the nutrients concentrations are low in the area of advection of the transformed subtropic water with the Soya Current (Figure R17-23).

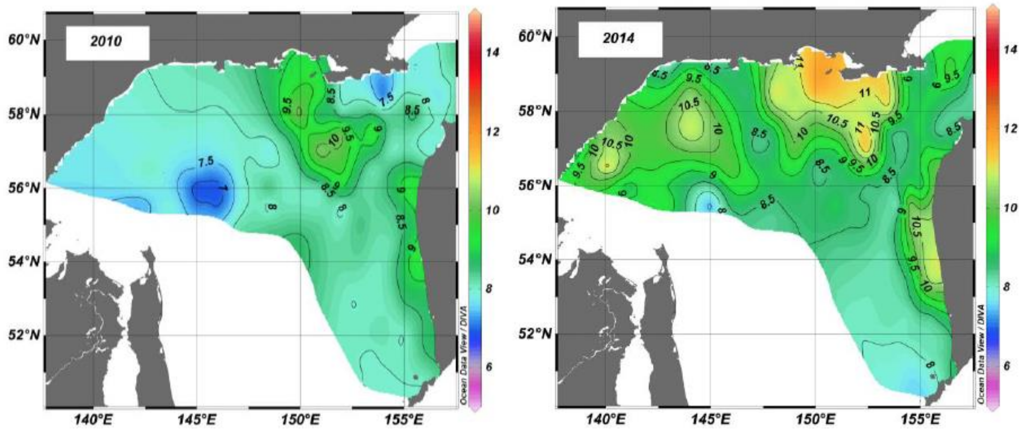


[Figure R17-22] Spatial distribution of dissolved oxygen (A, mL/L), phosphorus (B, μM/L), silicon (C, μM/L), and nitrate (D, μM/L) at the 100 m depth in April-May (averaged for 2008-2016)

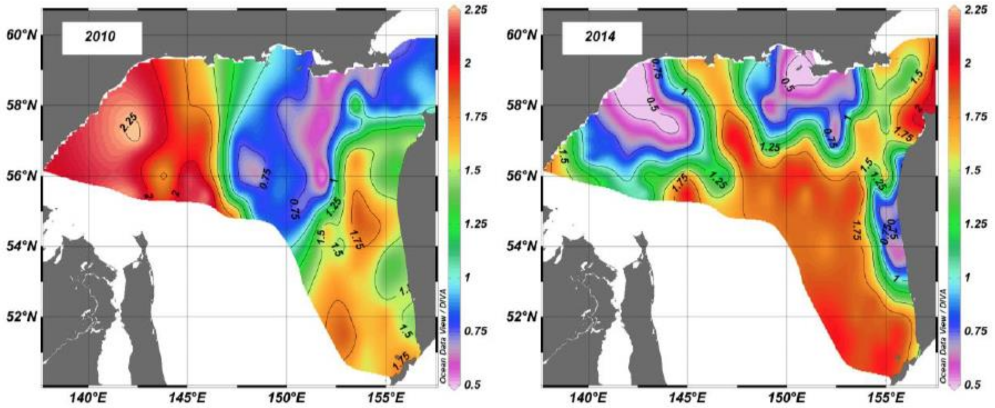


[Figure R17-23] Spatial distribution of dissolved oxygen (A, mL/L), phosphorus (B, μM/L), silicon (C, μM/L), and nitrate (D, μM/L) at the 100 m depth in October-November of 2017

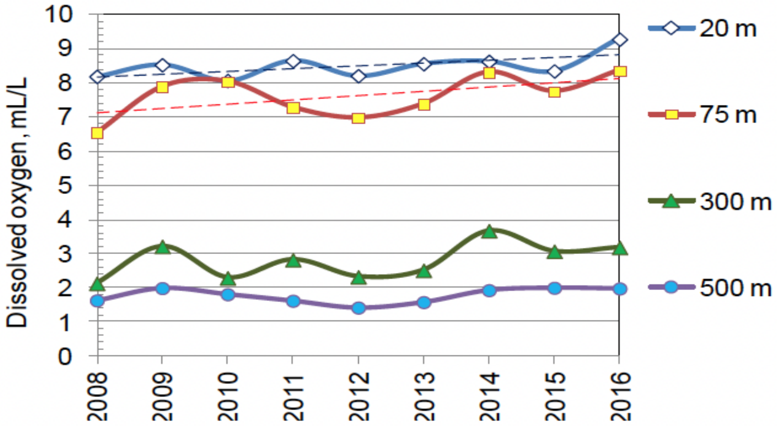
Interannual variations of the biogeochemical processes in the upper layer depend mainly on thermal regime that determines the timing, strength and length of spring and fall blooms. In relatively warm conditions, the sea surface heats fast, and spring bloom starts earlier, after stable stratification forms. This results in more oxygen accumulating in the upper layer compared with the same summer date in relatively cold years (Figure R17-24). In opposite, the nutrient concentrations are higher in conditions of a relatively cold summer (Figure R17-25). A tendency to higher oxygenation of the upper layer in summer appears recently because of warming in the Okhotsk Sea (Figure R17-26). Naturally, it is absent in the deeper layers where the oxygen content is controlled by ventilation, not photosynthesis. On the climatic scale, the oxygen content in the intermediate layer is decreasing because of the weakening of the ventilation process in the Okhotsk Sea in conditions of winter warming, but in recent years it is almost stable (Figure R17-26).



[Figure R17-24] Dissolved oxygen content at the depth 10 m in April-May of relatively cold (2010) and warm (2014) years, mL/L.



[Figure R17-25] Inorganic phosphorus concentration at the depth 10 m in April-May of relatively cold (2010) and warm (2014) years, μM/L



[Figure R17-26] Interannual change of dissolved oxygen content at selected depths in the northern Okhotsk Sea (northward from 50°N) in April-May

6. Chlorophyll

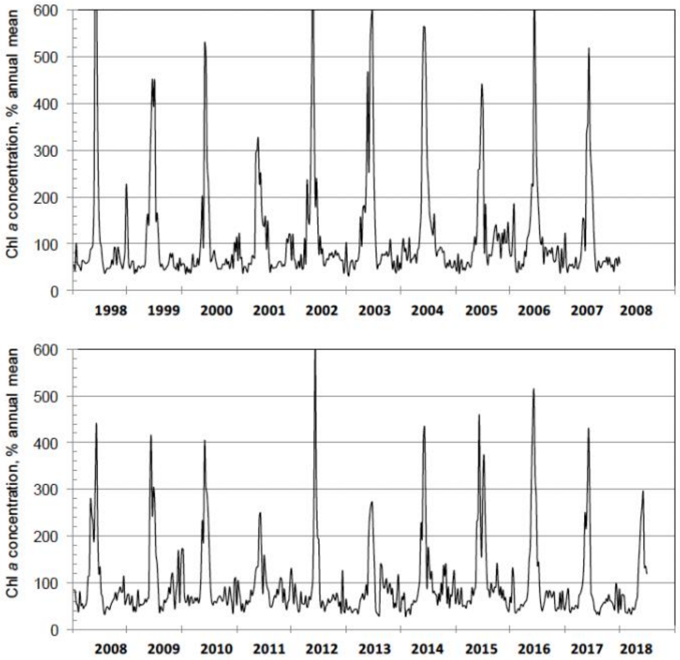
Contributors: Yury Zuenko

Phytoplankton abundance at the sea surface can be characterized by the sea color scanned from satellites that depends on concentration of chlorophyll *a* – a green photosynthesizing pigment of phytoplankton. This dependence is rather complicated and is to be determined separately for each region, in particular coastal areas, but some standard algorithms are used by world centers of satellite information. These standard algorithms could make mistakes for certain areas or seasons but are suitable for large-scale studies in the deep-water sea. Accordingly, dynamics of the mean concentration of chlorophyll *a* for a large area in the central deep-water Okhotsk Sea is considered. It is calculated from the data of composite satellite images of color scanners SeaWiFS and MODIS for 1-degree squares and 8-days periods within the area 48-55° N 147-154° E, using the standard algorithm OCEANCOLOUR_GLO_CHL_L4_REP_OBSERVATIONS_009_082 (http://marine.copernicus.eu/services-portfolio/ access-to-products/). The data and algorithm are provided by Copernicus Marine Environment Monitoring Service (EU). The annual mean concentration of chlorophyll *a* for this area for the last decade (2008-2017) is estimated as 0.6 mg/m^3. Seasonal and interannual variations of chlorophyll *a* concentration are analyzed relative to this mean value.

