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Sea of Okhotsk

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highlights

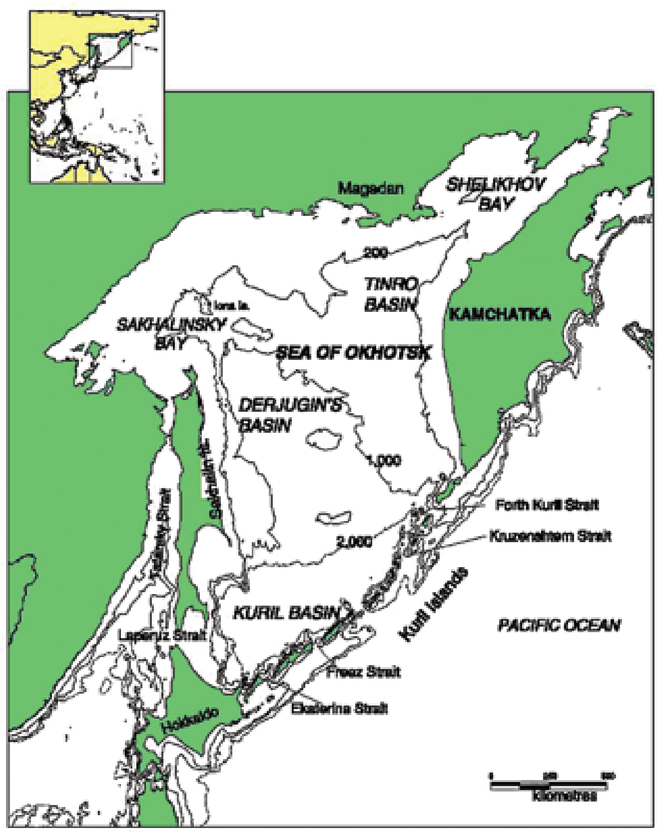
- When determined from a broad area located upwind of the Sea of Okhotsk, average winter air temperatures indicated a warming trend. At individual meteorological stations in the Okhotsk region, the preferred model at 9 of 10 stations was an abrupt shift to warmer winters in 1989 rather than a long-term trend.
- Sea ice extent in the Sea of Okhotsk has decreased by about 20% in 30 years; ice cover in April 2009 was the minimum observed in the last 50 years.
- The co-occurrence of warming and decrease in dissolved oxygen concentration in the northwestern North Pacific, originating from the Sea of Okhotsk (Nakanowatari et al. 2007), implies that overturning in the northwestern North Pacific has weakened. Such a trend could possibly affect the material cycle and biological productivity in the North Pacific.
- Reductions in the formation of intermediate layer water have been reported but the most recent data from the central Sea of Okhotsk do not exhibit a continuation of this trend, despite the decreasing ice cover and warmer air temperatures.
- Recent observations (Nishioka et al. 2007) suggest that the ventilated intermediate water from the Sea of Okhotsk is a potential source of iron for the iron-limited, high-nitrate, low-chlorophyll North Pacific.
- The advection of Pacific water into the Sea of Okhotsk was near average from 2002-2009.
- Returns of pink salmon continued to increase in both even- and odd-year cycles and coastal catches in 2006 and 2007 reached record highs of 180,700 and 178,500 mt, respectively. Total salmon catch on the Russian coast of the Sea of Okhotsk reached the historical high in 2009 at 345,000 mt, including 275,000 mt of pink salmon.

- The walleye pollock spawning stock increased by 10.1 billion fish in 2009 with the 2004 and 2005 year-classes accounting for 80% of this growth.
- The abundance of commercially valuable invertebrate species (crabs, shrimp, and snails) remains at a low level.
- Surveys conducted in 2002 indicated that the macrozoobenthic community in the Sea of Okhotsk has changed little since the last major survey twenty years earlier.
- Large-scale ecological changes developed from a causal chain of changing oceanographic conditions that led to earlier declines in abundances of walleye pollock and Japanese sardine, which in turn decreased the grazing pressure on zooplankton resulting in an increase of zooplankton forage species and subsequently an increase in the abundance of predatory zooplankton and the biomass of other fish species.

Introduction

The Sea of Okhotsk is a semi-enclosed marginal sea bounded by Russia to the north and west and Japan to the south (Fig. OK-1).

The Kuril Island archipelago separates it from the Pacific Ocean. Its area (1,528,100 km²) is similar in magnitude to the Bering Sea (2,315,000 km²). The exchange of water with the North Pacific Ocean has a considerable effect on circulation and intermediate-water formation. The bottom topography is rugged, featuring the deep Kuril Basin, Academy of Science of USSR Rise, and the Oceanology Institute Rise in the southern deepwater part of the Sea of Okhotsk. Two troughs connect the deeper waters of the Sea of Okhotsk with its two hollows (Derjugin's Hollow and TINRO Basin). These are deep cuts in the wide northern shelf. The shelf zone occupies almost 40% of the total area (Larina 1968) and is widest in the north (up to 400 km). Two large bays (Shelikhov in the northeast and Sakhalinsky in the southwest) constitute ›25% of the shelf zone. The shelf zone is somewhat isolated from direct water exchange with the open ocean by the Kamchatka Peninsula. Waters of Pacific origin penetrate mainly through the northern Kuril straits: from the shallow First Kuril Strait to the northern part of Boussol Strait (depth: 2318 m).



[Figure OK-1] Sea of Okhotsk. Modified from Udintsev (1957).

Large-scale circulation in the Sea of Okhotsk is cyclonic with northward flow in the northeastern part due to the West Kamchatka Current, and southward flow in the west due to the East Sakhalin Current (Leonov 1960; Moroshkin 1966; Kitani 1973; Favorite et al. 1976). Their interaction with the coastline and bottom relief generates several smaller currents (Chernyavsky 1981; Markina and Chernyavsky 1984; Chernyavsky et al. 1981; Luchin 1982; Tally and Nagata 1995). On the northern shelf, the westward current is deflected southward by the shore, then leaves via the southern Kuril straits. A branch of the East Sakhalin Current turns eastward off eastern Sakhalin Island and carries water and ice out to the Pacific Ocean through Boussol Strait. Two-way flow has been reported through this strait with outflow in the upper layers in the southwestern part and inflow in the northwestern part and in deeper layers (Leonov 1960; Kurashina et al. 1967; Riser 1996).

The heat balance at the sea surface (usually calculated without taking horizontal advective heat flux into consideration) is -25 kcal·cm^{-2}·yr^{-1} (Batalin and Vasyukova 1960), but this apparent deficit is compensated by warmer water entering from the Pacific Ocean or by poleward flow through Soya Strait. Over an annual cycle, the sea absorbs heat in the northwest and gives it back to the southern and eastern parts, especially near the western Kamchatka coast.

Seasonal changes are distinctive. There can be ice from November (rarely in October) to June. In March, the Sea of Okhotsk is mostly covered by ice, except near Kamchatka and the Kuril Islands. A meridional region of open water occurs along the western Kamchatka coast in winter, reflecting the influence of warmer Pacific waters. Because of severe cooling on the northern shelf in winter, the water structure of the Sea of Okhotsk is characterized by a residual frigid layer whose core is -2°C. This cold intermediate (dicothermal) layer is a unique feature of the Sea of Okhotsk and it can remain throughout the warm season. There is a significant temperature difference between the surface and subsurface waters. The sea surface temperature (SST) rises to 11°-13°C over most of the area and to 18°-19°C near Hokkaido and southern Sakhalin due to insolation, vertical mixing and increased Pacific water influx during the warm season.

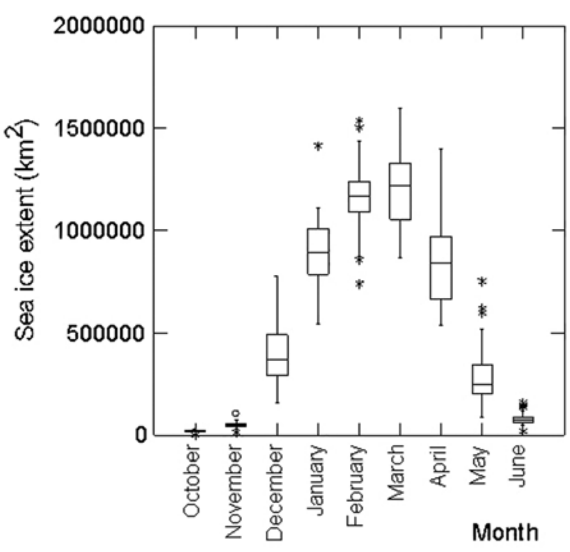
What follows in the remainder of this chapter is an attempt to capture the current status and trends in the Sea of Okhotsk, especially during the period from 2003-2008 (hereafter, the *focus period*). Analyses and descriptions of the focus period, to the extent that data are available, have been interpreted within the context of historical observations and the extent of sampling during the focus period.

2.0 Climate

2.1 Air temperature and sea ice

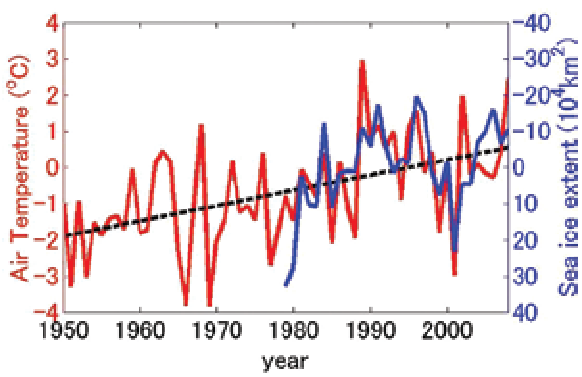
(Ohshima, McKinnell)

The coldest place in the northern hemisphere is located immediately upwind of the Sea of Okhotsk so sea ice is prevalent in the cold season (Ohshima 2008). The seasonal expansion and contraction of ice cover affects air-sea heat flux, water column mixing and stratification, and renewal rates of the subsurface cold residual layer, etc. Therefore, the extent of ice cover is usually closely correlated with the other physical and biological indices. Interannual variability is greatest on the shoulders of the main part of the ice season (maximum in March and April) (Fig. OK-2).

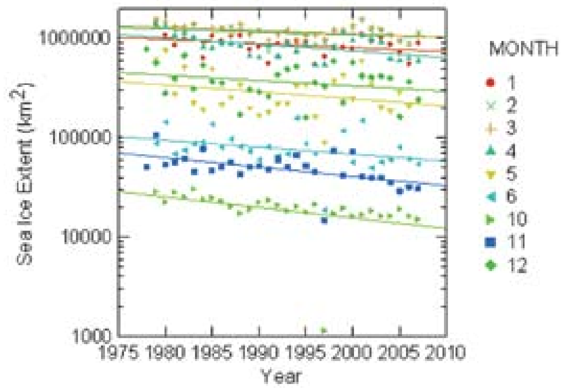


[Figure OK-2] Box and whisker plots indicating median ice extent by month in the Sea of Okhotsk. Data available from the U.S. National Snow and Ice Data Center (http://nsidc.org/data/smmr_ssmi_ancillary/area_extent.html#graphs).

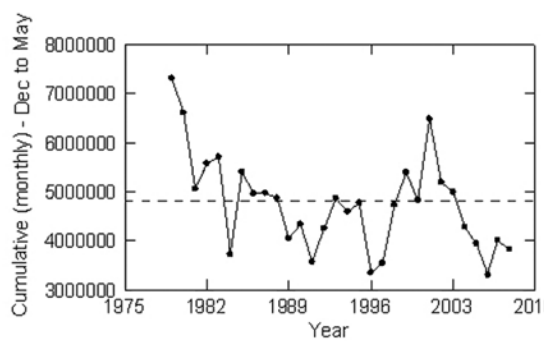
Since accurate observation by satellite became possible, the sea ice extent in the Sea of Okhotsk (blue line in Fig. OK-3) has decreased by about 20% in 30 years, or by approximately 150,000 km², equivalent to ~10% of the entire area. The maximum extent of sea ice has a linear declining trend in all months when sea ice is present, although the trend is not statistically significant in every month (Fig. OK-4). From 2002-2006, the area of maximum ice cover decreased gradually after experiencing the second largest value in March of 2001 (1,516,700 km²), or 97% of the total Sea of Okhotsk area. After this progressive decline, the seasonal maximum ice cover has dropped to 903,800 km², or 57.8% of the total area. The winter of 2005-2006 had the least integrated sea ice cover (sum of the monthly sea ice areas from December to May) of any year in the record up to that time (Fig. OK-5). In the winters of 2006-2007 and 2007-2008, maxima of the Sea of Okhotsk ice cover recovered up to 1,073,000 – 1,106,900 km² but remained less than average (Ishizaki 2008, 2009).



[Figure OK-3] Time series of surface air temperature anomaly in the cold season (October to March) and the linear trend over northeastern Eurasia (50°-65°N, 110°-140°E) from 1950 to 2008 (red solid and dashed lines, respectively), and the annual sea ice extent anomaly in the entire Sea of Okhotsk in February from 1979 to 2008 (blue line). The scale of the sea ice extent anomaly is indicated on the right axis and inverted. The surface air temperature anomaly is derived from (Jones 1994), and the sea ice extent anomaly is derived from the Met Office Hadley Centre's sea ice data set (Rayner et al. 2003). The surface air temperature anomaly with respect to the 27 year average from 1979 to 2005 is shown for the benefit of comparison with the sea ice extent anomaly. Updated after Nakanowatari et al. (2007).



[Figure OK-4] Linear trends in sea ice extent (km²) in the Sea of Okhotsk , by month from 1978 to 2007. Data available from the U.S. National Snow and Ice Data Center (http://nsidc.org/data/smmr_ssmi_ancillary/area_extent.html#graphs).



[Figure OK-5] Cumulative monthly sea ice extent from December to May for each year 1978/1979-2007/2008; plot points correspond to the year of the January in each sum.

