Assessment

This section presents the results of the assessment of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Table 12.

Table 12 Scoring tables for the Russian Arctic region.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter).

IMPACT 0 No known impact; IMPACT 1 Slight impact; IMPACT 2 Moderate impact; IMPACT 3 Severe impact

The arrow indicates the likely direction of future changes. ↗ Increased impact; → No changes; ↘ Decreased impact

Kara Sea	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	0* →	1 →	1 →	0 →	0.5	5
Modification of stream flow	0					
Pollution of existing supplies	1					
Changes in the water table	0					
Pollution	2* ↗	1 →	2 →	2 →	1.8	2
Microbiological pollution	0					
Eutrophication	0					
Chemical	2					
Suspended solids	0					
Solid waste	1					
Thermal	0					
Radionuclides	1					
Spills	2					
Habitat and community modification	1* ↗	2 →	3 →	3 →	2.3	1
Loss of ecosystems	1					
Modification of ecosystems	1					
Unsustainable exploitation of fish	1* →	2 →	1 →	1 →	1.3	3
Overexploitation	2					
Excessive by-catch and discards	0					
Destructive fishing practices	0					
Decreased viability of stock	1					
Impact on biological and genetic diversity	0					
Global change	1* →	1 →	0 →	1 →	0.8	5
Changes in hydrological cycle	1					
Sea level change	0					
Increased UV-B radiation	1					
Changes in ocean CO_2 source/sink function	1					

Laptev, East Siberian and Chukchi seas	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	0* →	1 →	0 →	0 →	0.3	5
Modification of stream flow	0					
Pollution of existing supplies	0					
Changes in the water table	0					
Pollution	1* →	0 →	1 →	2 →	1.0	2
Microbiological pollution	0					
Eutrophication	0					
Chemical	1					
Suspended solids	0					
Solid waste	0					
Thermal	0					
Radionuclides	0					
Spills	1					
Habitat and community modification	1* →	1 →	3 →	3 →	2.0	1
Loss of ecosystems	1					
Modification of ecosystems	1					
Unsustainable exploitation of fish	0* →	1 →	1 →	1 →	0.8	4
Overexploitation	1					
Excessive by-catch and discards	0					
Destructive fishing practices	0					
Decreased viability of stock	1					
Impact on biological and genetic diversity	0					
Global change	1* →	1 →	0 →	1 →	0.8	3
Changes in hydrological cycle	1					
Sea level change	0					
Increased UV-B radiation	1					
Changes in ocean CO_2 source/sink function	1					

* This value represents an average weighted score of the environmental issues associated to the concern.

** This value represents the overall score including environmental, socio-economic and likely future impacts.

*** Priority refers to the ranking of GIWA concerns.

Freshwater shortage

Kara Sea **Laptev, East Siberian and Chukchi seas**

The three largest river basins in the region are Yenisei, Ob and Lena, the first two draining into Kara Sea and the latter into Laptev Sea. Other large river basins in the Kara Sea drainage area are Taz and Pur rivers. The main rivers of the East Siberian Sea Basin are the Indigirka and Kolyma rivers. The quiality of these water bodies is affected by industrial and domestic pollution such as wastewater and atmospheric emissions. The two issues modification of stream flow and changes in water table were both assessed as having no known impacts in the region and are therefore not further discussed.

Environmental impacts

Pollution of existing supplies

Kara Sea

Pollution of existing supplies was assessed to have a slight impact in the Kara Sea sub-system. The main rivers of the Kara Sea Basin are the Ob, the Pur, the Taz and the Yenisei. The Ob and the Yenisei are among the largest rivers in the Arctic. The quality of the water bodies in the Ob Basin is greatly affected by industrial atmospheric emissions, and the effects of forest tracts (often swamped), which enrich the water with a great amount of organic substances that do not dissolve easily, including phenols, and low- and high-molecular petroleum hydrocarbons. The downstream portion of the Ob is polluted by phenols, petroleum, and iron compounds (Table 13). The maximum concentrations found were 0.009 mg/l for copper, 0.15 mg/l for zinc, 1.75 mg/l for petroleum, and 0.085 mg/l for phenols (Roshydromet 1997-2002). It should be noted that the petroleum pollution levels in the vicinity of large industrial enterprises are lower than in the vicinity of intensive oil production. The main contributor to water pollution in the lower Yenisei River is the wastewater of the Podtesosk ship-repair yard, the Yenisei timber-rafting agency, the Lesosibirsk and Novoyeniseisk sawmills and wood-working integrated works, the Igarka timber transhipment integrated works, and the Igarka river port. The water is most polluted by petroleum, copper, zinc and iron (Table 13) (Roshydromet 1997-2002).

Laptev, East Siberian and Chukchi seas

Generally, no known impact of pollution of existing supplies was assigned to the Laptev, East Siberian and Chukchi seas sub-system. However, local impacts occur. The large rivers that empty into the Laptev Sea are the Anabar, Olenek, Lena and the Yana. The Lena is the second largest river in the Arctic after the Yenisei River (Figure 8). Wastewater from the Lenarechenergo, Lenzoloto, and Siberian Gold companies, and river crafts, ports, petroleum bases, and shipyards have a pronounced effect on water quality of the Lena River. The downstream waters are polluted by phenols, copper compounds, and zinc (Table 13) (Roshydromet 1996a, 1996b, 1997-2002). Waters in the Anabar River contain concentrations of copper compounds as high as 0.013 mg/l, as well as high concentrations of petroleum. The waters of the Yana are heavily polluted by phenols, and by copper, zinc, and iron (Table 13) (Roshydromet 1996a, 1996b, 1997-2002).

Table 13 Water pollution in some of the rivers in the Russian Arctic region.

River	Phenols (mg/l)	Petroleum (mg/l)	Iron (mg/l)	Copper (mg/l)	Zinc (mg/l)	Mercury (mg/l)
Ob	0.026	0.7	1.3	ND	ND	ND
Yenisei	ND	0.25-0.6	0.1-0.5	0.005-0.015	0.01-0.05	ND
Lena	0.002-0.007	ND	ND	0.001-0.012	0.01-0.03	ND
Yana	0.001-0.005	ND	0.1-1.1	0.002-0.009	0.01-0.04	ND
Kolyma	0.001-0.004	0.1-0.4	0.1-0.3	0.002-0.006	ND	ND
Indigirka	0.006-0.008	ND	0.1-1.8	0.002-0.007	ND	0.015

Note: ND = No Data.

(Source: Roshydromet 1996a,b, 1997, 1998, 1999, 2000, 2001, 2002)

The main rivers of the East Siberian Sea Basin are the Indigirka and the Kolyma. The water volume of the Kolyma is more than two times that of the Indigirka. The main pollution sources in the Kolyma River Basin are the wastewater from the gold mining industry, housing and communal services. The water is polluted by petroleum, phenols, copper compounds and iron (Table 13). Maximum concentrations of petroleum, phenols, and copper compounds amounted to 0.45, 0.016 and 0.011 mg/l, respectively (Roshydromet 1996a, 1996b, 1997-2002). The Indigirka River is polluted by phenols, copper compounds and iron (Table 13). Mercury was also found in the water with concentraions up to 0.015 mg/l. The maximum phenol concentration was 0.037 mg/l (Roshydromet 1996a, 1996b, 1997-2002).

Socio-economic impacts

The socio-economic impacts of freshwater shortage are not significant in the region. However, the GIWA Task team assessed economic and health impacts to be slight. There is no precise statistical evidence of diseases caused by pollution of freshwaters, but there are single records of diseases resulting from poor water quality (dysentery, hepatitis) in the Kara Sea sub-system There are no records of other social and community impacts in the region.

Conclusions and future outlook

Freshwater shortage is not a problem for the region under present conditions, and it is unlikely that it will become a problem in the near future.

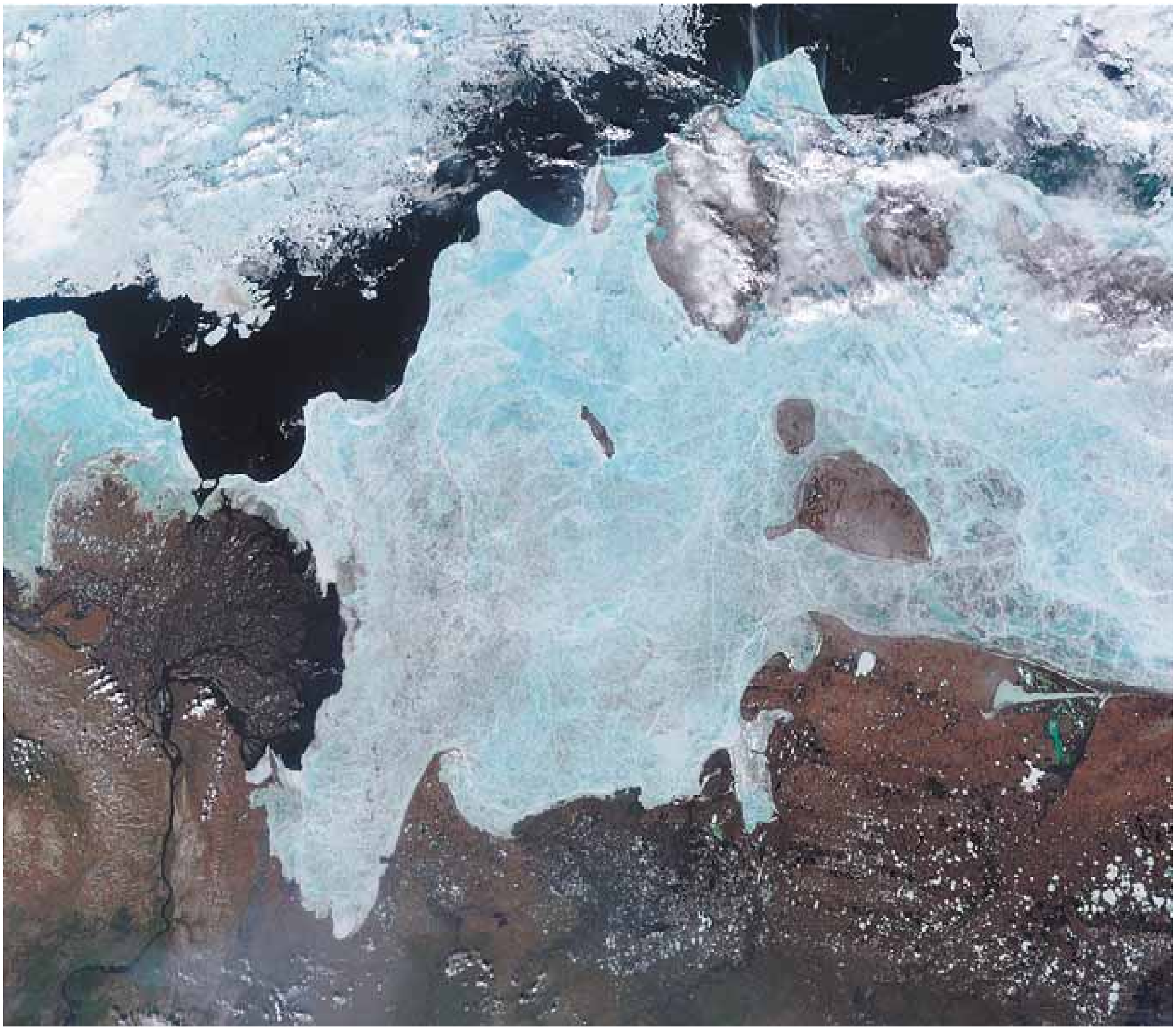

Figure 8 Lena River Delta and East Siberian Sea.
(Photo: NASA)

Pollution

Kara Sea **Laptev, East Siberian and Chukchi seas**

The current anthropogenic impact on the Arctic marine environment consists mainly of the increasing rate of pollutant transport from both local and regional sources. Anthropogenic activities in the Russian Arctic region causing pollution include:

- Direct dumping of waste from industrial, municipal, and agricultural enterprises situated on the coast;
- Burial of toxic material;
- Maritime accidents;
- Run-off via rivers from various land uses;
- Operation of transport facilities such as marine and river craft, aviation, timber rafting, road and pipeline transport;
- Mineral extraction;
- Atmospheric pollution from e.g. industries.

The large river run-off has substantial effects on the Arctic seas. This flow is the equivalent of about 10% of the total global run-off. Significant quantities of chemically reactive and biogenic material may be transported by the rivers. Human activities have significant direct

and indirect consequences for the amount and timing of the run-off into the Arctic Ocean.

At present, large mining and smelting integrated plants (Pechenga-Nickel, Monchegorsk, Norilsk), many open pits and polygons, and an extensive network of pipelines are operated in the Russian Arctic region. In addition, 25 coal mines, five strip mines, more than 20 large mines and associated concentrating mills, 200 gold excavation and precious metal mining and hundreds of oil and gas wells are operated in the region. Carbon dioxide emissions in the Russian Arctic account for 33% of the total emissions from Russia's entire territory; emissions of copper, nickel, sulphuric acid, soot and chlorine account for 61, 88, 82, 23 and 40% of the country's total emissions, respectively. Oil pollution is becoming highly problematic in some bays and offshore regions of the Arctic seas (SB RF 1995).

