X-26 Sea of Okhotsk: LME #52

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The Sea of Okhotsk LME is bordered by Russia and northern Japan, with an extensive area of 1.6 million km^2, of which 0.09% is protected, and which contains 0.04% of the world's sea mounts (Sea Around Us 2007). The entire sea is located in the cold temperate zone, with intense ice formation in almost all areas of the sea. There are marked differences in climate, hydrography and biology between its northern and southern parts. Variations in climate and hydrography are related to atmospheric processes over the northwest Pacific. The current system is complex and characterised by three large cyclonic gyres (Baklanov *et al*. 2003). The straits connecting the Sea of Okhotsk LME to the Sea of Japan/East Sea and the Pacific Ocean allow water exchange between the basins, which has a pronounced effect on the distribution of the hydrological characteristics of the LME. A book chapter and report pertaining to this LME are by Kuznetsov *et al*. (1993) and UNEP (2006).

I. Productivity

The Sea of Okhotsk LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}y^{-1}$). The total annual production of zooplankton has been estimated at 3 billion tonnes and benthic production at 3.4 billion tonnes (Kuznetsov *et al*.1993). Plankton and benthic species are unevenly distributed throughout the LME as a result of the complex circulation patterns. The most productive zones are in the upwelling areas and waters off Kamchatka, and the northern and western areas are especially rich in plankton, while the central deep area is relatively poor (Markina & Chernyavsky 1984). High plankton concentrations in the areas of downwelling are also observed and primarily attributed to mechanical accumulation.

Overfishing followed by climatic variability are primary forces driving biomass change in the Sea of Okhotsk (Sherman 2003). High interannual variability in the climate and hydrography affects the reproductive conditions and trophic relationships of the marine organisms (Shuntov 2001). The productivity dynamics in this LME are characterised by the relatively small role of herbivorous zooplankton, the substantial role of carnivorous zooplankton and the large portion of production by herbivorous plankton and demersal organisms that is converted to detritus.

At least 16 species of marine mammals inhabit the LME seasonally or year round and include grey, humpback and killer whales, as well as eared, fur and ribbon seals. The grey, bowhead, northern fin and humpback whales are listed as endangered in the Russian Red Book.

Oceanic fronts (Belkin et al. 2009): This LME is characterised by a very energetic tidal regime and intense water mass exchange with the open Pacific Ocean; as a result, several fronts (Figure X-26.1) of various physical natures exist here (Belkin and Cornillon 2003, 2004). A branch of the Kamchatka Current penetrates into the Okhotsk Sea via the First Kuril Strait to form the West Kamchatka Current associated with a water mass front (WKCF). Robust tidal mixing fronts develop over the western and northern shelves (WSF and NSF, respectively), especially off Magadan (MSF) and within Shelikhov Gulf (SGF), where the tidal magnitude peaks at 12 to 13 m. Very sharp tidal mixing fronts surround Kashevarov Bank (KBF) and Shantarsky Islands. An estuarine front bounds the Amur

River plume; this front continues southward along the east coast of Sakhalin as the East Sakhalin Current Front (ESCF) (Belkin and Cornillon 2003; Belkin et al. (2009)).