A feature that was characteristic of 2007-2009 was a quick retreat of ice in the second half of the cold season. In the spring of 2009, for example, the thaw occurred so intensively that the ice extent quickly decreased to 320,000 km² by late April, 37% below the long-term average. Average ice cover in April of 2009 was 428,000 km². This is the minimal value observed since the winter of 1956-1957 and is 30% lower than the recent minimum observed in April of 1989 (611,000 km²). The month of maximum extent of sea ice has moved from March to February during the last two years.

Interannual variability of sea ice extent in the Sea of Okhotsk is highly correlated with that of surface air temperature (red line in Fig. OK-3) in the preceding fall and winter (October to March) in the region immediately upwind (50°-65°N, 110°-140°E) of the Sea of Okhotsk (r = -0.61) (Ohshima et al. 2006). Of particular note is that this air temperature has increased considerably during the past 50 years (2.0±1.4°C). This value of 2.0° far exceeds the rate of average temperature increase worldwide (0.65° over the past 50 years), thereby clearly indicating that the region is significantly affected by global warming. The correlation between this temperature and the sea ice extent suggests that decreases in the sea ice preceded the beginning of satellite observations. Visual observations at the Hokkaido coast, located on the southern boundary of sea ice extent in the Sea of Okhotsk, also show the decreasing trend of sea ice season length during the past 100 years (Aota 1999). These suggest that sea ice generation has decreased during the past 50 years. Since Dense Shelf Water is produced by active sea ice production on the northwestern shelf of the Sea of Okhotsk (Shcherbina et al. 2003), the properties of intermediate waters in the Sea of Okhotsk and the North Pacific, which are ventilated through Dense Shelf Water, are possibly affected by global warming.

2.2 Shift or trend *(McKinnell)*

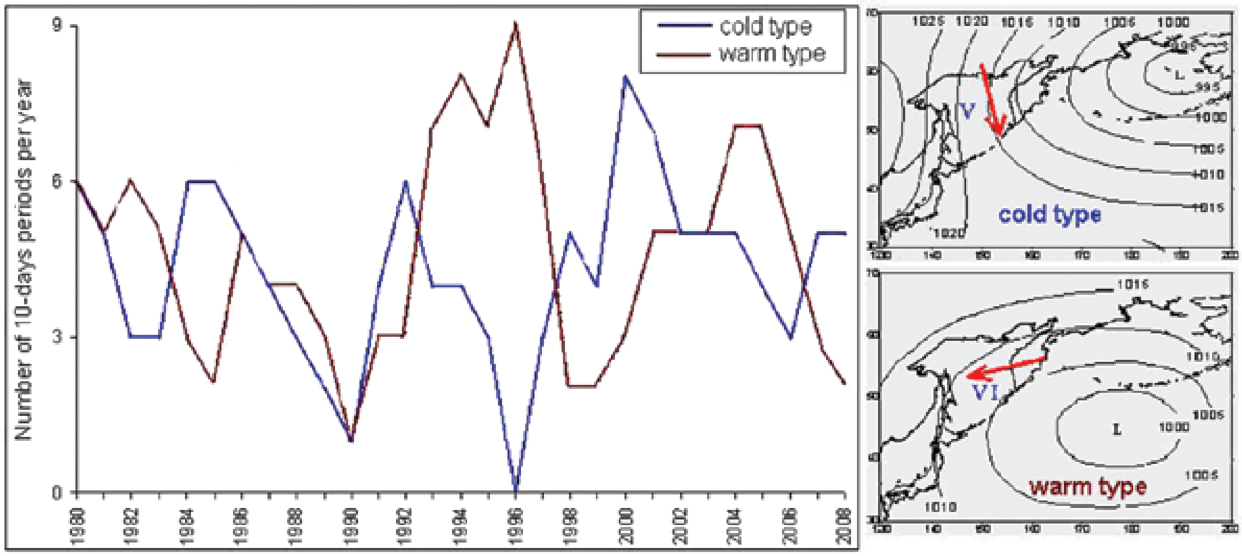
An issue of some interest is whether the higher average winter air temperatures in the last 20 years are the result of a persistent trend or an abrupt change. When average temperatures are determined over a broad area upwind of the Sea of Okhotsk, the result is an increasing trend in air temperature (Fig. OK-3; Ohshima 2008). However, when data from individual meteorological stations in the region are examined, the preferred model at 9 of 10 stations was an abrupt shift to warmer winters at 1989 rather than a long-term trend (Table OK-1). The trend model was preferred at only one station (Okhotsk) which also had the least average increase after 1989. The magnitude of the average increase from 1989 at all other stations varied from a low of 1.06°C to a high of 2.96°C. At least some of the higher average temperature can be attributed to a decrease in average winter monsoon over the region from 1989.

[Table OK-1] Evaluation of two models of increasing mean winter (JFM) air temperatures in the Okhotsk region (linear trend versus sudden shift in 1989). The model with the lowest AICC is the better fit to the observed data (best fit in red). Average increases after 1989 are reported under Temperature Difference. The name of the meteorological station is reported in the last column. Data from U.S. NASA GISS (Goddard Institute for Space Studies) Surface Temperature Analysis.

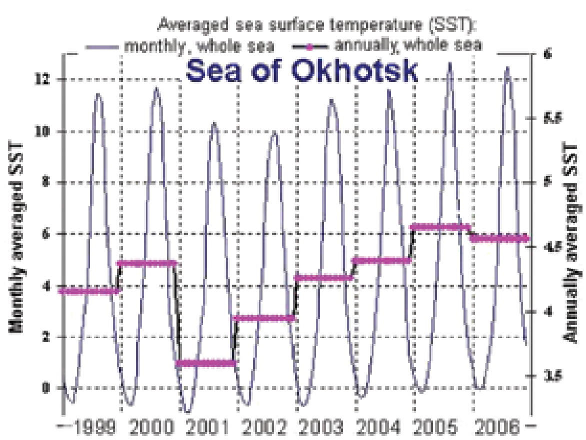
Corrected Akaike Information Criterion		Temperature Difference (°C)	Station
Trend	Shift at 1989		
184.55	165.24	1.93	Abashiri
206.04	200.72	1.58	Ajan
242.87	233.61	2.56	Im. Poliny Osipenko
234.87	228.55	2.96	Jakutsk
177.10	161.88	1.60	Nemuro
214.11	209.16	1.64	Nikolaevsk-na-Amure
227.27	226.92	1.06	Ojmjakon
189.18	190.86	0.73	Okhotsk
177.26	160.79	1.49	Wakkanai
206.60	198.71	1.68	Yuzhno-sakhalinsk

2.3 Sea level pressure *(Radchenko)*

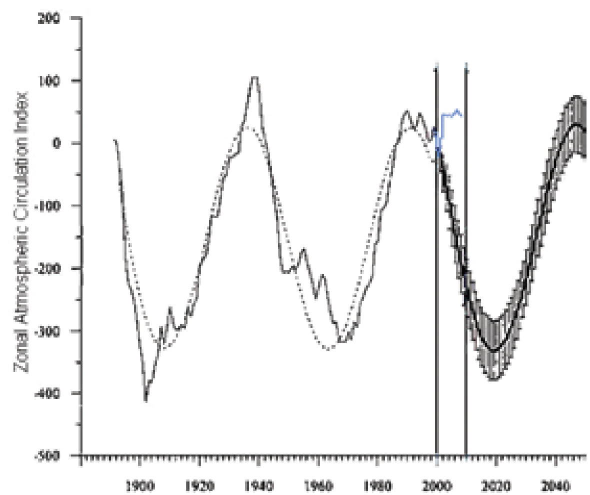
There is a large pressure gradient between the Siberian High Pressure Core and the Aleutian Low Pressure region. The gradient causes powerful winds over the northern Sea of Okhotsk coast and Shelikhov Bay. Beginning in the early 1990s, the magnitude of the pressure gradient declined and a warmer zonal atmospheric circulation has predominated (Fig. OK-6). Local cooling was observed in the Sea of Okhotsk in 2000-2002 with the strongest northeasterly (cold) air flow from January–March of 2001 (Glebova 2006) which produced heavy ice conditions in winter of 2000-2001. A relatively short period of cooling was followed by a warmer period that has lasted until the present (Fig. OK-7) which defies an earlier forecast of a strong reversal to a "cold" meridional epoch from 2000- 2010 (Klyashtorin and Lyubushin 2005). The warm zonal circulation type persists (Fig. OK-8) (Dumanskaya and Fedorenko 2008).



[Figure OK-6] Patterns of "cold" (V) and "warm" (VI) types of atmospheric circulation above the Sea of Okhotsk, in accordance to classification by Glebova (2006, updated).



[Figure OK-7] Monthly and annual SST dynamics in the Sea of Okhotsk, 1999-2006 (after Khen et al. 2008).



[Figure OK-8] Long-term dynamics of the Atmospheric Circulation Index:WE zonal atmospheric circulation index (thin solid line), 1891-1999, dashed line – its model (harmonic oscillation). Thick solid line with standard deviation error bars is the forecast for 2000-2050 (Klyashtorin and Lyubushin 2005). Blue fragment – additional observed data from Dumanskaya and Fedorenko (2008).

During the warm season (April to September), the Far-Eastern Low is situated above the eastern edge of the Asian continent. It has a significant influence on the synoptic conditions above the Sea of Okhotsk region where it reaches its full development in July before diminishing. In the first half of the 2000s, atmospheric pressure at the center of the Far-Eastern Low was relatively high and the centre of the Far-Eastern Low moved eastward. This tends to weaken the summer monsoon, increase air temperatures throughout the region in late summer and autumn, and decrease precipitation in the northeastern part of the Sea of Okhotsk region (Shatilina and Anzhina 2008).

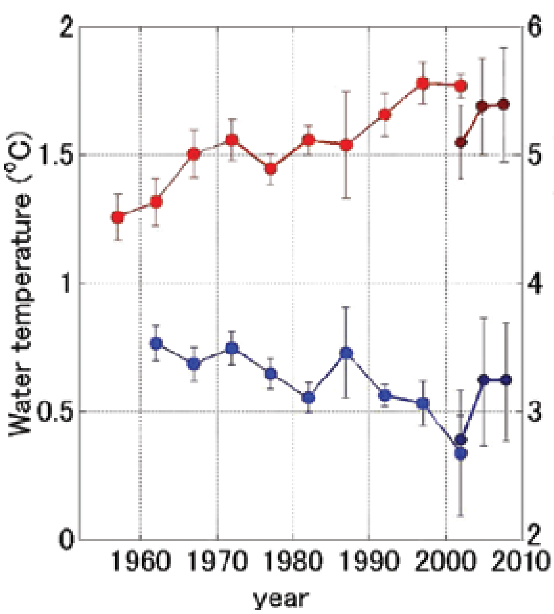
3.0 Physical Ocean

3.1 Ocean circulation and temperature

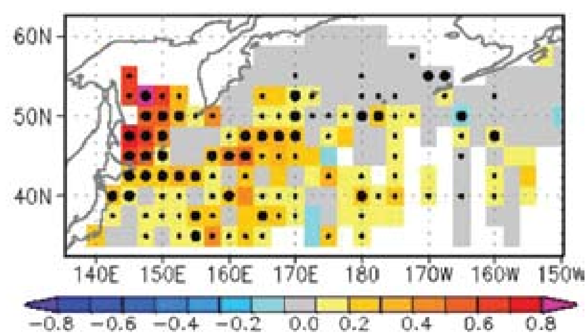
(Radchenko, Ohshima, Figurkin)

Vertical mixing in the Sea of Okhotsk in winter affects the oceanography of much of the North Pacific Ocean (Yasuda 1997). Sinking cold, oxygen rich, dense water from the surface creates a vertical circulation (i.e. overturning) down to intermediate depths (200-800 m). The temperature of the intermediate layer in the Sea of Okhotsk has increased over the past five decades. As warmer water generally holds less oxygen, the dissolved oxygen concentration in this layer has decreased (Fig. OK-9) suggesting a reduction in the formation of the intermediate layer as a result of decreased sea ice production. The downstream effects are evident in the intermediate water in the Northwest Pacific (Ono et al. 2001; Nakanowatari et al. 2007). However, this interpretation was based on data collected before 2003 and on the limited area of the Sea of Okhotsk (Wakatsuchi 2006; Gilbert et al. 2009). The most recent data from the central Sea of Okhotsk do not exhibit a continuation of this trend despite the negative trends of seasonal ice cover parameters (Fig. OK-4). In 2005 and 2008, the temperature of intermediate water in the Sea of Okhotsk (50°12' - 50°40' N, 146°52' - 149°00' E) at 27.0 σ_θ, corresponding to 200-600 m depth, was 1.67-1.69°C. The average oxygen concentration varied little, from 3.23-3.24 ml·l^{-1}. Oxygen concentrations in this part of the water column varied from 5.04 ml·l^{-1} at 200 m to 1.60 ml·l^{-1} at 600 m.

From 1955-2004, water temperature in the intermediate layer of the North Pacific has a warming trend that is most prominent in the Sea of Okhotsk (Fig. OK-10). This could be a result of reduced volumes of Dense Shelf Water sinking in the Sea of Okhotsk which has weakened the overturning in the North Pacific, but this is not the sole mechanism of intermediate layer ventilation. In summer, cold water intrusions appear at depths of 250-400 m near the north-eastern Sakhalin Island coast. Tides stimulate propagation of the cold shelf water enriched by oxygen at depths of intermediate water layers (Sosnin et al. 2007). It can therefore be concluded that the situation did not worsen during the focus period.



[Figure OK-9] Time series of temperature (red line) and dissolved oxygen (blue line) of intermediate water in the Sea of Okhotsk at the 27.0 σ_θ isopycnal (~250-550 m depth) during the past 50 years. Additions for 2002, 2005 and 2008 are from the TINRO-Center surveys.

