
© Y. Yakovlev

Okhotsk Sea

background

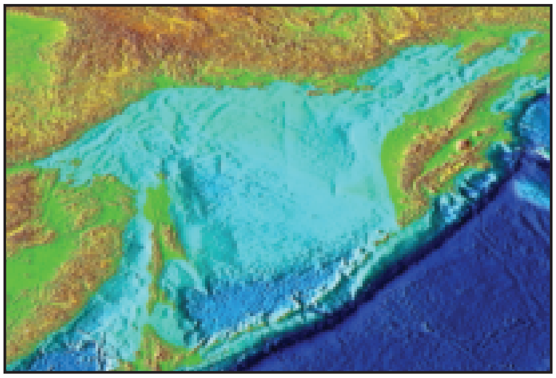
The Okhotsk Sea is bounded by the Siberian coast to the west and north, Kamchatka Peninsula on the east, the Kuril Island archipelago, Hokkaido and Sakhalin islands to the south.

The latitudinal range is from 44°N to 63°N, equivalent to the distance from the Columbia River to Bristol Bay (Alaska) along the North American coast. The 800m average depth of the Okhotsk Sea is due to a rather wide coastal shelf (up to 400 km) in the northern part, and deep Kuril Basin in the south. The shelf accounts for almost 40% of the total sea area. Below the 200-m depth contour, the bottom deepens forming a broad area with depths between 500 and 1500 m, that accounts for almost 42% of the total sea area.

The Okhotsk Sea is connected with the North Pacific Ocean by passes cutting through the Kuril Island chain; two straits are deeper than 1,000 m.

As a result, the Okhotsk Sea circulation is connected with the circulation of the subarctic North Pacific. Water properties in the Okhotsk Sea differ considerably from those of the North Pacific Ocean in most locations along the Kuril Islands, reflecting existence of a physical barrier. The Okhotsk Sea is connected via La Perouse (Soya) Strait to a source of relatively high temperature and salinity of incoming waters. The mouth of the Amur River is located near the northern part of Tartar Strait on the southwestern coast, and almost all of its runoff flows into the Okhotsk Sea.

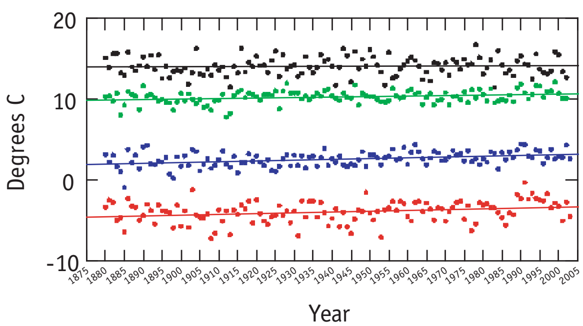
Fisheries in the Okhotsk Sea are important to the economies of northern Japan and especially Russia. The major fisheries in the eastern Okhotsk Sea are for walleye pollock, flatfish, halibut, and Pacific cod. Walleye pollock accounts for the largest portion of the total catch, with an assessed biomass being 74% of the total fish biomass, averaged for 1999-2001.



Status and Trends

Climate

The climate of the Okhotsk Sea region is influenced by variable seasonal synoptic patterns that reflect the Siberian High and the Aleutian Low pressure fields in winter and by the presence/absence of an Okhotsk Sea High in summer. Various synoptic patterns generate different conditions. Long-term air temperature records in the southern Okhotsk Sea (Nemuro, Japan) indicate significant long-term warming in fall, winter, and spring but not in summer (Figure 56). Records for the northern region (Okhotsk, Russia; not shown) have a similar pattern except that the season of no significant long-term trend occurs in fall rather than in summer.

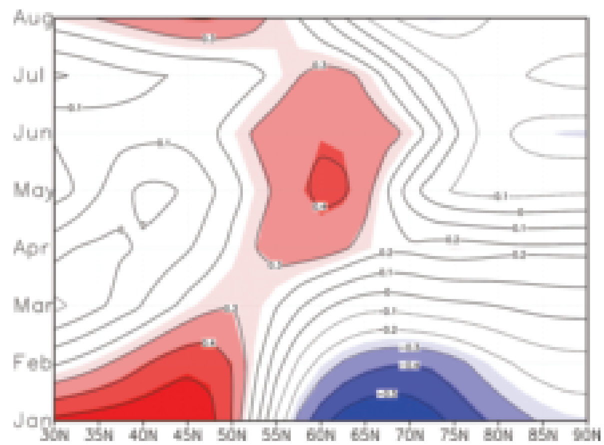


[Figure 56] Long-term trends for seasonal mean air temperatures at Nemuro, Japan from 1880 to 2000. Seasonal means are based on monthly groupings: DJF (red), MAM (blue), JJA (black), SON (green).

There is a tendency for colder winters and greater ice cover during winter El Niño events and warmer winters following a summer La Niña. After removing the effect of the long-term warming trend, correlations between the El Niño southern oscillation index and average winter air temperature ranges from 0.38-0.58, depending on site, indicating rather weak, but not insignificant correlation between the two parameters.

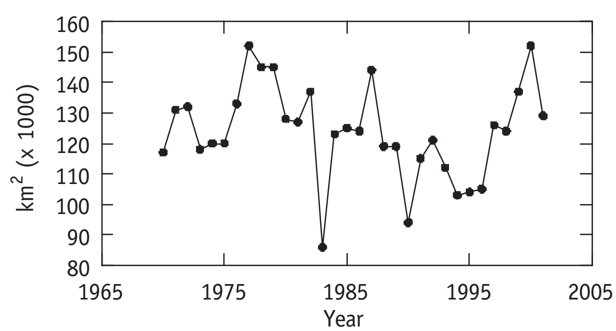
The establishment of an Okhotsk Sea high-pressure region in summer may be related to the state of the North Atlantic Oscillation (NAO) during the previous winter (Figure 57).

There is a positive correlation between the NAO index in winter and establishment of the Okhotsk Sea high. The latter is associated with cooler and wetter summers along the northeastern Asian continent due to the large-scale atmospheric circulation pattern.



[Figure 57] Lag correlation (red=positive, blue=negative) of monthly averaged zonal mean 500 hPa geopotential height with the winter NAO. Variable shadings indicate statistical significance.[96]

Ice formation plays a significant role in the physical and biological processes in the Okhotsk Sea. While the west coast of Kamchatka is typically ice free, the maximum extent of ice coverage varies among years by about a factor of two (Figure 58). There is no significant linear trend over the last 30 years or so; 1977 and 2000 had the most ice, while 1983 and 1990 had the least.