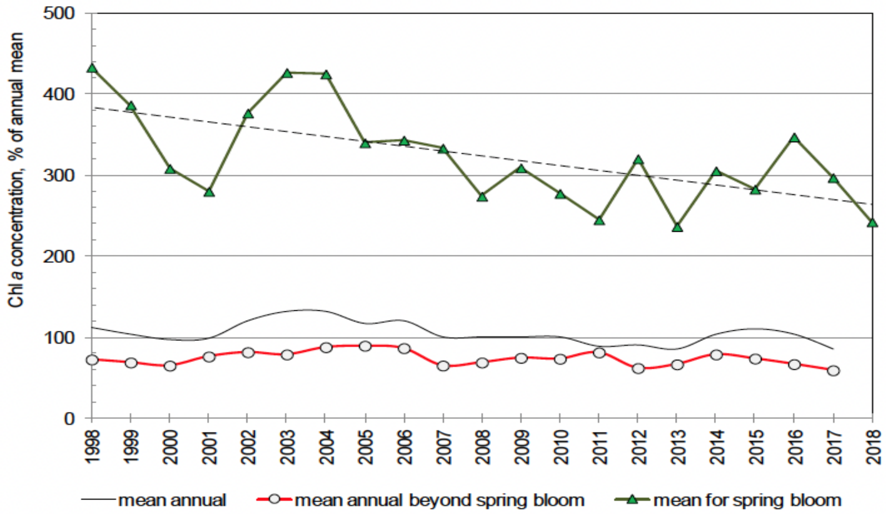
The highest concentrations of chlorophyll *a* at the Okhotsk Sea surface are observed in spring. They are so high that change of the sea surface color is easy visible – this phenomenon is known as “phytoplankton blooming”. Usually the “wave” of blooming starts in late March at southern Sakhalin (Aniva Bay, Patience Bay) and quickly runs around the sea along its western and northern coasts, where the blooming appears firstly at the river mouths. It occupies the whole shelf zone in May and spreads to the central deep-water part of the sea in late May – early June. The blooming with concentration of chlorophyll *a* > 1 mg/m^3 lasts 20-50 days in the deep waters, the mean concentration in this period exceeds the mean annual value by 2-4 times.

The mean annual concentration of chlorophyll *a* in the central Okhotsk Sea does not have any significant trend, with some year-to-year fluctuations (Figures R17-27, 28). Terms of the spring bloom are also rather stable. This stability on the background of changing physical and chemical conditions could be explained by their controversial influence on phytoplankton production that is limited by nutrients and light ability. Recently the nutrients supply is worsening in the Okhotsk Sea because of the convection weakening and stratification strengthening, but the latter process provides better light conditions in the surface layer. However, a tendency to decreasing of the spring bloom intensity is revealed for the last decades: the concentration of chlorophyll *a* in the blooming period became considerably lower in 2000s and remained relatively low in 2010s (Figure R17- 28).

Life cycles of mass zooplankton species are adopted to strong seasonal variation of phytoplankton production – they use the spring bloom period for spawning. So, some negative consequences of considerable weakening of the spring bloom for zooplankton populations could be expected.



[Figure R17-27] Variations of chlorophyll concentration at the Okhotsk Sea surface in its central deep-water area (48-55º N, 147-154º E) averaged by 8-day intervals (satellite data)

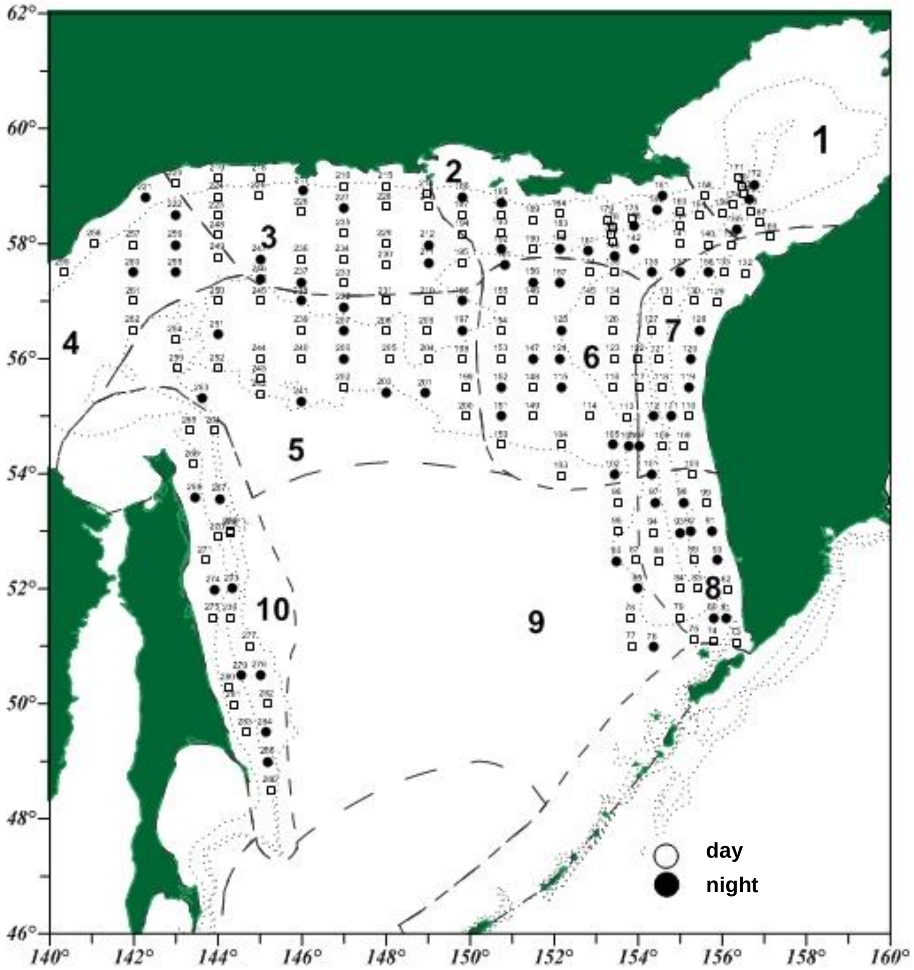


[Figure R17-28] Interannual changes of the annual mean, average for the spring bloom period, and average for the rest of year concentrations of chlorophyll at the sea surface in the area 48-55º N, 147-154º E (satellite data). Linear trend for the spring concentration is shown by dotted line.

7. Zooplankton

Contributors: Elena Dulepova

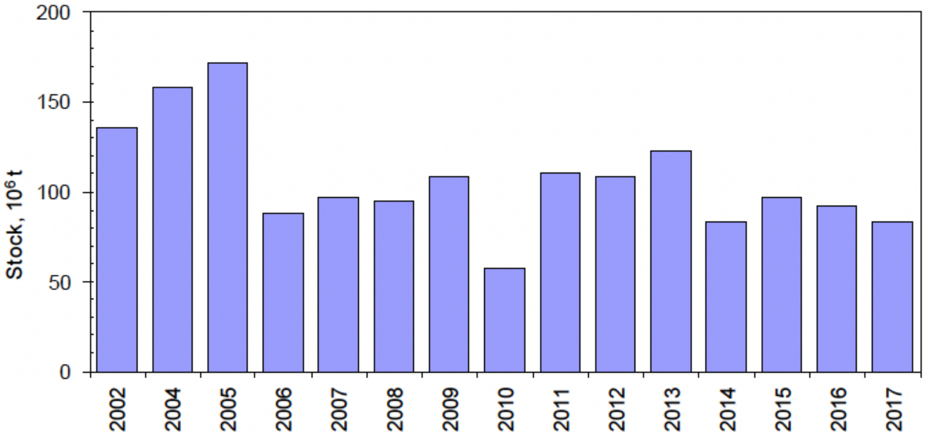
Regular monitoring of the Okhotsk Sea zooplankton has continued since 1984. The results are summarized in the series of scientific papers and monographs (Shuntov, 2010; 2016; Volkov, 2013a,b; Dulepova, 2013; Macrofauna… 2012; Shuntov and Volvenko, 2017; Gorbatenko, 2016a,b). The large-scale surveys in the Okhotsk Sea are usually conducted in spring and fall seasons (Figure R17-29).