Pollution sources

Mining and process industries make a significant contribution to environmental pollution in the Russian Arctic. They are sources of emissions containing sulphur dioxide, carbon and nitrogen oxides, ammonia, hydrogen sulphide, formaldehyde, phenol, benzo(a)pyrene, trace metals, dioxins, and polychlorinated biphenyls. The coal mining industry is a source of polycyclic aromatic hydrocarbons and a great amount of sulphur, nitrogen and carbon oxides, and trace metals. Wood processing industry complexes, especially integrated pulp-and-paper mills, discharge phenols, benzo(a)pyrene and formaldehyde.

Accidental oil spills associated with navigation, oil and gas production and exploitation on both the land and the Arctic shelf are a major issue for Arctic seas. As a result, there are practically no rivers in western Siberia that are free of oil pollution (MEPNR 1994, Roshydromet 1996a, 1996b, 1997-2002). Discharges of raw or inadequately purified wastewater also contaminate estuarine areas.

Table 14 shows areas most impacted by pollution in the Russian Arctic region as well as the adjacent GIWA region Barents Sea. Industries in the Murmansk and Arkhangelsk oblasts are a source of atmospheric and water contamination that is subsequently transported to the central and eastern Arctic regions. Due to the atmospheric and riverine transport of pollutants, the influence of the industrial centres can be seen over a substantial distance. This long-range transport has a pronounced effect on the state of marine ecosystems.

Atmospheric transport

The importance of atmospheric transport in polluting the world's oceans has only been recognised in the last few decades. For example, hundreds of thousand tonnes of lead compounds, and tens of thousand tonnes of chlorinated hydrocarbons, including PCBs, HCHs, dibenzodioxines and other toxic compounds precipitate from the atmosphere onto the ocean surface every year (Izrael & Tsyban 1989). Essentially all known contaminants have been found in the atmosphere above the Arctic. At the same time, there is relatively little specific data about these contaminants and their concentrations in the Arctic. Air samples have been collected by the Roshydromet background monitoring network (Rovinsky & Gromov 1996, Roshydromet 1997-2002) and in during different expeditions (Izrael & Tsyban 1992, Izrael & Tsyban 2000, Tsyban 1999, Bidleman et al. 1996, Chernyak et al. 1996).

The sources of air pollution above the Russian Arctic seas are primarily industrial centres, towns and settlements in the immediate vicinity of the seas. These sources, as a rule, are located in the western Arctic (Table 14). For example, every year, the following substances are discharged to the air (SB RF 1995, Igamberdiev & Tereshnikov 1994, Roshydromet 1997-2002):

- Murmansk region: 61 180 tonnes of solid substances, 12 070 tonnes of hydrocarbons, 1 140 tonnes of hydrocarbons and 10 tonnes of phenol.
- Arkhangelsk region: 55.3 tonnes of solid substances.
- Komi Republic: 138 800 tonnes of solid substances and dust.
- Taimyr Autonomous Area 29 700 tonnes of solid substances, 1 300 tonnes of nickel, 3 000 tonnes of copper and 44 tonnes of lead.
- Chukot Autonomous Area 13 700 tonnes of lead.

Atmospheric transport of dust and solid substances results in the deposition of materials of continental origin in the open areas of the

Table 14 Pollution impact areas in the Russian Arctic region.

Area (Industrial centres)	Pollution sources	Polluting substances
The Kola Peninsula (Murmansk, Nickel, Zapolarny, Monchegorsk, Olenegorsk) *	Metallurgy, mining industry, municipal sewage, nuclear power plants, transport and other	Trace metals, petroleum, PAHs, radionuclides, dust
Northern Dvina (Arkhangelsk, Novodvinsk) *	Pulp-and-paper industry, municipal sewage, thermal power plant and others	Phenols, petroleum, PAHs, chlorinated hydrocarbons, dust, trace metals, radionuclides
Timano-Pechersk	Oil and gas production, wood-working industry and others	Petroleum, phenols, trace metals, chlorinated hydrocarbons
Ob	Oil and gas production and others	Petroleum, phenols, chlorinated hydrocarbons, trace metals
Yenisei	Wood-working industry, river ports and others	Petroleum, phenols, chlorinated hydrocarbons, trace metals
Norilsk	Metallurgy, mining industry	Trace metals, PAHs, dust
Yana-Indigirka	Mining industry	Trace metals, radionuclides, petroleum, dust
Valkumeisk	Mining industry, thermal power plants	Trace metals, PAHs, radionuclides, dust

*Note: * Part of GIWA region 11 Barents Sea.*

(Source: SB RF 1995, MEPNR 1994, Roshydromet 1996a,b, 1997, 1998, 1999, 2000, 2001, 2002)

seas. They can also inhibit photosynthetic processes, resulting in the decreased transparency of the ocean's surface layers.

It is noteworthy that rather high concentrations of some pollutants have been found in the air above industrial centres in the Arctic. For example, above the Murmansk region industrial centres in the GIWA region Barents Sea, the benzo(a)pyrene (BP) concentration varied between 1.1 and 9.5 µg/m^3 while the concentration ranged from 1.2-2.0 µg/m^3 in the Chukchi Autonomous Area. It should be noted that BP possesses toxic, mutagenic and carcinogenic properties. BP also circulates actively in arctic ecosystems and accumulates in marine biota, including commercially valuable fish. Annually, about 1.4 tonnes of BP is transported to the Russian Arctic region, which represents 0.9% of the total emissions from CIS and Baltic countries (Izrael et al. 1992).

As a result of the long-range atmospheric transport of pollutants from industrial regions, the Arctic seas are contaminated when aerosolised pollutants are washed out of the atmosphere (Burova 1992). This is demonstrated in part by the contrast between HCH concentrations in the open regions of the Kara Sea, which were higher than those in offshore areas; a finding that can only be explained by atmospheric transport (GOIN 1996d).

The transport of air masses to the Arctic is complicated and highly variable. It is presumed that winter air masses come to the Arctic mainly from Eurasia, while in summer this flux moves in the opposite direction. Air masses also typically come from the northern regions of the Pacific (above Alaska) and Atlantic (from Greenland) Oceans. Thus, an important source of Arctic pollution is the long-range atmospheric transport of pollutants from the industrial zones of the northern hemisphere.

River run-off

River run-off plays one of the leading roles in the pollution of the Arctic seas. The huge catchment area and large water volume (70% of the total river run-off in the Russian Federation) means that river run-off transports a huge percentage of the Russian territory's total pollutant burden to the Arctic. This includes 65-75% of the organic matter, nitrogen, phosphorus, iron, and silicon compounds, 91% of petroleum, 95% of HCH isomers, 51% of DDT and 18% of DDE (Roshydromet 1996a).

The rivers of the region can be arranged in descending order based on their petroleum input to the Arctic seas (Roshydromet 1996-2002):
Ob River (Kara Sea); Yenisei River (Kara Sea); Anabar River (Laptev Sea); Lena River (Laptev Sea); Taz River (Kara Sea); Pur River (Kara Sea); Olenek River (Laptev Sea); Kolyma River (East Siberian Sea); and Indigirka River (the East Siberian Sea).

They can also be arranged with respect to organochlorine hydrocarbon (HCH, DDT, DDE) transport (Roshydromet 1996-2002):
Yenisei River (the Kara Sea); Ob River (the Kara Sea); Taz River (the Kara Sea); Anabar River (the Laptev Sea); Olenek River (the Laptev Sea); Lena River (the Laptev Sea); and Kolyma River (the East Siberian Sea).

Environmental impacts

Generally, the environmental impacts of pollution was assessed to be moderate in the Kara Sea sub-system and slight in the Laptev Sea, East Siberian Sea, Chukchi Sea sub-system. Specific impacts of the different pollution issues is discussed below. There are no records of microbiological, eutrophication or thermal pollution in the Russian Arctic region. There are either no obvious problems from water turbidity, suspended solids and associated limitation of water transparency. Solid waste was considered to have no known impact in the Laptev, East Siberian and Chukchi sub-system. These issues are therefore not further discussed. However, domestic solid waste and metal barrels pollute the shores of the Kara Sea Basin and these wastes can harm biological processes and ecosystems (GESAMP 2001). The issue was therefore considered to have slight impacts in this sub-system.

Chemical pollution

Water bodies in the region show minimal or insignificant chemical contamination. However, some chemical contaminants in the Kara Sea region are above Russian threshold limits. However, the existing level of pollution in the Laptev Sea, East Siberian Sea, Chukchi Sea sub-system is lower than the Permitted Marginal Concentration (state standards). Contaminant concentrations are described below.

Kara Sea

The Kara and Laptev seas play the leading role in the transport of ice and water masses in the Arctic. The largest Asian rivers, with catchment areas equal to almost half of the Russian territory, flow into the Kara Sea. The Ob and Yenisei river mouths create large estuaries where freshwaters mix with seawater. This freshwater influence can be traced hundreds of kilometres from the river mouths. The pollution sources for the Kara Shelf are the same as pollution sources for other Arctic seas. The largest Siberian rivers, the Ob and the Yenisei, carry a substantial amount of pollution to the Kara Sea. Almost 40% of the sea area is affected by continental freshwaters. Chemical monitoring data from the Roshydromet network (GOIN 1996d, Roshydromet 1997-2002) and the Arctic Monitoring Centre, show that trace metals and petroleum hydrocarbons are the most widespread pollutants in the Kara Sea.

According to GOIN (1996d) and Roshydromet (1997-2002) the mean DDT concentration was 0.27 ng/l in the range between 0.04 and 1.40 ng/l; the mean ΣHCH was 0.16 ng/l, with a maximum concentration of 0.37 ng/l found in the Baidarats Bay; and the mean PCB content amounted to 1.15 ng/l, with a maximum of 11 ng/l recorded in the Ob Bay. In 1995 the DDT concentrations in Kara Sea surface water varied from 0.03 to 2.5 ng/l. The maximum DDT concentrations (up to 249 ng/l) were found near Belyi Islands; maximum concentrations of HCHs (up to 2.25 ng/l) and of PCBs (up to 8.3 ng/l) were observed near the Ob Bay and near Cape Kharasavei (the southwestern sea), respectively (GOIN 1996d).

A one-time measurement of trace metal concentrations in Kara Sea surface waters in 1991 found lead, cadmium, and tin, and copper concentrations at tenths to hundredths of µg/l. Mn, Ni and Zn concentrations were found at several mg/l (GOIN 1992). Measurements in the coastal zone during the summer of 1992 found the following high concentrations (which reflect increased river discharges due to snowmelt and thawing ice): 58.8 µg/l of iron, 15.3 µg/l of zinc, 0.4 µg/l of lead, and 0.15 µg/l of cobalt (GOIN 1996a). In 1993 the highest concentrations were observed to the east of Belyi Island in the zone influenced by the Ob and Yenisei: 3.1 µg/l of manganese, 96 µg/l of iron, 0.5 µg/l of nickel, 1.9 µg/l of copper, 10 µg/l of zinc, and 0.07 µg/l tin; the Pyasina Bay showed the copper concentrations of 1.6 µg/l (GOIN 1996b). In 1994 the picture did not change: in the open sea the concentrations varied in the hundredths of mg/l for lead, cadmium, tin, and cobalt, in the tenths of µg/l for nickel, and in the tenths to whole units of µg/l for iron, manganese, copper, and zinc. Higher levels of trace metals were found in summer months in the areas of the Ob and Yenisei mouths (GOIN 1996c).

The levels of trace metal content of the seawater and bottom sediments of the Kara Sea are shown in Figure 9. It is noteworthy that higher concentrations of the pollutants in the water and bottom sediments were found in the estuaries of the Ob and Yenisei rivers as well as in the offshore area exposed to the river and terrigenous run-offs (Table 15) (GOIN 1996, Roshydromet 1997-2002).

The state of chemical water pollution in the offshore region of the Kara Sea has not changed appreciably in the last years. Toxic pollutants such as HCHs, DDTs and PCBs are found practically in all bays and estuarine zones. This fact causes serious concern in connection with the negative consequences of chronic impacts of contaminants on marine organisms.