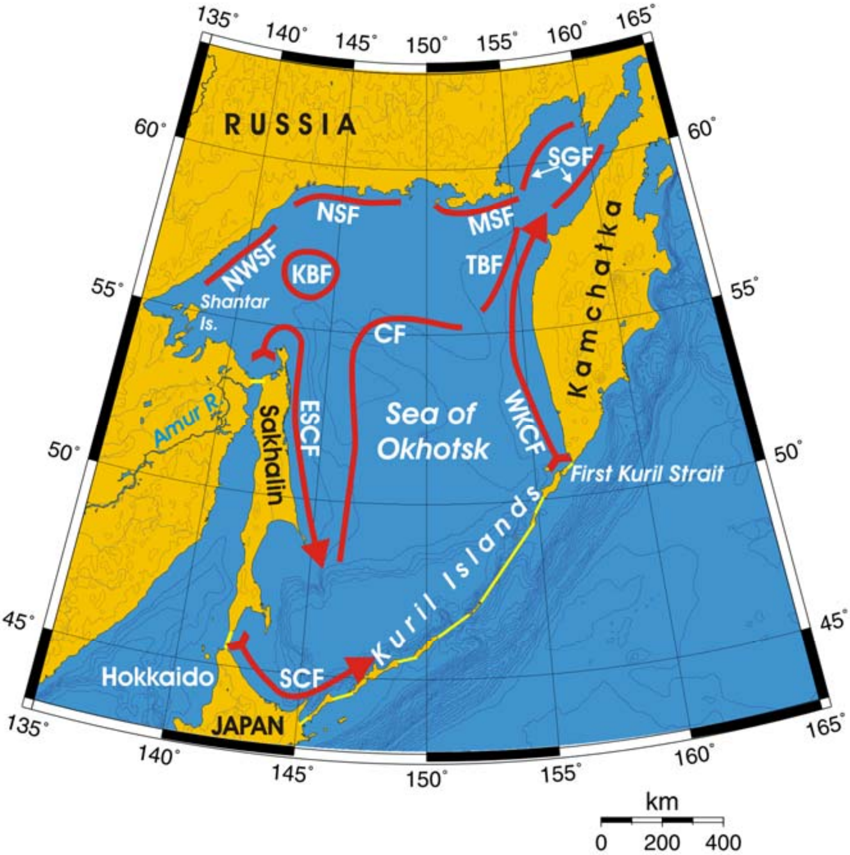

Figure X-26.1. Fronts of the Sea of Okhotsk LME. CF, Central Front; ESCF, East Sakhalin Current Front; KBF, Kashevarov Bank Front; MSF, Magadan Shelf Front; NSF, North Shelf Front; NWSF, Northwest Shelf Front; SCF, Soya Current Front; SGF, Shelikhov Gulf fronts; TBF, TINRO Basin Front; WKCF, West Kamchatka Current Front. Yellow line, LME boundary. After Belkin and Cornillon (2004) and Belkin et al. (2009).

Sea of Okhotsk LME SST (after Belkin, 2009)
Linear SST trend since 1957: 0.49°C.
Linear SST trend since 1982: 0.31°C.

The thermal history of the Sea of Okhotsk is strongly correlated with the Oyashio Current LME. In both LMEs, a major regime shift occurred in the late 1980s (Mantua et al., 1977; Hare and Mantua, 2000). The last cold year was 1987 (cf. 1988 in the Oyashio). The all-time maximum of 1990 was synchronous with the Oyashio. Both cold events, of 1992 and 2001, occurred approximately one year before similar cold events of 1992-93 and 2002-03 in Oyashio. The above one-year time lag between Okhotsk and Oyashio events suggests advective influence of the Okhotsk Sea on the Oyashio Current.

Using EOF analysis of the most recent satellite SST data, 1997-2006, Novinenko and Shevchenko (2007) found maxima in 1999 and 2006 and minimum in 2002; the last two extrema likely correspond to the 2005 maximum and 2001 minimum respectively, albeit with a one-year time lag.

Even though the pan-Pacific regime shift of 1976-1977 has not transpired in the Okhotsk Sea SST, it has caused substantial phenological changes across western subarctic North Pacific (Chiba et al., 2006, p. 907): “After the regime shift, the timing of the peak abundance was delayed one month, from March–April to April–May, in the spring community, whereas it peaked earlier, from June–July to May–June, in the spring–summer community, resulting in an overlap of the high productivity period for the two communities in May. Wintertime cooling, followed by rapid summertime warming, was considered to be responsible for delayed initiation and early termination of the productive season after the mid-1970s.” Chiba et al. (2006, p.207) have drawn a distinction between the regime shift of 1970s and the one of the 1990s: “Another phenological shift, quite different from the previous decade, was observed in the mid-1990s, when warm winters followed by cool summers lengthened the productive season.”