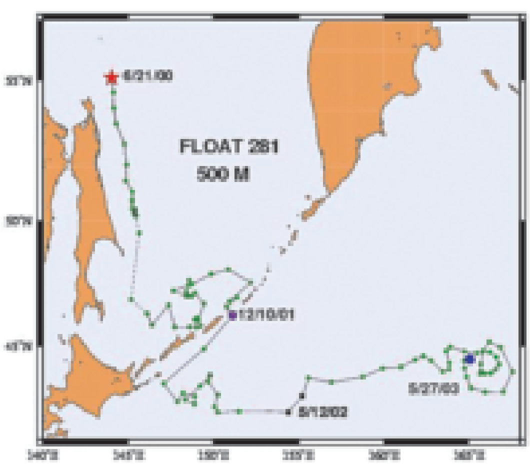


[Figure 58] Annual maximum ice cover in the Sea of Okhotsk[97]

Hydrography

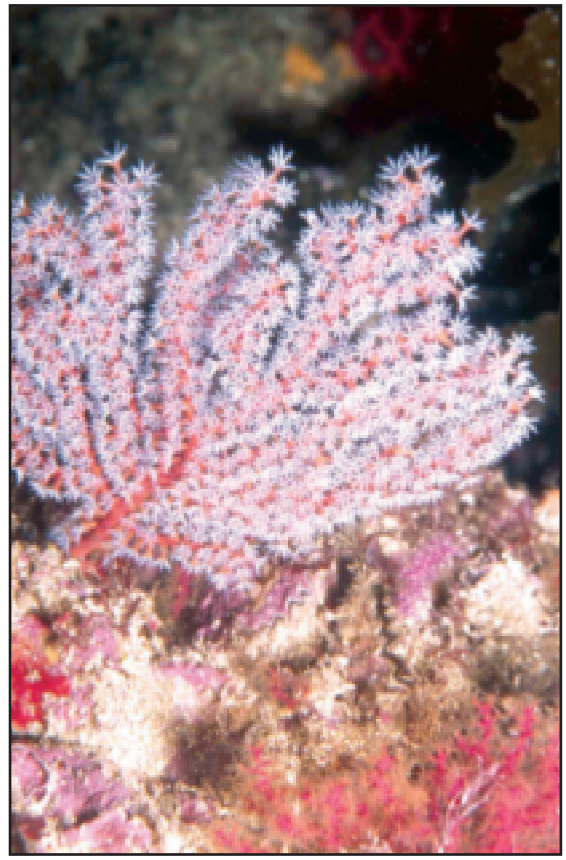
Modern autonomous profiling instruments are capable of providing incredibly detailed information about the temperature and salinity of the ocean. Follow the track of a profiling float (Figure 59) that was launched off northern Sakhalin Island on 6 June 2000 with instructions to measure temperature and salinity repeatedly from the surface to a depth of 500m. It left the Okhotsk Sea via Bussol' Strait during the winter of 2001, and after drifting westward in the North Pacific, was entrained within an eddy during the spring of 2003.

The water properties encountered along the path of float #281 reveal how dramatically different is Okhotsk Sea water from North Pacific water. Temperatures near or below 0 °C within the Okhotsk Sea change quickly to positive temperatures after passing through the Kuril Island chain into the Oyashio and subsequently into the North Pacific (Figure 60).

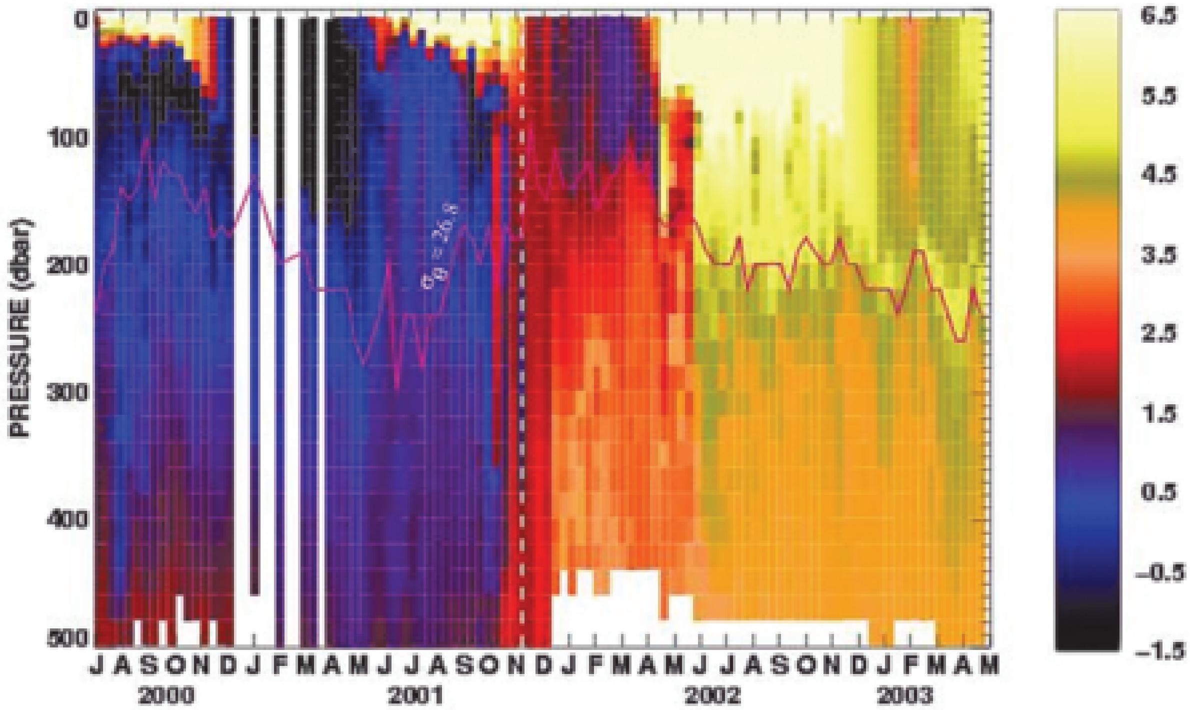


[Figure 59] Track of profiling float #281 from launch in June 2000 until May 2003.

When these observations are compared with the results obtained from the 1993 WOCE P1W cruise, a recent study found basin-wide warming of 0.1°-0.2°C and freshening of 0.05-0.1 psu.[98]

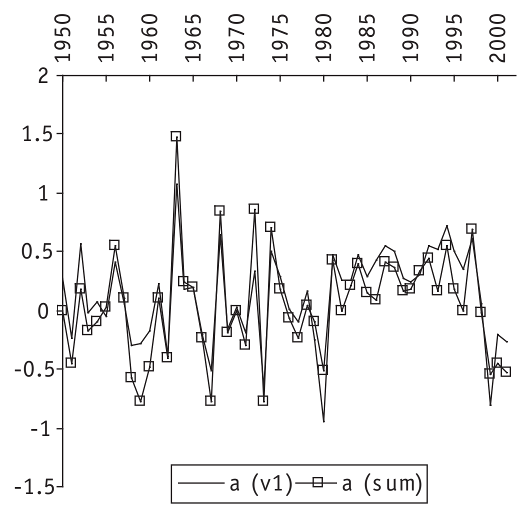


© Y. Yakovlev



[Figure 60] Vertical temperature profiles obtained from a profiling float #281 while in the Okhotsk Sea (left of vertical dashed line) and after it entered the North Pacific (right of the dashed line). White areas on the left are missing data; ice prevented satellite transmission. "Thin red line is 26.8 sigma Theta density"[99]

On the other hand, water temperature data obtained from ~94,000 profiles collected by Russian, Japanese and American scientists reveals an interesting pattern of interannual variability at 50-m depth during the last 50 years.[100] Prior to 1981, annual temperatures at 50 m were much more variable than during the period from 1981 to 1998 (Figure 61). These years were warmer than average and had neither the extreme high nor extreme low values that were observed both before and after this period. Compared to the previous 19 years, the decline in water temperature in 1999 and its persistence since, established a rather different thermal regime than had been experienced before. A notable feature is the lack of correspondence between water temperatures in the Okhotsk Sea and large-scale climate indices typically used in the North Pacific. There is little evidence of persistent increases in sea surface temperatures at stations in the Okhotsk Sea.



[Figure 61] Index of year to year variability in water temperature at 50 m depth throughout the Okhotsk Sea (EOF 1) compared with a similar index (EOF 1-4) for a region (54-56°N 151-154°E). Good correspondence between the two lines indicates that water temperatures off the West Kamchatka are generally representative of large-scale temperature variability throughout the Okhotsk Sea.