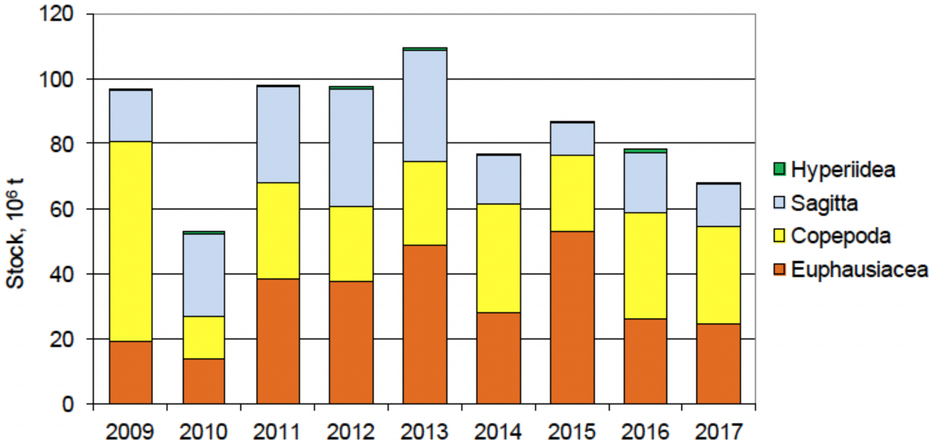
[Figure R17-29] Scheme of plankton tows in the survey conducted in the northern Okhotsk Sea in spring 2017. Biostatistical areas 1-10 are shown.

Large-sized animals with body length >3.2 mm prevail among the Okhotsk Sea zooplankton by biomass, in particular euphausiids (on average 37% of total biomass), copepods and arrowworms. The five most abundant species comprising 76-85% of the total biomass in the coastal waters are *Thysanoessa rashii, Metridia okhotensis*, *Sagitta elegans, Pseudocalanus minutus*, and *Calanus glacialis*, over the continental slope: *Pseudocalanus minutus, Thysanoessa rashii, Sagitta elegans, Neocalanus plumchrus,* and *Thysanoessa longipes,* and in the deep-water sea: *Sagitta elegans, Neocalanus plumchrus, Thysanoessa longipes, Themisto pacifica,* and *Metridia okhotensis.*

The zooplankton stock in the Okhotsk Sea has declined since the early 2000s (Figure R17-30). However, variations of the biomass of certain taxonomic groups in certain areas are observed with huge (2-3 times) year-to-year changes. The abundance of species is influenced by different factors, such as environmental changes and cyclic processes within populations (Figure R17-31; Volvenko, 2016). In general, when abundance of some species is decreasing, abundance of others is increasing (Shuntov et al., 2007).



[Figure R17-30] Dynamics of total zooplankton stock in the northern Okhotsk Sea (northward from 54° N) in the spring (April-May) of 2002-2017.



[Figure R17-31] Stock dynamics for the main taxonomic groups of zooplankton in the northern Okhotsk Sea in the spring (April-May) of 2009-2017

The zooplankton biomass in the Okhotsk Sea is rather high all throughout the year, although it is higher in spring-summer than in fall-winter. The long-term averaged estimates are 152 g/m^{2,} in spring-summer and 119 g/m^2 in autumn. The highest abundance of zooplankton is observed in its northwestern part, mostly because of high abundance of copepods and arrowworms in this area, whereas euphausiids and amphipods are distributed more evenly. In the early 2000s, mean zooplankton biomass in the northeastern Okhotsk Sea was estimated, by seasons, as 662 mg/m^3 in winter, 1010 mg/m^3 in spring, 1004 mg/m^3 in summer, and 955 mg/m^3 in autumn (Shuntov, 2016).

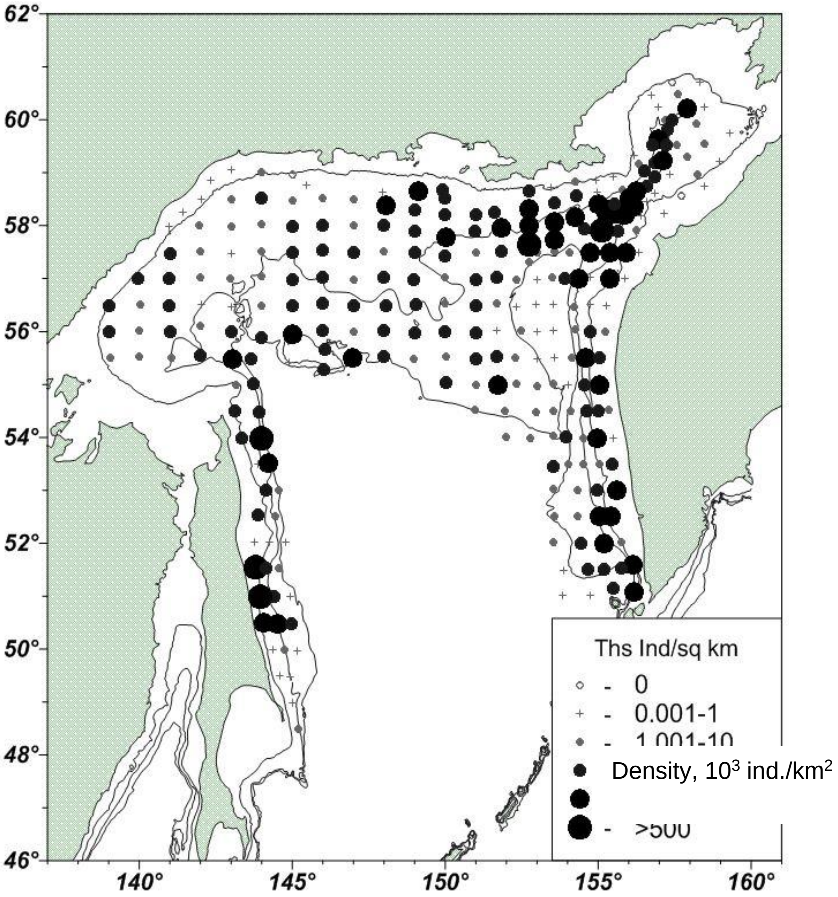
Recent changes in the zooplankton community of the Okhotsk Sea are mainly the results of copepod and euphausiid dynamics. The total biomass of macroplankton decreases in the spring of recent years (2016-2017), but the biomass of its large-sized fraction (>3.2 mm) has increased, presumably because of earlier spawning of the large-sized species in conditions of heightened water temperature.

8. Fishes and Invertebrates

Contributors: Eugene Ovsiannikov, Sergey Loboda, Nadezhda Aseeva, Alexander Zolotov, Anna Dubinina, Valery Koblikov, Alexander Lysenko

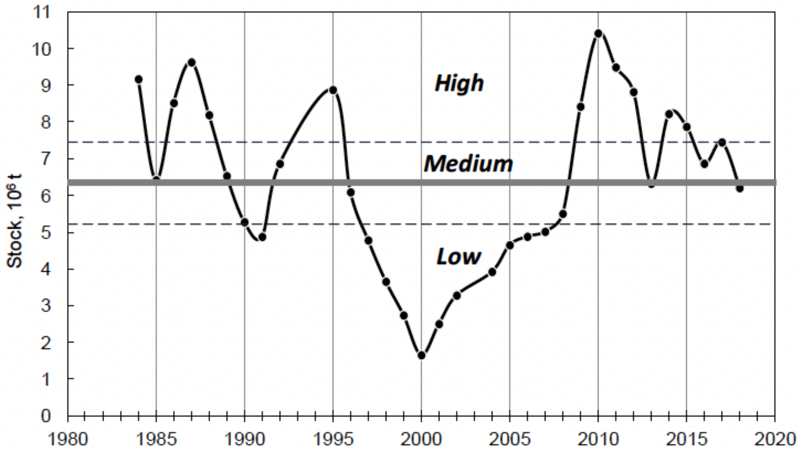
8. 1 Walleye Pollock

Walleye pollock is the most numerous fish species in the Okhotsk Sea and the most important species in the Russian fishery. It dwells mostly in its northern part, where 95-97 % of total annual catch of this species within the sea is landed (Figure R17-32).



[Figure R17-32] Walleye pollock distribution density in the northern Okhotsk Sea, by results of the midwater trawl survey on April 11 – May 30, 2014

However, the pollock stock has great fluctuations caused by variations in the strength of year-classes. The spawning stock increased in the early 1990s, up to $8.9 \cdot 10^6$ t in 1995, based on strong year-classes born in 1988-1989 (Avdeev et al., 2001). Later the stock decreased, with the minimal level of $1.7 \cdot 10^6$ t in 2000, because of combination of several weak year-classes in 1991-1993 and overfishing. New strong year-classes appearing in 1995 (in the eastern part of the sea) and 1997 (in the northern and western parts) weren't enough to turn the dynamics but had stabilized the stock at a relatively low level (Avdeev, Ovsiannikov, 2005). Generally, the 1990s were characterized by warm conditions in the Okhotsk Sea, with the highest temperature in 1997, but the late 1990s years and the early 2000s were distinguished by anomalous cooling of waters on the northern and western shelves. Pollock recruits hatched in 1997 in the northwestern Okhotsk Sea supported the stock at West Kamchatka and it started to grow again in 2002. The next strong year-classes of 2000 and 2002 appeared in the eastern Okhotsk Sea with the relatively warm conditions due to the inflow of the Pacific waters. These classes provided growth of the stock that had increased from $3.5 \cdot 10^6$ t in 2004 to $4.5 \cdot 10^6$ t in 2007. The warming of the Okhotsk Sea waters that started in 2002 and continues till present was favorable for the pollock reproduction, and strong year-classes appeared in its northwestern part in 2004 and 2005 that promoted the further growth up to $10.8 \cdot 10^6$ t in 2010 (Ovsiannikov et al., 2013). Then, despite apparently favorable conditions, several weak year-classes appeared in the 2007-2010, and the stock has declined since 2011. This decline was not so disastrous as the previous one, and after the appearance of new strong year-classes in 2014 and 2015 the spawning stock stabilized at a medium level (Figure R17-33).