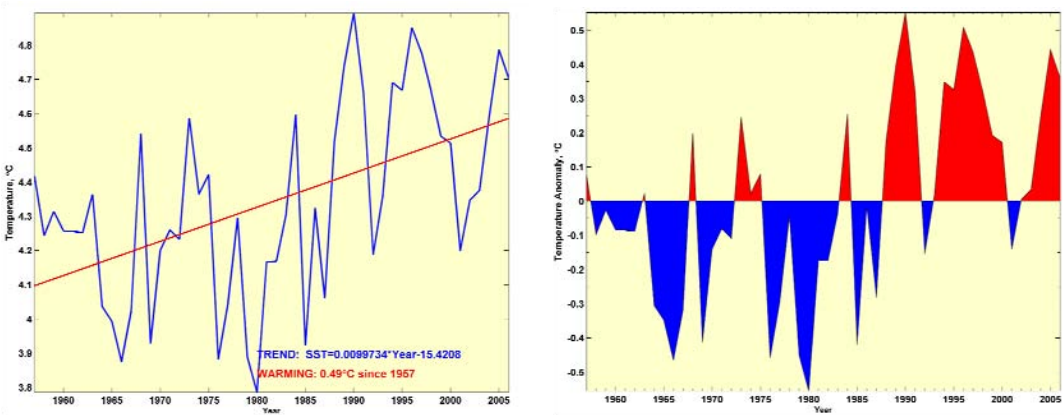

Figure X-26.2. Sea of Okhotsk LME mean annual SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

Sea of Okhotsk LME Chlorophyll and Primary Productivity: The Sea of Okhotsk LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}y^{-1}$).

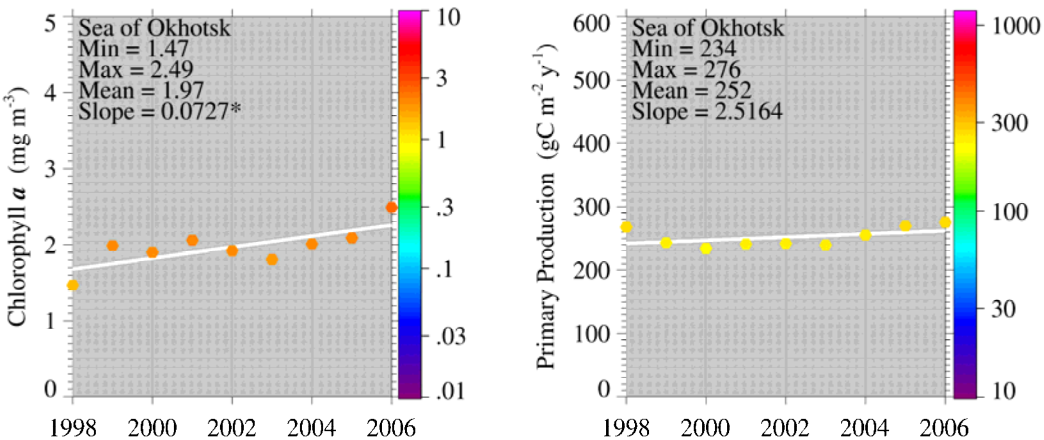

Figure X-26.3. Sea of Okhotsk LME, trends in chlorophyll a (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O’Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The Sea of Okhotsk LME is rich in fisheries resources, with approximately 300 commercially exploited species. Within the Russian EEZ, the fish stocks have been estimated at 26 million tonnes including 16 million tonnes of gadoids (Project SEA 1998). Species of commercial importance include Alaska pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasii*), Pacific saury (*Cololabis saira*), flounders (e.g., *Atheresthes evermanni*, *Hippoglossoides robustus*, *Limanda punctatissimus*, *Liopsetta glacialis*), Pacific salmon (*Oncorhynchus tshawytscha*), halibut (e.g., *Hippoglossus stenolepis, Paralichthys olivaceus*), cod (*Gadus macrocephalus*), capelin (*Mallotus villosus*), South American pilchard (*Sardinops sagax*; a.k.a sardine), king crab (*Paralithodes* sp.) and shrimp. Fluctuations in the abundance of some fish stocks (e.g., pollock, herring) have been attributed primarily to overfishing and secondarily to climatic and oceanographic factors, in particular fluctuations in warm and cold years (Kuznetzov *et al*. 1993).