Chemistry

The high biological productivity of the Okhotsk Sea is related to nutrients abundance. Recent studies showed that there are approximately 50-70 mkg of phosphates l^{-1} in the surface layer and 60-90 mkg l^{-1} in the subsurface layers in winter. The content of silicates is about 1200-1500 mkg l^{-1} in the surface layer, and 1200-1700 mkg l^{-1} in the subsurface layers.[101,102,103] In 1990, prior to the algal bloom, phosphorus, silicon and nitrogen concentrations ranged from 1.3-2.2, 30-65, and 17-27 mkg-atom l^{-1}, respectively, across the ice-free areas.[104] Later in spring, the surface nutrients concentration decreased notably due to the intensive photosynthesis. The southern Okhotsk Sea waters are generally richer in nutrients than northern areas, and eastern richer than western.[105] This pattern derives from the two main sources of nutrient-rich waters: Pacific water flows and vertical mixing in the Kuril straits.[101]

Plankton

Bacterioplankton The biomass of bacteria in the warm surface layer varies from 50 to 150 mg m^{-2} at the majority of the stations in the open sea. Integrated biomass of the southeastern deep-sea spots was calculated as 2.2-2.9 g m^{-2} which is lower than in the deep-sea parts of the Bering Sea. In shelf areas the bacteria biomass varied depending on the amount of organic material. In the case of diatom blooms an integrated biomass of 7.8-14.3 g m^{-2} is suggested.

The vertical and horizontal distribution of bacteria in the Okhotsk Sea is the same as in the Bering Sea. Upper warm layers are characterized by high bacteria concentration. Under the thermocline at the depth of more than 50 meters the biomass was calculated as 30-60% of the amount in the upper layer. At depths from 100 to 400-900 meters the biomass was quite stable (10-40 mg m^{-2}). The rate of bacterial production in the Okhotsk Sea is high in summer: P/B factor is 0.2-0.9. In the warm southeastern waters it varied from 0.7-0.9 during the survey. At a cold coastal Sakhalin Island station, it was half as much. Integrated values of day and night bacterial production vary from 1 to 2 gm^{-2} at most stations in the Okhotsk Sea. In the shelf and slope areas this data is higher at 2.8-5.1 g m^{-2}. In the year of 1992 the integrated bacterial biomass in the Okhotsk Sea was approximately the same as in the Bering Sea. But in 1992-1994 years it increased to 1.5 times as much.

One hydrological peculiarity of these years was the high blooming of microweeds, which was the reason for high productivity of bacteria plankton. The integrated biomass of bacteria plankton was 17.2 g m^{-2} at the southern part of the Okhotsk Sea in the 0-200m layer in 1993, and 9.3 g m^{-2} in the 0-50m level in 1994. The annual bacterial production was 68 g C m^{-2} or 639 g m^{-2} of the living substance.[105] As for the whole area of the Okhotsk Sea bacteria plankton production was calculated as $0.96 \cdot x10^9$ t of living material.

Microzooplankton Microzooplankton groups are widely distributed during summer time. Data on horizontal distribution of infusorians suggest that their biomass is decreasing from 1.3-2 times towards deep-water areas that are under the influence of oceanic waters. The largest aggregations of infusorians, up to 60-100 mg m^{-2}, were found above the thermocline. The total biomass of the group is about 1.5 - 2.5 g m^{-2} in this season with maximum and minimum values of 3-6 and 0.8-0.9 g m^{-2}, respectively. The number of nanoheterotrophous organisms in the upper mixed level is the same or may be higher than the number of protozoa for all areas of the Far East in summer.[105] In the summer of 1993 in the Okhotsk Sea the infusorians biomass varied from 0.25 to 1.32 g m^{-2} and the nanoheterotroph biomass was from 0.24 to 1.4 g m^{-2}. In 1994 of the same season the range of the infusorians biomass changes was 1.2-5.0 g m^{-2}, and that of the nanoheterotrophs was 1.3-3.9 g m^{-2}. The biomass of protozoa in the western part of the Bering Sea in the summer has been estimated at 164±24 thousand tC d^{-1} and in the Okhotsk Sea 235±25 thousand tC d^{-1}.[106] which is equivalent to 0.78 tC m^{-2} d^{-1} and 0.94 tC m^{-2} d^{-1}, respectively. The production of microzooplankton has been estimated at 27gC m^{-2}.[105]

Phytoplankton The study of phytoplankton and primary production in the Okhotsk Sea has not been consistent. Reliable data on primary production were collected during summer periods. A regular supply of biogenic elements in the area results from complicated hydrodynamics and considerable river runoff. The latter flow permanently supplies the photosynthetic zone with nutrients.[105]

In the 1980s in some parts of the Okhotsk Sea wet weights of phytoplankton varied greatly: in Kashevarov Bank it constituted 16,800 mg m^{-3}, between Shantar and Iona regions it was 21,640 mg m^{-3}, while in the coastal region it was 902 mg m^{-3}.[107]

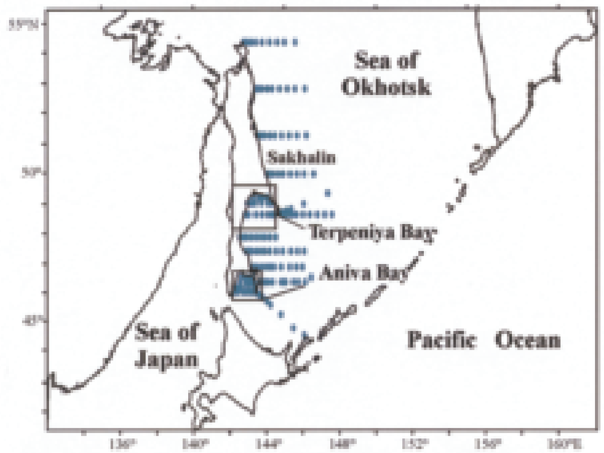
Due to the internal recycling of nutrients, a high level of phytoplankton biomass can be observed following the spring bloom. In 1993, phytoplankton biomass (mainly diatoms) increased from June to August. Regions of high biomass ranged from 5,000-10,000 mg m^{-3}. In 1993 the increased level of biomass was caused by abnormally high water movement.[108]

The range of primary production estimations in the Okhotsk Sea is wide (from 101-350 gC m^{-3}).[109,110] It was accepted that primary production in the Okhotsk Sea was about 450 gC m^{-2} including phythobenthos, and for the entire Okhotsk Sea 720,106 tC y^{-1} or $14.4x10^9$ t.[111]

The rate of algae photosynthetic activity depends on a season. When seasons are defined as in the calendar, an estimated seasonal relative share of primary production is 35% in spring, 45% in summer, 18% in autumn, and only 2% in winter.[105] If we suggest that spring lasts as long as the algae bloom period, then about 50% of the total annual primary production will be associated with spring in the Okhotsk Sea.[112] The algae bloom begins in the Okhotsk Sea in April, in its southern areas and in the western Kamchatka shelf.[113,114,105] First evidence of spring algae bloom (increased chlorophyll concentrations and *Thalassiosira spp*. biomass) can be detected in March.[115,114] off the southwestern Kamchatka coast. During May, spring bloom moves with retreating ice edge, and then spreads over the northern and northwestern Okhotsk Sea areas. Peak of algae photosynthetic activity is usually observed in the northeastern Okhotsk Sea in May, and in its northwestern part – in June, and in the western region around the Shantarsky Archipelago even later.[105] A suggestion that favorabe conditions for phytoplankton bloom are found in the Sea of Okhotsk in June-July holds only for some northern regions.[116]