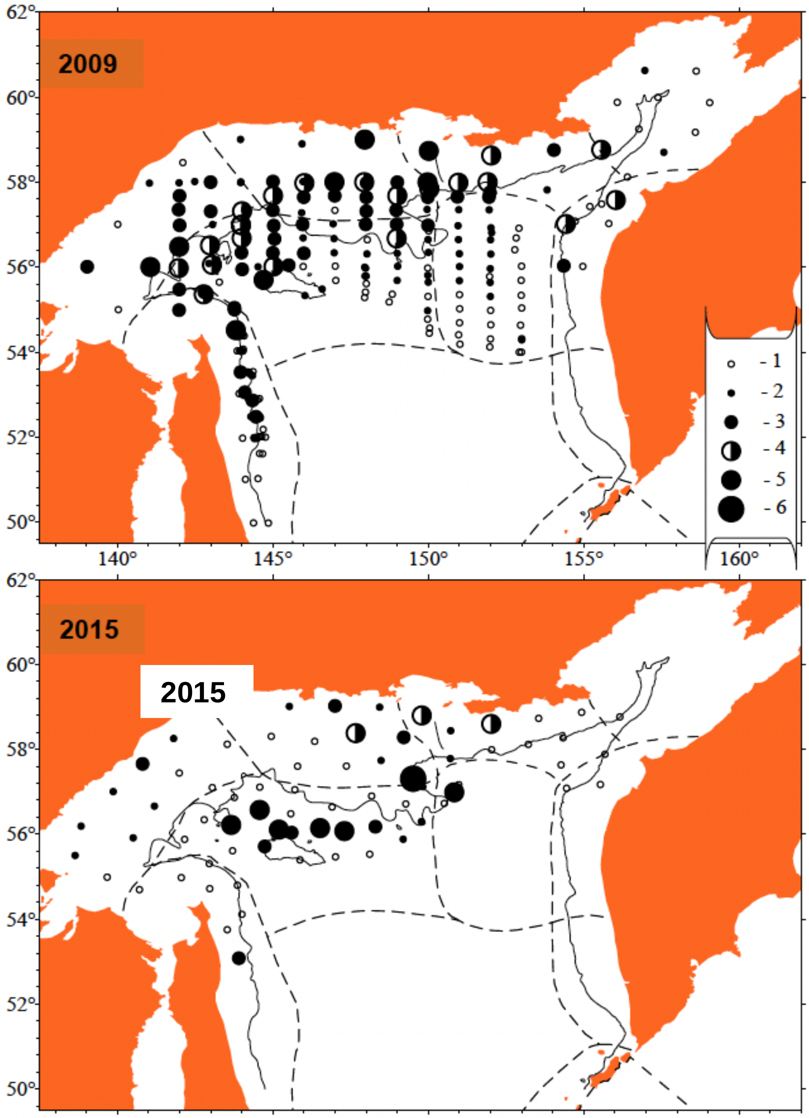


[Figure R17-33] Dynamics of walleye pollock spawning stock in the northern Okhotsk Sea relative to the mean level (thick grey line), from the results of spring trawl surveys. The 0.99 confidence intervals for the mean level estimation is shown by dashed lines.

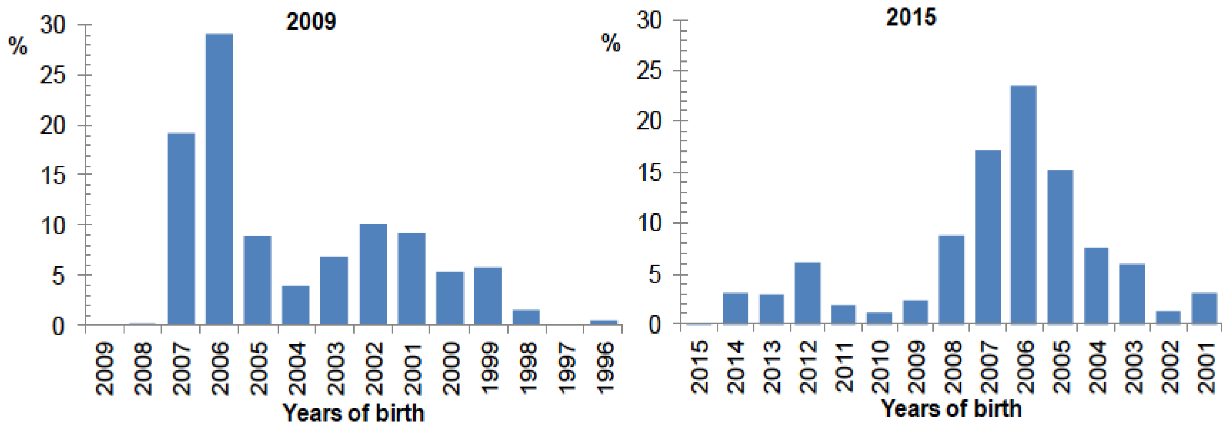
8. 2. Pacific herring

Pacific herring dwell [good to mention the full species name here] mainly on the northern shelf of the Okhotsk Sea from the coast line to the 300-350 m isobaths (Figure R17-34). Two big populations of herring are distinguished in the Okhotsk Sea: the Okhotsk population in its northwestern part and the Gizhiga-Kamchatka population in its northeastern part (Naumenko, 2001). Each of these populations has two partially isolated groupings (Melnikov and Loboda, 2004). In the spawning season (spring), adults of the former population distribute on spawning grounds along northwestern shores and of the latter one – in the northeastern area northward from 54° N, with the densest aggregations in the Shelikhov Bay. They concentrate again in autumn in feeding aggregations at St. Iona Island and Kashevarov Bank and southward from the Tauyskaya Guba Bay, respectively.

In the last two decades the total stock of Pacific herring in the Okhotsk Sea is rather stable and high and is estimated on average in $1.6 \cdot 10^6$ t, fluctuating between $1.94 \cdot 10^6$ t (2009) and $1.44 \cdot 10^6$ t (2011). However, this level is supported by more and more old fish of several relatively strong year-classes of 2005-2008, while the recruitment is not numerous. The portion of young herring (below 4 years) in the catches was about 50 % in 2009 but only 14 % in 2015 (Figure R17-35).



[Figure R17-34] Distribution of Pacific herring in fall seasons of 2009 (upper panel) and 2015: (lower panel): 1 – no herring; 2 - < 0.1 t/km^2; 3 – 0.1-1 t/km^2; 4 - 1-10 t/km^2; 5 - 10-100 t/km^2; 6 - >100 t/km^2 .

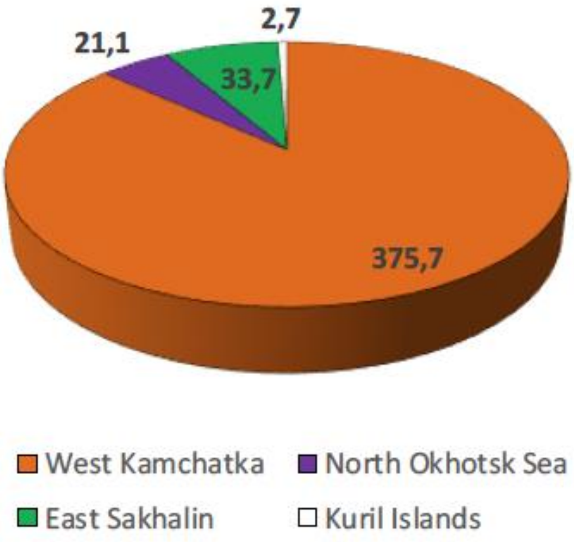


[Figure R17-35] Age composition of Pacific herring in the catches in the Okhotsk Sea in fall seasons of 2009 and 2015.