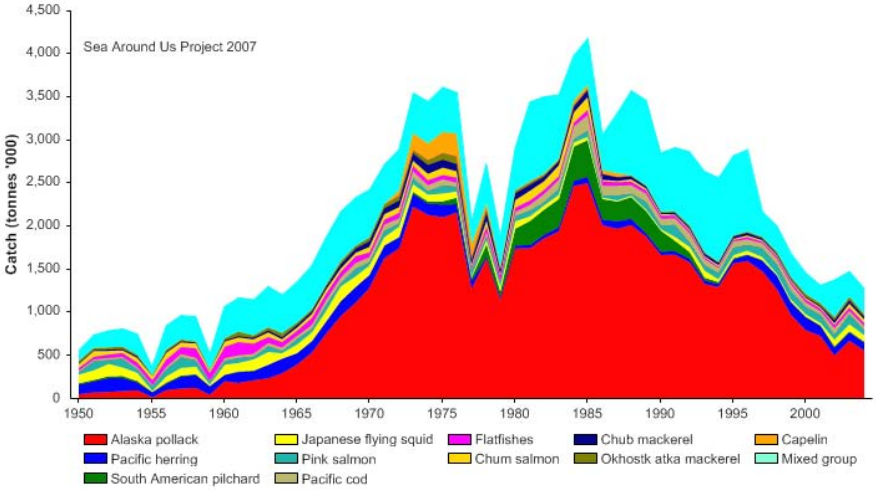

Figure X-26.4. Total reported landings in the Sea of Okhotsk LME by species (Sea Around Us 2007).

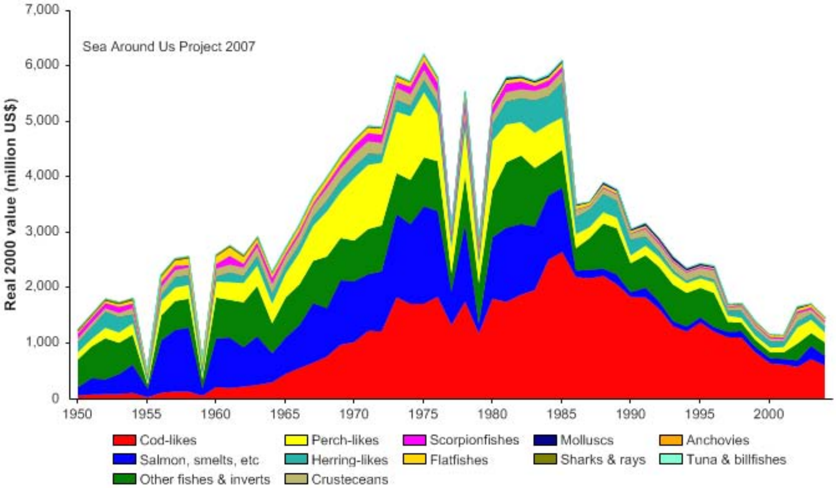

Figure X-26.5. Value of reported landings in the Sea of Okhotsk LME by commercial groups (Sea Around Us 2007).

Total reported landings showed two peaks with 3.6 million tonnes in 1975 and 4.1 million tonnes in 1985 (Figure X-26.4). Alaska pollock accounted for almost two-thirds of the total landings in the mid 1980s. The reported landings were valued at over US$5 billion (in 2000) during the peak landings of the mid 1970s and the early 1980s (Figure X-26.5). The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in the LME reached 50% of the observed primary production in the mid 1980s, but has declined in recent years (Figure X-26.6). Russia has the largest share of the ecological footprint in this LME, but Japan accounted for the largest footprint in the 1960s and 1970s.