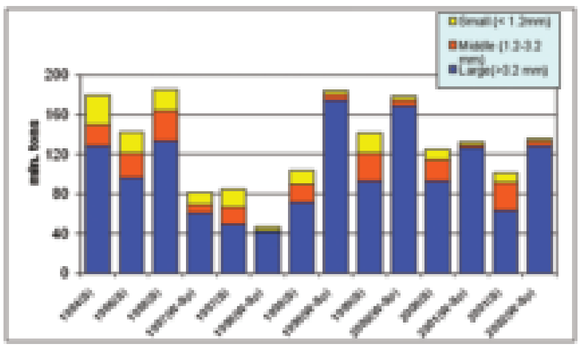
Diatoms bloom mostly in spring in the Okhotsk Sea and other Far-Eastern Seas. Species composition in alga communities varies with season and among investigated regions.[117,113,118,119,120,114] However, the cryophilic species mostly predominate among the spring phytoplankton. The following early-spring species are highly abundant in the neritic zone: *Thalassiosira nordenskioldii, Th. gravida, Th. decipiensis, Th. hyalina, Bacterosira fragilis, Fragilaria islandica, F. striata, F. oceanica, Thalassiotrix longissima, Coscinodiscus oculus iridis, Detonula confervaceae, Porosira glacialis, Asterionella kariana*. The following late-spring species appear with the seasonal water warming: *Chaetoceros subcecundus, Ch. debilis, Ch. furcellatus, Ch. compressus, Ch. constrictus, Ch. radicans*. Neritic algae species are characterized by wide distribution range and can be found in the deepwater areas of the Okhotsk Sea. On the whole, phytoplankton composition in that area is somewhat different. Other diatoms are predominant within the offshore planktonic algae communities in Okhotsk Sea: *Thalassiosira exentrica, Coscinodiscus marginatus, Chaetoceros atlanticus.* Among the peridinium algae, *Peridinium pellucidum, P. pallidum, P. depressum, P. brevipes, Ceratium arcticum* are abundant in spring. During the warm season, algae species composition changes gradually.[105]

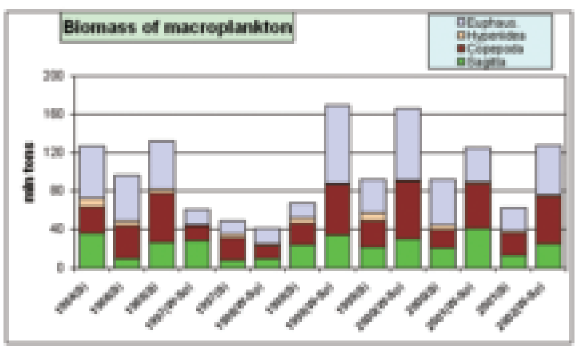
Zooplankton[121] Regular sampling of zooplankton has been conducted by SakhNIRO in the southwestern Okhotsk Sea (east and south coasts of Sakhalin Island) for many years (Figure 62). Generally, cold-water species (*Thysanoessa raschii, Parasagitta elegans, Metridia okhotensis,* and *Pseudocalanus minutus*) accounted for a majority of the biomass, but in the southernmost stations warmer water species are found in small numbers. The seasonal and year-to-year changes in zooplankton biomass were similar in magnitude. During the period 1987 to 1996, zooplankton biomass had an absolute minimum in 1991. Preliminary investigations indicated a strong impact of the environment on species structure and distribution of net zooplankton in the southwestern part of the Okhotsk Sea. The annual biomass was highly correlated (r= -0.98) with the temperature of the 50-100 m depth layer; in the cold years, zooplankton biomass in the samples was greater than in warm years.



[Figure 62] Zooplankton sampling grid in the southwestern Okhotsk Sea

Large-scale zooplankton research by TINRO-Centre in the Okhotsk Sea began in 1984. A Jedy net is used for sampling zooplankton, taking into consideration correction coefficients for different groups of zooplankton. The Okhotsk Sea is generally characterized by high zooplankton biomass except in some years during the period between 1980-1990 (Figure 63). Zooplankton biomass and resources, including macrozooplankton, are at the level of 1980 when fish productivity and fisheries in the Okhotsk Sea were very large. Only in 1997-1998 was a great quantity of zooplankton not observed (Table 11).





[Figure 63] Dynamics of size and taxonomic group biomass in the northern part of the Okhotsk Sea. W-winter, Sp-spring, S-summer.[122]

According to a series of complex macro-surveys conducted in the area of the Okhotsk Sea during the 1980s, the average zooplankton biomass is 223 g m^{-2} in the upper level in summer, but in fall this declines to 180 gm^{-2}. The total zooplankton biomass is about 590 million t, and in fall it is 424 million t.[123] The majority of zooplankton biomass consists of macroplankton irrespective of season. Among them are euphausiids, copepods, hyperiids, chaetognaths.

A literature survey of zooplankton feeding in the Okhotsk Sea indicated that the biomass of phyto- and euryphagous zooplankton was 171 g m^{-2} in summer, 125 g m^{-2} in fall. As for predatory zooplankton, the number is 51 g m^{-2} in summer, 56 g m^{-2} in fall. On the whole the share of the predatory zooplankton in 1990s was higher than in 1980s. Obviously this is connected with ecosystem reorganizations,[124] which are known to take place in the Far Eastern Seas. These are caused by a considerable reduction in the number of the most plentiful planktivorous fishes – walleye pollock and Pacific sardine. At the end of the 1990s, the state of plankton communities became stable and thus, the share of predatory zooplankton decreased. Copepods of different sizes form the basis of phyto- and euryphagous species production (70%), while the small copepods take the main part (up to 50%) in this formation. One of the main sources of the predatory zooplankton production is chaetognaths. Converting to units of area, and taking into account the plankton of depth level average, annual non- predatory and predatory zooplankton production is 1672 and 320 g m^{-2}. For the Okhotsk Sea average annual non-predatory production is 2507 million t, predatory zooplankton production is 542 million t.

Zooplankton biomass sampled by Japanese scientists with a NORPAC zooplankton net from 150 m depth to the surface indicates variability from year to year. Some of this variability is related to the abundance of juvenile pink and chum salmon. In years when juvenile salmon are abundant in the autumn in the Okhotsk Sea, zooplankton biomass tends to be low, at least during the small number of years of sampling. The table below gives an indication of the variability among years.