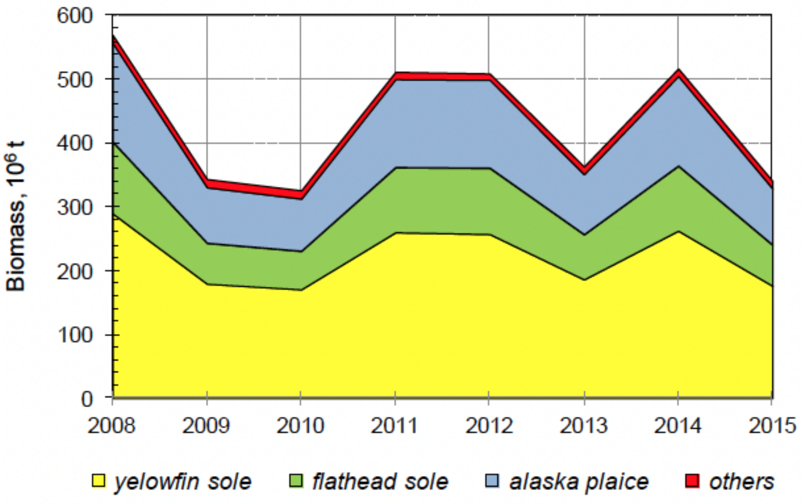
8. 3. Flounders

Flounders dominate in the bottom fish community in the Okhotsk Sea. Their mean portion in the total biomass of bottom fish (excluding pollock) is estimated as 58 % on the Kamchatka shelf, 63 % on the northern Okhotsk Sea shelf, and 35 % on the Sakhalin shelf (Borets, 1997; Zolotov et al., 2013). They have considerable species diversity – 18-20 species over the whole Okhotsk Sea, excluding halibuts. However, only four species are abundant: yellowfin sole (*Limanda aspera* and *Limanda sakhalinensis*) – on average 51.3 % of the total commercial stock of flounders in the 2008-2015, Alaska plaice (*Pleuronectes quadrituberculatus*) – 26.5 %, and flathead sole (*Hippoglossoides sp.*) – 19.4 %. These species prevail in the bottom trawl catches everywhere, with exclusion of the shelf of Hokkaido and south Kuril Islands where more diverse species composition is conditioned by the warm Soya Current invasion.

Total biomass of flounders in the Okhotsk Sea was estimated in the range 0.57-1.23$\cdot 10^6$ t in the period 2008-2015, with an average of 0.86$\cdot 10^6$ t. The dynamics are determined mostly by changes of in the abundance of *Limanda sakhalinensis,* a rather small-sized fish considered to be non-commercial. Commercial species are concentrated mostly on the shelf of West Kamchatka; this area provided about 87 % of the flounders commercial stock in the 2008-2015 (Figure R17-36). Other fishing grounds of flounders are located on the northern Okhotsk Sea shelf and in the Patience Bay (at Sakhalin). The commercial stock was rather stable in the period 2008-2015 (340-570$\cdot 10^3$ t, on average 433$\cdot 10^3$ t). The small fluctuations were related with changes of yellowfin sole biomass (Figure R17-37).



[Figure R17-36] Spatial sharing of the flounders commercial stock in the Okhotsk Sea. Values of the summary commercial stock averaged for 2008-2015 are shown, 10^3 t

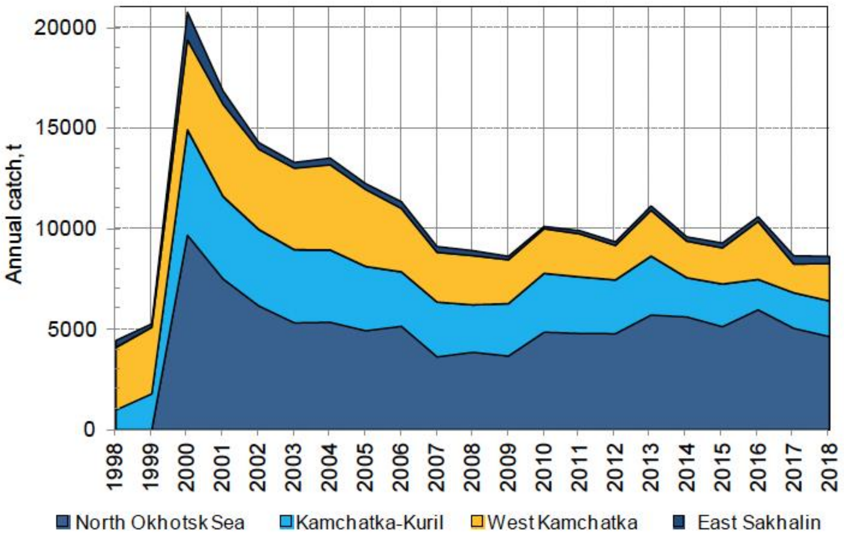


[Figure R17-37] Dynamics of commercial stock of flounders in the Okhotsk Sea, by species

8.4. Greenland halibut

The Greenland halibut *Reinhardtius hippoglossoides* is distributed over the whole Okhotsk Sea and dwells in the bottom layer at shelf and continental slope at depths from 50-75 to 1500-2000 m. The main spawning grounds are at southern Kamchatka (southward from 52°N) at a depth of 380-900 m. The densest concentrations also form in this area. The biggest halibut do not leave the eastern Okhotsk Sea eastward from 150°E, others migrate there for spawning annually. However, the main portion of the halibut stock, including both juveniles and adults, occupies the northern part of the Okhotsk Sea. The total stock of Greenland halibut in the Okhotsk Sea was estimated by the trawl survey in 2010 as $322.5 \cdot 10^3$ t, including $199.9 \cdot 10^3$ t of adult fish (spawning stock). The mean size (length) of Greenland halibut was 64.6 cm; this parameter has decreased recently and is considered to be a sign of active reproduction of the population.

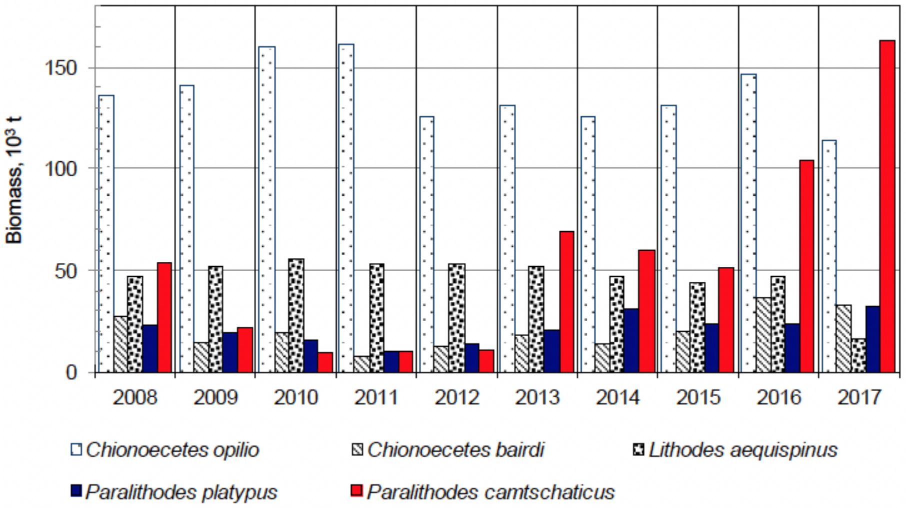
About 10,000 t of Greenland halibut are landed in the Okhotsk Sea annually, mostly in the northern half of the Sea (Figure R17-38), with a tendency to growth after the late 2000s definitely corresponded to a positive dynamics of its stock, mostly because of the biomass increasing within the North Okhotsk Sea fishery district. The main fishing gear for the halibut fishery is a longline with CPUE of 4-9 t per vessel-day, that also have a tendency to increasing. On the contrary, the bottom net fishery has declined recently because of catch grazing by orcas. The longline fishery is the most successful in summer.



[Figure R17-38] Annual catch of Greenland halibut in the Okhotsk Sea, by fishery districts

8. 5. Crabs

Crabs are the most valuable commercial invertebrates in the Okhotsk Sea, with the main fishing grounds located at West Kamchatka and on the northern shelf. Among commercial crabs, the most abundant species in the last decade were (in decreasing order of commercial stock size): *Chionoecetes opilio* (snow crab), *Lithodes aequispinus*, *Paralithodes camtschaticus* (red king crab), *P. platypus*, and *Chionoecetes bairdi* (Figure R17-39). Snow crab dwells mostly on the northern Okhotsk Sea shelf. Red king crab with the main aggregations on the shelf of West Kamchatka was historically the most abundant crab species in the Okhotsk Sea, but its stock was overfished. Catch of this species was banned in the period 2009-2012. This had a positive effect on the population, and since 2017 this species dominated again.