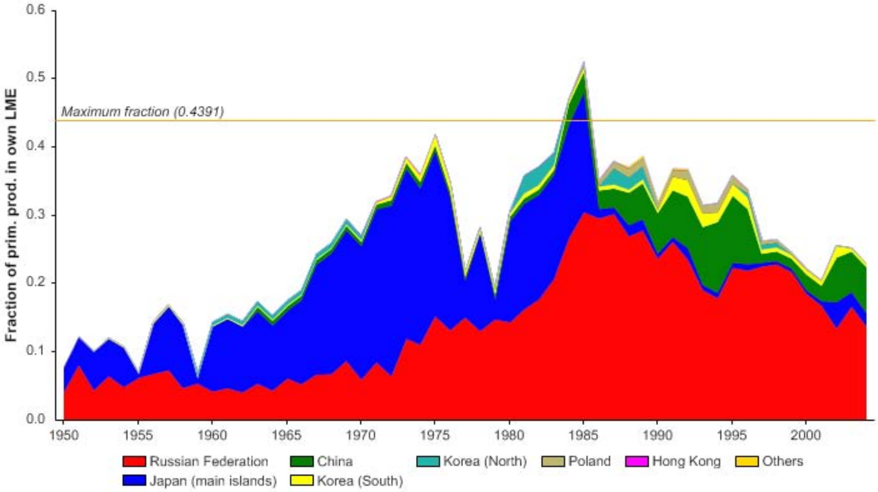

Figure X-26.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Sea of Okhotsk LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic levels of the reported landings (i.e., the MTI; Pauly & Watson 2005) underwent a steady decline to the late 1980s (Figure X-26.7 top), suggesting a 'fishing down' of the local food webs (Pauly *et al.* 1998), despite the expansion of fisheries in the region over the same period as evident by the increase in the FiB index, which levelled off in the early 1990s (Figure X-26.7 bottom). Yet, as the landings in the LME became predominantly that of Alaska pollock, a high trophic species, in the 1990s, the mean trophic level began to increase despite the decline in the total landings.

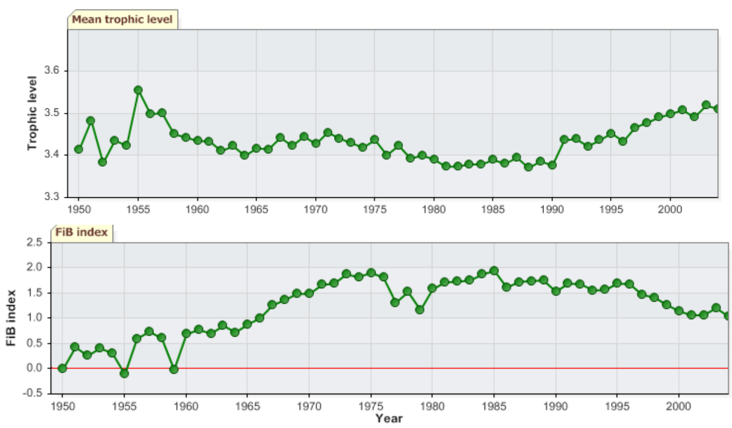

Figure X-26.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Sea of Okhotsk LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that the number of collapsed and overexploited stocks in the LME have been increasing, to about 90% of the commercially exploited stocks (Figure X-26.8, top) and these stocks account for the majority of the catch (Figure X-26.8, bottom).