[Table 10] Zooplankton biomass collected by Japanese research vessels in the open waters of the Okhotsk Sea south of 51°N.[125]

Year	N	mg m^{-3}
1993	20	122.9
1996	15	75.8
2000	5	257
2002	18	65.6

[Table 11] Dynamics of average biomass in the northern part of the Okhotsk Sea in 1997-2002 , mg m^{-3}

Seasons, size and taxonomic dimensional groups	1997	1998	1999	2000	2001	2002
Spring						
Small dimensional groups	108	35	38	41	26	18
Middle dimensional groups	73	11	55	49	24	45
Large dimensional groups	547	373	1561	1510	1136	1150
Including:						
Euphausiids	144	145	731	670	326	459
Hyperiids	8	13	9	10	12	17
Copepods	135	124	466	541	417	444
Sagittas	258	91	313	269	370	222
All zooplankton	**729**	**418**	**1654**	**1600**	**1186**	**1213**
Summer-fall						
Small dimensional groups	190	119	142	105	88	-
Middle dimensional groups	155	125	220	195	251	-
Large dimensional groups	460	567	859	845	563	-
Including:						
Euphausiids	131	125	314	417	206	-
Hyperiids	33	51	99	50	29	-
Copepods	214	185	238	170	201	-
Sagittas	78	186	184	194	121	-
All zooplankton	**805**	**811**	**1220**	**1119**	**903**	**-**

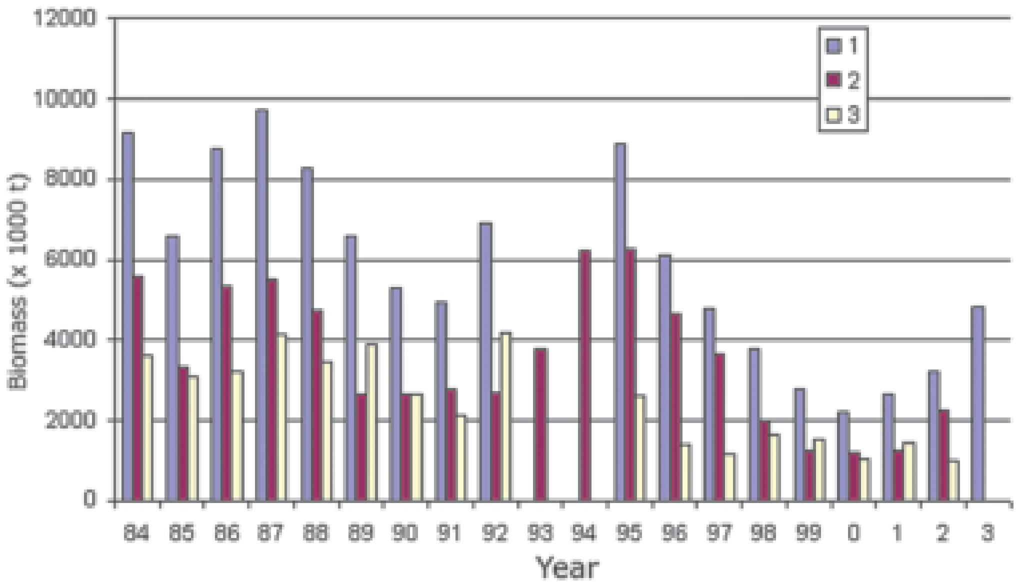
Fish and Invertebrates

Fisheries in the Okhotsk Sea account for 50% of total Russian harvests in the Pacific Ocean. From 1999-2001, walleye pollock accounted for 74% of the biomass. Various flatfishes, mostly yellowfin sole (11.5%), Pacific cod (4.7%) and saffron cod (4%) were important but accounted for far less of the total biomass removed. Recently, the role of bycatch in various fisheries has been a focus of attention as bycatch had not been considered in fisheries statistics nor in establishing catch quotas.

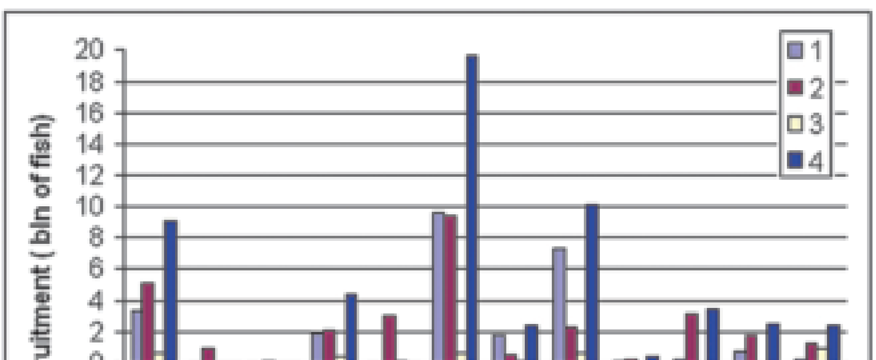
Some species make seasonal use of the Okhotsk Sea. During the 1980s, biomass estimates for Japanese sardine exceeded 1 million t. The dramatic decline of this species throughout the northwestern Pacific was also observed in the Okhotsk Sea and after 1993, no sardines were caught.

Summer migrants from the south are now dominated by anchovy and arabesque greenling.[126] Their abundance appears to depend on the warmth of the southern Okhotsk Sea and the magnitude of the Soya Current.

Walleye pollock The walleye pollock fishery in the eastern Okhotsk Sea was started by the Japanese during the 1950s. The Russian fishery began in 1963 and became almost exclusively Russian after 200-mile exclusive economic zones were established during the late 1970s. The fishery targets spawning and pre-spawning fish as they form dense aggregations. Spawning stock biomass declined through the late 1990s, reaching its lowest value in the 20 year record in 2000. Recent egg and ichthyoplankton surveys indicate an increasing trend during the early part of this century (Figure 64).



[Figure 64] Estimates of walleye pollock spawning stock biomass in the Okhotsk Sea from 1984-2003, determined from ichthyoplankton surveys in (1) entire northern Okhotsk Sea, (2) western Kamchatka, and (3) northwestern Okhotsk Sea.



	92	93	94	95	96	97	98	99	0	1	2	3
1	3.37			1.88		9.64	1.78	7.26	0.12	0.23	0.75	0.2
2	5.09	0.92	0.05	2.09	3.02	9.35	0.51	2.25	0.23	3.14	1.75	1.27
3	0.59			0.36	0.07	0.65	0.07	0.59	0.02	0.01	0.01	0.98
4	9.05			4.33		19.6	2.36	10.1	0.37	3.39	2.52	2.45

[Figure 65] Estimates of recruitment of age-2 walleye pollock (in billions of fish) by sample year in (1) northern Okhotsk Sea, (2) western Kamchatka, (3) Shelikhov Bay, and (4) total Okhotsk Sea.

During the last 12 years, the estimated recruitment of 2-year old walleye pollock in the entire Okhotsk Sea was highest in 1997, followed by 1999 and 1992 (Figure 54). No recruitment peaks have been observed this century and 2000 may have been at a record low level. Although only the western Kamchatka area was surveyed in 1993 and 1994, the strong correlation between recruitment on the west Kamchatka shelf and total Okhotsk Sea recruitment (r= 0.908, on log transformed data), suggests that total recruitment was low in these years as well. There is some concern that a year of better recruitment in 1997 (1995 year-class) did not result in an abundance of older fishes in subsequent years. The intensity of the fishery on this year-class is a possible cause. Recruitment to the spawning stock by the strong 1997 year-class, considering measures of concentation of the stock, has, on the other hand, resulted in some growth of biomass in 2002-2003.

The 2000-2002 year-classes are average or even strong according to preliminary estimtes so there is a potential for increasing walleye pollock resources in the Okhotsk Sea in the second half of the current decade.

Mesopelagic fishes About 61 species of mesopelagic fish belonging to 53 genera and 33 families have been recorded in the Okhotsk Sea midwater layer.[127] According to data collected in trawl surveys in 1987-1991, the total mesopelagic fish biomass ranged from 19 to 30 million t.[128] Northern smoothtongue (*Leuroglossus schmidti*) predominated and contributed about half of this value: 42-66%. Another bathylagid fish, *Lipolagus ochotensis*, and several myctophids (*Stenobrachius nannochir, S. leucopsarus, Diaphus theta*) are also important members of mesopelagic fish community. These species undertake daily vertical migrations to the surface and form significant aggregations and sound-scattering layers in the upper horizons at night and in midwater layers during the daytime.