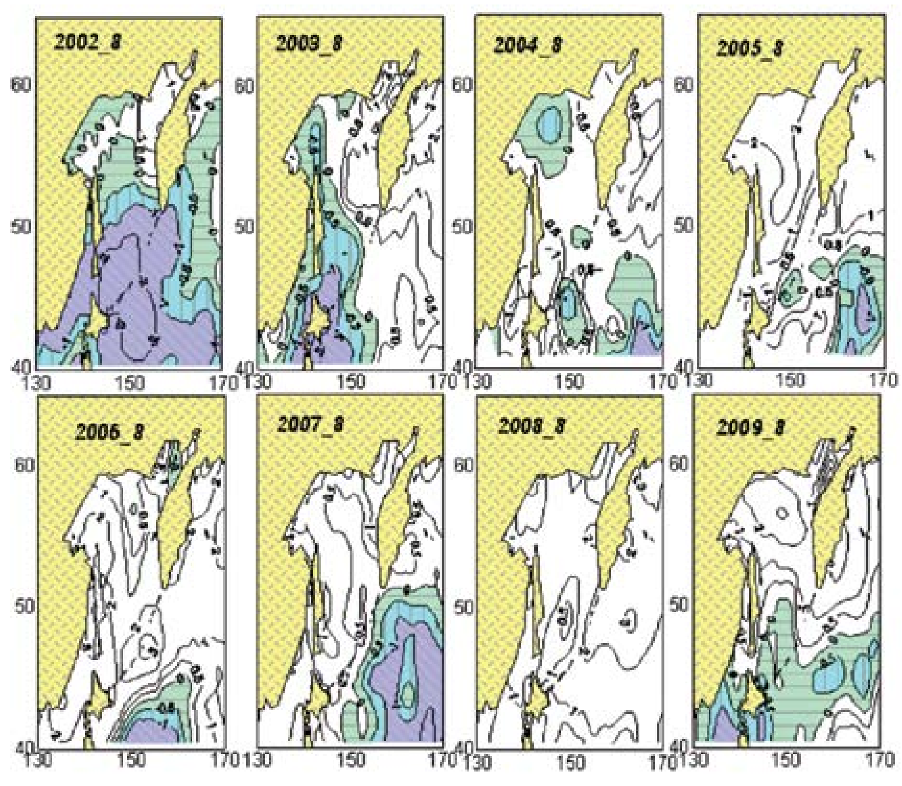


[Figure OK-10] Linear trend of water temperature anomalies (°C per 50 y) at density of 27.0 σ_θ from 1955-2004 in the northwestern North Pacific. Large and small dots indicate the grid boxes at which the linear trend is significant at the 99% and 95% confidence level, respectively. White color indicates the grid boxes with <10 years of data for the linear trend calculation (after Nakanowatari et al. 2007).

A recent review on progressive hypoxia in the coastal and open ocean (Gilbert et al. 2009) shows that oxygen trends from 1976–2000 are more negative than was observed during the 1951-1975 period. However, the trend in median oxygen from published results is more negative than the trends in median values computed from raw oxygen data. It suggests a publication bias in favor of strongly negative trends that is likely due to the adverse ecosystem implications of hypoxia.

The advection of Pacific water into the Sea of Okhotsk was near average from 2002-2009. It had decreased in the 1990s during a period when zonal atmospheric circulation dominated. The observed decrease was likely due to an intensification of the Subtropical Gyre (with the strengthening of the California Current) and decrease in the Subarctic Gyre (with the weakening of the Alaska Stream along the North America coast). The East Kamchatka Current, flowing along the eastern Kamchatka Peninsula coast from the Bering Sea weakened considerably (to 0.7-1.5 Sv) in the period from 1950 to the mid-1960s. Thereafter, a more active period (3-5 Sv) persisted from 1965 until 1989 when it weakened again in the 1990s with the minimum occurring in 1999 (0.2 Sv). In the beginning of the 21st century it has intensified but still remains below the climatic value of 2.3 Sv (Khen and Zaochny 2009). SST changes in the Sea of Okhotsk tend to occur two years later than in the Bering Sea. Through most of the focus period (2003-2006), the warmest years were 2003 in the Bering Sea and 2005 in the Sea of Okhotsk (Khen et al. 2008). The SST anomalies above +2°C occupied a vast domain in the northern Sea of Okhotsk in 2005 (Fig. OK-11).

Surface layer inflow from the Pacific Ocean intensified during the second half of the 1990s (Fig. OK-12). However, the waters carried by this flow originated in the East Kamchatka Current, where the average annual SST was low (3.63°C) in 1999 (Khen et al. 2008). It has increased gradually and reached 5.04°C in 2003, two years before the warmest year in the Sea of Okhotsk. Therefore, the warm conditions in the Sea of Okhotsk in 2005 were determined not only by the most intensive water transport by the West Kamchatka Current but also by the high heat budget of propagated waters. The situation was almost repeated



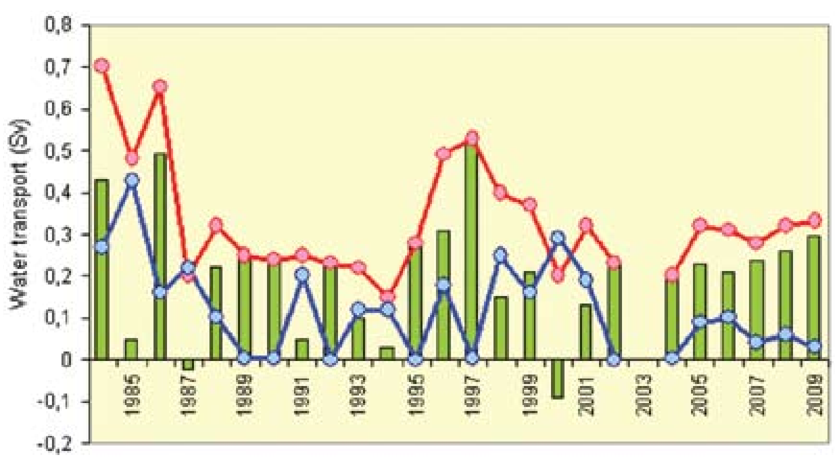
[Figure OK-11] SST anomalies (°C) in the northwestern Pacific Ocean in August of 2002-2009 (after Figurkin et al. 2008) with additions for the last years.

in 2008 when positive SST anomalies covered not only the Sea of Okhotsk but also the Pacific Ocean off Kamchatka and the Kuril Islands (Fig. OK-11).

Thermal conditions in the northern Sea of Okhotsk are also dependent on the distribution of West Kamchatka Current waters. In winter, the circulation pattern in the northern Sea of Okhotsk varies with the ice cover conditions (Figurkin et al. 2008). The most significant extremes were an icy 2001 and an iceless 1997. In the iceless winters, relatively warm waters of the West Kamchatka Current propagated westwards farther than 148°E longitude. In winter of 1997, they even reached the Okhotsk Settlement coast (59°23' N 143°18' E). In icy winters, the West Kamchatka Current waters did not penetrate the northern shelf area farther than 149° - 150°E. In 2001, there was a unique situation, when these warm waters did not reach the shelf on the whole. The warming influence of the West Kamchatka Current was limited by the continental slope in the TINRO Basin and the Shelikhov Bay mouth. The Compensational Current (Figurkin et al. 2008) flows in the opposite direction (southward) to the West Kamchatka Current and carries away penetrations of relatively warm waters. This current has intensified slightly since 1998 (Fig. OK-12). The balance of the relatively warm water transport on the northern shelf shifted to negative values in 2000. Since 2002, the volume of the poleward water transport and total transported waters balance was restored and has persisted at an average level of 0.31 Sv.

Correlation between ice extent and cold, saline water on the northern shelf diminished during 2002-2008 (Fig. OK-13). In 2002 and 2004, lower amounts of dense salty water corresponded with a reduction in ice cover. However, the correlation was disrupted after the relatively ice-free winters of 2005 and 2006 (Fig. OK-13). After the winter of 2006, negative temperature anomalies occupied almost all shelf areas. Note that the intensity of the southward flowing Compensational Current in 2005 and 2006 was maximal in these years. In 2007, the situation resembled what had occurred in 1997, at least in the northeastern part of the Sea of Okhotsk where the intensity of southward flow along the Kamchatka Peninsula decreased (Fig. OK-12). The diminished correlation likely emphasizes a growing significance of spring conditions and the changing formation of warmer waters suggests a change in the thermal structure of the Sea of Okhotsk shelf waters since 2005 (Figurkin et al. 2008).

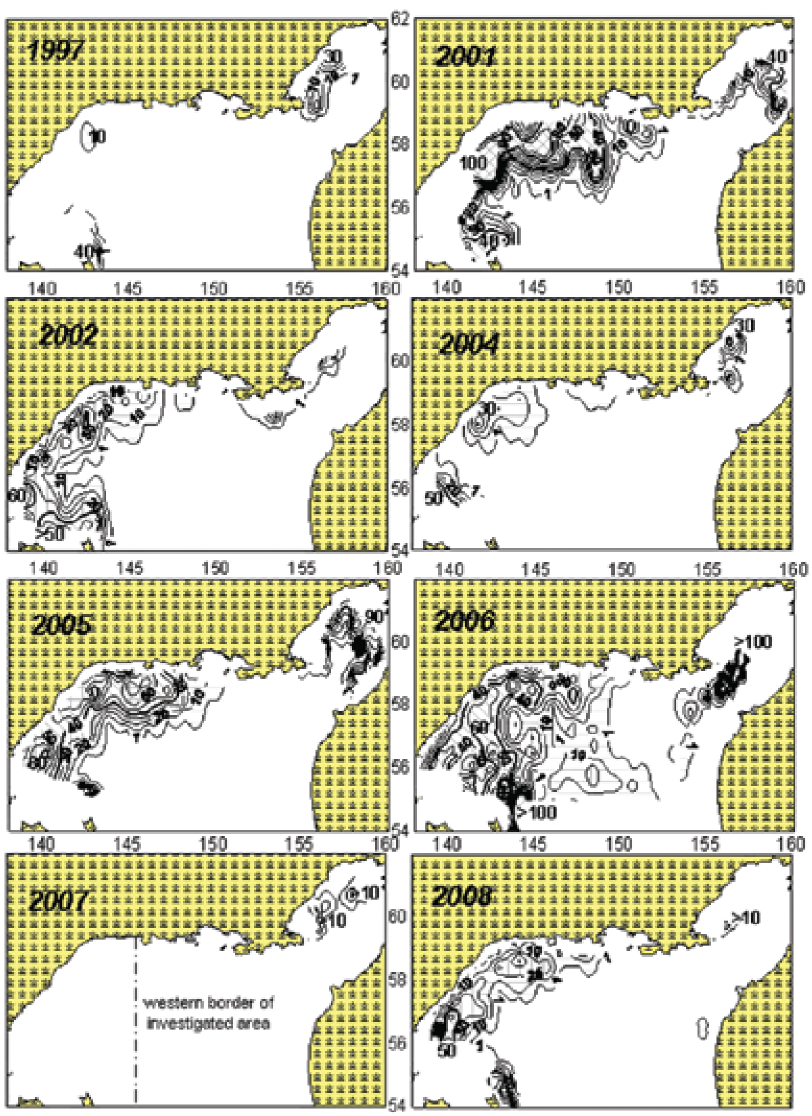
In the southern Sea of Okhotsk where circulation patterns were traditionally determined by the locations of eddies, hydrographic conditions were more stable than in the north. In the month of August, SST has increased gradually through the focus period, from negative anomalies (>2°C) covering nearly the whole region in 2002 (see Fig. OK-11). From 2006 to 2008, SST anomalies in the southern Sea of Okhotsk in August were positive despite a noteworthy decreased in temperature in 2007. In 2009, negative SST anomalies in August returned. In autumn (October-November), SST in recent years was the lowest in 2001 (Table OK-2). Autumns of 2004, and 2006-2008 can be defined as relatively warm. In 2005, there was local cooling related to more intensive water transport by the East Sakhalin Current from the northern shelf and more intensive seasonal vertical water mixing after the SST maximum in August.



[Figure OK-12] Water transport (1,000,000 $m^3 \cdot s^{-1}$) in the upper 200 m in April to early May along the Kamchatka Peninsula west coast from 1984-2009 in the West Kamchatka Current northern branch (red) and Compensative Current (blue). Columns indicate northward and southward transport.

[Table OK-2] Mean water temperature at the different depths in the southern Sea of Okhotsk, October – November 2001-2008. (after Figurkin et al. 2008).

Year	0 m	50 m	100 m	150 m	200 m
2001	6.62	3.53	0.43	0.77	0.90
2002	7.92	2.98	0.81	1.06	1.09
2003	8.06	3.04	1.19	1.17	1.18
2004	7.78	4.10	1.07	1.10	1.25
2005	6.95	3.68	0.87	0.95	1.06
2006	7.54	3.51	0.96	1.17	1.30
2007	7.37	3.03	0.76	-	1.28
2008	7.42	3.18	0.85	-	1.16
Average	7.46	3.38	0.87	1.04	1.15

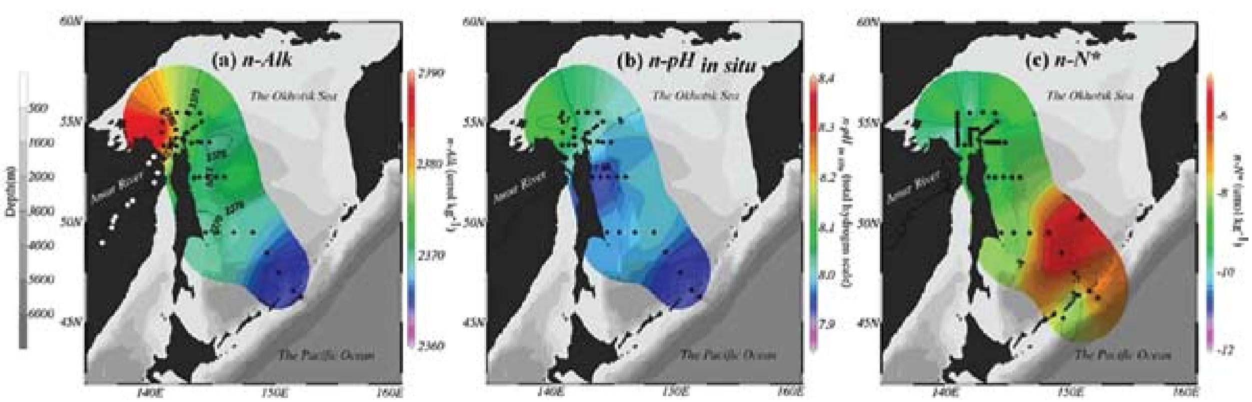


[Figure OK-13] The thickness (m) of near-bottom water layer with temperatures ≤1.5°C and salinity ≥33.2 psu in the northern Sea of Okhotsk in spring of 1997, and 2001-2008 (after Figurkin et al. 2008) with additions for the last years.