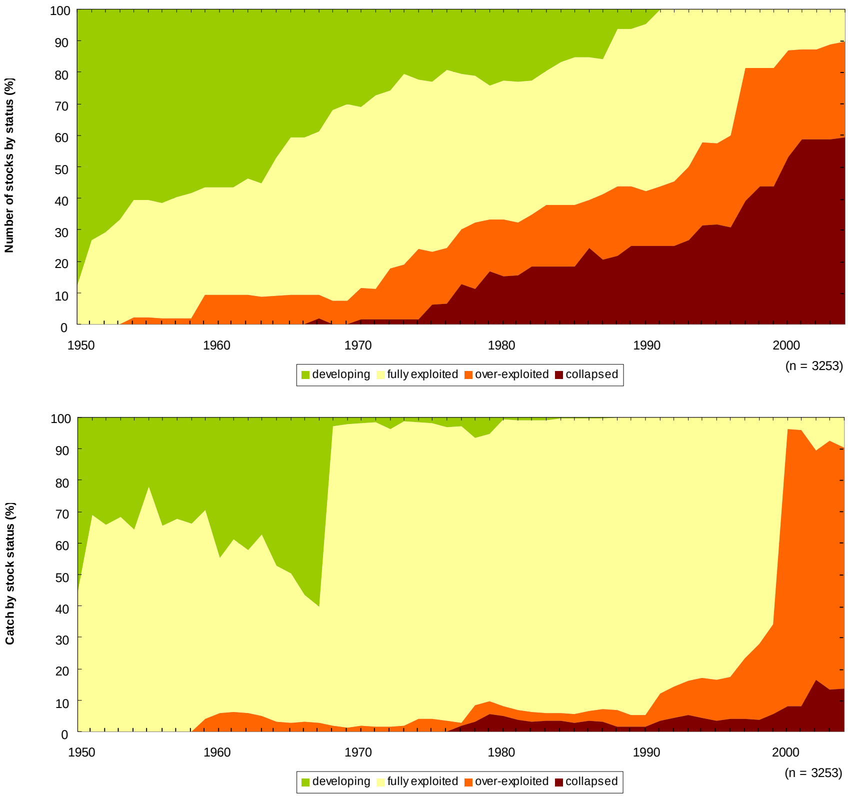

Figure X-26.8. Stock-Catch Status Plots for the Sea of Okhotsk LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

Despite fisheries regulations and control measures, most of the major fish stocks in the Okhotsk Sea LME are severely overexploited (UNEP 2006). Historical records show changes in the status of the living resources because of fishing. The high catch and discarding of young pollock in the 1990s have contributed to reducing the adult stock biomass. Flounder stocks were depleted after intensive exploitation in the late 1960s and herring catches declined in the mid-1970s. Several species such as grenadier (*Coryphaenoides* sp.), eel pout (*Bothrocara brunneum*) and skate (e.g., *Bathyraja* sp.) are caught as bycatch in the halibut fishery. The reduction of fish stocks through high fishing pressure increases their vulnerability to unfavourable environmental conditions. Increasing the catches to the maximum sustainable yield may create overall instability in the populations, leading to further stock decline. On the other hand, under relatively stable climatic and oceanographic conditions and at moderate fishing intensity, relatively high stock levels of species such as pollock can be maintained (Kuznetsov *et al*. 1993). Therefore, environmental variability must be taken into account in the management of the LME's fisheries.

III. Pollution and Ecosystem Health

Pollution: Pollution was assessed as slight, although chemical pollution and oil spills are of some concern (UNEP 2006). The exploitation of oil and natural gas off Sakhalin's east coast and shelf and throughout the LME increases the risk of pollution. Contrary to prohibitions under Russian laws, the toxic waste products of drilling and oil production on the Sakhalin shelf are discharged into the sea. The quantity of these wastes is expected to exceed many million tonnes with the further development of oil fields in the region. In the area of drilling operations, discharges of mud and toxic drilling fluids cause changes in the structure of the benthic communities (Shuntov 2001). In North Sakhalin the deterioration of ecological conditions from oil and gas exploitation has already disturbed about 40% of salmon spawning grounds, including the loss of 130 small rivers (Moiseychenko & Abramov 1994). Tanker traffic and extreme weather conditions in the LME increase the risk of oil spills and vessel collisions on the Northern Sea Route. Since the 1990s, about 3,800 tonnes of oil products have been spilled as a result of three major accidents at sea. The coastal currents of Sakhalin Island could propagate oil pollution to the southern Kuriles and to the Japan coast.