Squid Squid are a very important item in the food web of the Okhotsk Sea ecosystem. Sixteen species of squid, belonging to nine genera and six families, are known there. The family *Gonatidae* contains ten species, two of which (*Berryteuthis magister and Gonatopsis borealis*) are the most abundant cephalopods.[129,130] Total squid biomass was estimated at 3.5–4 million t in the 1990s, and the annual consumption of squid is about 12 million t, a figure made possible by the highly productive characteristics of this group of animals. Gonatid squid also migrate to the sea surface at night and participate in the sound-scattering layers.

Groundfish The total groundfish biomass was estimated as 3.5 million t in the Okhotsk Sea shelf in the 1980s and the average concentration was 5.4 t km^{-2}. Among them 50 % are flatfish, 21 % cods, and 11 % sculpins. These three groups of groundfish play the main role in the fish productivity of the Okhotsk Sea shelf. The relative share of other species is not so large, though the biomass of families as Liparidae, Zoarcidae, Rajidae can be up to the high level. The main groundfish resources are concentrated in the northeastern part of the Okhotsk Sea. The West Kamchatka shelf is the most important region in terms of fish productivity, where the catch of the fish was equal to 21.4 - 21.7 t km^{-2} during the late 1970s, with a high quantity of cods, flatfish and crabs. In the 1980s, catches of yellow-finned sole (*Limanda aspera*) and Pacific cod (*Gadus macrocephalus*) were predominant in this region. Pacific cod is characterized by a high productivity speed: its P/B ratio is 0.58. For plain sculpin (*Myoxocephalus jaok*) the P/B ratio is slightly less at 0.53 and P/B ratios for other species are within the range 0.3 - 0.52. The yellow-bellied flounder (*Pleuronectes quadrituberculatus*) has the lowest P/B ratio. Sakhalin flounder (*Limanda sakhalinensis*) is also characterized by a low P/B ratio.

The average P/B ratio for groundfish is 0.496 in the West Kamchatka shelf, taking into consideration the species composition in the 1980s. Thus groundfish production was 942.8 thousand t (excluding ground walleye pollock). In the Kamchatka shelf in the 1980s groundfish biomass on the shelf and the Okhotsk Sea slope was estimated as 3.5 million t.[111] The production runs up to 1.7 million t with the average data almost 2 t km^{-2} for the part of the sea mentioned above. Using the entire area of the Okhotsk Sea, average groundfish production was 1.1 t km^{-2}.

[Table 12] Dynamics of groundfish biomass (,000 t) West Kamchatka shelf 1996-2002

Groups	1996	1997	1998	1999	2000	2001	2002
Gadidae (except pollock)	213.6	199.5	153.2	107.1	63.4	53.3	67.9
Pleuronectidae	822.9	1076.3	554.1	368.3	383.2	531.3	405.3
Cottidae	111.5	114.5	105.4	101.8	121.2	179.0	182.1
Agonidae	8.7	19.0	18.1	15.7	36.6	35.6	29.2
Liparidae	7.3	5.2	3.9	3.0	4.3	17.3	64.7
Rajidae	3.9	9.2	5.6	7.2	8.7	9.0	5.7
Zoarcidae	1.3	3.0	2.8	4.4	3.4	4.8	11.5
Other fishes	5.2	10.3	6.2	16.1	24.2	54.4	109.3
Total	1174.4	1437.0	849.3	623.6	645.0	884.7	875.7

By 2000, the biomass had decreased considerably to 1.6 million t, according to the results of the Second Basin Okhotsk Sea expedition. The share of each species, within the benthic nekton community, and the P/B coefficient decreased respectively. As the result of these changes, the reduction of groundfish productivity occurred which was 0.704 million t in 2000 with the average quantity for the shelf and slope - 0.82 t km^{-2}, and 0.449 t km^{-2} in the whole sea.

Nektobenthos communities of the Okhotsk Sea were studied more thoroughly in comparison with the studies of the last 5 years. In 1997 and 2000 synchronous surveys were conducted by several vessels of the far-eastern fishery institutes up to a depth of 1000 m.

Although there has been a considerable reduction in the biomass of groundfish in the Okhotsk Sea over a short time, the reduction was not the same for different species (Table 12). Insignificant biomass increases for some species were observed. But the catch didn't exceed CPUE during fishing for the most of ground fish in the Okhotsk Sea. And for some species, including cods and flatfish, it was even less. Thus a sharp decrease of flatfish biomass was unexpected, especially in the West Kamchatka shelf which is the main area of flatfish in the Okhotsk Sea. Nektobenthos biomass changes of this fish production region had a great impact on the total groundfish biomass of the Okhotsk Sea.[122]

Pacific salmon Reports of total Russian catches of adult Pacific salmon in the northwestern Pacific until 2001 can be found in the *Pacific Salmon* chapter of this report.

Japanese research vessels have conducted surveys for Pacific salmon and zooplankton in the Okhotsk Sea in 1993, 1996, 2000, and 2002. In 2002, salmonids were distributed widely in the research area, although they were less abundant south of 49°N and north of 54°N. Chum salmon dominated in the northeastern waters, and arabesque greenling dominated in the southwestern waters of the Okhotsk Sea. Small numbers of masu salmon and sockeye salmon were also caught. The seasonally warm upper layer varied in thickness from 25 to 60 m deep, overriding the cold (< 0°C) layer at ~70-120 m depth. Chum and pink salmon were found in the surface layer between 5-12°C. The echosounder indicated many targets from the surface to 10 m while most of largest fish schools were distributed between 15 and 30 m.

Pacific herring Trawl survey data identified a considerable drop in the biomass of Pacific herring in 2002. The decline was primarily connected with natural and fishery elimination of older fishes (age 10+ and higher) whose biomass exceeded 500 thousand t in 2001 but decreased to 134.4 thousand t in 2002. Severe oceanographic conditions during the winter of 2000/01 reduced the feeding period in the summer/autumn of 2001, and apparently resulted in an increased natural mortality of all age groups.

[Table 13] Invertebrate fisheries in the Okhotsk Sea by region

Area	Historical[1]	Current[1]	Trend[2]	Status[3]
Snow crab (*Chionocoetes opilio*)				
W Kamchatka	M	?	?	D
Deepwater	L	M	P	F
E Sakhalin	L	M/L	D	F
Tanner crab (*C. bairdi*)				
W Kamchatka	M/L	?	?	F
Angled Tanner crab (*C. angulatus*)				
N Okhotsk	M	?	?	U
Hair crab (*Erimacrus isenbaeckii*)				
Kuril	S	M	?	F
E Sakhalin	S	S	?	F
Hokkaido	L	M	?	F
Red King crab (*Paralithodes camtschaticus*)				
W Kamchatka	L	S	D	F
NW Okhotsk	M	S/M	P	F
Kuril	S	?	?	F
E Sakhalin	S	S	D	F
Hokkaido	S/M	S	?	F
Hanasakigani (*P. brevipes*)				
Okhotsk Sea – Not reported				
Blue King crab (*P. platypus*)				
E Shelikov	L	M	P	F
NW Shelikov	M	M	P	F
Iona Island	S	S	D	F
NE Sakhalin	S	S	D	F
Hokkaido	S	?	?	F
Golden King crab (*Lithodes asquispinus*)				
E Sakhalin	S	S	?	F
N Okhotsk	L	S	D	F
Kuril	M/L	M	D?	F
Hokkaido	S	?	?	F
Northern shrimp (*Pandalus borealis/eos*)				
W Kamchatka	S/L	L	?	D/F
N Okhotsk	M/L	L	?	D/F
E Sakhalin	M/L	L	?	D/F
Humpy shrimp (*P. goniurus*)				
W Kamchatka	S	S	?	U/D
S Sakhalin	S/M	S	?	U/D
Hokkai shrimp (*P. latirostris*)				
S Sakhalin	M	S/M	P	D/F
S Kuril	M	S/M	P	D/F

1. Abundance (relative to historical): L= Large, M= Medium, S= Small, ?= Unknown
2. Longterm Trend: D= Declining, P= Periodic fluctuations, ?= unknown
3. Status: F=Fully developed, D=Developing, U=Undeveloped.