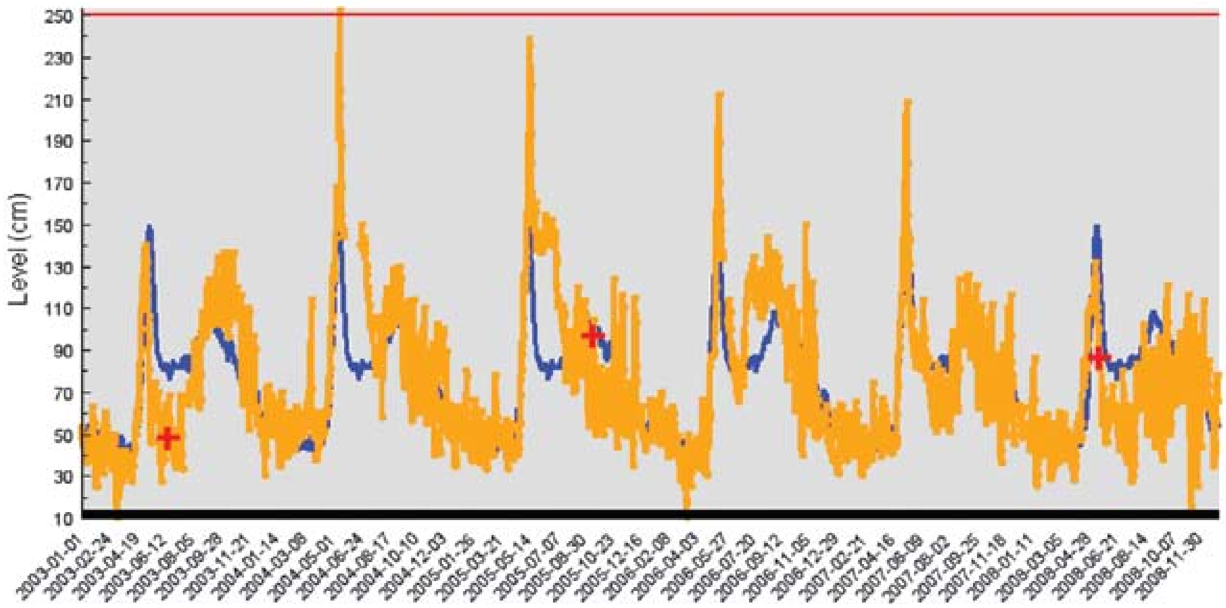
4.0 Chemical Ocean *(Radchenko, Nishioka)*

The high biological productivity in the Sea of Okhotsk is a result of nutrients that enrich the surface layer during the period of intensive vertical mixing in autumn and winter. They are almost completely used by phytoplankton during the spring bloom. Production continues through the summer by nutrient recycling and by upwelling. The post-winter nutrient concentrations in the deeper parts of the Sea of Okhotsk are roughly: 1000-1250 $mmol \cdot m^{-2}$ of nitrogen, 60–100 $mmol \cdot m^{-2}$ of phosphorus, and 1000–1500 $mmol \cdot m^{-2}$ of silica (Arzhanova and Zubarevich 1997). Amur River discharge also contributes notably to the Sea of Okhotsk chemistry including an effect on the acid-base balance (Watanabe et al. 2009).

Hydrochemical studies were not conducted regularly in the Sea of Okhotsk from 2003 to 2008 although a few expeditions were associated with other scientific projects (KOMEX, Amur-Okhotsk Project, TINRO-Center cruises). An expedition on the R/V *Professor Khromov* sampled the water column from 0 m to 3000 m at 34 stations in a region of intermediate water formation, measuring alkalinity and dissolved inorganic carbon. At 51 stations samples were collected for nutrient assays (NH3, NO2, NO3, PO4, Si(OH)4, DO) during August to early September in 2006 (Fig. OK-14, after Watanabe et al. 2009). An index of nitrogen fixation-denitrification was estimated from the collected and normalized nutrient data as N* (= [NO3] + [NO2] + [NH3] - rN/P * [PO4] + 2.9. Significant changes of alkalinity, pH, and nitrogen fixation-denitrification indices were identified in subsurface waters (26.5 – 27.3 σ_θ) in comparison with 1999-2000. Salinity-normalized alkalinity increased by 2.6±0.1 $mmol \cdot kg^{-1} \cdot y^{-1}$ while the increase in dissolved inorganic carbon (DIC) was almost half of that of alkalinity. Therefore, pH has increased by 0.013 ± 0.001 pH $unit \cdot y^{-1}$ (Watanabe et al. 2009). On the other hand, the rate of change of the n-N* index was from -0.8 to -0.5 $mmol \cdot kg^{-1} \cdot y^{-1}$ which implies an intensification of the denitrification process in the intermediate waters in the Sea of Okhotsk. It was also reported that the increase of alkalinity in the Amur River was the dominant cause for the increased alkalinity in the Sea of Okhotsk from 1999 - 2006. The average concentration of Ca^{2+} in the Amur River increased from 0.16 to 0.26 $mmol \cdot l^{-1}$ from 1999-2006 and the discharge of the Amur River has been increasing over the past five years at an average of 2.2×10^{10} $m^3 \cdot y^{-1}$ (Watanabe et al. 2009). Amur River water levels exceeded the multi-year average from 2003-2008 (Fig. OK-15). Bottom sediments are another notable deep water source of Ca^{2+} due to intensive geochemical activity in the near-bottom layer of the Derjugin's Basin (Pavlova et al. 2008).

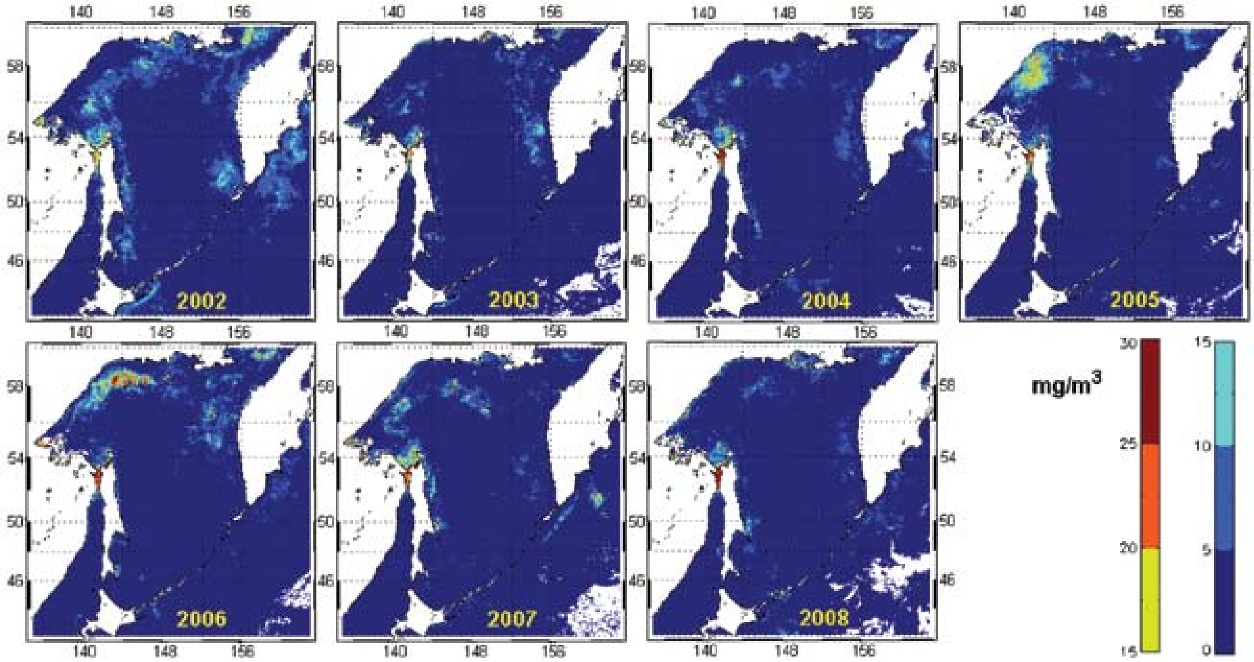


[Figure OK-14] Distributions of (a) n-Alk, (b) n-pH *in situ* and (c) n-N* on the 26.5σ_θ isopycnal in 2006. Black and white circles are the oceanic and riverine sampling locations. Pairs of n-Alk and n-DIC, were used to calculated n-pH *in situ* based on Dickson and Goyet (1994). After Watanabe et al. (2009).



[Figure OK-15] Dynamics of the Amur River water-level at the Nikolayevsk control post, 2003-2008. Floodplain height is indicated by orange line. Blue line indicates the multi-year average. Red crosses indicate corrected data. Data/image are courtesy of FSUE Center of Register and Cadastre in Khabarovsk, Russia.

Waters around the Kuril Islands have high concentrations of iron (Nakatsuka et al. 2004; Nishioka et al. 2007). The main sources of iron in the water column are atmospheric deposition, fluxes from sediments, and regeneration. The contributions from riverine discharge are small (Okunishi et al. 2007). Iron plays an important role in maintaining high primary production in the Sea of Okhotsk. Dense Shelf Water that is formed in the polynyas of the northwestern shelf during winter plays an essential role in transporting all chemical materials. Chlorofluorocarbons (CFCs) and dissolved inorganic carbon (DIC) concentrations in this water are high and almost saturated with respect to atmospheric CFCs, indicating that the Dense Shelf Water experiences active gas exchange with the atmosphere during its formation (Wong et al. 1998; Yamamoto-Kawai et al. 2004; Wakita et al. 2003). Due to strong tidal mixing on the shelf, Dense Shelf Water contains large amounts of re-suspended sedimentary particles, which include particulate and dissolved organic carbon (POC, DOC) and iron (Nakatsuka et al. 2002, 2004; Nishioka et al. 2007). Therefore DIC, CFCs, POC, DOC, and iron are transported with this water from the northwestern shelf of the Sea of Okhotsk to the Kuril Basin via intermediate water transport. These intermediate waters affect the chemical properties of the North Pacific Intermediate Water (Tally 1991; Watanabe et al. 1994; Hansell et al. 2002; Nishioka et al. 2007; Yamashita and Tanoue 2008).



[Figure OK-16] Chlorophyll concentrations (mg·m⁻³) in the Sea of Okhotsk surface layer from 2002 to 2008, averaged for April-June of each year. Data are from TeraScan remote sensing, SakhNIRO, Yuzhno-Sakhalinsk.

5.0 Biological Ocean

5.1 Phytoplankton and primary production *(Radchenko, Dulepova, Tsoy)*

The ungrazed spring production is estimated at 500,000 cal·m⁻², or about 52 gC·m⁻² (Sorokin and Sorokin 1999). Diatom blooms occur in spring but also in autumn in the western Sea of Okhotsk. The estimated seasonal proportions of production are: 35% in spring, 45% in summer, 18% in autumn, and 2% in winter (Shuntov 2001). Nakatsuka et al. (2004) considered that silicate chemistry must play an important role in the growth of phytoplankton in both spring and autumn in this region. Whereas nitrates are used first by phytoplankton cells, they can be supplemented by recycling. Silicate recycling, on the other hand, is complicated by slow rates of dissolution of diatom frustules and their rapid sedimentation (Arzhanova and Zubarevich 1997). In spring and autumn, the maximum concentration of chlorophyll is located at the uppermost depth at which silicate can be detected. The surface layer of the western Sea of Okhotsk is continuously re-supplied with silicate because of riverine input, especially by the Amur River which provides large amounts of nutrients, especially silicate, to the surface water (Nakatsuka et al. 2004; Nagao et al. 2008). Biological production, especially diatom production, along the East Sakhalin Current may be influenced directly by Amur River discharge into this region, as well as being influenced by re-suspended nutrients from the shelf (Andreev and Pavlova 2010).

While the skill of determining chlorophyll concentrations from remote sensing data is still under discussion, interannual comparisons from ocean color data are informative. The lowest chlorophyll concentrations occurred in 2003 and 2008 corresponding to lower Amur River discharge in those years (Figs. OK-15, OK-16). Near the Hokkaido coast, the phytoplankton bloom timing was closely related to ice conditions. Longer ice cover in 1999, 2001 and 2003 with the presence of ice until early April and shortened ice cover in 1998, 2000, 2002 and 2004 with the occurrence of ice until early March were recognized at this area (Mustafa and Saitoh 2008). Higher chlorophyll concentrations were observed in the initial bloom when sea ice melting was delayed. As sea ice extent decreased in the southern Sea of Okhotsk after 2004, it may have influenced gross primary production in those waters.

5.2 Zooplankton *(Radchenko, Dulepova)*

New data on the Sea of Okhotsk zooplankton were obtained in the 2000s confirming previous observations of region-specific characteristics made from the 1980s to the beginning of the 1990s (Volkov 1996; Shuntov 2001; Dulepova 2002). Zooplankton biomass and distribution in the epipelagic layer have varied at interannual and longer periods (Fig. OK-17). Nighttime sampling in the Sea of Okhotsk can be stratified by period: 1984-1990, 1991-1995, and 1996-2006. Average zooplankton biomass in the epipelagic layer over the shelf was highest in the early 1990s and approximately equal before and after that period. Over the continental slope, biomass was lowest in the early 1990s and highest in the more recent period. Over deeper waters, biomass declined after the 1980s reaching its lowest level in the 1996–2006 period.

Taxonomic and size-based measures of diversity of zooplankton differ because of daily vertical migration as well as from seasonal changes. Average zooplankton concentrations in the upper layers decrease during the cold season. Within the top 200 m layer, the magnitude of the overall decrease is generally twofold, and rarely threefold so the epipelagic layer remains inhabited by zooplankton even in winter (Volkov 1996; Shuntov et al. 1993; Shuntov 2001). High zooplankton biomass, especially in spring, summer and autumn, create favorable conditions for planktivorous fish (Table OK-3).