Habitat and community modification: There are no records of serious habitat modification in the Okhotsk Sea LME, although some habitats show slight degradation (UNEP 2006). Oil and gas prospecting, drilling, navigation, and oil spills are a potential danger for marine mammals, particularly the endangered grey whale, whose feeding and reproduction are disturbed by these activities. Massive oil and gas development in the waters off Sakhalin Island, an important breeding site for the spotted seal, could also affect the population of this marine mammal.

Drilling and excavating, in combination with the possible impact of oil or chemicals spills on the benthic communities of the Okhotsk Sea LME, are also of concern. Studies in the vicinity of drilling platforms on the Sakhalin shelf showed that the plankton community has been subjected to considerable pressure from the waste of drilling operations. Increased oil transport through the LME is a serious potential threat.

IV. Socioeconomic Conditions

The coastal zone of the Sea of Okhotsk LME is inhabited by about 700,000 people. Beginning in 1992, Russia experienced a population decline due to death and migration. Major industries include fisheries, oil and gas extraction, coal mining, sea transport and ship repair. Oil and natural gas deposits were recently discovered off Kamchatka's west coast and the peninsula is also rich in deposits of gold, silver, copper and coal. However, the remoteness of this area and its lack of infrastructure hinder regional development.

Marine fisheries, including fish processing, provide an important economic basis for the lucrative Sakhalin fishing industry as well as for fishing companies based in Kamchatka and Japan. Employment in the fishing industry is about 48% in the Kamchatka region and 16.6% in the Far-Eastern region as a whole (Baklanov *et al*. 2003). However, the reduction in fish catches due to overexploitation has led to an increase in the number of unprofitable enterprises and conflicts among fishers for larger quotas throughout the region, with economic losses in 2000 exceeding US$100 million.

V. Governance

The LME is governed by Russia, although the issue of sovereignty over the south Kuril Islands involves Japan. Because of its great natural resource wealth (petroleum, gas and fish), the LME is of geo-political interest to a number of countries, including the USA and Japan. National regulations on the protection of living aquatic resources (including fisheries resources) adopted in accordance with UNCLOS are the Federal Law of the Continental Shelf of the Russian Federation, the Federal Law of the Exclusive Economic Zone of the Russian Federation and the Law of the Protection and Exploitation of Marine Living Resources of the Russian Federation aimed at establishing the principles of sustainable fishing.

Legislative frameworks related to oil spills include international conventions such as MARPOL. At the national level, measures to control oil spill accidents are regulated by the Russian Federal Law of Environmental Protection. Russian authorities and international companies are perceived as being more interested in developing Sakhalin Island's oil and gas fields than in improving the island's capacity to prevent and respond to oil spills. Two environmental organisations (Sakhalin Environment Watch and the California-based Pacific Environment and Resources Centre) invited a team of independent experts to the island to review local spill prevention and response measures. The investigation resulted in 78 detailed recommendations. While some of these recommendations, including the conduct of a comprehensive vessel traffic risk assessment of the Sakhalin coast, were implemented by the Russian government, there is still major international concern over this issue.

References

Baklanov, P.Ya., Arzamastsev, I.S., Kachur, A.N., Pomanov, M.T., Plink, N.L., Gogoberidze, G.G., Rostov, I.D., Preobrajenskii, B.V., Urasov, G.I., Svarichevskii, A.S., Melnichenko, Yu.I., Juk, A.P. (2003). Management of Nature in a Near-shore Area: Problems of Control on Far East of Russia,,Dal'nauka Publishing House, Vladivostok, Russia. (In Russian).

Belkin, I.M. (2009) Rapid warming of Large Marine Ecosystems. Progress in Oceanography, in press.

Belkin, I. M. and Cornillon, P.C. (2003) SST fronts of the Pacific coastal and marginal seas. Pacific Oceanography 1(2): 90-113.

Belkin, I. M. and Cornillon, P.C. (2004) Surface thermal fronts of the Okhotsk Sea. Pacific Oceanography 2(1-2): 6-19.