The following concentrations of pollutants have been measured in precipitation above the central Kara Sea (expedition KAREX-94):

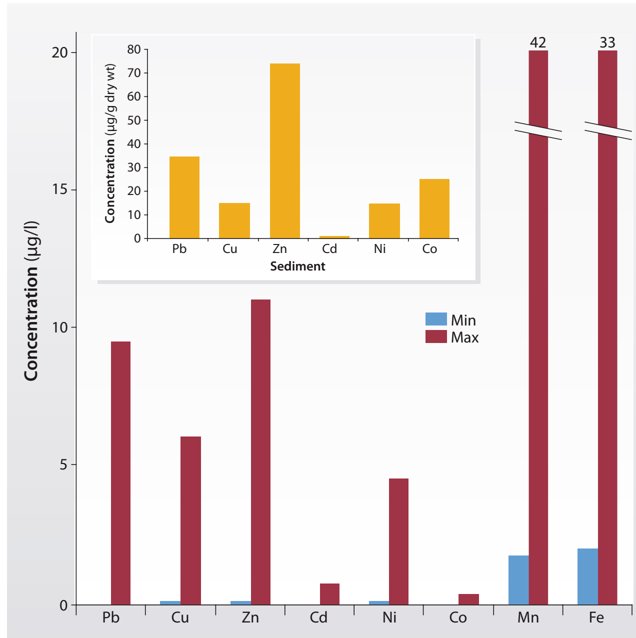

Figure 9 Metal concentrations in the Kara Sea waters and bottom sediments.

(Source: GOIN 1996, Roshydromet 1997,1998, 1999, 2000, 2001, 2002)

0.33-0.53 ng/l of α-HCH; 0.25-0.26 ng/l of γ-HCH; 0.35-0.95 ng/l of DDE; 0.07-0.33 ng/l of DDD; 0.10-0.44 ng/l of DDT; and 3.1-11.0 ng/l of PCBs (GOIN 1996c). The data presented confirm that pollution in the waters of the Arctic basin has resulted from long-range atmospheric transport, particularly in view of the fact that DDT has not been used in the Kara Sea Basin since 1977 (Roshydromet 1996a).

Table 15 Pollutants above maximum allowed concentrations in the Kara Sea sub-system.

Region	Above maximum allowable concentration								
	DDT	HCH	PCBs	PHs	Cu	Zn	Mn	Fe	PAHs
Yenisei Bay	√	√		√	√	√	√	√	√
Ushakov Island region	√								
Ob Bay		√	√	√	√	√	√	√	√
Pyasina Bay		√			√				
Taz Bay				√					
Baidarats Bay	√			√					
Yamal Coast			√						
Belyi Island region	√								
Kharasavei Cape			√	√					
Dikson				√					
Amderma				√					

(Source: GOIN 1996, Roshydromet 1997, 1998, 1999, 2000, 2001, 2002)

In air samples above the Chukchi Sea in the area of Vrangel Island, the α-HCH and γ-HCH content amounted to 73 and 20 pg/m^3, respectively (Jantunen & Bidleman 1995, Bidleman et al. 1995). In the western Arctic the PCB concentration reached 904 pg/m^3 in 1988 and 382 pg/m^3 in 1993; the DDT content was 38.00 and 34.82 ng/m^3, respectively (Hinckley et al. 1992, Izrael & Tsyban 2000). It should be noted that according to data from Bidleman et al. (1995), in the period from 1988 to 1993 the HCH content of the atmosphere above the Bering and Chukchi seas declined considerably while the HCH concentration in these seas has remained relatively unchanged since the early 1980s. The Arctic seas are currently losing their function as an HCH sink and are becoming a new HCH source for the Arctic (Bidleman et al. 1995).

Discharges of trace metals from the non-ferrous metallurgy industry make a substantial contribution to both air and ocean pollution in the region. In Norilsk (see Figure 13), for example, respectively 2 800, 1 250 and 68 tonnes per year of copper, nickel and cobalt have been emitted (Rovinskiy & Gromov 1996).

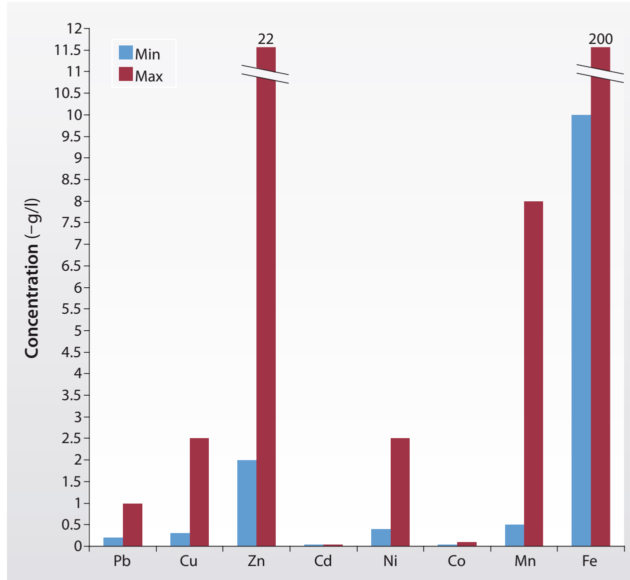

Figure 10 Metal concentrations in Laptev Sea waters.
(Source: GOIN 1996, Roshydromet 1997,1998, 1999, 2000, 2001, 2002)

Laptev, East Siberian and Chukchi seas

Because of its geographical position and hydrologic conditions, the Laptev Sea qualifies as a continental margin sea. Most of the sea is shallow; half its total area is no deeper than 50 m. The shelf regions of the sea are polluted by a number of inland activities, including oil and gas exploration and production, inland water and sea transport, ore mining and processing enterprises, accidental oil spills, floating and sunken wood, and discharges and effluent from towns and settlements situated on the coast and along rivers. River run-off and atmospheric transport play an important role in marine pollution.

Phenol concentrations in the Laptev Sea are the highest of all Arctic seas (GOIN 1996d, Roshydromet 1997-2002). The highest phenol concentrations (up to 65 mg/l) are typical for coastal areas, that are under the influence of floating and sunken wood. In 1991 the concentrations of ΣHCH amounted to 17 ng/l (GOIN 1992). In 1992 the highest concentrations of ΣDDT (up to 0.9 ng/l) were found in the region of the northern lands, while the highest concentrations of ΣHCH and ΣPCB were observed near the Novosibirsk Islands and in the Vilkitsky Strait, respectively (GOIN 1996a). In 1993 the DDT content was 2.7 ng/l in Khatanga Bay and 1.3 ng/l near the Novosibirsk Islands; the HCH concentration amounted to 1.2 ng/l near Little Taimyr Island and 2.9 ng/l in the Shokalsky Strait; and the PCB content was 5.5 ng/l near Stolbovoi Island, 4.5 ng/l in Anabar Bay and 4.5 ng/l in Olenek Bay (GOIN 1996b). The average content of the DDT group amounted to 0.2 ng/l (varying from 0.01 to 1.20 ng/l), and the HCH and PCB concentrations varied from 0.3 to 1.0 ng/l and from 2.4 to 7.0 ng/l, respectively. The highest pollution levels were found in the estuarine areas, in the Zarya Strait and near the Novosibirsk Islands (GOIN 1996, Roshydromet 1997-2002). The water concentrations of trace metals in the Laptev Sea are presented in Figure 10.

The East Siberian Sea is a marginal sea fully situated on the continental shelf. Water depths of 20 to 25 m predominate. The sources of water pollution in the East Siberian Sea, as in other Arctic seas, are marine and inland water transport, depots of combustible materials and lubricants, refuelling points, mining enterprises, towns and settlements situated on the sea coast and along rivers, transport of contaminants by air fluxes and Arctic ice, accidental spills, sunken wood, etc. According to routine statistical data collected over the last decade (GOIN 1996, Roshydromet 1997-2002), about 300 kg of oil, about 18 000 tonnes of particulate matter, 215 tonnes of sulphates, 83 tonnes of chlorides, about 980 kg of nitrates, and 167 kg of fats were discharged in the Chaun region of the East Siberian Sea. A broad spectrum of trace metals was discovered in the water and bottom sediments of the East Siberian Sea, with iron and zink being the main pollutants (Figure 11).

The Chukchi Sea is also a marginal sea, where depths of 40 to 60 m predominantly. The maximum depth is 1 256 m. The Chukchi Sea, with a high biological productivity and high species diversity, is one of the unique regions of the world's oceans. Additionally, because the area receives a substantial flux of carbon dioxide from the atmosphere, the Chukchi Sea plays an important role in shaping the Earth's climate. The

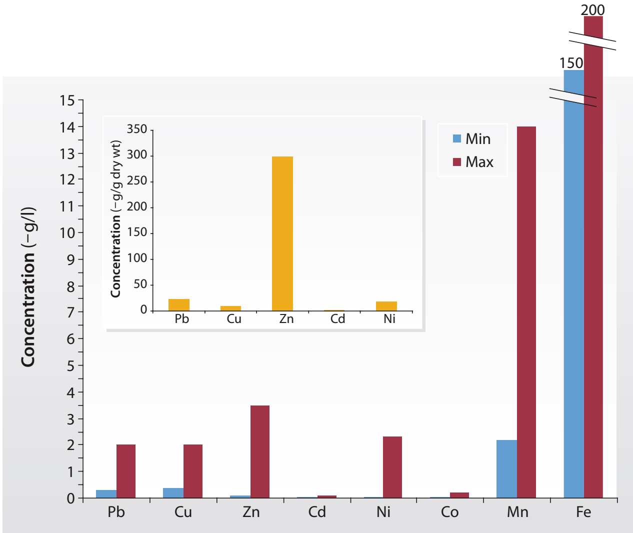

Figure 11 Metal concentrations in East Siberian Sea waters and bottom sedimets.
(Source: GOIN 1996, Roshydromet 1997,1998, 1999, 2000, 2001, 2002)

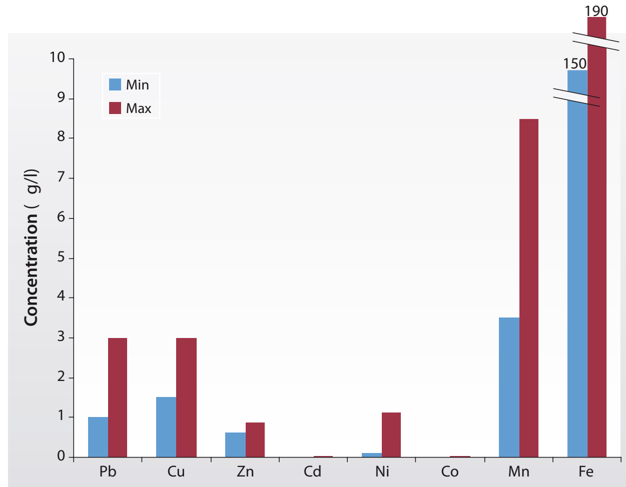

Figure 12 Metal concentrations in Chukchi Sea waters.
(Source: GOIN 1996, Roshydromet 1997,1998, 1999, 2000, 2001, 2002)

coastal waters of the Chukchi Sea are polluted by local sources, such as sewage from settlements, ships, accidental spills of combustible materials and lubricants, and decaying sunken and floating wood. According to routine statistical data collected over the last decade (GOIN 1996, Roshydromet 1997-2002), 200 kg of oil, 105 tonnes of particulate matter, 48.5 tonnes of sulphates, 65 tonnes of chlorides and 2 462 kg of nitrates have been discharged from the Russian territory (from the Schmidt Region alone) into the coastal zone of the Chukchi Sea. The open sea is mainly polluted by the transport of contaminants in the air and Arctic ice.

In spite of the considerable remoteness of the Chukchi Sea, heavy metals, aromatic and chlorinated hydrocarbons, and new contaminants (endosulfan, bromoform, dibromomethane, etc.) have been discovered over the last few years in all the main components of its ecosystems. Figure 12 shows a broad spectrum of trace metals in the surface waters of the Chukchi Sea.

A study of the chemical regime in the Chukchi Sea over the past decade (Izrael & Tsyban 1992, Tsyban 1999, Izrael & Tsyban 2000, Roshydromet 2001) has shown that the distribution of organic pollutants is becoming more and more pronounced from year to year. At the present time, it is believed that hexachlorocyclo-hexanes (HCHs) rank among the most widespread chlorinated pesticides in the Arctic seas (Bidleman et al. 1995). For example, the HCH content of water samples in Chukchi Sea waters exceeds that of other chlorinated hydrocarbons, such as polychlorinated biphenyls (PCBs) and DDTs (Table 16). While the atmospheric concentration of HCH isomers has decreased considerably, the α-HCH content of the sea water has remained unchanged for the last 5 years and that of γ-HCH has decreased 4- fold. Table 16 shows that the α-HCH accumulation in the bottom sediments is growing while that of γ-HCH has decreased pronouncedly, probably owing to biodegradation (Hinckley et al. 1992, Izrael & Tsyban 2000).

Data from a long-term investigation of the HCH distribution in the waters of the Chukchi Sea and Bering Sea show that the HCH concentration in Arctic seas has remained relatively constant since the early 1980s, while its atmospheric concentration has decreased considerably (Jantunen et al. 1995, Bidleman et al. 1995). These authors indicate that the Chukchi and Bering seas are losing their function as a HCH sink and are becoming a new HCH source to the Arctic atmosphere.

Table 16 Chlorinated hydrocarbons in the Chukchi Sea.