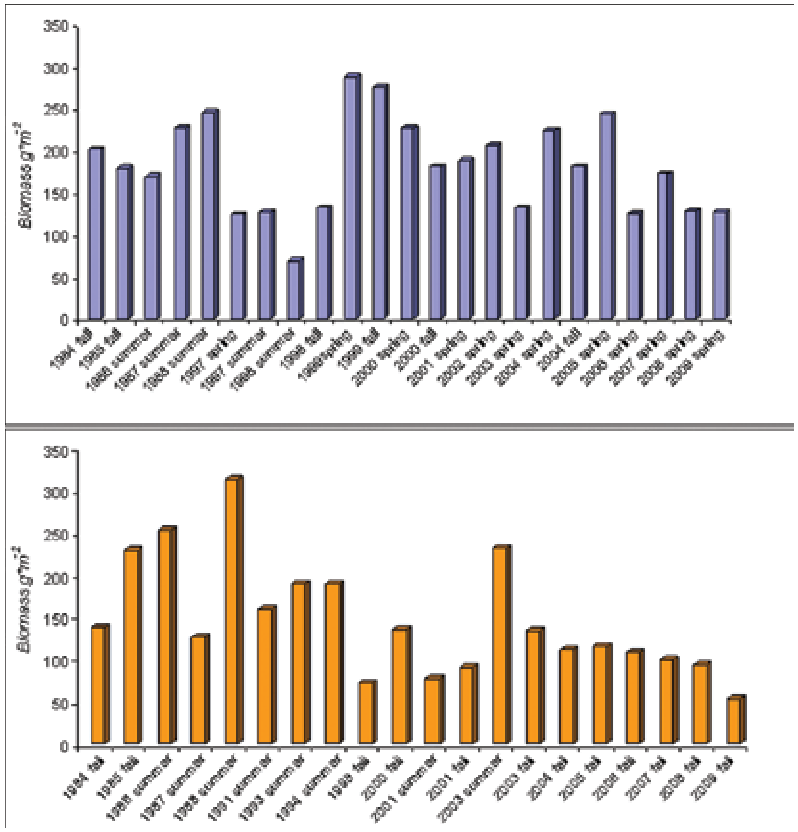
	1984-90	1991-95	1996-06
1	1261	1525	1218
2	1055	812	1139
3	1159	1022	793

[Figure OK-17] Long-term average composition (%) and biomass (mg·m⁻³) of night-time macroplankton in the Sea of Okhotsk epipelagic layer in three regions: (1) inner shelf, (2) outer shelf and continental slope and (3) deepwater. Portion of macroplankton in the total plankton biomass is indicated in brackets. After Shuntov et al. (2007).

[Table OK-3] Average biomass ($mg \cdot m^{-3}$, wet weight) of night-time zooplankton in the Sea of Okhotsk in the different seasons, 1984-2006.

Season	Biomass
Winter	452-2019
Spring	1057-6890
Summer	1151-2042
Autumn	630-1948

Interannual analysis of the size and taxonomic composition and trophic structure in the Sea of Okhotsk identifies two plankton communities: northern and southern. In the southern Sea of Okhotsk, the macroplankton portion of the total zooplankton biomass is always higher (76-92%) than in the northern part (56-78%). Portions of small and medium zooplankton are correspondingly lower in the southern part. Euphausiids and copepods predominate in the northern and southern communities, ranking either first or second place by biomass. Usually, copepods predominate in the south and euphausiids in the north. Productivity of the plankton communities was higher in the north during the period of investigation (1997-2006) since animals with higher individual production rates predominate there (Dulepova and Merzlyakov 2007). Faster growing small- and middle-sized zooplankton are more abundant in the north and the portion of predatory planktonic animals is notably lower. Multi-year monitoring reveals the cyclic nature of zooplankton biomass with a multi-year period (Fig. OK-18) and occasional extremes. Zooplankton biomass was low for the entire period of observation throughout the Sea of Okhotsk in 1998. During the focus period, no trends were evident in Sea of Okhotsk zooplankton biomass or distribution. In general, during the last 25 years, zooplankton standing stock has not decreased below a level that would limit the abundance of things that eat zooplankton (Shuntov et al. 2007).



[Figure OK-18] Long-term dynamics of the average biomass (mg·m⁻²) of zooplankton in the northern (upper) and southern (lower) Sea of Okhotsk from 1984 to 2006. Update from Shuntov et al. (2007).

6.0 Fishes and Invertebrates

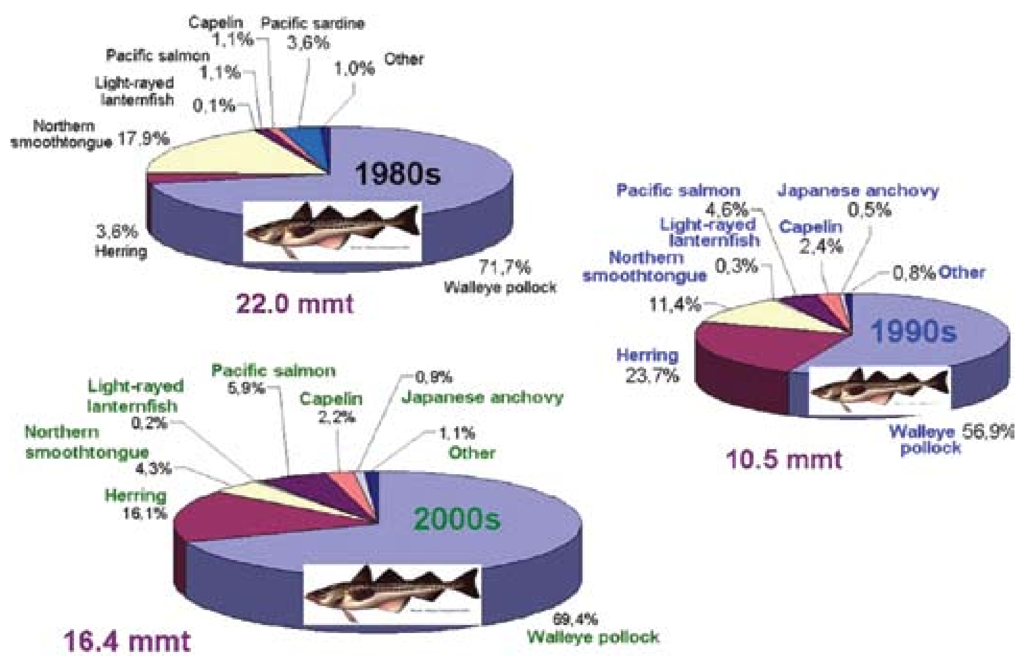
(Radchenko)

In the 1980s, total fish biomass in the Sea of Okhotsk was likely >55 million metric tons (mmt) with walleye pollock at about 15.6 mmt, groundfish at 5.7 mmt, and other epipelagic fish at 2-3 mmt (Fig. OK-19). The predominance of walleye pollock in the Sea of Okhotsk pelagic fish community was evident for those years (Shuntov et al. 1993). About 1 mmt of Pacific sardine migrated annually into the Sea of Okhotsk for summer feeding until the beginning of the 1990s. The estimated biomass of mesopelagic nekton was 27.8 mmt (Iljinskiy and Gorbatenko 1994). Other gadid fish (Pacific cod and saffron cod) also had high biomass in the demersal fish community on the shelf. Among the benthic groundfish, grenadiers predominated with biomass of about 2.0 mmt and small flatfish species combined for a total of 0.94 mmt. Pacific cod biomass reached 0.66 mmt, saffron cod 0.2 mmt, Greenland turbot 0.57 mmt, eelpouts 0.43 mmt, skates 0.37 mmt, and others 0.57 mmt.

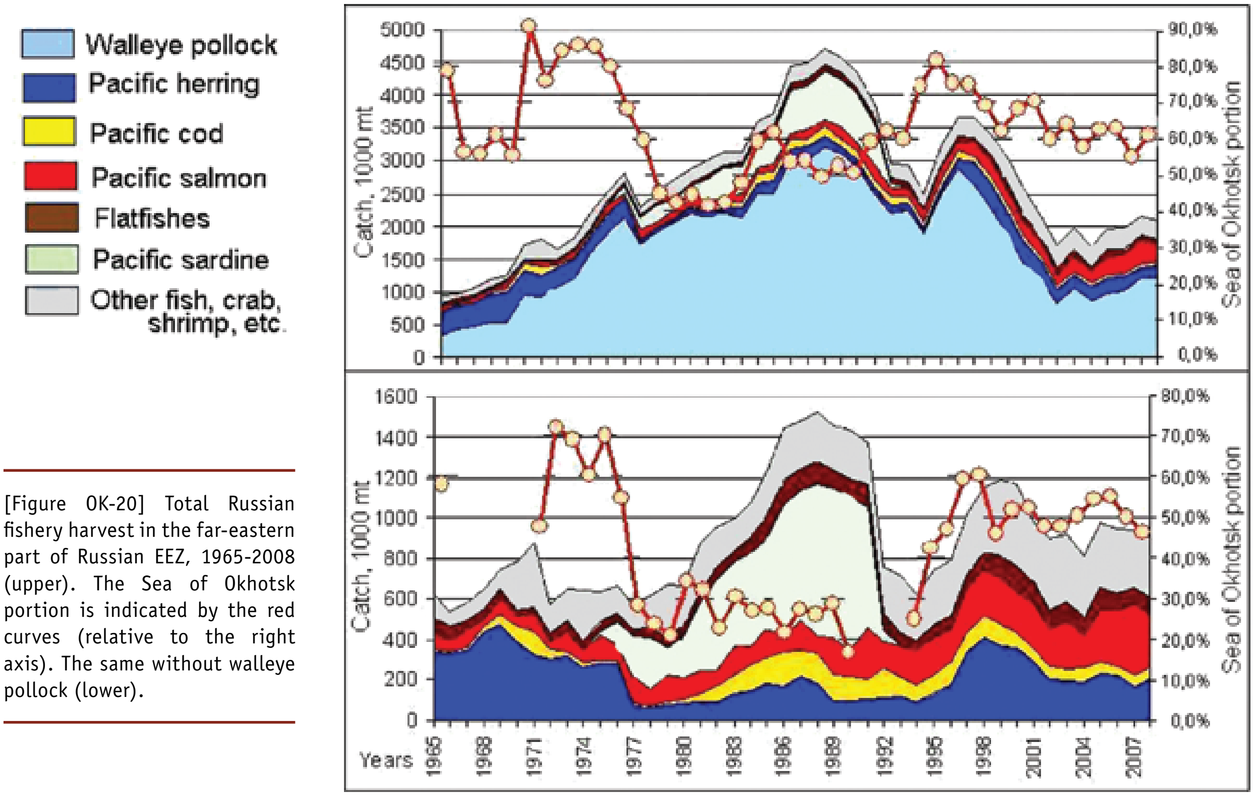
There is an opinion that the maximum biomass of commercial fish species is observed in the North Pacific during warm periods (Klyashtorin and Lyubushin 2005). The 1980s were warmer and notably more productive years for fish harvests than the relatively cool period during the late 1990s. The years 2003-2009 were a period of stabilization and gradual growth in abundance of the pelagic fishes, especially walleye pollock, groundfish species, and notably, Pacific salmon (Fig. OK-20, Fig. OK-21).

6.1 Walleye pollock

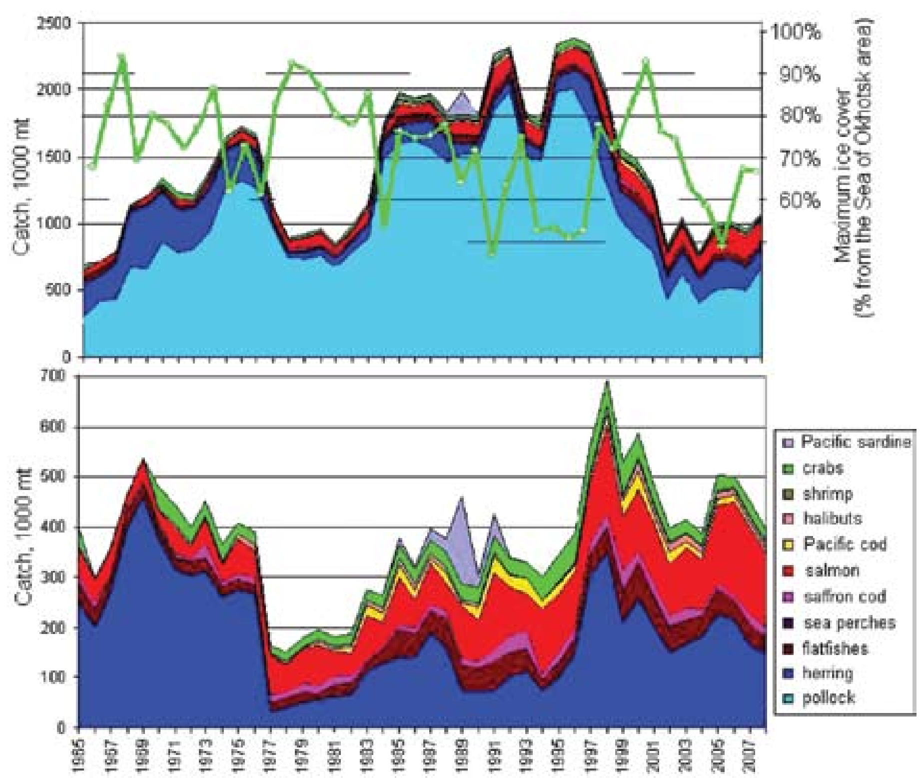
The walleye pollock is a relatively long-lived fish that keeps the fishery in good conditions when the stock consists of several strong and super-strong year-classes. When in poor condition it is usually made up of solely one strong year-class. Two strong year-classes in 1995 and 1997 maintained an exploitable level of biomass in the first half of the 2000s (Fig. OK-22). The 2004 and 2005 year-classes initially appeared to be relatively strong and this was reflected later by surveys and fishery statistics. In 2009, the walleye pollock spawning stock increased by 10.1 billion fish with the 2004 and 2005 year-classes accounting for 80% of this growth. The combination of an intensive inflow of Pacific water with the West Kamchatka Current, a low intensity of the Compensating Current, and mild ice conditions create favorable pre-conditions for strong recruitment. There are weak correlations between the Compensative Current volume transport and walleye pollock year-class abundance at age 2 (with lag = 2 years): r = -0.46, year-class abundance in ages 3-4, r = -0.30 (with lag = 3.5 years).