[Figure R17-39] Dynamics of commercial stock for the main crab species in the Okhotsk Sea, 10^3 t

9. Benthos

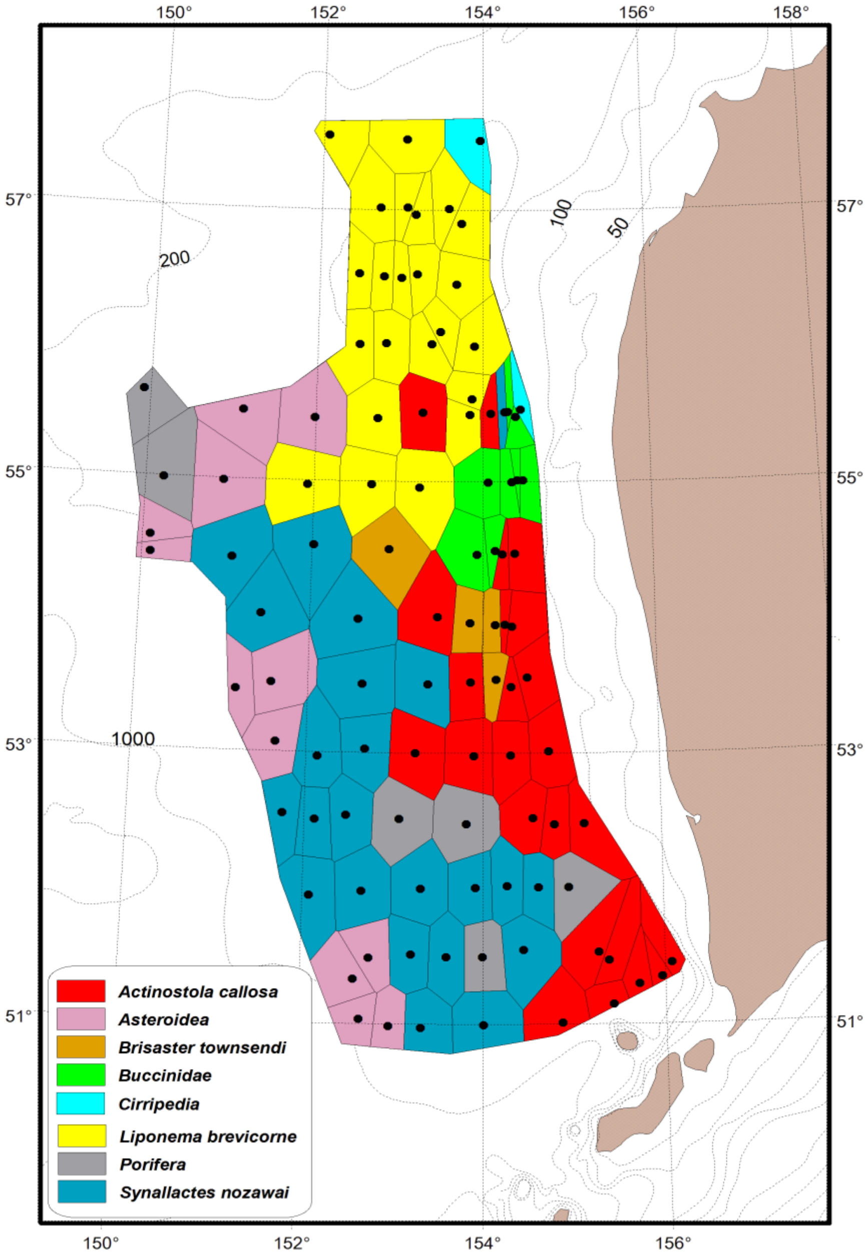
Contributors: Victor Nadtochii, Nickolay Kolpakov

Macrozoobenthos composition, abundance, and distribution on the shelf and continental slope of West Kamchatka (depth 150-980 m) were surveyed by bottom trawl in September-October, 2013. In total, 35 species of macrobethos were found with their summary biomass varied in the range 1.5-30113 kg/km^2, on average 1541.3 kg/km^2 (Table R17-2).

[Table R17-2] Biomass (kg/km^2) and percentage of mass groups of macrobenthos on the shelf and slope of West Kamchatka in 2013 (RV Professor Kaganovsky).

Taxon	Biomass Mean ± SE	Portion, %
Porifera	**468.5 ± 309.1**	**30.40**
Anthozoa:		
Pavonaria finmarchica	3.4 ± 1.7	0.22
Actiniaria:		**29.33**
Actinostola callosa	**376.6 ± 109.4**	**24.43**
Liponema brevicorne	69.6 ± 23.3	4.51
Actiniaria varia	6.0 ± 4.8	0.39
Cirripedia	72.6 ± 68.1	4.71
Gastropoda (Buccinidae)	89.4 ± 10.5	5.80
Asteroidea:		**11.24**
Crossaster papposus	2.1 ± 1.3	0.13
Hypasteria spinosa	10.5 ± 2.3	0.68
Crossaster borealis	3.1.± 1.1	0.20
Ceramaster patagonicus	39.9 ± 12.8	2.59
Cheiraster dawsoni	15.5 ± 8.5	1.00
Diplopteraster multipes	19.8 ± 5.5	1.28
Myxoderma sp.	24.7 ± 8.3	1.60
Ctenodiscus crispatus	37.3 ± 10.8	2.42
Asteroidea varia	20.4 ± 5.1	1.33
Echinoidea:		
Brisaster townsendi	72.9 ± 32.8	4.73
Holothuroidea		
Synallactes nozawai	199.0 ± 64.5	**12.91**
Crinoidea:		
Heliometra glacialis	10.2 ± 6.3	0.66
Total:	**1541.3 ± 336.5**	**100.00**

Eight benthic communities are defined on the shelf and slope by their dominant species (Figure R17-40). The highest biomass is detected for the community of sea sponges Porifera with localities in the southern and northwestern parts of the surveyed area with the depth 270–560 m. The community of barnacles Cirripedia occupies two localities in its northern part with the depths 200 and 540 m. Other communities with high biomass are dominated by actinia *Actinostola callosa*, sea urchin *Brisaster townsendi* and holothuria *Synallactes nozawai*.



[Figure R17-40] Communities of macrozoobenthos on the shelf and slope of West Kamchatka

The deepest part of the surveyed area is occupied by a rather poor community of starfish Asteroidea. The holothurian community occupies the middle continental slope with the depth 360–800 m. The upper slope in its southern part is occupied by the community of *Actinostola callosa* distributed in the depth range 150–820 m. This actinia belt continues northward, but *A. callosa* is replaced by other actinia species – *Liponema brevicorne*; the northern community biomass is considerably lower. The poorest by biomass is the community of gastropods Buccinidae in the central part of the shelf.

High species diversity and abundance of macrozoobenthos are noted at West Kamchatkathat means a good state of benthic ecosystems in this area of active commercial fisheries.

10. Pollutants

Contributors: Mikhail Simokon, Lidia Kovekovdova

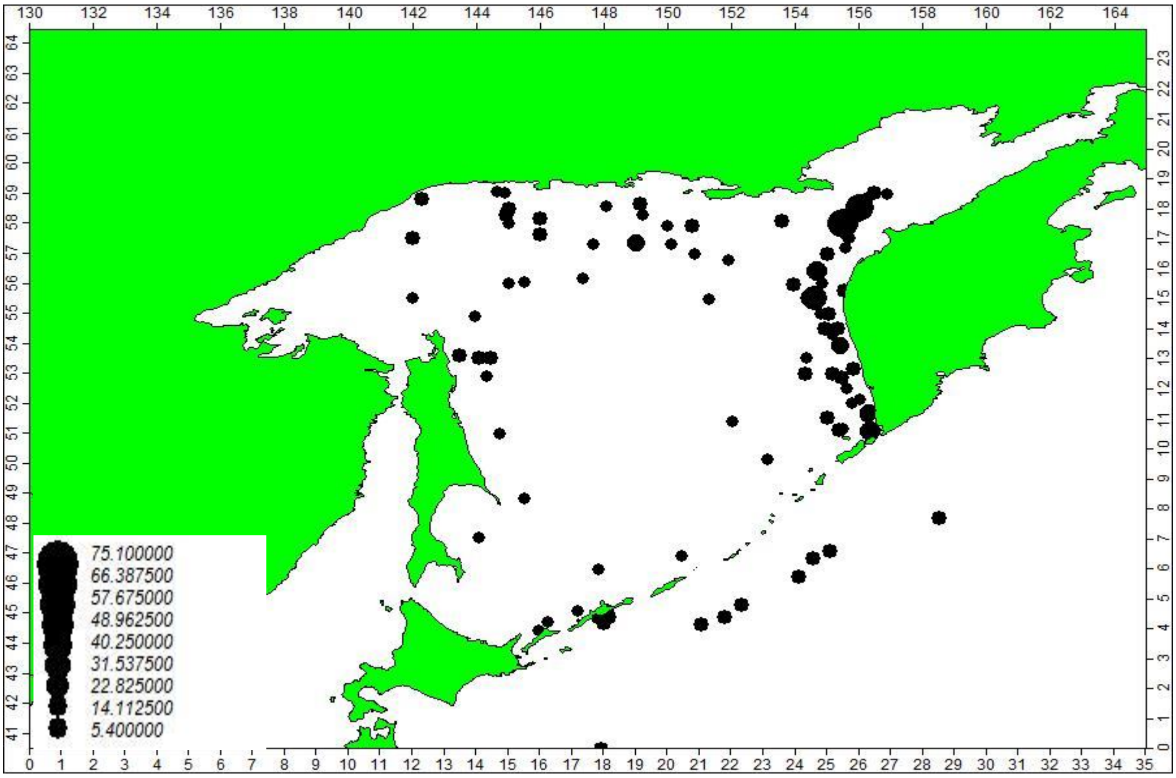
The water pollution by trace metals and persistent organic pollutants (POPs) is monitored by fishery institutions, so far as these pollutants could be dangerous for fishery resources. Pollutants enter the marine environments from both natural and anthropogenic sources. Their main natural sources are: terrestrial water discharge, aeolian suspension (aerosols) and bottom hydrothermal flows. Anthropogenic sources are located mostly at the coast, as sewage, dumping, ship drains, etc.