	Region	Water (ng/l)		Air (pg/m^3)		Sediments (ng/g)	
		1988	1993	1988	1993	1988	1993
α-HCH	Western part	2.33	2.22	212	70	0.92	ND
	Eastern part	2.41	2.43	214	74	0.27	0.43
	Vrangel Island	ND	2.07	ND	73	ND	ND
γ-HCH	Western part	0.59	0.16	57	20	0.21	ND
	Eastern part	0.61	0.15	57	19	0.11	0.02
	Vrangel Island	ND	0.14	ND	20	ND	ND
DDT	Western part	0.003	0.08	38.0	34.8	3.49	ND
	Eastern part	0.004	0.095	ND	32.4	0.14	0.60
	Vrangel Island	ND	0.17	38.0	46.9	ND	ND
PCB	Western part	0.43	0.63	904	382	13	ND
	Eastern part	0.55	0.56	904	550	8.7	16.3
	Vrangel Island	ND	0.50	ND	ND	ND	ND

Note: ND = No Data.
(Source: Hinckley et al. 1992, Izrael and Tsyban 2000)

Pollution of the Chukchi Shelf by polychlorinated biphenyls (PCBs) is of major concern. Although their atmospheric content decreased in 1993 as compared to that of 1988, the water concentrations of these toxics remained unchanged. The PCB content of the bottom sediments has increased two-fold from 1988 to 1993, from 8.7 to 16.3 ng/g (Hinckley et al. 1992, Izrael & Tysban 2000). This fact demonstrates the accumulation of organochlorines in Chukchi Sea ecosystems. It is noteworthy that the long residence time of these compounds (several decades) in the marine environment determines their active circulation along food webs and accumulation in marine organisms, including commercial species. For example, the coefficients of PCB accumulation in particulate matter, plankton and neuston samples amounted from 100 to 10 000. Substantial accumulation of all chlordane components (50-100 ng/g of fat) has been found in the zooplankton samples (Hinckley et al. 1992, Izrael & Tysban 2000).The following chlorinated hydrocarbons have been found in Chukchi Sea ice: 34 ng/l of HCHs, 0.016 ng/l of DDTs, and 0.9 ng/l of PCBs (Hinckley et al. 1992, Chernyak et al. 1996).

New non-natural contaminants like endosulfan, bromoform, dibromomethane, and chloroiodomethane; as well as the pesticides chloropyriphos, chlorothalonil, phenvalerate, trifluarin have been found in the near-to-surface air layer, in fog and in Chukchi Sea waters (Chernyak et al. 1996). Their arrival is associated with long-range atmospheric transport.

In spite of the fact that many countries have limited or banned DDTs since the 1970s, these compounds are widespread and are found in many marine ecosystems owing to the combination of their long-term use and the long-range atmospheric transport of pollutants. For example, in 1988-1993 the pp'-DDT content of the Chukchi water ranged from 0.003 to 0.095 ng/l (Table 16). However, in 1993 concentrations were 20 times higher than in 1988 (Hinckley et al. 1992, Izrael & Tysban 2000). The maximum concentrations of DDT (like those of α- and γ-HCH) in the Chukchi Sea were found in the coastal waters of Alaska. Of special concern is the fact that DDT continues to accumulate in the sea bottom sediments. The coefficients of DDT accumulation in particulate matter and in zooplankton amount to 100-1 000 and 10 000-100 000, respectively. It should be noted that such hydrophobic substances as DDTs and highly chlorinated PCBs are absorbed by particulate matter and are easily transferred from the surface layers of the ocean to the depths.

A study of Chukchi Sea chemical pollution conducted by Institute of Global Climate and Ecology (IGCE) specialists used indicator organisms to evaluate the ecosystem. In the Chukchi Sea, the presence of these organisms remains low, but their distribution has expanded every year, and currently they can be found nearly everywhere (IGCE 1996).

Radionuclides

Radioactive contamination has resulted from three primary sources: atmospheric nuclear weapons testing during 1950-1980; releases from European nuclear reprocessing plants e.g. Sellafield, which peaked in the mid-1970s; and fallout from the Chernobyl accident in 1986 (AMAP 1997). There are no evident data on high concentration of radionuclides in the region (AMAP 1997, 2002). From 1992 to 1994, a joint Norwegian-Russian expert group sampled water, sediments and biota in the Barents and Kara seas (including the region of Novaya Zemlya). The results show that there is no significant contamination of the Kara Sea. In fact, the levels of radionuclides in the water are lower than in many other marine areas, such as the Irish, Baltic and North seas (AMAP 1997).

Spills

It is mainly the coastal areas of western Siberia that are exposed to oil spills. One of the main reasons for these spills is that about half of the petroleum pipelines in the region have not been maintained properly. Pipelines in western Siberia burst as often as 35 000 times per year. Only about 300 of these pipeline bursts are officially registered. Each burst pipeline discharges about 10 000 tonnes of oil. Different estimates put the total volume of the oil lost to the water at about 3-10 million tonnes from the time when oil was first exploited in the region. For example, 100 000 tonnes of oil was lost as a result of the Usinsk oil disaster, polluting about 60 km^2 (Barsegov et al. 2000). The planned growth of mining on the continental shelf of the Arctic seas will aggravate pollution problems situation in the western parts of the Kara and Chukchi seas.

Kara Sea

Navigation, oil and gas production and exploitation frequently result in oil spills in the sub-system. As a result, there are practically no rivers in western Siberia that are free of oil pollution (MEPNR 1994, Roshydromet 1996a, 1996b, 1997-2002). The Kara Sea Basin is a region that is constantly subjected to oil pollution, from both ongoing oil spills and oil that washes from the shores. Equipment is aging, obsolete technologies are in use and safety requirements for oil production are not abided by.

Trace metals and petroleum hydrocarbons are the most widespread pollutants in the Kara Sea, according to the chemical monitoring data of the Roshydromet network (GOIN 1996, Roshydromet 1997-2002) and the Arctic Monitoring centre. In 1991-1992 in the open Kara Sea, the content of petroleum hydrocarbons (PHs) ranged from 0 to 20 μg/l, while in the Baidarats, Ob and Taz bays, it did not exceed 50-70 μg/l. The Maximum Allowable Concentration (MAC) was exceeded at Cape Kharasavei (up to 92 μg/l) and near the Arctic settlements of Amderma and Dickson (above 200 μg/l) (GOIN 1996a). A lower concentration of

Figure 13 Nickel foundry at Norilsk, Russia.
(Photo: Arcticphoto)

petroleum hydrocarbons (PHs) was observed in 1993-1994, but in the Ob Bay in 1994 a concentration of 100 mg/l was observed (GOIN 1996c). Currently, the mean concentration of PHs amounts to 24 µg/l, with a maximum concentration found in Yenisei Bay (105 mg/l) (GOIN 1996, Roshydromet 1997-2002).

Laptev, East Siberian and Chukchi seas

In 1991 in the Laptev Sea, oil pollution was estimated to be at about 15-20 µg/l; the concentrations of petroleum hydrocarbons exceeded the MACs in Tiksi Bay (70 µg/l), Bugor-Khaya firth (a lane route) (130 µg/l), and in Olenek Bay (80 µg/l) (GOIN 1992). In 1992 the concentrations of petroleum hydrocarbons varied within narrow limits (12-39 µg/l) and only in Bugor-Khaya firth the maximum level (up to 200 µg/l) (GOIN 1996a). In 1993 the level of petroleum hydrocarbons in the Laptev Sea did not exceed the MACs (GOIN 1996b). The measurements carried out in recent years have found an average concentration of petroleum hydrocarbons of 17.1 µg/l in the open waters and up to 114 µg/l in Bugor-Khaya firth (GOIN 1996, Roshydromet 1997-2002).

The average concentration of petroleum hydrocarbons in the East Siberian Sea in 1991 amounted to 16 µg/l (a maximum of up to 50 µg/l was found in Chaun Bay) (GOIN 1992). In 1992 the PHs content somewhat increased (up to 27 µg/l), with maximum concentrations (up to 80 µg/l) observed near the Novosibirsk Islands and Wrangel Island (GOIN 1996b). Currently, oil pollution in the East Siberian Sea has stayed at approximately at the same level (GOIN 1996, Roshydromet 1997-2002).

In all the components of the Chukchi Sea ecosystems, benzo(a)pyrene (BP) - an indicator of carcinogenic polycyclic aromatic hydrocarbons (PAHs) - has been found. Some PAHs, for example BP, easily convert to mutagenic and carcinogenic epoxydiols, which interact with DNA. In the last few years the BP concentrations in Chukchi seawater have been 0.01-0.5 ng/l and 0.01-0.6 ng/l in the surface and bottom layers respectively. The average BP content of the bottom sediments has reached 2.28 mg/kg. However, the coefficients of BP accumulation in particulate matter and in biota have proved to be rather high (Izrael & Tsyban 1992, Tsyban 1999, Izrael & Tsyban 2000, Roshydromet 1997-2002).

The lowest mean oil pollution level for the Arctic seas, 7.2 µg/l, was observed in 1991, according to the data of the Roshydromet chemical monitoring network. In 1992 it amounted to 10.5 µg/l, the maximum of 20 mg/l was observed in the southern sea near the Chukchi Peninsula coast (GOIN 1996a). In 1993 near the settlement of Vankarem, the concentration of petroleum hydrocarbons amounted to 40 µg/l, although the general oil pollution level in the sea was low (GOIN 1996b). At the present time, the oil pollution in the different areas of the Chukchi Sea has remained at approximately the same level (GOIN 1996, Roshydromet 1997-2002).

A serious concern is also raised by the existing projects that involve the prospecting for and production of oil and gas on the Chukchi continental shelf. Exploration and industrial drilling for oil and gas production on the shelf result in a number of anthropogenic factors that affect the state of pelagic and bottom ecosystems, beginning with the hazardous consequences of seismic prospecting and the pollution of water and bottom sediments by drilling fluids and slurries, and ending with oil, copper and other metal pollution.

Socio-economic impacts

Economic impacts were considered slight in the Kara Sea sub-system. Economic impacts relate to the lack of funding needed to reconstruct and modernise water treatment plants to decrease the pollution of rivers of western and eastern Siberia. These problems are mainly linked to the general economic conditions in Russia, which are more problematic in the northern parts. After 1990, an abrupt decrease in production, reduction of investments, and an increase in consumer costs occured. A score of no known economic impact was assigned to the Laptev , East Siberian and Chukchi seas sub-system.

Health impacts were moderate and slight in the Kara and Laptev, East Siberian and Chukchi seas sub-systems respectively. The human health situation in the Arctic region in general is poor. Morbidity directly connected with chemical pollution of the catchments that drain to the Arctic seas (especially in the Kara Sea sub-system) is particularly troubling. Nowadays some Arctic regions (Pechenga-Nickel, Monchegorsk, Norilsk etc.) are referred to as ecologically unstable. Agricultural products and wild berries that come from these regions may contain higher-than-acceptable concentrations of heavy metals and other pollutants. Petroleum contamination and heavy metals spoil the quality of river and lake fish (Yevseev 1996).

The migration of pollutants in food chains (both terrestrial and aquatic) often results in the accumulation of these pollutants at a higher trophic level. For example, large numbers of deer meat deliveries from western Siberia to Scandinavian countries have been rejected as unacceptable because of higher-than-acceptable levels of heavy metals (Vilchek 1996).

The pollution problem is most acute in the region's large industrial cities such as Norilsk and Vorkuta. Residents of these cities, mostly children, are subject to chronic diseases such as bronchitis, pneumonia, lung cancer, bronchial asthma, and allergies. Women have had pregnancy complications. Heavy metals and PAHs are strongly mutagenic. In Norilsk the frequency of congenital defects in infants is 11.2 per 1 000 (the Russian average is 6 to 8). In addition to the unstable ecological situation, a decrease in living standards, a change for the worse in medical care, changes in the traditional way of life and nutrition patterns, all result in a growth in morbidity and mortality, including in children (Revich 1994). The mortality rate from different diseases in the region is 2.5 times higher than the Russian average. More detailed information is available in Annex V.

Other social and community impacts were assessed to be moderate in both sub-systems. Massive changes in the distribution of traditional indigenous populations are connected with the widening scope of oil, gas, and other resource production, transport routes and construction. Because lands are expropriated for industry and are tainted by industrial pollution, the rural population loses not only its pastures but hunting lands and fishing sites, as well as territories to collect wild berries and mushrooms. The indigenous population must therefore abandon historical residences and life styles.

It is important to note that most of the region's indigenous population (75%) is rural. Residence in multinational settlements and cities entirely changes indigenous peoples' lifestyles, resulting in many negative consequences. For example the death rate for the indigenous population is higher than for the immigrants. Additionally, traditional trades are largely unprofitable, which causes a serious unemployment problem. About 25-35% of the indigenous people in the region have no permanent job and survive only on the income from gathering berries and mushrooms. The unemployment level is especially high for women and young people. More detailed information is provided in Annex V.