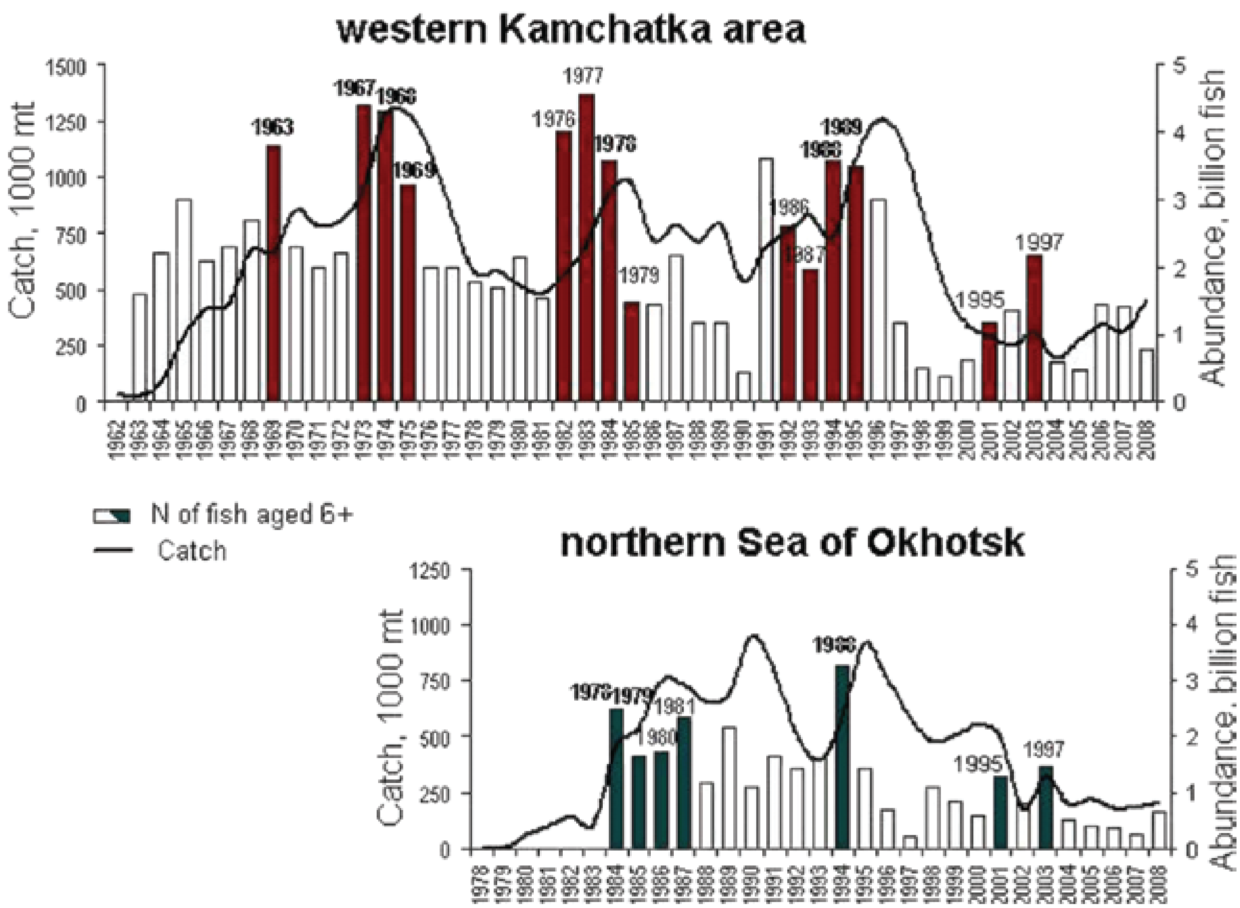
[Figure OK-19] Quantitative composition of the epipelagic fish community in the Sea of Okhotsk in the 1980s, 1990s, and 2000s (2000-2005).



[Figure OK-20] Total Russian fishery harvest in the far-eastern part of Russian EEZ, 1965-2008 (upper). The Sea of Okhotsk portion is indicated by the red curves (relative to the right axis). The same without walleye pollock (lower).



[Figure OK-21] Total Russian fishery harvest in the Sea of Okhotsk, 1965-2008 (upper). The maximal ice cover in the Sea of Okhotsk is indicated by the green line (relative to the right axis). The same without walleye pollock (lower).



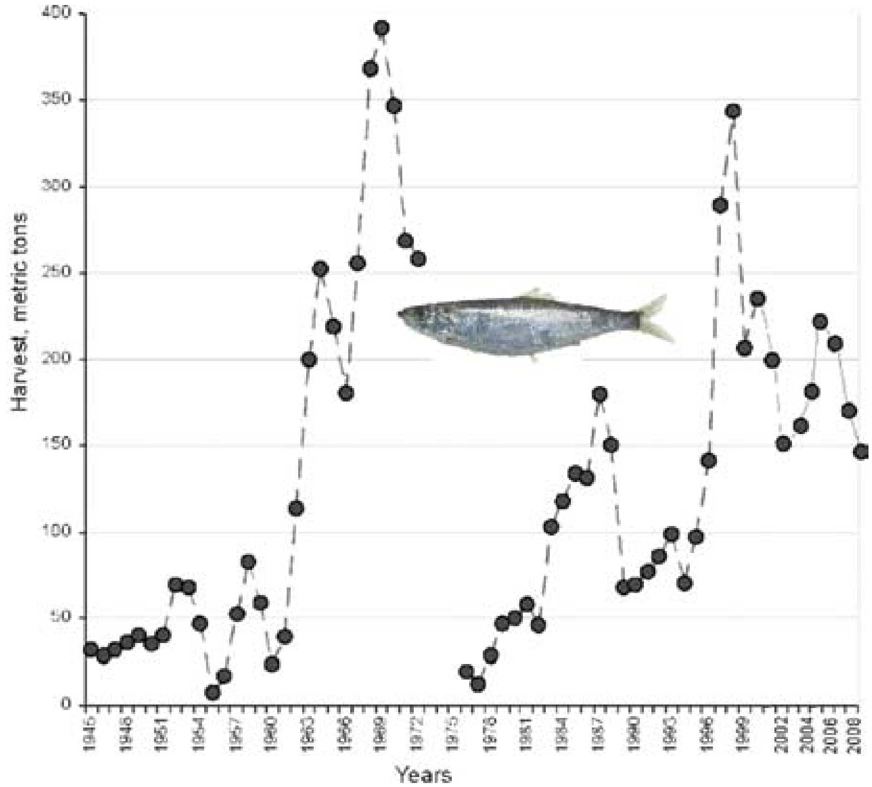
[Figure OK-22] Walleye pollock catch in the northern and north-western Sea of Okhotsk and abundance of fish aged 6+, 1962-2008 (after Ovsyannikov 2009). Bars indicating strong year-classes are colour-filled with the year of occurrence indicated above each.

6.2 Herring

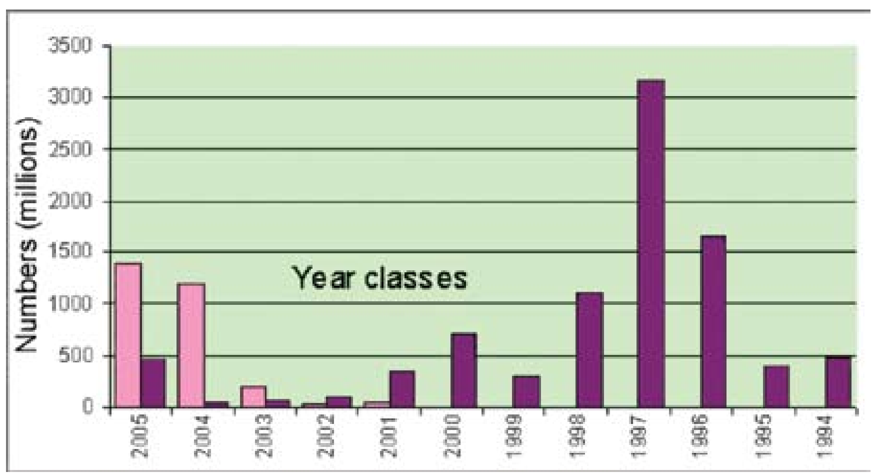
In the northern Sea of Okhotsk, herring biomass reached 2.5 mmt in 1997 and 3.0 mmt in 2003-2004. In recent years, the herring stock declined and the annual harvest was <150,000 t (Fig. OK-23). A decrease was anticipated due to a lack of strong year-classes in the first half of the 2000s (Fig. OK-24, after Loboda 2007). In 2006, herring biomass decreased to 2.5 mmt, and by 2007 it was <1.24 mmt (Loboda 2008).

6.3 Groundfish

Biomass declined suddenly (and unexpectedly) in 1998 from 1.437 to 0.849 mmt and continued at 0.623 mmt in 1999, and 0.645 mmt in 2000. Thereafter, groundfish biomass began growing and returned to higher levels of the 1980s by 2005. The decline was caused by reductions in common flatfish species and Pacific cod, whose biomass decreased fourfold. Increases in saffron cod and several sculpin species were responsible for the growth observed in 2005. These dynamics cannot be explained by fishing pressure since the harvest rates never reached the recommended TAC for common groundfish. Increasing biomass was observed in several regions of the northwestern Pacific, including the southwestern Bering Sea (Balykin 2006). These changes have been attributed to a climate regime shift and autocorrelation processes in the fish populations (Shuntov et al. 2007).



[Figure OK-23] Okhotsk herring stock harvest by the Russian fishery, 1945-2008. Fishing was prohibited from 1973-1975.



[Figure OK-24] Numbers of Pacific herring (1+ and older) in the autumn of 2006 in the northeastern Sea of Okhotsk (rose, n = 2.68 billion) and northwestern Sea of Okhotsk (purple, n = 8.48 billion). After Loboda (2007).

6.4 Capelin

Capelin was abundant in the pelagic communities during the period of low abundance of walleye pollock and herring in the 1970s. In the early 1990s capelin abundance in the Sea of Okhotsk increased for only two-three years. Since 2002, there was a new “splash” of capelin in the northeastern and southwestern parts of the Sea of Okhotsk. Near the East Sakhalin coast, capelin biomass was estimated at 0.5 mmt in 2001. The historically high spawning abundance occurred in 2002 (Velikanov et al. 2003). The spawning stock biomass on the southern Sakhalin coast exceeded 0.13 mmt, but there was no comparable abundance in the 2003-2009 when the spawning stock did not exceed 6,000 t. On the West Kamchatka coast, capelin was abundant in 2001-2003 when the harvest reached 1600-1750 t (Naumova 2008). From 2004 to 2007, it decreased to an average of 516 t and dropped to 60 t in 2008. These abundance dynamics follow the positive trends of walleye pollock abundance in recent years.

6.5 Pacific Salmon

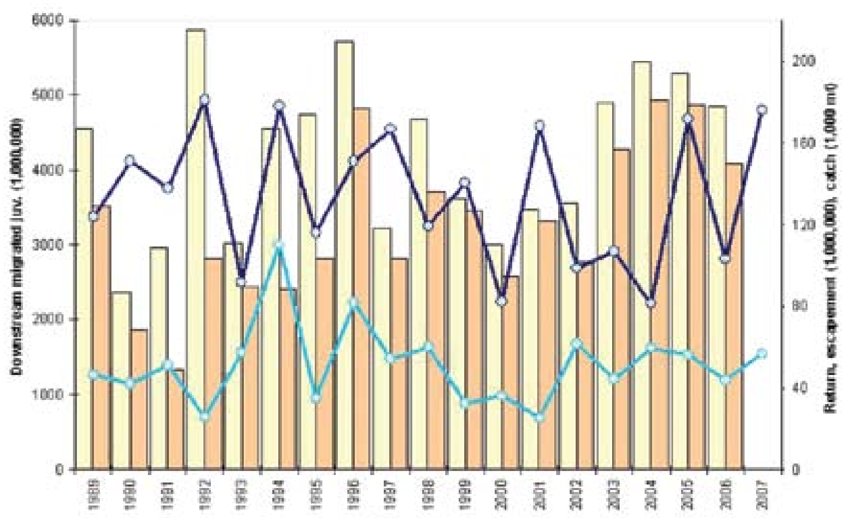
6.5.1 Pink salmon

The dynamics of pink salmon abundance in the Sea of Okhotsk basin did not undergo significant changes in the 2000s (Fig. OK-25). Returns of pink salmon continued to increase in both even- and odd-year cycles and coastal catches in 2006 and 2007 reached record highs of 180,700 and 178,500 mt, respectively. In 2008, the total Russian catch of pink salmon decreased slightly including that of the Sea of Okhotsk. Compared with the 1990s, the number of outmigrating juveniles increased by 13.2% for odd year spawners, and decreased by 34.6% for even year spawners (Fig. OK-25). The difference is likely related to the divergence that is apparent in the abundance trends for the odd- and even-year cycles (Radchenko 2006).

High yielding pink salmon populations like the odd-year East Sakhalin stock and the even-year West Kamchatka stock were characterized by high abundance in the 2000s. On the other hand, the odd-year West Kamchatka pink salmon stock had a catch of 15,600 t in 2007 after zero catches during the 1990s and negligible catches (54-322 t) at the beginning of the recent decade. On the East Sakhalin coast, the situation was even more extreme with 86,000 t caught in 2006. That year, the annual catch in Aniva Bay (south Sakhalin Is.) exceeded the previous regional historical high (1994) by 5.5 times.