Monitoring of trace elements in the Okhotsk Sea was started in 2011 and is continuing, Total concentrations of the elements fluctuated in the following ranges (µg/L): As – 1.35-8.9; Cd – 0.078-0.407; Co – 0.02-0.43; Cr – 0.28-0.97; Cu - 0.65-6.4; Fe – 5.2-75.1; Hg – 0.025-0.9; Mn – 0.21-1.9; Ni – 0.16-1.8; Pb – 0.05-0.50; Zn – 0.52-90.0. Their threshold levels determined in Russia for the water bodies exploited by fishery are (µg/L): As – 10; Cd - 10; Co - 5; Cr – 20; Cu – 5; Fe - 100; Hg – 0.1; Mn - 50; Ni – 10; Pb - 10; Zn - 50. So, the threshold levels of Cu, Hg, and Zn were exceeded in some cases in the coastal zone, though generally the concentrations of all trace elements were considerably below these values (Figures R17- 41, 42). Mercury concentration only exceeds the threshold significantly, maximally in 9 times at south-western Kamchatka in 2011. The cases of high mercury concentrations coincide well with submarine volcanic activities, so they could be caused by seeps through the sea bottom. Dangerous pollution by other metals was observed in single cases: by zinc in 2011 and by copper in 2012. Thus, in terms of trace metals pollution, the water environments of the Okhotsk Sea are considered as natural. Persistent organic pollutants were not found in all samples collected in the Okhotsk Sea – their concentrations were lower than the limit of detection (LOD) of the facilities.

Statistically significant correlations between spatial variations of certain trace elements are revealed (Table R17-3). They form two clusters with similar patterns: Fe-Cr-Co (strong correlation between Fe and Cr) and Zn-Hg-Ni-Cd-Pb (strong correlations between Zn, Hg, and Ni). Distribution of the elements from the first group is determined by terrestrial water discharge that is less important for the elements of the second group, which presumably come to the Okhotsk Sea waters mainly from the atmosphere.

[Table R17-3] Correlation matrix for spatial variation of trace elements at the Okhotsk Sea surface (N=110, bold numbers are statistically significant with $p < 0.05$)

	As	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
As	**1,00**	**0,19**	0,05	-0,05	**0,30**	-0,16	0,00	0,18	0,19	**0,38**	0,18
Cd	**0,19**	**1,00**	0,00	-0,01	0,14	0,05	0,18	0,05	**0,27**	**0,20**	**0,26**
Co	0,05	0,00	**1,00**	0,10	**0,33**	**0,26**	0,02	-0,01	0,01	0,15	0,06
Cr	-0,05	-0,01	0,10	**1,00**	**-0,28**	**0,77**	-0,07	-0,01	-0,17	-0,11	**-0,20**
Cu	**0,30**	0,14	**0,33**	**-0,28**	**1,00**	**-0,24**	0,05	-0,03	**0,19**	**0,22**	**0,22**
Fe	-0,16	0,05	**0,26**	**0,77**	**-0,24**	**1,00**	-0,05	-0,04	**-0,20**	-0,12	**-0,21**
Hg	0,00	0,18	0,02	-0,07	0,05	-0,05	**1,00**	-0,08	**0,60**	0,07	**0,91**
Mn	0,18	0,05	-0,01	-0,01	-0,03	-0,04	-0,08	**1,00**	0,01	0,04	-0,03
Ni	0,19	**0,27**	0,01	-0,17	**0,19**	**-0,20**	**0,60**	0,01	**1,00**	0,19	**0,71**
Pb	**0,38**	**0,20**	0,15	-0,11	**0,22**	-0,12	0,07	0,04	0,19	**1,00**	0,19
Zn	0,18	**0,26**	0,06	**-0,20**	**0,22**	**-0,21**	**0,91**	-0,03	**0,71**	**0,19**	**1,00**



[Figure R17-41] Values of total iron concentration (µg/L) at the sea surface measured in the 2011-2016 period.

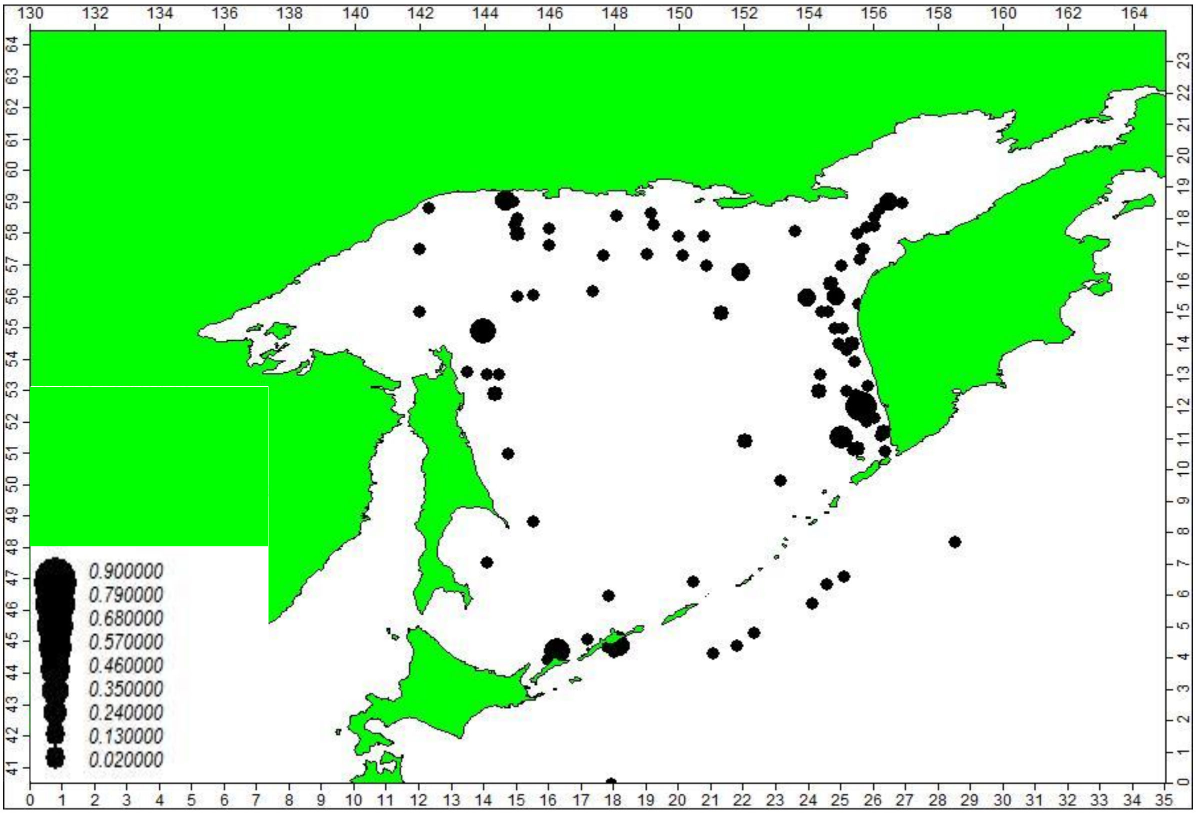


Figure R17-42. Values of total mercury concentration (µg/L) at the sea surface measured in the 2011-2016 period

11. Climate Change, Ecosystem Considerations & Emerging Issues

Contributors: Yury Zuenko

Given the background of definite warming of the Okhotsk Sea waters in the last decades (in all layers, in all seasons), the changes of biotic components of its ecosystem are not so clear: they have different directions and their relationships with changes in the environments are vague. The low trophic levels followed the expected pattern - decreased primary production caused by a reduction of available nutrients in the euphotic zone resulting from weakened winter convective mixing. This in turn resulted in reductions in the biomass of copepods and euphausiids which graze on phytoplankton. However, even the next trophic level of predatory zooplankton does not follow this tendency and the biomass of amphipods and arrowworms increased, presumably because of more favorable earlier conditions for their spawning. So, even for the 2nd–3rd tropic levels the conditions of reproduction are more important than the conditions of feeding, possibly because of excessive food supply in the Okhotsk Sea. This dependence on conditions of reproduction dominates absolutely for higher tropic levels such as fishes, which show various dynamics of their populations corresponding with features of their life cycles.