Invertebrates In 2001, PICES Working Group 11 published a report on commercially important crabs, shrimps, and lobsters in the North Pacific Ocean.[131] The status and trends of invertebrate fisheries in the Okhotsk Sea were summarized (Table 13). With the exception of the northern shrimp, the current abundance of invertebrate species taken in fisheries in the Okhotsk Sea is either lower than or equivalent to historical abundance levels. Long-term trends for most king crab species are reported as either declining or unknown, with some species thought to vary with periodic fluctuations. The long-term trends of all invertebrate fisheries occurring in Hokkaido are reported as unknown.

Macrozoobenthos The history of zoobenthos research of the Okhotsk Sea started in the 1960s[132] and continued through the 1980s.[133,134,135] A Bottom Drag Ocean-50 was used to estimate benthos. The biomass of the large species was estimated from trawl survey data. They were conducted on the Okhotsk Sea shelf in 1981-1988. In some regions the surveys took place several times and the average of many years was used.

The average macrozoobenthos biomass is 384 g m^{-2} in the Okhotsk Sea (shelf). Due to benthic research conducted in the 1980s, the fauna can be divided into 2 trophic levels[123]. The average biomass of the second trophic level (Rhizopoda, Spongia, Hydroidea, Priapuloidea, Echiuroidea, Sipunculoidea, Bryozoa, Bivalvia, Cirripedia, Ophiuroidea, Echiuroidea, Holoturoidea, Ascidia, 90% of Amphipoda and Gastropoda biomass and 70% of Polychaeta biomass) is equal to 352 g m^{-2} in the shelf of the Okhotsk Sea. The highest concentration of this level (up to 491-535 g m^{-2}) is found in the Shelihov Bay. There are some regions where predatory species concentration is above the average one. In the West Kamchatka shelf and in the Terpenie Bay the predatory species constitute 10-15%, while in the other regions their quantity is at the most 6.6 - 10 %.

The average biomass of the third trophic level (Asteroidea, Nemertini, Decapoda, Anthozoa, 10% Gastropod and Amphipod biomass and 30% Polychaeta biomass) is almost 10 times less than the biomass of the second level at 32 g m^{-2} or 8.3 % of the total benthos biomass. The average production of the second trophic level is 534 g m^{-2}. The total production of this community is estimated to be 466 g m^{-2}. An analysis of biological production rates showed that the P/B coefficient of the second trophic level varies from 1.18 to 1.164 and 1.02-1.31 at the third level.

After the long break, macrobenthos surveys recommenced in the Okhotsk Sea in 2001-2002. The macrobenthos biomass had increased in the regions surveyed. One of the reasons for this increase was a reduction of species feeding on benthos - groundfish (especially cods). Though detailed analysis of the community structure is continuing, we can conclude that there are no reasons to speak about a crisis in the groundfish community of the region in question. There is no basis for describing the groundfish species as undernourished.

Marine Birds and Mammals

Seabirds No data reported.

Pinnipeds In the Okhotsk Sea there are 4 species of the true seal (Phocidae): ringed seal (*Pusa hispida*), ribbon seal (*Histriophoca fasciata*), bearded seal (*Erignatus barbatus*), larga (*Phoca largha*); and two species of eared seal: northern fur seal (*Callorhinus ursinus*) and Steller sea lion (*Eumetopias jubatus*). The Kuril Islands are inhabited by the island form of the common seal, the antour (*Phoca vitulina stejnegeri*). On the whole, fin-footed resources in the Okhotsk Sea and the Kurils make up 1.8 million animals; 90% of them are the true seals while the rest are eared seals. Among the former, ringed seal and ribbon seal are the most numerous, amounting to 40 % and 20 %, respectively, of all seals in the region. Bearded seal and larga have equal abundance at 12% each. The true seals were commercially harvested in the past. Before 1968 sealing was not regulated, with annual catch of 66,000-102,000 animals that resulted in harsh population decline. Due to a reduction in total sealing (down to 38,000-47,500 animals) the seal stock was restored. Thereafter, sealing continued within scientifically based recommendations. Since the mid-1980s the harvest has increased to 72,000-89,000 animals per year, reaching 95 % of the catch limits in the Okhotsk Sea and 70-80 % in the Bering Sea.[136]

Considering the current stability of seal abundance in the Okhotsk Sea during surveys in the 1990s, and the prolonged absence of sealing, as well as a positive population response to reduction of hunting, biologists in Russia suggest that the seal stock in the Okhotsk Sea is in a safe state at present. However, in organizing sealing for true seals in the future, we should keep in mind that it must not be as large-scale as it was in the past.

Steller sea lions in the Okhotsk Sea have several rookeries, bachelor haul-out sites and places for juveniles. The most numerous group of Steller sea lions inhabits the Kuril Islands. The total number of sea lions inhabiting the Kurils is a little more than 5,000 individuals, of which 1,900 are pups.[137] A rather numerous group of Steller sea lions is situated on the Iona Islands, where 952 pups were born in 2001, and the registered number of adult individuals exceeded 1,500.[138] At Tyuleniy (Robben) Island in 2002, the number of adult Steller sea lions was close to 1,500, with more than 400 pups. In the Iamskiy Islands in 2001 the number of newborns totaled 360, and the number of adults exceeded 900 animals. On the Lisyanskiy Peninsula there lay a little more than 200 adults and two dozens newborns in 2000. There is one (not large) bachelor haul-out here too. On the Zavyalova Island there was a juvenile haul-out site with a total of about 100-130 individuals.[138] One bachelor haul-out with unsteady number (200-500 animals) is at the Opasnostiy Rock in the LaPerouse Strait, and another is at the Sivuchiy Cape (Western Kamchatka), where the number of individuals ranges from a few dozens to 2,500 in winter and in March.[137] In summary, the number of Steller sea lions on the Kuril Islands has been in steady state after the depression of 1970-90s, while on the rookeries of other parts of the Sea of Okhotsk it is increasing each year.

The number of northern fur seals at the Tyuleniy (Robben) Island has been increasing steadily since 1993, and on the Kurils it has apparently remained constant since 1988.

Cetaceans As has occurred elsewhere in the North Pacific, killer whales (*Orcinus orca*) in the Okhotsk Sea have been letting humans catch their food since the autumn of 2000. The Greenland halibut, or turbot (*Reinhardtius hippoglossoides*), is the target species of a longline fishery in the eastern Okhotsk Sea. Observations from a commercial longliner indicated that about 10% of fishing operations were affected by killer whales. The loss of catch to *O. orca* is estimated to be about 1100 t.

There was a significant increase in the number of Minke whales and Dall's porpoise observed in the northern Okhotsk Sea in 1997.[139] The Minke whale abundance was previously estimated at 25,000 specimens in the Okhotsk Sea and adjacent waters.[140] Total dolphin numbers were estimated at more than 100,000 specimens.[111]

issues

Seasonal and interannual variability in climatic and synoptic current patterns are very high in the Okhotsk Sea. There is a paradox concerning the prevalence of northerly flows in the warm season that should be solved.