Belkin, I.M., Cornillon, P.C., and Sherman, K. (2009) Fronts in Large Marine Ecosystems. Progress in Oceanography, in press.

Chiba, S., Tadokoro, K., Sugisaki, H. and Saino, T. (2006) Effects of decadal climate change on zooplankton over the last 50 years in the western subarctic North Pacific, *Global Change Biology*, **12**(5), 907-920.

Hare, S.R., and Mantua, N.J. (2000) Empirical evidence for North Pacific regime shifts in 1977 and 1989**,** *Progress in Oceanography*, 47**(**2-4)*,* 103-145.

Kuznetsov, V.V., Shuntov, V.P. and Borets, L.A. (1993). Food chains, physical dynamics, perturbations and biomass yields of the Sea of Okhotsk, p 69-78 in: Sherman, K., Alexander, L. and Gold, B.D. (eds), Large Marine Ecosystems – Stress, Mitigation and Sustainability. AAAS, Washington D.C., U.S.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M. and Francis, R.C. (1997) A Pacific decadal climate oscillation with impacts on salmon, *Bulletin of the American Meteorological Society*, **78**(6), 1069-1079.

Markina, N.P. and Chernyavsky, V.I. (1984). Some data on quantitative distribution of plankton and benthos in the Sea of Okhotsk. Inzvestiya Tikhookeanskogo Nauchno-Issledovatel'skogo Instituta Rybnogo Khozyajstva i Okeanografii 109:94-99. (In Russian).

Moiseychenko, G.V. and Abramov, V.L. (1994). A resistance of young salmons and their forage reserve to the effect of drilling components, p 126-127 in: Proceedings of 5th All-Russian Conference for Taxonomy, Biology and Breeding of Salmons St. Petersburg, Russia.

Novinenko, E.G., and Shevchenko, G. V. (2007) Spatial and temporal variability of the Okhotsk Sea surface temperature from satellite data, *Earth Research from Space* (*Issledovanie Zemli iz Kosmosa*), English edition, Issue 5, pp. 50-60 (Russian edition: pp. 1-11).

Pauly, D. and Christensen, V. (1995). Primary production required to sustain global fisheries. Nature 374: 255-257.

Pauly, D. and Watson, R. (2005). Background and interpretation of the ‘Marine Trophic Index’ as a measure of biodiversity. Philosophical Transactions of the Royal Society: Biological Sciences 360: 415-423.

Pauly, D., Christensen, V., Dalsgaard, J., Froese R. and Torres, F.C. Jr. (1998). Fishing down marine food webs. Science 279: 860-863.

Project SEA (1998). Hydrometeorology and Hydrochemistry of the Seas. Vol. IX. Sea of Okhotsk. Hydrochemical Conditions and Oceanologic Bases of Formation of Biological Efficiency. Release 2. SPb: Hydrometizdat, 1998.

Sea Around Us (2007). A Global Database on Marine Fisheries and Ecosystems. Fisheries Centre, University British Columbia, Vancouver, Canada. www.seaaroundus.org/lme/Summary Info.aspx?LME=52

Shuntov, V.P. (1985). Biological resources of the Sea of Okhotsk. Agropromizdat, Moscow, Russia. (In Russian)

Shuntov, V.P. (2001). Biology of the Far East seas of Russia. Vol. 1. Vladivostok: Pacific Research Fisheries Centre, TINRO-Centre, Russia. (in Russian)

UNEP (2006). Alekseev, A.V., Baklanov, P.J., Arzamastsev, I.S., Blinov, Yu.G., Fedorovskii, A.S., Kachur, A.N., Khrapchenkov, F.F., Medvedeva, I.A., Minakir, P.A., Titova, G.D., Vlasov, A.V., Voronov, B.A. and Ishitobi, H. Sea of Okhotsk, GIWA Regional assessment 30. University of Kalmar, Kalmar, Sweden. www.giwa.net/publications/r30.phtml.