Specifically the stock of the most numerous species in the Okhotsk Sea – walleye pollock changes with typical for dominant species cyclicity driven by negative dependence between the spawning stock and recruitment, widely known in ichthyology (e.g. Nikolsky, 1974), and particularly for pollock (Zuenko and Nuzhdin, 2018). In the last three decades, periods with strong year-classes of pollock (1988-1990, 1995-1997, 2004-2006, 2011-2013) were interrupted by periods with stably unsuccessful reproduction (1991-1994, 1998-2003, 2007-2010). The duration of these cycles corresponds to the life span of walleye pollock. This intra-population regulating mechanism is distorted by environmental and other outside impacts. For example, overfishing in the 1990s was very important for the pollock population in the Okhotsk Sea. There are no doubts that the climate change has influence on this population, too. However, the year-to-year dynamics of this stock is still determined by intra-population mechanisms of regulation.

Reproduction of Pacific herring is more affected by environments because of its spawning in the coastal zone with unstable conditions. Alternatively, instability of this species reproduction is compensated by its long life span. Recent conditions of winter warming are generally unfavorable for spawning of the largest Okhotsk population of herring because of the absence of polynyas along the northwestern coast of the sea, but earlier melting of the sea ice may partially compensate for this negative effect, and the stock of herring is still high. Fortunately, the polynyas are not so necessary for spawning of other populations of this species in the Okhotsk Sea, such as the Gizhiga-Kamchatka herring.

The populations of the bulk of demersal fishes and bottom invertebrates are rather insensitive to the climate changes, living in less variable environments of the deeps and being distinguished by long life span. However, all mass deep-water species in the Okhotsk Sea have slight growth (or recovering) of their stocks recently. This may be explained by better survival of their larvae under higher temperatures. Decreasing productivity obviously has no negative effect for these populations. Deoxygenation of the deep waters has no negative impact on their stocks, but some signs of their redistribution are noted. Dynamics of some valuable species (pollock, halibuts, crabs) are determined by measures of fishery regulation or absence of sufficient measures.

Similar changes of biotic and abiotic components of a large regional-scale ecosystem were noted earlier in the other Far-Eastern seas, Such as the PICES region 19. These reconstructions could be generalized as the following conception: climate change toward the sea warming, followed with weakening of vertical mixing and heightening of water temperature, causes reconstruction of subpolar marine ecosystems toward decreasing of productivity and increasing of efficiency of their functioning.

References

Avdeev, G.V., Smirnov, A.V., Fronek, S.L. 2001. Main features of walleye pollock abundance in the northern Okhotsk Sea in 1990s. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 128: 207-221 (in Russian).

Avdeev, G.V., Ovsiannikov, E.E. 2006. Results of stock assessments for walleye pollock in the northern Okhotsk Sea by ichthyoplankton survey in 2005. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 145: 120-145 (in Russian).

Borets, L.A. 1997. Bottom ichthyocenes of the Russian shelf in the Far-Eastern Sea: composition, structure, elements of functioning and commercial value. Vladivostok: TINRO: 217 p. (in Russian)

Dulepova, E.P. 2013. Utilization of forage resources by nekton in periods of its high abundance in the Okhotsk Sea. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 173: 146–163 (in Russian).

Gorbatenko, K.M. 2016a. Distribution, biomass, and year-to-year dynamics of Sagitta in the Okhotsk Sea. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 184: 168-177 (in Russian).

Gorbatenko, K.M. 2016b. Quantitative distribution and feeding of euphausiids in the Okhotsk Sea. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). V.185: P.204-214 (in Russian).

Macrofauna of the pelagic Okhotsk Sea: tables of occurrence, abundance and biomass, 1982-2009 (ed. V.P. Shuntov, L.N. Bocharov). 2012. Vladivostok: TINRO: 800 p.

Melnikov, I. V., & Loboda, S. V. (2004). Interannual variation of the pacific herring stocks in the Okhotsk Sea in connection with last years cooling. *PICES Sci. Rep*, *26*, 127-131.

Muktepavel, L.S. 2006. Spatio-temporal variability of near shore polynyas on the main spawning grounds of Okhotsk herring. Voprosy promyslovoy okeanologii (Problems of Fisheries Oceanography). 3: 314-332 (in Russian).

Muktepavel, L.S., Shatilina, T.A. 2009. Some features of forming the extreme low-ice winters in the Okhotsk Sea. Modern problems of remote sensing of the Earth from space. 6-1: 435-440 (in Russian).

Naumenko, N. I. 2001. Biology and fishery of marine herrings in the Far East. Petropavlovsk-Kamchatsky: Kamchatsky Publishing House: 330 p. (in Russian).

Nikolsky, G.V. 1974. Theory of fish shoal dynamics. Moscow: Pishchevaya promyshlennost: 447 p. (in Russian).

Melnikov, I.V., Loboda, S.V. 2004. Interannual variation of the pacific herring stocks in the Okhotsk Sea in connection with the last years cooling. PICES Sci. Rep. 26: 127-131.

Ovsiannikov, E.E., Ovsiannikova, S.L., Sheybak, A.Y. 2013. Dynamics and structure of walleye pollock stock in the northern Okhotsk Sea in the 2000s. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 172: 133-148 (in Russian).

Shatilina, T.A., Anzhina, G.I. 2006. Variability of parameters for the Asian and Far-Eastern Lows in the second half of the 20th century. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center. 144: 247-258 (in Russian).

Shuntov, V.P. 2010. Some results of ecosystem studies of biological resources in the Far-Eastern Seas in connection with the problems of future studies. Concept of the Far-Eastern basin program for the pacific salmon studies. 5: 186-195 (in Russian).

Shuntov, V.P. 2016. Biology of the Far-Eastern Seas of Russia. Part 2. Vladivostok: TINRO: 604 p. (in Russian).

Shuntov, V.P., Dulepova, E.P., Temnykh, O.S., et al. 2007. State of biological resources in connection with dynamics of macroecosystems in the exclusive economic zone in the Far-Eastern Seas of Russia. In: Dynamics of ecosystems and modern problems of preservation of bioresource potential in the seas of Russia. Vladivostok: Dalnauka: 75-176 (in Russian).

Shuntov, V.P., Volvenko, I.V. 2017. Supplements to the quantitative assessments of zooplankton in the Far Eastern Seas and adjacent waters of the North Pacific. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 191:130-146 (in Russian).

Tyurnin, B.V. 1980. Spawning area of Okhotsk herring. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 86: 12-20 (in Russian).

Volkov, A.F. 2013a. Seasonal and long-term dynamics of epipelagic plankton in Sakhalin waters, the Okhotsk Sea. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 174:170-186 (in Russian).

Volkov, A.F. 2013b. Seasonal and long-term dynamics of epipelagic plankton in Kamchatka waters of the Okhotsk Sea. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 175: 206-233 (in Russian).

Volvenko, I.V. 2016. First experience of using a new database on net zooplankton in the Far-Eastern Seas and adjacent Pacific waters. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 187: 19-47 (in Russian).

Zavernin, Y.P. 1972. Influence of hydrometeorological conditions on timing of herring migration to spawning and strength of its year-classes. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 81: 44-51 (in Russian).

Zolotov, A.Y., Terentiev, D.A., Novikova, O.V., Ilyin, O.I. 2013. Long-term dynamics of biomass for bottom fishes on the shelf of West Kamchatka. Izvestia TINRO (Newsletters of Pacific Fish. Res. Center). 173: 30-45 (in Russian).

Zuenko, Y.I., Nuzhdin, V.A. 2018. Impact of modern changes of oceanographic conditions in the Japan Sea on state of the Primorye pollock population. Vorprosy rybolovstva (Problems of Fisheries). 19, 3: 377-386 (in Russian).