Return rates calculated from total pink salmon fry outmigration exceeded 20% (Kaev 2007). Some have linked these unexpectedly high abundances with the success of the hatchery program. Another hypothesis is a "change of dominance" event, which sometimes occurs in the regional pink salmon groupings. However, the abundance of these pink salmon broodlines began to decrease in all regions of the Sea of Okhotsk coast. It is remarkable that the decreasing abundance of these formerly non-productive populations along the eastern and western Kamchatka coasts has occurred during the freshwater stage not during the early marine or oceanic stages (E. Shevlyakov, pers. comm.).

On the Japanese coast, pink salmon are found mainly in eastern Hokkaido. Their population size was low, ranging from one million individuals for the even year cycle to two million for the odd year cycle during the 1970s and 1980s. In the early 1990s, however, the population increased sharply and shifted from odd-year to even-year dominance. More recently, odd-year dominance has resurged (Nagata 2009).



[Figure OK-25] Pink salmon escapement (light blue line, right ordinate axis) and numbers of downstream migrants (navy line, left ordinate axis) superimposed on total returns (light columns) and catch (darker columns) of corresponding brood years in the Sea of Okhotsk, 1989-2007. Note that the years indicated are spawning years of the parent broodline.

6.5.2 Chum salmon

Russian catches of chum salmon continued a gradual growth. In 2008, the chum salmon harvest by coastal fishery doubled in comparison with 2004 and reached 62,200 t (45,368 t in the Sea of Okhotsk basin). After 2005, almost all notable chum salmon groupings showed increasing abundance. Trends for southern and northern regions became slightly different in the last three years. Southern chum salmon populations had significant increases in fishery yields, especially in the Amur River and southern Kuril Islands (Fig. OK-26). The latter can be attributed to hatchery program development. Declining abundance in chum salmon populations at their southern range limit (due to global warming) was not observed on the Russian coast. Although Hokkaido chum salmon have maintained high abundance (over 40 million fish), recent return rates have varied between brood years and between local populations. Return rates of chum salmon on the Sea of Okhotsk side of Hokkaido have increased sharply since the 1990s. The same trend occurred on eastern Sakhalin Island (Fig. OK-27). In contrast, return rates of chum salmon toward the southern extent of their range in Asia, including those released from Korean, have declined (Fig. OK-28). High mortality of chum salmon occurs in their early ocean life. Recent coastal studies in the Sea of Okhotsk suggest that a long period of optimal seawater temperature from 8-13°C in coastal waters after seaward migration may positively effect survival of chum salmon (Nagata et al. 2007). However, if a decrease in sea ice is caused by global warming, optimal seawater temperatures for chum may become scarce within 50 years.

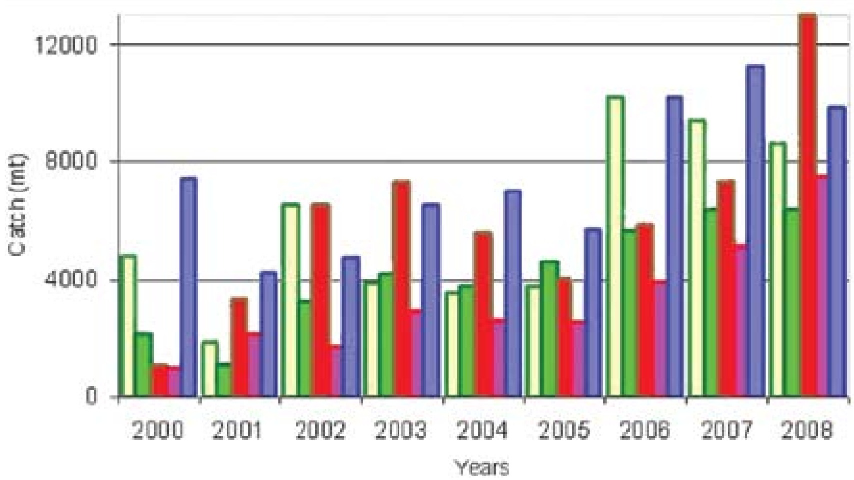
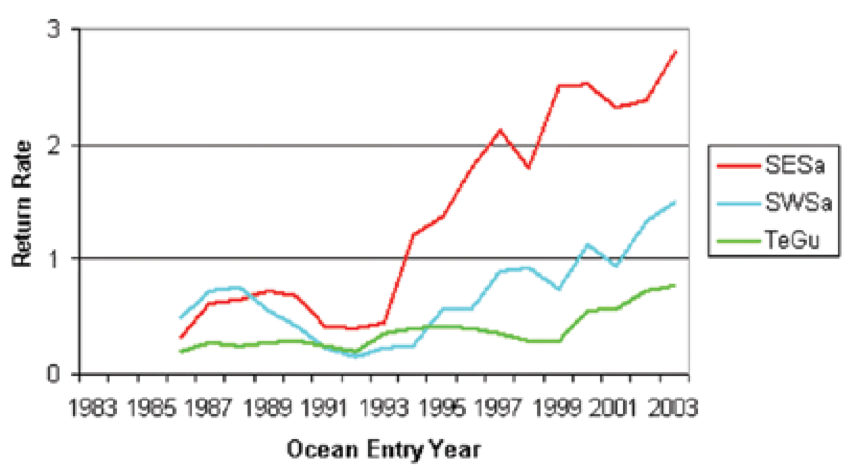
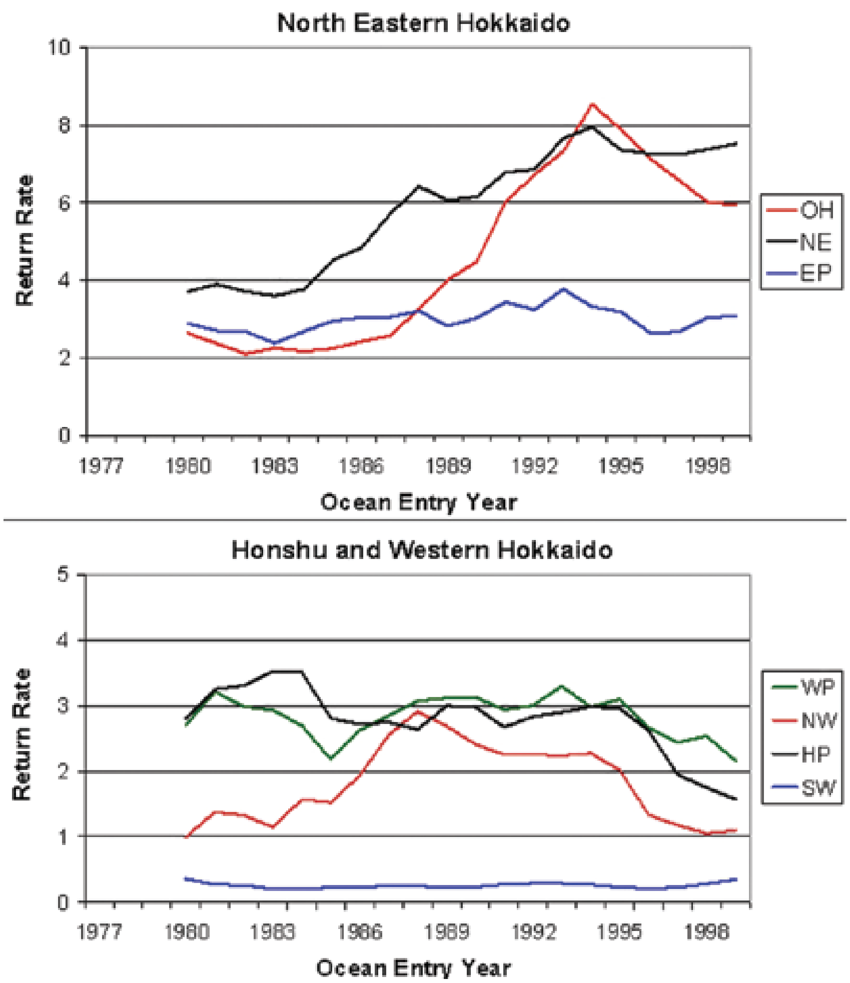


Figure OK-26 Russian chum salmon catch in the main fishery regions in the Sea of Okhotsk, 2000-2008. Columns (from left to right): western Kamchatka Peninsula, eastern Sakhalin, southern Kuril Islands, Amur River, northern Sea of Okhotsk coasts.



[Figure OK-27] Four year running average of return rates (%) starting at 1983-1986 ocean entry year for hatchery chum salmon from Sakhalin Island (data from Kaev and Ignatiev 2007, courtesy of A. Kaev). Regions are indicated by SESa for SE Sakhalin (Okhotsky Hatchery), SWSa for SW Sakhalin (Kalininsky Hatchery); and TeGu for the Gulf of Terpenia (Buyuklovsky Hatchery).



[Figure OK-28] Four year running average of return rates (%) starting at 1977-1980 ocean entry year for hatchery chum salmon from seven regions of Japan (data from Saito and Nagasawa 2009, courtesy T. Saito). Region abbreviations are: NE-Nemuro; OH-Okhotsk; WP-West Hokkaido Pacific; EP-East Hokkaido Pacific; HP-Honshu Pacific; NW-Northwest Hokkaido; and SW-Southwest Honshu.

6.5.3 Sockeye salmon

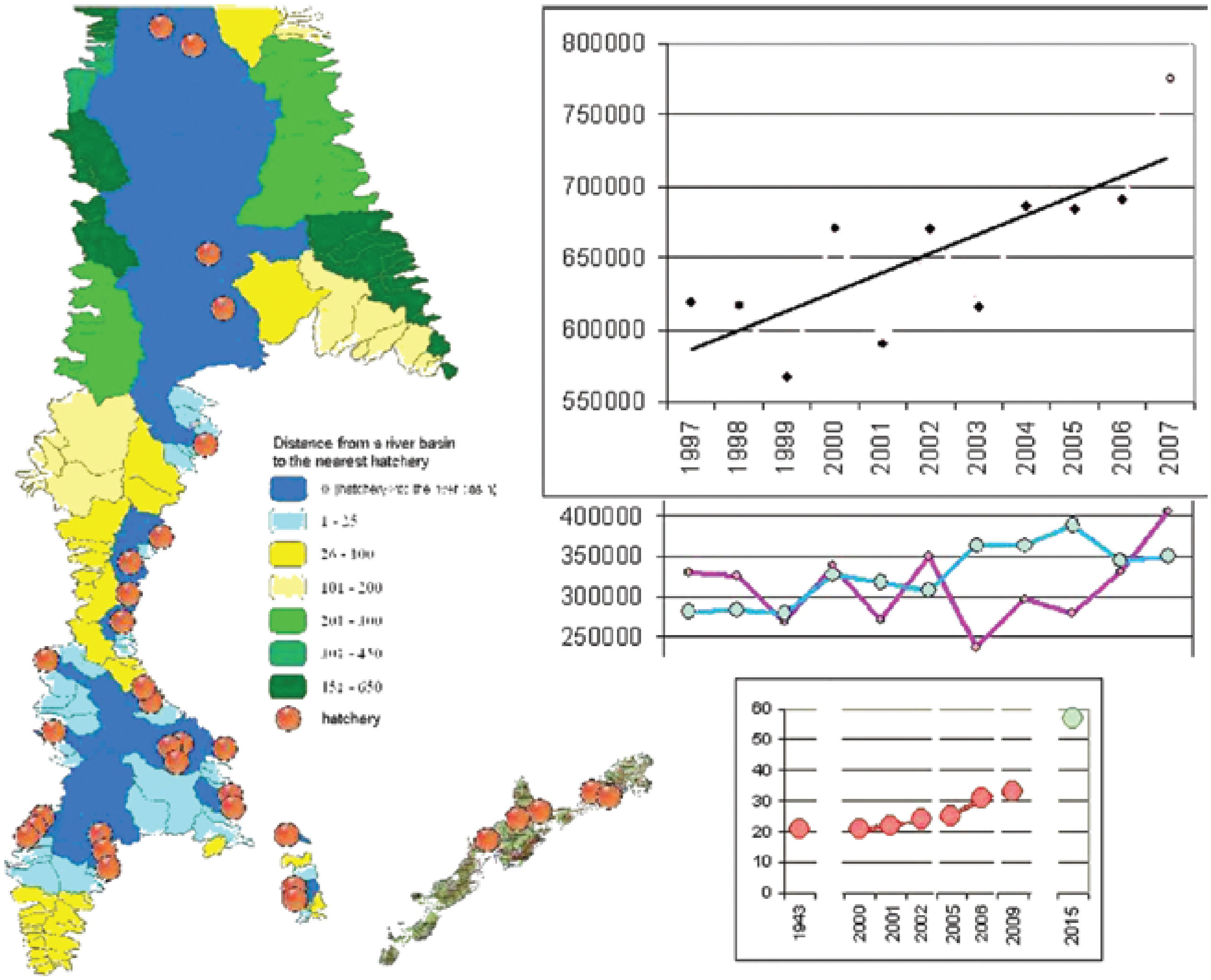
Coastal catches of sockeye salmon doubled in comparison to 2000 and reached 30,000 t in 2007. In 2008, sockeye salmon catch was lowered to 27,000 t (20,000 t in the Sea of Okhotsk basin). The increase in catch was related to an increase in the quota for pre-season marine monitoring in the Russian EEZ. In 2009, no quota was allotted for this purpose due to administrative changes in the organization of scientific research. According to preliminary data, the coastal catch of sockeye salmon did not exceed 30,000 t.

6.5.4 Salmon production

Some climate indices suggest that oceanic conditions for Pacific salmon stocks will change in the near future (e.g. PDO of Mantua et al. 1997). Contrary to expectations for a notable decrease to levels of the 1980s and early 1990s, Pacific salmon have remained abundant in the Sea of Okhotsk. Some of this is due to hatchery renovations and some to the construction of new hatcheries. Some hatcheries are producing chum salmon where hatching was not possible previously. According to long-term plans, the total number of hatcheries on the Sakhalin and Iturup Islands will reach 57 at 2015 (Fig. OK-29). In 2009, Pacific salmon catch on the Russian coast of the Sea of Okhotsk reached the historical high at 0.345 mmt, including 0.275 mmt of pink salmon.