Conclusions and future outlook

The open waters of the Arctic seas are clean, with the concentration of pollutants low or absent, and the state of the pelagic ecosystems as a whole is good. However, some of the shelf regions and essentially most of the coastal zones are considerably polluted and the state of a number of bays, gulfs and estuarine areas is as critical or even catastrophic. The ecological situation in these regions is aggravated by the presence in the

bottom sediments of high concentrations of numerous contaminants of anthropogenic origin, which has accumulated for many years.

The character of marine pollution is specific to each of the regions of the Arctic seas and depends on the degree of anthropogenic loading and the specific features of pollution sources. The main contribution to pollution in the Russian Arctic region results from diffuse, non-point sources such as river run-off and long-range atmospheric transport as well as localised sources in the high latitudes or directly on the Arctic coast. Given their large catchment areas and run-off volumes, northern rivers exert a powerful influence on the character and level of pollution in the Arctic seas, particularly in the estuarine and shelf regions. More than half of the organic toxics (including phenols and chlorinated hydrocarbons), as well as nitrogen and phosphorus compounds, and the bulk of oil pollution that are exported from the Russian territory are carried by river flow to the Arctic Ocean. Practically all petroleum hydrocarbons and chlorinated hydrocarbons are transported to the Arctic seas by the run-off from the Ob and Yenisei rivers.

Air transport also contributes to the broad-scale pollution of the Arctic, especially in winter. As a result of long-range atmospheric transport, a substantial amount of contaminants from the industrial regions of Eurasia reaches the high latitudes and precipitates directly onto the surface of the Arctic seas.

Local coastal sources determine the specific distribution of pollution and its severity. Local fluxes of anthropogenic pollutants are mainly formed from the atmospheric emissions and wastewater produced by large cities, public services, industrial zones and transportation. The greatest number of point sources of contaminants is centred in the western Russian Arctic in the territories of the Murmansk and Arkhangelsk regions.

The major hazard for the Arctic seas results from oil and its components that enter marine ecosystems from sewage discharges, accidental spills, navigation, and gas and oil production, especially directly on the shelf. Trace metals and chlorinated hydrocarbons in combination with other contaminants undoubtedly constitute a threat to life in the Arctic seas. Pollution is one of the main problems in the Russian Arctic region. Chemical pollution and spills are the most alarming issues. Eutrophication, microbiological pollution, suspended solids, solid waste, thermal pollution and radionuclide have an unknown or slight effect in the region. Over the next 20 years, environmental impacts from oil pollution are expected to remain significant. Chemical pollutants such as chlorinated hydrocarbons, heavy metals are considered to pose a moderate threat.

Habitat and community modification

IMPACT **Kara Sea** IMPACT **Laptev, East Siberian and Chukchi seas**

This concern encompasses two environmental issues: losses of ecosystems or ecotones, and modification of ecosystems or ecotones. Because of the difficulties in the individual assessment of the two issues, and because the expertise did not fully cover all habitats, the decision was made in favour of a clumped assessment. The scores for each of the selected habitats were derived from educated guesses and estimations. Assessments were conducted only for habitats related to the Russian Arctic region.

Ecological indicators

Estimates of the state and the level of degradation in marine ecosystems are based on the results of the study and joint analysis of the following inter-connected problems (Tsyban 1999, Izrael et al. 2002). Box 1 shows the main functions of ecological indicators.

1. Study of chemical pollution in the marine environment.
2. Investigation of the rate of contaminant production-destruction processes, defining a balanced state for the formation and destruction of organic matter in the ecosystem, and with definition of the meaning of biomass of separate groups of organisms as well.
3. Study of the ecological consequences of anthropogenic impacts on the marine environment and determination of the extent of ecosystem degradation.
4. Study of natural processes, including those that result in the modification or elimination of polluting substances, and determining the stability of the marine ecosystem in view of anthropogenic impacts.

Environmental impacts

Loss and modification of ecosystems or ecotones

There are no records of serious habitat loss in the region. However, evidence of degradation of some habitats have been documented in the region. There is evidence of changes in species composition due to species extinctions or introductions. The changes are local in character. Changes in the region's marine and freshwater ecosystems and their degradation as a result of anthropogenic impacts can be manifested by: (i) decreased species diversity, changes in species and the dimensional structure of communities; (ii) decreases in the total number and biomass of organisms, especially of benthofauna; (iii) a pronounced predominance of species most resistant to pollution; and (iv) a decreased intensity and seasonal instability in biological processes,

Box 1 Main functions of ecological indicators.

Harmful changes in the natural environment are to some extent compensated for by the assimilative capacity of ecosystems, a capacity that in part determines ecosystem stability. The determination of standards for assimilative capacity is one of the most important problems posed by sustainable development. Included in this determination are economic, social, and ecological issues, as well as the demands of nature protection and other characteristics of the natural environment and society, all of which can be represented by indicators.

Indicators should be comprehensible and sufficient for the assessment of critical situations in natural ecosystems as well as economics, and should also be able to determine responses to negative impacts (Moldan & Billharz 1997). There are several definitions of indicators. All definitions agree that an indicator is a measure that sums up the information related to some phenomenon, parameter or a derivative of closely related parameters that describe the state of the phenomenon/process (Gallopin 1997).

The use of indicators is the most important goal in the assessment of stability of individual systems. This problem has not been adequately developed yet, but at present it is attracting more and more attention from the scientific community. According to current concepts (Moldan & Billharz, 1997), many factors and processes - from key natural phenomena to leading social problems - can be used as potential indicators. One cannot help but infer that the most important advantage in the use of indicators consists of the possibility of facilitating and expediting the taking of decisions at the national or regional level.

The main functions of ecological indicators are as follows (Gallopin 1997):

- To assess environmental conditions and process trends;
- To compare different natural situations;
- To assess environmental conditions with respect to a particular target;
- To provide an early warning system;
- To provide a system that can forecast the environmental state and variability of processes.

Taking into consideration modern approaches in the selection of stable development indicators and also considering the results of long-term interdisciplinary investigations and monitoring in the Russian seas and other region (e.g. Izrael, Tsyban, 1989, 1990, 1992, Gidrometeoizdat 1990, Izrael et al. 2000, Tsyban 1997, 1999), the GIWA Task team suggests the following ecosystem indicators to be used for the assessment of the stability and variability of marine ecosystems.

- Changes in the most important physical processes (temperature, wind, circulation and other regimes);
- Changes in the hydrochemical regime;
- The level of anthropogenic impact (chemical, biological, temperature, radioactive pollution, eutrophication, removal of renewable biological resources);
- The rate of changes in production /destruction processes;
- Changes in biodiversity;
- The rate of microbial degradation of organic contaminants;
- The rate of the flux of contaminants in the process of biogenic sedimentation;
- Adaptation at the organism level;
- Intensity of natural processes determining the stability of marine ecosystems that include deposition (biosedimentation) and destruction (microbial transformation) of organic matter (including toxics).

The activity of microorganisms is determined by environmental conditions (temperature, availability of easily assimilated organic compounds, oxygen regime, biotic factors, and particulate matter distribution). The functioning of the microbial population in the surface microlayers of the water column is particularly important. The complex of microorganisms that develops in these layers constitutes the first biological structure that performs the transformation and degradation of many chemical toxicants in the surface film of the ocean. Biosedimentation of particulate organic matter is the most important component of the process of photic layer purification of contaminants, especially from chemicals that possess a high bioaccumulative ability.

An ecosystem's ability to provide protection against alien intervention with the use of a spectrum of biological, physical and chemical processes is its natural immunity, which is measured by assimilative capacity. In this case any important perturbations of the structural and functional characteristics of marine biocenoses are accompanied by changes in their biogeochemical functions and reflect a change in the circulation of matter and energy in the marine ecosystem as a whole.

According to this approach, the GIWA Task team used the rating scale to reflect the extent of anthropogenic degradation of the marine ecosystem, as presented earlier. The main ecological indicators were taken into account in characterising the state of the marine environment. The scale includes the following stages:

- Stable ecosystem;
- Transient ecosystem;
- Crisis ecosystem;
- Disaster ecosystem.

In recent years many aspects of the anthropogenic impact on high-latitude marine ecosystems have been determined, these aspects include increasing levels of chemical pollution in near-shore waters (intensive pollution) and areas of chronic pollution by stable chemical compounds in low concentrations in open water (factors of low intensity). Both intensive pollution and factors of low intensity are hazards for the ecological safety of the Arctic seas.

especially of production/destruction. The overall score of slight impact was given to both sub-systems. For lagoons, estuaries and neritic systems in the Kara Sea sub-system, the environmental impacts were moderate. To characterise the activity of biological processes and assess the state of the Russian Arctic ecosystems data from the Roshydromet marine network (1997-2002) and Gidrometeoizdat (1990, 1992a, 1992b, 1993, 1996) have been used.

Kara Sea

Bacteriological observations included the determination of the total bacterial number, raw biomass, the number of heterotrophic, saprophytic, oil- and pheno-oxidising bacteria, and indices showing the relationships between the total number and the number of each of the above groups of bacteria in the offshore area. Note that the determination of indicator bacteria was carried out for the purpose of biological indication of chronic pollution of marine ecosystems.

Over the last few years in the Vega Strait near the settlement of Dickson the total number of microorganisms had an average of 200 000 cells/ml. Bacterioplankton biomass had an average of 0.34 mgC/m^3 in February. The seasonal dynamics of the total number and biomass of microorganisms was typical for the seas of the Arctic region. The maximum was observed in summer and early autumn, while the minimum occurred in winter. The dynamics of microbiological indices has remained constant during the last few years.

The number of heterotrophic and saprophytic bacteria ranged from 10 to 50 cells/ml, that of oil-oxidising bacteria ranged between 10 and 30 cells/ml. The quantitative indices of the development of indicator bacteria have not changed over the last years. The relationship between the total bacterial number and the number of saprophytic microorganisms (the coefficient of relationships) has changed in the range from 0.0001 to 1%.

The waters of the Vega Strait can be characterised by bacteriological indices as slightly polluted. In the Yenisei Bay, where observations were carried out from April to May, the mean values of the total bacterial number and biomass amounted to 195 000 cells/ml and 0.34 mgC/m^3. The maximum number of heterotrophic saprophytic bacteria was observed in April and amounted to tens of cells/ml. The minimum number fell in May. During investigations of all the areas studied, indicator microflora (oil-oxidising and phenol-oxidising microorganisms) were found.

The relationships calculated between the total bacterial number and that of indicator microorganisms makes it possible to characterise the waters of the Bay as slightly polluted. In the Pyasina Bay the total number of bacteria in April-May of 1993 to 230 000 cells/ml on average, and the mean bacterial biomass was 0.36 mgC/m^3. The mean number of saprophytic microflora turned out to be insignificant. Oil- and phenol-oxidising microorganisms were found over the entire water area studied, where their mean number ran into units of cells/ml. Pyasina Bay can be characterised as slightly polluted.

In Gydan Bay, the mean values of microbiological indices are as follows: the total bacterial number, biomass and the number of saprophytic bacteria were 210 000 cells/ml, 0.33 mgC/m^3 and units of cells/ml, respectively. Oil- and phenol-oxidising microorganisms were found in some cases. The waters of Gydan Bay can be placed, with respect of microbiological indices, in the category of slightly polluted. In 1993 the chlorophyll a content of the water in the offshore areas of the Kara Sea amounted to 0.8-22 mg/m^3. This value is five times greater than in the open sea. It should be noted that in the Ob Bay, in conditions of low water transparency and with a high concentration of biogenic elements, the physiological activity of phytoplankton was not high (Vedernikov et al. 1994).

The distribution and quantitative aspects of indicator microorganism development are indicative of the chronic pollution of water areas by low doses of persistent pollutants. The ecosystem state in the investigated regions of the Kara Sea as a whole is considered stable to transitional. The overall environmental impact for Habitat and community modification in the Kara sub-system was slight. However, for lagoons, estuaries and neritic systems, the environmental impact was moderate in the Kara Sea sub-system.

Laptev Sea

In the last few years in Balunkan Bight of Tiksi Bay the total number of bacteria has become as high as 1 million cells/ml, amounting to an average of 400 000-600 000 cells/ml. The dispersion of the concentration values of saprophytic bacteria has proved significant - from ten to hundreds of thousands of cells/ml, which also corresponds to the level of eutrophic waters.

Systematic studies of the distribution of indicator bacteria, i.e. of heterotrophic bacteria that have adapted to higher concentrations of toxic contaminants and acquired an ability to destroy persistent organic compounds, including non-natural substances, as a result of a change in the genotype, demonstrates mutations in microbial populations and reflects their dynamics and hence the variability of the ecosystem (Tsyban et al. 1992b). According to bacteria indicators, the waters of Tiksi Bay and Bulunkan Bight, where the Tiksi port is situated, can be placed into the category of eutrophic and chronically polluted waters. Indicator bacteria are widespread in the Bulunkan Bight. The maximum concentration of oil- and phenol- oxidising bacteria reached 1 000 cells/ml, which is indicative of the chronic pollution in that area of the sea. Over the rest of Tiksi Bay the total amount of microorganisms has also proved to be high (0.1-1.2 million cells/ml). The number of saprophytic bacteria has varied over a wide range (from 100 cells/ml to 600 000 cells/ml), amounting to an average of 10 000 cells/ml. The number of oil- and phenol-oxidising bacteria reached 1 000 cells/ml.