The impact of numerous eddies on the vertical transport of nutrients is critical for ecosystem productivity. Their topography and dynamics, particularly on interannual time-scales, needs further studies.

Deepwater circulation of the Sea of Okhotsk remains poor studied. Analysis of long-term variability of ice cover, taking ice thickness into account, is necessary. A conveyor ice formation mechanism in the "polynyas" requires the attention of quantitative modellers. The interannual and long-term dynamics of the Okhotsk Sea heat budget, during regime shifts and relatively stable periods, remains unclear. Understanding of the role of water column stratification in the Sea of Okhotsk heat budget needs to be revisited.

Another important task for hydrochemical studies concerns cycles of nutrients and organic compounds in the Okhotsk Sea ecosystem, their interannual and long-term dynamics. The Okhotsk Sea is characterized by an extremely high primary productivity, which has a seasonal character and is dominated by siliceous plankton. The bottom topography and water depth of the Sea of Okhotsk are strongly variable. Therefore, several types of sediment facies ranging from pelagic mud to organic-rich slope sediments can be found. This variety presents an excellent opportunity to study paleoceanographical time slices of varying resolution. Melt water influence, ice cover, river input and glacial-interglacial changes are control mechanisms for biological production, especially for carbon and siliicon cycles. Contaminant cycles have become significant in the recent years.

During the last few years, the phytoplankton and photosynthesis studies using new technique and methodology have increased estimates of gross primary production in the far-eastern seas ecosystem.

It is important to define how much the present understanding reflects the real values. Further researches of stock abundance dynamics of the plankton common species need to be continued. Optical and satellite (mostly for phytoplankton) techniques for the plankton abundance estimation have been developed in the last dozen years. Intercalibration studies are important for all these technical equipment for plankton sampling both in the ocean surface layer, and in the water column. At the present time, marine ecology deals with the results of calculation not with exact plankton abundance value. Verified assessment will be a basis for the lower trophic level modeling and connection of models to the existing higher trophic level models.

Factors affecting zooplankton reproduction success are poorly studied. Further research must include both the monitoring of planktonic community characteristics, and the collection of physical surrounding data series. Only preliminary estimates exist for contribution of bacterioplankton and planktonic infusoria, nano- and picoplankton in primary production and organic matter destruction. Similarly, almost nothing is known about the microbenthos and meiobenthos organisms composition, distribution, abundance and dynamics. Their role in food supply formation for the higher trophic level can be determinative. It needs an integrated research project development.

Higher trophic communities should be monitored on the level with other Okhotsk Sea ecosystem elements and parameters. Regulations of fish and squid stock abundance dynamics must be specified in the physical condition of a new climatic and oceanographic regime.

It is a way to develop understandings of the evolution of common species and whole nekton community in the variable environment.

Analysis is necessary to compare the present and 1950s-1960s climatic and oceanographic epochs in the Okhotsk Sea ecosystem. The likelihood and possible nature of the next large-scale changes must be predicted. The ability to make an early prediction of a regime shift is a critical issue of practical importance for marine science. To this end, the teleconnection between the Okhotsk Sea and other large marine ecosystems in the North Pacific and Arctic have to be studied in the nearest future.

Significant oil and gas reserves were first discovered on the northeastern Sakhalin shelf.

The total amount of oil and gas on the northeastern shelf of Sakhalin Island is estimated at 1.2 billion t and 800 billion m^3, respectively. In recent years, one shelf oil field began to be explored from a sea platform and two others are prepared for industrial exploration. Considerable oil and gas reserves can be located on the Okhotsk Sea shelf. Evidence of this assumption is the fact that the Okhotsk Sea is characterized by the highest potential methane production rate in the Northern Hemisphere.[141] The shelf areas around Sakhalin, off the northern Okhotsk Sea coast, west of Kamchatka, the Kurile Island Arc and the Kurile-Kamchatka subduction zone belong to an area with highly active methane and fluid vents. High methane production can be associated with oil and gas fields.

critical factors causing change

The dynamics of atmospheric activity centers over the ocean cause large-scale changes in atmospheric pressure patterns that repeat on decadal scales. The decreasing frequency of some types of atmospheric circulation and increases of the others are peculiar to each period. Corresponding changes occur on the ocean surface as well. The transition from meridional to zonal transport in atmosphere in the 1970-80s was followed by an intensification of ocean surface currents, and a renewal of Okhotsk Sea waters. On the return to generally meridional flows, water exchange with the Pacific Ocean decreased. In the early 1990s, a decrease of water exchange between far eastern seas and the Pacific Ocean also contributed negatively to heat budget of the upper pelagic layers.

Cooling of shelf waters is intensive in the far eastern seas due to variability in atmospheric processes. Beginning from the late 1990s, the seasonal development of atmospheric processes over the northwestern North Pacific was like the “cold decades” of the 1960s and 1970s. The duration of the cold season increased. The number of days with a zonal pattern of atmospheric circulation decreased.

It is known that cold Arctic air masses move into the Bering and northern Okhotsk seas during periods of low zonal atmospheric circulation. This results in decreased air temperatures and corresponding surface water cooling.[142] These factors establish intensive winter cooling of shelf waters that lead to temperature declines in subsurface layers through sinking of dense cool surface water during the cold season.

It was forecast that during the 1990–2000s a regime shift would return conditions to those of the 1950s-1960s. The predicted changes were most pronounced in the pelagic plankton and nekton communities after the 1989. They developed in accordance with the following cause-effect chain: oceanographic conditions changes caused walleye pollock and Japanese sardine biomass to decline, which decreased the grazing pressure on zooplankton. The resultant growth of zooplankton forage species biomass resulted in a growth in predatory zooplankton and alternative fish species (herring, Japanese anchovy, Japanese common squid) biomass. In turn, this led to a decrease in forage zooplankton biomass and a balancing of plankton and nekton communities in the new environmental conditions.

© Y. Yakovlev

Authorship

Elena Dulepova
Pacific Research Institute of Fisheries & Oceanography (TINRO-Center)
4 Shevchenko Alley
Vladivostok
Russia 690950
E-mail: dep@tinro.ru

Vladimir Radchenko
Sakhalin Research Institute of Fisheries & Oceanography (SakhNIRO)
196 Komsomolskaya Street
Yuzhno-Sakhalinsk
Russia 693023
E-mail: vlrad@sakhniro.ru

Contributors

Some of this material was provided by participants at the 3rd PICES Workshop on the Okhotsk Sea and Adjacent Areas that was convened at TINRO-Center in Vladivostok, Russia from 4-6 June 2003.

Irina Brigina SakhNIRO, Yuzhno-Sakhalinsk, Russia
Konstantin A. Karyakin TINRO-Center, Vladivostok
Alexey E. Kuzin TINRO-Center, Vladivostok, Russia
Elena Ustinova SakhNIRO, Yuzhno-Sakhalinsk, Russia
S. V. Loboda TINRO-Center, Vladivostok, Russia
Vladimir Luchin FEHRI, Vladivostok, Russia
Igor V. Melnikov TINRO-Center, Vladivostok, Russia
A. S. Perlov TINRO-Center, Vladivostok, Russia
Pavel Tischenko Pacific Oceanological Institute, Vladivostok, Russia
Juji Seki National Salmon Resources Center, Sapporo, Japan
Georgy Shevchenko SakhNIRO, Yuzhno-Sakhalinsk, Russia
E. P. Shvetsov TINRO-Center, Vladivostok, Russia
Elena Ustinova SakhNIRO, Yuzhno-Sakhalinsk, Russia
Alexander I. Varkentin KamchatNIRO, Petropavlovsk-Kamchatsky, Russia