6.6 Macrozoobenthos *(Radchenko, Dulepova)*

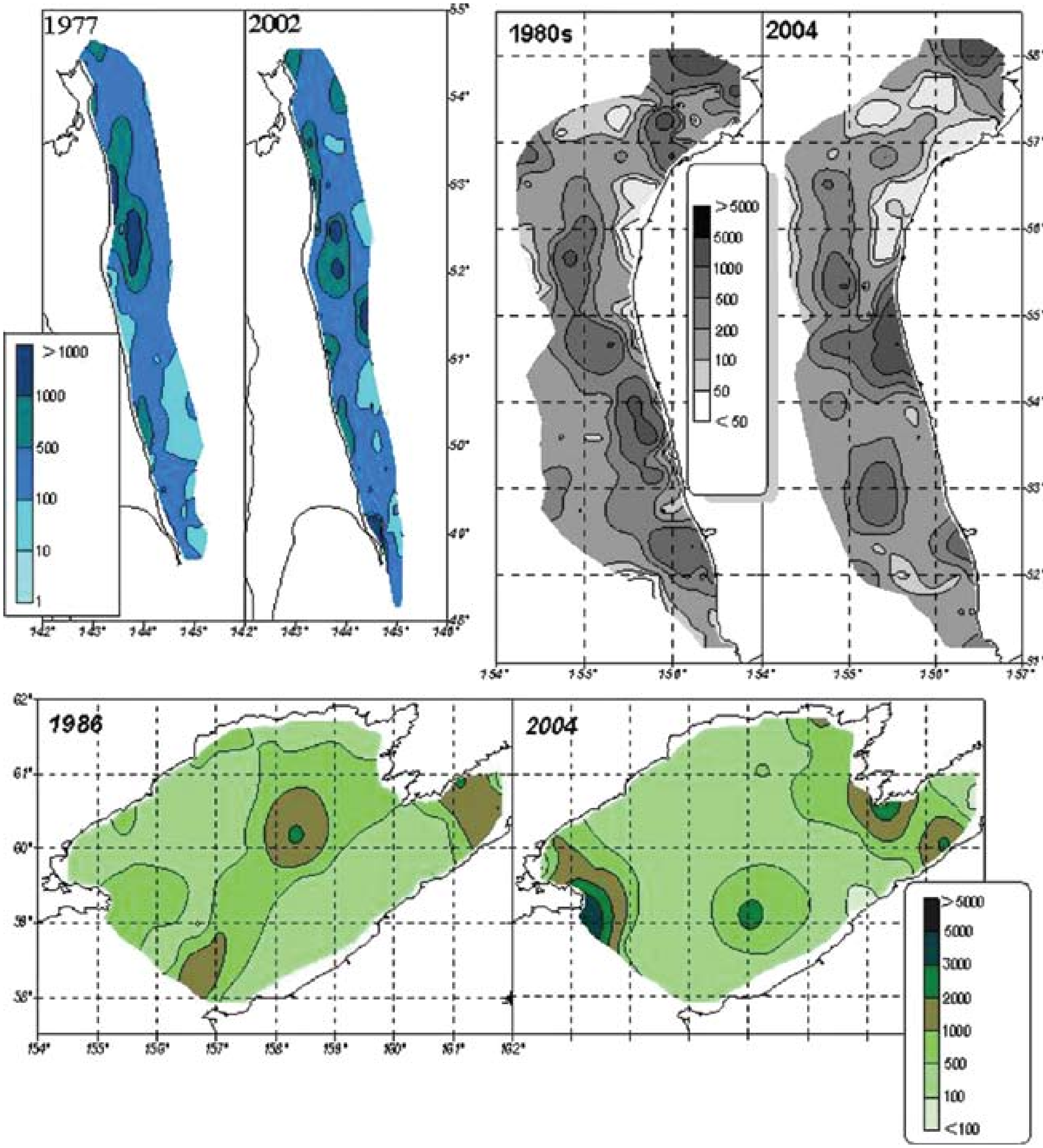
After a 20 year gap, a new series of macrozoobenthos surveys was conducted on the Sea of Okhotsk shelf in 2001-2005: near eastern Sakhalin, western Kamchatka, and in Shelikhov Bay (Nadtochy et al. 2004, 2007; Nadtochy and Budnikova 2005). Sampling was conducted using the same spatial grid and the same sampling gear. Benthic biomass was slightly higher in all regions surveyed. In most cases, there were relatively insignificant changes in the main



[Figure OK-29] Characteristics of Pacific salmon artificial propagation in the Sakhalin-Kuril region: hatchery distribution on the Sakhalin and Iturup Islands, modified after Springmeyer et al. (2007); number of fry released (1,000 fish, upper panel) on the Russian Far East, including pink (middle panel, pink line) and chum (middle panel, blue line); number of functioning hatcheries on the Sakhalin and Iturup Islands (lower panel, green dot indicate projected number for 2015).

taxonomic groups contributing to the food supply of demersal fish, crabs, and other benthic consumers. On the eastern Sakhalin shelf, benthic biomass varied from 19 to 4454.5 $g \cdot m^{-2}$, averaging 421.5 ±58.7 $g \cdot m^{-2}$, for a total of about 15.0 mmt. The main taxonomic groups were sand dollars, bivalves, polychaetes, amphipods, barnacles, sponges and sipunculid worms, contributing to 80% of total biomass. Most of the bottom was occupied by benthic communities with a biomass range of 100-500 $g \cdot m^{-2}$. In 1977, benthos biomass varied from 9.2 to 2167.4 $g \cdot m^{-2}$ and averaged 408.2 ±44.3 $g \cdot m^{-2}$. Comparison of distributional maps for 1977 and 2002 showed that the largest biomass (>1,000 $g \cdot m^{-2}$) occurred in the central shelf at depths 50-150 m near 52°N latitude in both years (Fig. OK-30). In this region, the benthos was made up of mostly echinoderms, amphipods, cumaceans, bivalves, sipunculid worms, polychaetes, and actiniae.

On the West Kamchatka shelf (depths 19-241 m) benthic biomass varied from 7 to 5173.5 $g \cdot m^{-2}$, averaging 323.1 ±50.1 $g \cdot m^{-2}$, and totaling about 17.0 mmt. Most of the bottom was occupied by communities with biomasses in the range 100-300 $g \cdot m^{-2}$. The largest biomasses occurred in the same places as before (Fig. OK-30). However, if echinoderms, polychaetes, and bivalves were the dominant groups in 1982, the last two of these had exchanged



[Figure OK-30] Total macrozoobenthos biomass (g·m⁻²) distribution on the eastern Sakhalin shelf (left), western Kamchatka shelf (right), and Shelikhov Bay (lower). After Nadtochy et al. (2004, 2007) and Nadtochy and Budnikova (2005).

places by 2004. The main taxonomic groups included sand dollars (29.7%), bivalves (28.0%), polychaetes (16.5%), and holothurians (6.3%), all contributing ~80% of total biomass in the region. Sand dollars also predominated in the 1980s (40%) while bivalves and holothurians were significantly less abundant (10.6% and 1.8%, correspondently). The proportion of biomass in sponges decreased from 11% to 3.2%. The average polychaete biomass did not change.

The largest average benthic biomass (604.87 ±135.61 $g \cdot m^{-2}$) was found in Shelikhov Bay where it had increased slightly from 544.69 ±80.62 $g \cdot m^{-2}$ in 1986. The same six taxonomic groups predominated including bivalves, brittle stars, sea urchins, barnacles, polychaetes, and sponges. Their composition changed to a degree with bivalves remaining as the most abundant group, and sea urchins at third place in total benthic biomass. The proportion of brittle stars had increased threefold by 2004 and proportion of sponges decreased by 2.5 times. The contribution by barnacles and polychaetes changed insignificantly.

In Aniva Bay, benthic biomass decreased about twofold on the shelf areas affected by inflow from Soya Strait (Labay and Kochnev 2008). The decrease was related to a notable change in the abundance and distribution of common bivalve mollusks. The cause of the decline was attributed to a general negative trend in productivity of the benthos communities in the southern part of the north-western Pacific (Labay and Kochnev 2008).

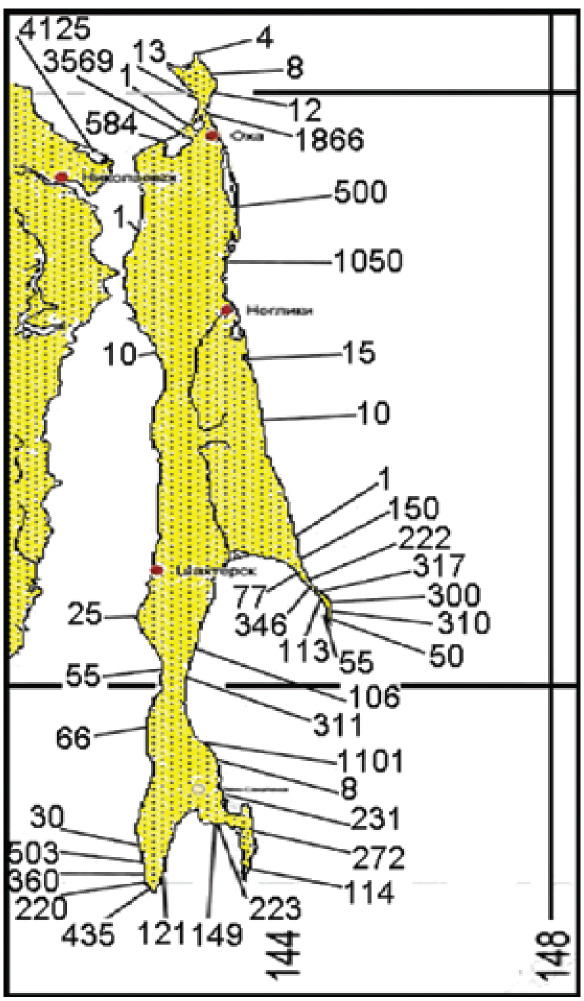
On the whole, the macrozoobenthos community in the Sea of Okhotsk has remained at previous high levels, despite an intensive bottom trawl fishery in western Kamchatka and eastern Sakhalin regions during the 1980s. The proportions of the main taxonomic groups varied gradually, except in Shelikhov Bay where there was little change. Some negative changes in benthic biomass appeared in the southern Sea of Okhotsk but this information needs verification.

6.7 Crabs

The current abundance of the commercial invertebrate species (crabs, shrimp, and snails) remains at a low level. For the shelf crab species, status is mainly assessed as "deep depression" with unclear perspectives for restoration. Some commercially significant abundances remain for the blue king crab (*Paralithodes platypus*) on the West Kamchatka shelf, golden king crab (*P. aequispinus*) and snow crab (*Chionocoetes opilio*) on the northern shelf and continental slope, and brown king crab (*P. brevipes*) in the north-western part of the Sea of Okhotsk. As for the famous red king crab (*P. camtschaticus*) stock on the West Kamchatka shelf, issuing a zero quota is widely discussed among scientists and managers for maintaining the overfished crab population. The assessment of the status of deepwater crab species was likely too optimistic for the triangle Tanner crab (*Chionocoetes angulatus*). Its TAC will decrease for 2010, in comparison with the 2008-2009 values, which were not supported by corresponding high catches. Total crab harvest in 2003-2008 decreased twofold from 47,400 t in 1996-2002. Snow crab has contributed 48.2% to the total crab harvest. Vermilion crab (*Paralomis verrilli*) stock abundance was recently assessed and the species has been recommended for a fishery target but it does not meet the current market demands.

[Table OK-4] Estimates of marine mammal abundance and biomass in the Sea of Okhotsk, 1999-2003 (after Miyashita et al. 2005).

Species	Abundance	Individual weight (t)	Biomass (t)
Fin whale	13,105	45	589,725
Minke whale	19,209	2.5	48,023
Humpback whale	232	27	6,264
Gray whale	100	30	3
North Pacific right whale	922	90	82,980
Killer whale	721	4.5	3,245
Sperm whale	86	40	3,440
Dall's porpoise	316,646	0.17	53,830
Harbour porpoise	6,517	0.065	424
Pacific white-sided dolphin	27,759	0.15	4,164
Baird's beaked whale	660	9	5,940
Other beaked whales	159	2.5	398



7.0 Marine Birds and Mammals

(Radchenko)

From 1999-2003, three visual surveys were conducted in the Sea of Okhotsk to estimate the abundance of whale and dolphin species (Table OK-4). They showed a significant increase of numbers of baleen whales including fin whale (13,200 specimens), and Minke whale (19,200). In comparison, total numbers of baleen whales in the Russian EEZ from the late 1980s to the early 1990s were estimated at 7,200 specimens in summer and 3,200 in autumn (Shuntov 1993). This visual survey was conducted beyond the Russian territorial waters and limited to 155°E and 58°N, so whale abundance is probably underestimated.

True seal (Phocidae) abundance was not surveyed throughout the Sea of Okhotsk scale in the 2000s. In the 1990s, however, it was estimated that there were 1,300,000 seals by species as follows: ringed seal – 543,000, ribbon seal – 345,000, bearded seal and spotted seal – 190,000 each, and harbour seal – 7,000. Seals have likely increased in the 2000s due to a cessation of sealing and food supply stability. Positive trends were also determined for the Steller sea lion (Burkanov and Loughlin 2005).

Local seal abundance was estimated by aerial visual surveys conducted around the Sakhalin Island coast in August and September of 2009 (Fig. OK-31). Almost 14,000 seals were estimated in 40 groups. Additionally, 4,125 seals were found off the south-western coast of Sakhalin Bay (near the mainland) but the main concentrations were found in the northern and north-eastern bays, and also along the southern Sakhalin coast from Cape Terpeniya to Cape Krilyon. These were main areas of pink salmon spawning migrations so the spotted seals were concentrated there to feed on them. In comparison with data of previous calculations, the seal abundance has increased during the last 30 years.

[Figure OK-31] Seal abundance in vicinities of the Sakhalin Island coast. Data of air visual survey in August and September of 2009.

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