In Neelov Bay, the total number of microorganisms has ranged from 0.1 to 1.4 million cells/ml, amounting to an average of 0.7 million cells/ml. The number of saprophytic bacteria has varied between 10 and 100 000 cells/ml, the average value being 10 000 cells/ml. The concentration of oil-oxidising bacteria in Neelov Bay has reached 100 cells/ml and remained at this level over the last few years. Neelov Bay waters can be placed, according to bacteriological indices, into the category of eutrophic and moderately polluted.

In Bulunkan Bight 36 species of phytoplankton were found (Table 17). The predominance of diatoms is indicative of a change in the phytoplankton community. In summer the species of green algae are also widespread in the Bight. The trend was a decrease in the total number and biomass of phytoplankton as compared with preceding years. The interseasonal long-term analysis of the phytoplankton community functioning in Bulunkan as a whole is indicative of its depressed state.

In the remainder of Tiksi Bay, 81 species of phytoplankton were found. In summer the phytoplankton number varied from 30 000 to 185 000 cells/l. The trend was for a decrease in the number and biomass as compared with the preceding years. In Neelov Bay a total of 137 species of phytoplankton were discovered. In summer the number of phytoplankton reached the maximum of 1 325 000 cells/l and the biomass 2.22 mg/l, at the expense of the active vegetation of the diatoms, green and blue-green algae (Table 17).

In Buor-Khaya Bay the phytoplankton diversity was very poor; 17 species were found, including 15 diatoms and 2 species of green algae. Over the last few years the quantitative indices of phytoplankton development have been extremely low: the maximum number and biomass were 110 000 cells/l and 0.12 mg/l, respectively. The mean values of the phytoplankton number and biomass amounted to 28 750 cells/ml and 0.07 mg/l, respectively, which is 5 times less than the mean

Table 17 Phytoplankton in the Laptev Sea.

Location	Phytoplankton (number of species)					Phytoplankton				Zooplankton		
	Diatoms	Green algae	Blue-green algae	Flagellates	Total	Number (cells/l)		Biomass (mg/l)		Number of species	Number (specimens/m³)	Biomass (mg/m³)
						Variation	Average	Variation	Average			
Bulunkan Bight	31	3	1	1	36	65 000-285 000	ND	ND	0.23	18	7 440	467.3
Tiksi Bay	66	10	3	2	81	30 000-185 000	94 100	0.01-0.31	0.15	16	1 715	53.3
Neelov Bay	112	14	7	4	137	ND	576 600	ND	0.97	27	5 931	182.0
Buor-Khaya Bay	15	2	-	-	17	ND	28 750	ND	0.07	ND	ND	ND

Note: ND = No Data.

(Source: Roshydromet 1997, 1998, 1999, 2000, 2001, 2002, Gidrometeoizdat 1990, 1992a, 1992b, 1993, 1996)

values reported in 1992 (Table 17). The state of the phytoplankton in Buor-Khaya water is depressed and that there is a trend toward the degradation of important biotic components. In Olenek Bay the phytoplankton biomass also proved to be very low (0.02 mg/l). In Yana Bay the phytoplankton number and biomass amounted to 82 500 cells/l and 0.22 mg/l, respectively.

In the summer in Bulunkan Bight, 18 species of zooplankton were observed. Over the rest of the Tiksi Bay water area, 16 species of zooplankton were found, to be compared to 1992 when 19 species were found. Copepods formed a predominant group with 95% of the total number and 99% of the total biomass. The seasonal course of variation of the number and biomass of zooplankton in Buor-Khaya Bay was similar to that of 1992, however the absolute values varied substantially. In Neelov Bay, 27 species were revealed to be compared to 31 species in 1992. In summer the number and biomass of zooplankton were 5 931 specimens/m^3 and 182.0 mg/m^3, respectively, which is somewhat lower than the level of 1992 (Table 17). The species composition of benthos in Bulunkan Bight and Tiksi Bay has stayed at the same level in recent years, but is represented only by oligochaetes and amphipods. However the quantitative characteristics varied over wide limits. For example, in Bulunkan Bight the number ranged from 40 specimens/m^2 in September-November to 420 specimens/m^2 in January, and amounted to an average of 182.5 specimens/m^2. The total biomass varied from 1.2 g/m^2 in September-November to 8.0 g/m^2 in August, with mean values being equal to 3.7 g/m^2.

The maximum values for the total zoobenthos number in Tiksi Bay were observed in January and amounted to 3 000 specimens/m^2. The maximum zoobenthos biomass was observed in May (70 g/m^2) when its mean value was 18 g/m^2. In Buor-Khaya Bay, the highest quantitative indices were observed in July: the total number reached 4 850 specimens/m^2 and the total biomass was 38.5 g/m^2, while the mean values were 1 950 specimens and 28.3 g/m^2, respectively.

In Neelov Bay the highest values of the abundance and biomass of benthos were observed in March (840 specimens/m^2 and 10 g/m^2, respectively). The mean values were 191 specimens/m^2 and 5.4 g/m^2, which was at the level of 1992. In Olenek Bay, the maximum quantitative indices of zoobenthos development were also observed in spring. They reached 1 160 specimens/m^2 (the total number) and 18.9 g/m^2 (the total biomass), when the mean values were 780 specimens/m^2 and 18.4 g/m^2, respectively.

In Yana Bay and the Dmitry Laptev Strait, the species diversity of benthofauna remained unchanged, as in preceding years. The maximum values of the total number, 4 290 specimens/m^2, were observed in March in Yana Bay and 2 940 specimens/m^2 in the Dmitry Laptev Strait. The mean values were 1 657 and 1 900 specimens/m^2, respectively. The total zoobenthos biomass amounted on average to 17.7 g/m^2 in Yana Bay and to 30.5 g/m^2 in the Dmitry Laptev Strait.

Thus, changes in the biotic component of the coastal ecosystems of the Laptev Sea manifested themselves in the wide distribution of indicator microflora, low values of the total number and biomass of phyto-, zooplankton and zoobenthos, a decrease in the species diversity of benthofauna, and predominance in its composition of oligochaetes and polychaetes; hydrobionts-indicators of chronic chemical pollution of the marine environment. The state of the ecosystem in the open sea as a whole can be characterised as stable. In the coastal areas and in estuarine zones of large rivers, the ecosystems can be characterised as transient (Box 1).

East Siberian Sea

In the region of the Pevek tongue as a whole, the total number of bacteria varied from 60 000 to 7.6 million cells/ml. The seasonal variability of the total bacterioplankton number is only slightly expressed. The lowest values were observed in March and April, while the highest values occurred in September. The mean annual total number of bacterioplankton near the Pevek tongue amounted to 1.2 million cells/ml.

Saprophytic bacteria were found in all the East Siberian water studied. Their most probable number (MPN) varied within the limits of natural variability from 4 cells/ml in March to 500 cells/ml in January, amounting to 90 cells/ml per year on the average. Oil-oxidising bacteria were discovered during all seasons of the year. The maximum of their most probable number reached 250 cells/ml in April. Variations of the MPN of oil-oxidising microorganisms occurred within the range from 0 to 15 cells/ml. According to bacteriological data, the waters seaward of the Pevek tongue remain slightly polluted. In Chaun Bay, the total bacterial number varied from 270 000 cells/ml in May to 1.8 million cells/ml in September. The mean annual total bacterial number in Chaun Bay was 816 000 cells/ml.

The saprophytic microflora content also changed within the limits of natural variations from 0 to hundreds of cells/ml, amounting to 100 cells/ml per year on the average. The MPNs of oil-oxidising bacteria were within the range from 0 to some tens of cells/ml. The data obtained over the last three years confirm a trend toward stabilisation and even to some decrease in the values of saprophytic and oil-oxidising microflora in the Chaun Bay, pointing to some improvement of the ecological situation in the investigated areas.

According to microbiological data, the waters in the investigated areas remain slightly to moderately polluted. In the region of the Pevek tongue of Chaun Bay, 43 species - representing 14 large taxa of invertebrate animals and plants - were found in the benthos composition. The widest species diversity (16 species) was found in polychaetes. The average number of benthic organisms amounted to 7 783 specimens/m^2. The highest density of settlements was typical for oligochaetes. The predominant species were *Oligochaeta g.* sp., *Nereimyra aphroditoides, Cistenides granulata* and others. The average biomass reached 130 g/m^2. The benthos biomass was mainly formed by bivalves, e.g. *C. granulata, Leionucula inflata, Macoma incospicua,* and *Terebelioides stroemi*. The species composition and quantitative characteristics of the bottom biocenoses were within the limits of long-term variations, and the state of the benthos community remained stable (Box 1). It should be noted that the bottom sediments in this region are chronically polluted by inclusions of small pieces of coal, slag, and solid waste.

In the water of Chaun Bay, 17 to 56 species of macrophytes and invertebrate animals belonging to 25 taxonomic groups were discovered. Like in the preceding years, polychaetes (up to 21 species at a station) and bivalves (up to 9 species) remained the characteristic predominant groups. Polychaetes and bivalves predominated in number and in biomass, respectively, in most of the investigated areas of Chaun Bay. The number and biomass of benthos amounted to 4 400 specimens/m^2 and 195 g/m^2 respectively.

Judging from the species diversity and quantitative characteristics of the investigated biocenoses, the bottom ecosystems of Chaun Bay are in good condition. Based on these observations, it was determined that the benthos state in the coastal regions that were investigated of the East Siberian Sea is characterised as stable (Box 1).

The level of oil pollution in the investigated areas has been substantially reduced over the last decade, from mean values of 11-13 MAC to 1 MAC, and the waters are not polluted by synthetic surface active substances (SSAS), while contamination by metals and PCBs is insignificant. Hydrochemical characteristics of Chaun Bay waters make it possible to consider them clean as a whole, with appearance of zones with local pollution by some contaminants, like trace metals, petroleum, etc.

The state of microbial populations and bottom fauna in Chaun Bay has remained unchanged since the observations started in 1984. Variations discovered for the microbiological characteristics studied correspond to seasonal and inter-annual fluctuations. At the same time there has been a trend toward an improvement in the ecological situation. Based on microbiological indices, the waters in the studied areas of the sea may be defined as varying from relatively clean to lightly and moderately polluted (in local zones in summer). The zoobenthos state in Chaun Bay is stable (Box 1). In the light of the above facts, the state of the coastal ecosystems of the East Siberian Sea may be defined as not impacted.

Chukchi Sea

In further defining the negative consequences of Chukchi Sea chemical pollution, the partial biodegradation of chlorinated hydrocarbons by marine microorganisms must be taken into account. For example, from 8 to 45% of benzo(a)pyrene can be removed by microbial degradation. The greatest amount of microbial activity has been found in the southern Chukchi Sea (at the level of 80%). In the low-temperature waters of the Chukchi Sea, only low chlorinated PCB congeners (from mono- to pentachlorbiphenyls) are subject to microbial transformation. These congeners account for only 18% of the total amount, and the maximum level of their degradation, in 10 days, does not exceed 50% for dichlorbiphenyls and only 10% for tetrachlorbiphenyls. Highly chlorinated PCB components containing more than six chlorine atoms have proved to be resistant to microbial degradation at low temperature.

Microbial degradation of α- and γ-HCH in the Chukchi Sea was first studied in 1993. Unlike polychlorinated biphenyls, these compounds

Figure 14 The Fedor Matisen in the pack ice of the Chukchi Sea near Mechigmen Bay, Russia.
(Photo: Corbis)

are subject to more active microbial degradation. For example, in the southern Chukchi Sea, the microflora of the surface layers proved able to transform up to 40% of an HCH mass with an initial concentration of 40 ng/l in a period of five days. Thus, substantial proportions (from 40 to 100%) of persistent organic pollutants are capable of microbial transformation in Arctic sea conditions and actively accumulate in marine organisms and bottom sediments.

The negative ecological consequences of Chukchi Sea pollution also include the processes of bioaccumulation of pollutants possessing toxic, carcinogenic and mutagenic properties. The ecological situation in the Chukchi Sea as a whole can be considered as not impacted. However, continued chemical pollution will perturb the functioning of plankton communities, resulting in decreased biological diversity and continuing accumulation of hazardous pollutants in marine organisms of commercial value.

Socio-economic impacts

The overall socio-economic impacts of Habitat and community modification was moderate in both sub-systems. At the same time, the GIWA experts assigned a severe impact for the indigenous populations in the region. It is recommended that GEF considers combining the issues that concern the northern Russia's indigenous populations into a separate problem. The people who inhabit the Russian Arctic coast (including the old-settler Russians and the Yakut population) traditionally made their living by hunting, fishing, and reindeer husbandry. This lifestyle, which was common until the 1960s, promoted the development of a special type of cultural landscape, which, in the best case, appeared to outsiders as virgin lands, or more often, as waste lands, which did not need any land use regulation. Generations of experience allowed indigenous people to balance economic demands against the ecological capacity of the fragile environment. The specialisation and the structure of this type of nature management corresponded to the natural landscape

structure, which provided stable functioning of its components and supported the ethnic groups who made their living from the land (Yevseev 1996).

Industrial development in the Arctic has been accompanied by severe natural resource losses. Nowadays, rivers, lakes and wetland ecosystems in the vast territories of the region have lost their value as a result of this development, which has affected the ability of indigenous populations to survive. Recent decreases in area and quality of reindeer pastures have resulted in decreases in herd size. For example, in the Yamalo-Nenets AD, the total area of reindeer pasture has decreased by 7.1 million ha in the last few years.

At the beginning of 1990s, the local population was no longer supported by the state as had been done under the old system of the planned economy. The combined effects of the destruction of natural ecosystems, along with the displacement of indigenous peoples from their traditional lands as a result of industrial development and the errors of economic reforms, caused huge damage to the local economy. After 1990, there was a one-third decrease in the harvest of fish, furs, and marine animals, and the gathering of berries, mushrooms, nuts, medical plants and algae nearly ceased. High transportation costs meant that around 60% of what is produced is lost since it cannot be shipped to markets.

Local products such as deer meet, fish and wild berries have traditionally occupied an important place in the nutrition of the indigenous and old settlers population alike. Thus, compared to the new arrivals, the indigenous population consumed 3-5 times more deer and wild animal meat, 8 times more marine mammal meat and fat, and 2-8 times more river fish. Both the indigenous peoples and new arrivals often eat local wild plants and marine fish. The raising of deer for slaughter accounts for almost half of the animal stock production in the region.

Nutritional imbalances, as a result of a decrease in local food consumption and the adoption of a European diet, mean that the population does not consume enough calories or foods rich in microelements. In view of the contamination of local products, the current situation contributes to a growth in morbidity and an increased death rate of the indigenous population.

The growth of poverty and the increasing unemployment levels on the Russian Arctic coast is closely connected with the destruction of natural ecosystems and the loss of traditional relationships with nature. Changes in employment opportunities for local populations and associated changes in social structures also contribute to the problem. These broad cultural changes have resulted in a loss of educational and scientific values, as well as a modification or loss of cultural heritages. More than 30% of deaths in the region are the result of violence. The suicides level is 3-4 times higher than the Russian average. Annex V contains more detailed information about health and social welfare in the region.

Conclusions and future outlook

Changes in the region's marine ecosystems, and their degradation as a result of anthropogenic impacts are manifested by the following negative effects: decreased species diversity, changes in species and the dimensional structure of communities, decreases in the total number and biomass of organisms, especially of benthofauna, a pronounced predominance of species most resistant to pollution, and a decreased intensity and seasonal instability in biological processes, especially of production/destruction.

Currently, the anthropogenic impact on the Russian Arctic marine ecosystems mainly consists of a more rapid arrival of contaminants at both local and regional scales. Thus, Habitat and community modification is an important issue for the Russian Arctic region. It is expected that over the next 20 years, the ecological situation in the Neritic ecosystems will experience changes. The major concern with regard to neritic ecosystems is linked to changes in the structure of the community, such as an increase in indicator bacteria, an increase in the quantity of tumour-like anomalies (TLA) in zooplankton, and a decrease of species diversity.

Unsustainable exploitation of fish and other living resources

IMPACT **Kara Sea** IMPACT **Laptev, East Siberian and Chukchi seas**

Fish catches and use of other aquatic resources harvested from the Arctic Ocean add up to about 950 000 tonnes annually or more than 20% of the total Russian catch (Anon. 2000). The businesses and organisations located in the Murmansk and Archangelsk regions are responsible for these catches as most of the harvest is from the Barents and White seas in the adjacent GIWA region Barents Sea. The number of species and the total stocks of biological resources in the the Kara, East Siberian, Chukchi and Laptev seas are limited. In these seas the fish stocks are not large enough to allow the establishment of a large industrial fishery. However, these coastal areas, along with fish stocks

in the region's rivers, are of great importance in supporting the small settlements of the Arctic coastal zone.

As described above, the marine part of the region has a not known impact of unsustainable exploitation. The central and eastern Arctic seas do not have a significant fishing industry, except in a narrow band near coastal areas, and they are basically called "non-fishery seas" (Zenkevich 1977). Commercial fish are essentially unavailable in these seas, hence fishery production research is negligible.

However, the rivers of the region do have some valuable fish and are of great importance in providing fish for the local population. Therefore, the assessment of this concern is focused on the region's river systems. Generally, the Kara Sea sub-system was assessed to have slight environmental impacts of Unsustainable exploitation of other living resources, while the Laptev Sea, East Siberian Sea, Chukchi Sea sub-system had no known impact. Current harvesting practices show no evidence of excessive by-catch and/or discards. There is also no evidence of habitat destruction due to fisheries practices or impact on biological and genetic diversity. These issues are therefore not further discussed.

Environmental impacts

Overexploitation

Siberian rivers, particularly those of the Kara Sea sub-system, are historically of great importance in providing fish for the local population. Valuable roundfish such as whitefishes, sturgeons and nelma amount up to 40% of the total catch in the rivers of western Siberia. The average annual catch in Ob-Irtysh Basin was about 40 000 tonnes in the period from 1946 to 1989. In the 1990s, the average annual catch decreased to 12 000 tonnes. In the Yenisei Basin, the average annual catch during that period decreased from 4 000 to 1 500 tonnes. This data shows that catches in western Siberia rivers decreased by a factor of three in the 1990s as compared to the previous 40-year period. In the rivers of western Siberia that flow in the Arctic seas, the average annual catch decreased from 10 000 tonnes in 1946-1989 to 2 000 tonnes in the 1990s (Luzanskaya 1970, Anon. 2000).

However, scientists do not link this decrease solely to the overexploitation of fish stocks. Among the major causes is a total decrease in the catch intensity due to economic reasons. The river fishery has never been highly profitable and it was sometimes supported with subsidies. As a result of economic crisis many small fisheries went bankrupt. The other cause of the reduction in catches is due to the uncertainty in catch statistics. Some experts believe the volume of fish that are unaccounted for equals or exceeds the amount tallied in statistics.

Scientists have also noted the sharp increase in poaching during the period of economic reforms. Poachers traditionally take the most valuable fish species, known as "Siberian delicacies". Stocks of major anadromous and catadromous fishes and populations of other valuable species are also stressed (Mikhailova 1995). The combination of these factors indicates that the most valuable fish species are overexploited.

Decreased viability of stock through pollution and disease

A slight impact was assigned to this issue in both sub-systems. The GIWA experts noted increased reports of parasitic infections in some fish but without evidence of widespread impacts on the main stock. The accumulation of high levels of pollutants has been noted in the tissues of marine organisms. It was concluded that the contamination in the Russian Arctic seas is not a problem for open water marine organisms. These marine organisms accumulate negligible quantities of chemicals (lower than anticipated as predicted by medical and biological estimates). Chemical pollution is more typically a problem for the European sector of the Arctic seas. However, oil and chemical pollution in Arctic coastal river systems, particularly in the Ob and the Yenisei, have resulted in morbidity and mortality in fish, along with a decreased viability of stock from pollution and (Mikhailova 1995).

Socio-economic impacts

The socio-economic impacts were assessed to be slight in the rivers of both sub-systems. A three-fold decrease in catches from the Siberian rivers during 1990s led to a loss of food sources for human or animal consumption. The overexploitation of valuable fish species and their death due to pollution has reduced the profitability of the catch and will require significant additional costs for the artificial restoration of valuable fish stocks. Because of the pollution of the Ob and other rivers by municipal wastes, as much as 60% of the Carp population and part of the Sig population is infected by opistharhosis and other helminth diseases, which make the fish dangerous for consumption (Anon. 2000). Other socio-economic impacts are for example bankruptcy of small fisheries, a growth in poaching and a conflict between user groups over shared resources, including space.

Conclusions and future outlook

Unsustainable exploitation of fish and other living resources is not a problem for the international waters of the region. Oil and gas extraction planned for the region will however increase the risk of anthropogenic impact on the region's river systems, which consequently will influence fisheries.

Global change

Kara Sea **Laptev, East Siberian and Chukchi seas**

Major physical and ecological changes are expected in the Arctic as a result of global climate change. Frozen areas will thaw and undergo substantial changes with warming. A substantial loss of sea ice is expected in the Arctic Ocean. As warming occurs, there will be considerable thawing of permafrost, leading to changes in drainage, increased slumping, and altered landscapes over large areas. Drainage systems in the Arctic are likely to change at the local scale. River and lake ice will break up earlier and freeze later. Polar warming probably will increase biological production but may lead to different species composition on land and in the sea. On land, there will be a tendency for northward shifts in major biomes such as tundra and boreal forest along with associated animals, resulting in significant impacts on species such as bear and caribou. However, the Arctic Ocean places a geographical limit on northward movement. Marine ecosystems will also move poleward. Animals dependent on ice may be at a disadvantage in polar areas. Figure 15 shows the annual winter temerature over Arctic during the period 1900 to 1996.

Environmental impacts

Changes in hydrological cycle and ocean circulation

The impact of this issue was slight in both sub-systems. A change in the hydrologic cycle due to global change will change in the distribution and density of riparian, terrestrial or aquatic plants but without influencing overall levels of productivity. There is some evidence of change in ocean and coastal currents due to global climate change, but without a strong effect on ecosystem diversity and productivity.

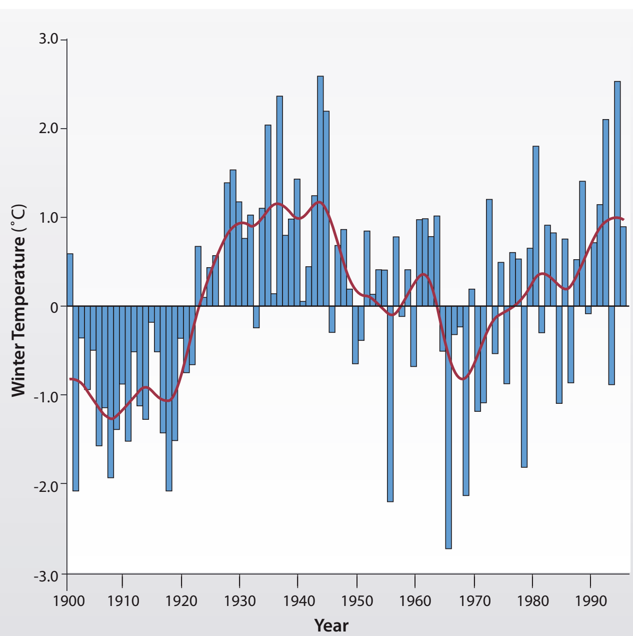

Figure 15 Annual winter temperature over Arctic 1900-1996.
(Source: IPCC 2001)

Sea level change

According to the IPCC (2001) there is no evidence of sea level change in the region. The issue was therefore assessed as having no known impact in the region.

Increased UV-B radiation as a result of ozone depletion

Ozone depletion and an associated increase in UV-B radiation have been observed in the Arctic over the past decade, and was assessed as having a slight impact in both sub-systems. This change may have a considerable effect on biological activity. Ozone depletion has occurred both as a steady decline and also in short, isolated areas with very low ozone (Watson et al. 1998). Climate change may increase ozone depletion. The cooling of the stratosphere is likely to increase this depletion with the current chlorine loading. However, chlorine loading can also be expected to decline considerably in the future. Some of the episodes of low ozone observed in the Arctic are not associated with chemical depletion but are due to the influx of low-ozone air from lower latitudes (Taalas 1993, Taalas et al. 1995). Whether these episodes will increase or decrease will depend on stratospheric circulation patterns near the Arctic; thus these episodes also may be influenced by climate change. The chemically induced and the dynamically induced episodes of low ozone that have occurred in the Arctic appear to be increasing in both frequency and severity (Taalas et al. 1997). These depletion events are most prevalent in the spring, when biological activity is highly sensitive to UV-B radiation. Increased levels are likely to affect human populations as well as aquatic and terrestrial species and ecosystems (Taalas 1993).

Arctic plants are also affected by increased UV-B radiation. In Arctic regions, UV-B radiation is low, but the relative increase from ozone depletion is large, although the ancestors of present-day Arctic plants were growing at lower latitudes with higher UV-B exposure. Over the past 20 years, stratospheric ozone has decreased approximately 10-15% in northern polar regions (Thompson & Wallace 2000). As a first approximation, a 1% decrease in ozone results in a 1.5-2% increase in UV-B radiation. The processes that damage organisms are temperature-independent, whereas repair processes are slowed by low temperatures. Hence, it is predicted that Arctic plants may be sensitive to increased UV-B radiation, especially because many individuals are long-lived and the effects are cumulative. In a study of responses by Ericaceous plants to UV-B radiation, responses varied from species to species and

were more evident in the second year of exposure (Björn et al. 1997, Callaghan et al. 1998). For unknown reasons, however, the growth of the moss *Hylocomium splendens* is strongly stimulated by increased UV-B, provided adequate moisture is available (Gehrke et al. 1996). Increased UV-B radiation may also alter plant chemistry, which could reduce decomposition rates and nutrient availability (Björn et al. 1997, 1999). Soil fungi differ with regard to their sensitivity to UV-B radiation, and their response also will affect the processes of decomposition (Gehrke et al. 1995). Therefore, measurable effects of UV-B radiation can be detected with respect to the behaviour or appearance of some aquatic species, without affecting the viability of the population.

Changes in ocean CO_2 source/sink function

The impact of greenhouse gases including CO_2 was considered and based on the IPCC assessment (IPCC 2001) the impact is slight.

Socio-economic impacts

In the past, when population densities of indigenous people were lower and economic and social structures were linked only weakly to those in the south, northern peoples showed significant flexibility in coping with climate variability (Sabo 1991). Now, commercial, local, and conservation interests have reduced their options, and they may be less well equipped to cope with the combined impacts of climate change and globalisation (Peterson & Johnson 1995). Increasingly, the overall economy is tied to distant markets. For example, in Russia 92% of exported oil is extracted from wells north of the Arctic Circle (Nuttall 1998). The value of native, local harvests of renewable resources has been estimated to be only 33-57% of the total economy of some northern communities (IPCC 2001). However, harvesting of renewable resources also must be considered in terms of maintaining cultural activities. Harvesting contributes to community cohesion and self-esteem, and knowledge of wildlife and the environment strengthens social relationships (Warren et al. 1995).

Predicted climate change is likely to have impacts on marine and terrestrial animal populations; changes in population size, structure, and migration routes also are probable (Beamish 1995, Gunn 1995, Ono 1995). Careful management of these resources will be required within a properly consultative framework, similar to recent agreements that are wide-ranging and endeavour to underpin the culture and economy of indigenous peoples (Nuttall 1998). Langdon (1995) claims that "the combination of alternative cultural lifestyles and altered subsistence opportunities resulting from a warmer climate may pose the greatest threat of all to the continuity of indigenous cultures in northern North America." An alternative view is that northern people live with uncertainty and learn to cope with it; this view suggests that "for indigenous people, climate change is often not a top priority, but a luxury, and Western scientists may well be indoctrinating Natives with their own terminology and agenda on climate change" (BESIS 1999).

Exploration, production, transportation of oil and gas, and associated construction of processing facilities are likely to be affected by climatic change (Maxwell 1997). Changes in a large number of climate and related variables will affect on- and offshore oil and gas operations. Use of oil drilling structures or ice-strengthened drill ships designed to resist ice, use of the ice itself as a drilling platform, and construction of artificial islands are likely to give way to more conventional drilling techniques employed in ice-free waters (Maxwell 1997). These likely changes are not without concerns. Although the use of regular drill ships may reduce operating costs by as much as 50% (Croasdale 1993), increased wave action, storm surges, and coastal erosion may necessitate design changes in conventional offshore and coastal facilities (McGillivray et al. 1993). This may increase the costs of pipeline construction because extensive trenching may be needed to combat the effects of coastal instability and erosion, especially that caused by permafrost melting (Croasdale 1993, Maxwell 1997). Design needs for onshore oil and gas facilities and winter roads are strongly linked to accelerated permafrost instability and flooding. The impact of climate change is likely to lead to increased costs in the industry associated with design and operational changes (Maxwell 1997).

The impact of climate warming on transportation and communications in Arctic regions is likely to be considerable. Within and between most polar countries, air transport by major commercial carriers is widely used to move people and freight. Irrespective of climate warming, the number of scheduled flights in polar regions is likely to increase. This will require an adequate infrastructure over designated routes, including establishment of suitable runways, roads, buildings, and weather stations. These installations will require improved engineering designs to cope with permafrost instability. Because paved and snow-ploughed roads and airfield runways tend to absorb heat, the mean annual surface temperature may rise by 1-6°C, and this warming may exacerbate climate-driven permafrost instability (Maxwell 1997). Cloud cover, wind speeds and direction, and patterns of precipitation may be expected to change at the regional level in response to global warming. At present, the density of weather stations is relatively low in Arctic regions. Increased air and shipping transports under a changing climate will require a more extensive weather recording network and navigational aids than now exists.

The impact of climate warming on marine systems is predicted to lead to loss of sea ice and opening of sea routes such as the Northeast and

Figure 16 Road flooded by the Lena River outside Yakutsk, May 23, 2001.
(Photo: Corbis)

Northwest passages. Ships will be able to use these routes without strengthened hulls. There will be new opportunities for shipping associated with movement of resources (oil, gas, minerals, and timber), freight, and people (tourists). However, improved navigational aids will be needed, and harbour facilities probably will have to be developed. The increase in shipping raises questions of maritime law that will need to be resolved quickly. These issues include accident and collision insurance, which authority is responsible for removal of oil or toxic material in the event of a spill, and which authority or agency pays expenses incurred in an environmental cleanup. These questions are important because sovereignty over Arctic waters is disputed among polar nations, and increased ship access could raise many destabilising international issues. Increased storm surges are predicted that will affect transport schedules.

Increased levels of UV-B radiation are likely to affect the human populations (Taalas 1993). Episodes of extreme cold and blizzards are major climate concerns for circumpolar countries like Russia and Canada (IPCC 2001). However, the polar regions will remain cold, so the direct effects of global warming are likely to have little effect on human health. Potential indirect effects, such as changes in infectious diseases and vector organisms, are largely unknown. UV-B radiation is increasing, which can damage the genetic (DNA) material of living cells (in an inverse relationship to organism complexity) and induce skin cancers, as shown in experimental animals. It also may affect human health: UV-B radiation is implicated in causing human skin cancer and lesions of the conjunctiva, cornea, and lens; it also may impair the body's immune system (IPCC 2001).

Climate change and economic development associated with oil extraction, mining, and fish farming will result in changes in diet and nutritional health and exposure to air-, water-, and food-borne contaminants (Bernes 1996, Rees & Williams, 1997, Vilchek & Tishkov 1997, AMAP 1998, Weller and Lange 1999, Freese 2000). People who rely on marine systems for food resources are particularly at risk because Arctic marine food chains are long (AMAP 1997). Low-lying Arctic coasts of western Canada, Alaska, and the eastern Russian Arctic are particularly sensitive to sea-level rise. Coastal erosion and retreat

as a result of thawing of ice-rich permafrost already are threatening communities, heritage sites, and oil and gas facilities (Forbes & Taylor 1994, Are 1999).

Along the coasts of the Bering and Chukchi seas, indigenous peoples report thinning and retreating sea ice, drying tundra, increased storms, reduced summer rainfall, warmer winters, and changes in the distribution, migration patterns, and numbers of some wildlife species. These populations say that they already are feeling some of the impacts of a changing, warming climate (Mulvaney 1998). For example, when sea ice is late in forming, certain forms of hunting are delayed or may not take place at all. When sea ice in the spring melts or deteriorates too rapidly, it greatly decreases the length of the hunting season. Many traditional foods are dried (e.g. walrus, whale, seal, fish, and birds) in the spring and summer to preserve them for consumption over the long winter months. When the air is too damp and wet during the "drying" seasons, food becomes mouldy and sour. The length of the wet season also affects the ability to gather greens such as willow leaves, beach greens, dock and wild celery. These accounts reflect the kinds of changes that could be expected as global warming affects the Arctic (Mulvaney 1998). As climate continues to change, there will be significant impacts on the availability of key subsistence marine and terrestrial species. At a minimum, salmon, herring, walrus, seals, whales, caribou, moose, and various species of waterfowl are likely to undergo shifts in range and abundance. This will entail local adjustments in harvest strategies as well as in allocations of labour and resources (e.g. boats, snowmobiles, weapons). As the climate changes, community involvement in decision-making has the potential to promote sustainable harvesting of renewable resources, thereby avoiding deterioration of common property. However, factors that are beyond the control of the local community may frustrate this ideal. For example, many migratory animals are beyond hunters' geographical range for much of the year, and thus beyond the management of small, isolated communities. Traditional subsistence activities are being progressively marginalised by increasing populations and by transnational commercial activities (Sklair 1991, Nuttall 1998).

The capacity of permafrost to support buildings, pipelines, and roads has decreased with atmospheric warming, so pilings fail to support even insulated structures (Weller & Lange 1999). The problem is particularly severe in the Russian Federation, where a large number of five-story buildings constructed in the permanent permafrost zone between 1950 and 1990 already are weakened or damaged, probably as a result of climate change. For example, a 2°C rise in soil temperature in the Yakutsk region has led to a decrease of 50% in the bearing capacity of frozen ground under buildings. It has been predicted that by 2030, most buildings in cities such as Tiksi and Yakutsk will be lost, unless protective measures are taken (Weller & Lange 1999). The impact of warming is likely to lead to increased building costs, at least in the short-term, as new designs are produced that cope with permafrost instability. Snow loads and wind strengths may increase, which also would require modifications to existing building codes (Maxwell 1997). There will be reduced demand for heating energy with warmer climate (Anisimov & Poljakov 1999).

Conclusions and future outlook

Changes in ecological situations and socio-economic activity caused by global climate change are expected. The hydrology of the Arctic is particularly susceptible to warming because small rises in temperature will result in increased melting of snow and ice, with subsequent impacts on the water cycle. There will be a shift to a run-off regime that is driven increasingly by rainfall, with less seasonal variation in run-off. There will be more ponding of water in some areas, but peatlands may dry out because of increased evaporation and transpiration from plants. In some areas, thawing of permafrost will improve infiltration. An expected reduction in ice-jam flooding will have serious impacts on riverbank ecosystems and aquatic ecology, particularly in the highly productive Arctic river deltas. Changes in Arctic run-off will affect sea-ice production, deepwater formation in the North Atlantic, and regional climate. A major impact would result from a weakening of the global thermohaline circulation as a result of a net increase in river flow and the resulting increased flux of freshwater from the Arctic Ocean.

Warming should increase biological production; however, the effects of increased precipitation on biological production are unclear. As warming occurs, there will be changes in species composition on land and in the sea, with a tendency for poleward shifts in species assemblages and loss of some polar species. Changes in sea ice will alter the seasonal distributions, geographic ranges, patterns of migration, nutritional status, reproductive success, and ultimately the abundance and balance of species. Animals that are dependent on sea ice, such as seals, walrus, and polar bears, will be disadvantaged. High-arctic plants will show a strong growth response to summer warming. It is unlikely that elevated CO_2 levels will increase carbon accumulation in plants, but plants may be damaged by higher UV-B radiation. Biological production in lakes and ponds will increase.

Climate change, in combination with other stresses, will affect human communities in the Arctic. The impacts may be particularly disruptive for communities of indigenous peoples following traditional lifestyles. Changes in sea ice, seasonality of snow, and habitat and diversity of food species will affect hunting and gathering practices and could

threaten longstanding traditions and ways of life. On the other hand, communities that practice these lifestyles may be sufficiently resilient to cope with these changes. Increased economic costs are expected to affect infrastructure, in response to thawing of permafrost and reduced transportation capabilities across frozen ground and water.

Priority concerns for further analysis

Pollution and Habitat and community modification in the Kara Sea sub-system were ranked as the priority concerns for the Russian Arctic region. The analysis of the main issues and levels of pollution suggests that the waters of the Russian Arctic region are much cleaner than other European seas and the Barents Sea. However, two of the issues from the concern Pollution have been chosen for further analysis in the Kara Sea sub-system: chemical pollution and spills.

After the decline in production during the 1990s as a result of economic reforms, rapid growth in production in the Kara Sea sub-system is expected. Some estimates predict that the economy will develop mostly as a result of the development of hydrocarbon stocks. Economic development will also hinge on the planned growth in the production of chromite and titanium-magnetite ores from Yamal-Nenets AD, as well as growth in the production of nickel, cobalt, copper and other metals from the Norilsk industrial complex (Dolgano-Nenets AD, Taimyr). Therefore it is expected that the negative impacts from chemical pollution and spills will remain at their current levels or will increase in the future.

The second prioritised concern that may increase in severity in the future is Habitat and community modification. The most threatening issue here is the modification of ecosystems, primarily the neritic systems of the Kara Sea sub-system. Spills and chemical pollutants such as chlorinated hydrocarbons, heavy metals are actively bioaccumulating at significant levels in the bottom sediments and in marine organisms, thereby disturbing the natural balance in existing ecosystem.